Conservation Agriculture in Africa

Climate Smart Agricultural Development

Edited by **Saidi Mkomwa**
and **Amir Kassam**

CABI

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Climate Smart Agricultural Development

This book is dedicated to the global conservation agriculture movement and particularly to all the farmers, researchers, educationalists and extension agents – as well as all those in the public, private and civil sectors and in the investment community – who are engaged in making conservation agriculture a global reality.

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Climate Smart Agricultural Development

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Foreword

Africa accorded the agricultural sector the priority which it deserves through the endorsement of the Comprehensive Africa Agriculture Development Programme (CAADP) by African heads of state and government in 2003 in Maputo, Mozambique, with the aim of transforming Africa's agriculture to ensure food and nutrition security in Africa, reduce poverty and create jobs. In June 2014 on the 10th anniversary of the implementation of CAADP, African heads of state and government meeting in Malabo, Equatorial Guinea adopted the *Malabo Declaration on Accelerated Agricultural Growth and Transformation for Shared Prosperity and Improved Livelihoods,* with a wider mandate and more targeted approach to achieve the agricultural vision of shared prosperity and improved livelihoods for the continent.

The specific goals and targets to be attained by 2025 include: recommitting to the principles of CAADP; enhancing investment finance in agriculture; ending hunger in Africa by 2025; by doubling productivity and halving the current level of post-harvest losses; halving poverty through improved agricultural growth and transportation; tripling intra-Africa trade in agricultural commodities and services; enhancing resilience in livelihoods and production systems to climate variability and other shocks; and commitment to mutual accountability to actions and results.

With five years to 2025, progress in achieving the Malabo Declaration goals has been slow as revealed by the 2020 African Union Biennial Review Report which indicates that only 4 out of the 49 countries that participated in the exercise are on track towards meeting these targets, though 36 other countries improved on their 2018 performance in the first Biennial Review Report. The major hindrances have been conflict accentuated by climate change and now COVID-19.

There is broad consensus by farmers and agrarian experts in Africa that we must change the way we farm, if we are to get different and better results to attain the envisaged Malabo goals as well as the Sustainable Development Goals and overcome the current soil-degrading and environment-polluting farming paradigm that has shaped African agriculture, making African youths turn their backs on farming. I believe that the transformation of African agriculture to a new farming paradigm must be conservation-based and reliant on system science if it is to deliver optimally on productivity and environmental sustainability. Such transformation would need radical reform in the institutional support from the public and private sectors as well as civil actors including creating the enabling environment for both public and private investment.

The key to transforming Africa's agriculture lies in the ability of the millions of farmers to improve the soil health and biodiversity of their smallholder farms, averaging two hectares. These groups of farmers have negligible access to mechanization and other inputs to improve production.

There is a great deal of accumulated scientific and empirical evidence about the relevance and feasibility of Conservation Agriculture as the core of climate-smart, sustainable production intensification systems for use across Africa. Success stories and the scientific evidence on the performance of Conservation Agriculture abound within Africa and across the Global South. The vision to learn from within and outside Africa, and protecting and embracing its diversity, was well articulated by the First Africa Congress on Conservation Agriculture (1ACCA) held in Lusaka, Zambia in 2014 and endorsed through the African Union's 2014 Malabo Declaration to have 25 million households practicing climate smart agriculture by 2025 (Vision 25x25).

It is now time to expand this evidence base through scientific experimentation to include smallholder farmers currently without access to mechanization and production inputs and spread the information to farmers, supporting institutions, investors and governments that Conservation Agriculture is applicable to their diversified agro-ecological and socioeconomic situations.

This book brings to the fore scientific and empirical evidence about Conservation Agriculture in Africa, articulated by the Second Africa Congress on Conservation Agriculture (2ACCA) held in Johannesburg in 2018. It describes how farmers in Africa are successfully adopting Conservation Agriculture as an alternative to the unsustainable conventional farming practices and as a solution to loss of agricultural productivity, soil erosion and land degradation, climate change challenges and ever-increasing food insecurity. The 2ACCA was organized by African Conservation Tillage Network (ACT), in collaboration with the Government of the Republic of South Africa, African Union Commission, African Union Development Agency–New Partnership for Africa's Development (AUDA–NEPAD), Regional Economic Communities, Norwegian Agency for Development Cooperation (NORAD), Food and Agriculture Organisation of the United Nations (FAO) and various bilateral and multilateral partners.

The theme of this book is: *Conservation Agriculture in Africa: Climate Smart Agricultural Development*. It is about how Conservation Agriculture can support the implementation of the African Union's Malabo Declaration and Agenda 2063 which calls for climate smart agricultural development. It provides development-oriented case studies and scientific evidence relevant to all stakeholders in the public, private and civil sectors who are engaged in building policy, institutional and human capacity to accelerate the mainstreaming of Conservation Agriculture across Africa.

Conservation Agriculture is also one of the Ten Elements of the Framework for Sustainable Agricultural Mechanization in Africa (F-SAMA) jointly developed by FAO and the African Union. Conservation Agriculture has the potential to contribute to the attainment of the African Union's 2014 Malabo Declaration Vision 25 x 25 which aims to send the 'hand held hoe' to the museum and liberate the African farmer from the back-breaking drudgery of manually tilling the land.

I recommend this book to all stakeholders, committed to facilitating the transformation of African agriculture in the coming decades. Such a transformation is unlikely to take place without Conservation Agriculture playing a central role in sustainable agricultural intensification. It is with a great sense of gratitude and pleasure that I warmly congratulate the Africa Conservation Agriculture Community of Practice, including all the farmers who have so far adopted Conservation Agriculture, for their remarkable success in their efforts to initiate an enduring foundation for sustainable agriculture development across the continent in such a short period of time.

H.E. Ambassador Josefa Leonel Correia Sacko
Commissioner for Agriculture, Rural Development, Blue Economy and Sustainable Environment
African Union Commission
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Preface

Tillage agriculture has led to widespread soil and ecosystem degradation globally, and more particularly in the developing regions. This is especially so in Africa where traditional tillage-based agricultural farming systems and practices have become unsustainable owing to soil disturbance and 'mining' of natural resources with negative impacts on productivity and the environment. In addition, agriculture in Africa today faces major challenges including increased cost of production inputs and energy, climate change and lack of an effective paradigm for sustainable production intensification.

Conservation agriculture (CA) has emerged as a major alternate sustainable agriculture practice in Africa and has spread to many African countries in the past decade as more development and research effort is directed towards its extension and uptake. The First Africa Congress on Conservation Agriculture was held in Lusaka from 18 to 21 March 2014 to share experiences and lessons, and to facilitate alliances to unblock hindrances to expand and scale-up adoption of CA, especially among the smallholder farming systems and related industry in Africa. The theme of the Congress included 'building resilient farming systems'.

This book is based on the material presented at the Second Africa Congress on Conservation Agriculture which was held in Johannesburg, South Africa, on 9–12 October 2018. The main theme of the Congress was: *Making Climate Smart Agriculture Real in Africa with Conservation Agriculture: Supporting the Malabo Declaration and Agenda 2063*. The Congress was aligned to mobilize stakeholders in all agriculturally related sectors to provide development support, impetus and direction to the vision and agenda for transforming African agriculture as set out by the Malabo Declaration and Agenda 2063.

The Congress illustrated the vast network of pan-African stakeholders in the public, private and civil sectors that are engaged in generating and applying knowledge, innovation and development action to support the transformation of agriculture across Africa. The stakeholders addressed five areas of needs: (i) policy and institutional support for mainstreaming CA; (ii) research and innovation to support the spread of CA; (iii) education and training to accelerate the uptake of CA by farmers; (iv) investment in CA sectors along the value chain, including mechanization; and (v) knowledge and communication for CA uptake.

The book illustrates that CA has amply shown itself to be a relevant and worthy core component of climate smart agriculture. The area under CA cropland in Africa has more than trebled since 2008/09, with at least 25 countries formally and actively promoting CA through public, private and civil society initiatives.

The book also shows that much new expertise and experience about CA has been gained, especially during the last decade, through research training and farmer innovation and also by increased agricultural investments in institution building. Consequently, CA now holds greater promise to serve as a sustainable pillar in the implementation of Agenda 2063. The Second Africa Congress on Conservation Agriculture and the work presented in the chapters of this book provide scientific and empirical evidence that CA is already contributing to advances in Africa's agricultural transformation. During the Official Opening of the Congress (reproduced in Chapter 30), the inaugural speech was given by the Director General of South Africa's Department of Agriculture, Forestry and Fisheries (DAFF), Mr Mzamo Michael Mlengana. He called for concerted efforts at all levels, including in policy and investments, to foster accelerated expansion and widespread practising of CA, as an integral part of community and national efforts in building sustainable and viable agricultural systems.

The Congress ended with a stakeholder action statement which highlighted key priority issues and action areas in pursuit of continued expansion of the practice of CA in the coming months and years leading up to the Third Africa Congress on Conservation Agriculture, which is expected to be held in 2022.

The book comprises 30 chapters, selected out of the 70 papers that were presented at the Congress, including papers from policy analysts and institution leaders who were involved in panel discussions on important fields in CA development. The book reflects the important development-related policy, scientific and technical work that is going on across Africa with regard to CA and its support of the Malabo Declaration and Agenda 2063. This book complements the material which CABI published from the First Africa Congress under the title *Conservation Agriculture for Africa: Building Resilient Farming Systems in a Changing Climate*.

The aim and scope of the book is to make available up-to-date knowledge regarding CA to all stakeholders who are or who should become engaged in supporting the transformation of conventional tillage agriculture into no-till CA. The book presents the reasons why conventional tillage agriculture in Africa must transform into commercial and mechanized no-till CA. It highlights the advantages and benefits – productivity, economic, environmental and social – that can be harnessed by farmers and society as a result.

The need for the book stems from the fact that the African Union (AU), NEPAD (AUDA)-CAADP and all African national governments have declared their agricultural development priorities in the form of the Malabo Declaration and the supporting Agenda 2063. However, they have not been specific with regard to which agricultural paradigm should be adopted for implementing Agenda 2063. Thus, the book is essentially about how CA can support the implementation of Agenda 2063, which calls for the development of climate smart agriculture.

In specific terms, the book is about how climate smart agricultural development in Africa can be made real as envisioned by the Malabo Declaration and elaborated in Agenda 2063. The book: (i) provides a record of current scientific and empirical evidence generated across Africa about the relevance of CA to meet the aims and objectives of the Malabo Declaration and Agenda 2063; (ii) illustrates the research, education and development efforts and investments under way to support the adoption and mainstreaming of CA as the best example of climate smart agriculture in Africa; and (iii) highlights the need for stakeholders in the public, private and civil sectors in Africa and internationally to become engaged in building policy, institutional and human capacity to accelerate the agricultural transformation based on CA to achieve Agenda 2063.

The book is organized in six parts. Part 1 deals with Making Climate Smart Agriculture Real in Africa (chapters 1–3). Part 2 deals with Mainstreaming of the Conservation Agriculture Paradigm in Africa (chapters 4–8). Part 3 deals with Research and Innovation for Conservation Agriculture Systems Development (chapters 9–18). Part 4 deals with Education and Training for Conservation Agriculture (chapters 19–23). Part 5 deals with Investing for Agricultural Transformation (chapters 24–29). Part 6 deals with The Future (chapter 30).

We hope that this book will serve as a source of scientific and empirical evidence to policy makers and institutional leaders in the public, private and civil sectors to help in decision making in support of greater investments in CA development; and to academics, scientists and students in formulating their strategic directions and priorities for an expanded and effective CA innovation and knowledge system for agricultural and economic development in Africa.

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Conservation Agriculture Federation (ECAF), the International Maize and Wheat Improvement Centre (CIMMYT), AUDA–NEPAD and the Government of the Republic of South Africa for hosting the 2ACCA deserve a special mention. The contribution by Mr Mzamo Michael Mlengana, Director General of DAFF, for his stimulating and hope-inspiring inaugural opening speech, is all the more important because CA is now a central part of the national development strategy of the Republic of South Africa: a large extent of its annual cropland is now being sustainably managed under CA systems.

We express our very special and grateful thanks to H.E. Josefa Leonel Correia Sacko, Commissioner for Rural Economy and Agriculture, AU Commission, for gracing the book with an inspiring and encouraging Foreword. H.E. Josefa Leonel Correia Sacko's contribution is of particular significance because, at the Congress, the AUC and FAO launched the Sustainable Agricultural Mechanization for Africa Framework. The Framework is aimed at the commercialization and mechanization of CA value chains and support services as a central part of the implementation of Agenda 2063.

Finally, we express our appreciation to any other persons or organizations not mentioned above that have contributed in one way or another to the accumulation and compilation of the material presented in this book.

Acronyms and Abbreviations

1ACCA	First Africa Congress on Conservation Agriculture
2ACCA	Second Africa Congress on Conservation Agriculture
AAA	Adaptation of African Agriculture
AAAID	Arab Authority for Agricultural Investment and Development
AAU	Association of African Universities
ACIAR	Australian Centre for International Agricultural Research
ACT	African Conservation Tillage Network
AE	Agronomic efficiency
AFD	French Development Agency
AfDB	African Development Bank
AFOLU	Agriculture forest and other land use
Agenda 2063	Africa's blueprint and master plan for transforming Africa into the global powerhouse of the future
AGRA	Alliance for a Green Revolution in Africa
ANAFE	Agroforestry and Natural Resources Education
APAD	Association pour la Promotion d'une Agriculture Durable (Tunisia)
APSIM	Agricultural Production Systems Simulator
ARD	Regional Development Agency
ASALs	Arid and semi-arid lands
AUC	African Union Commission
AUDA	African Union Development Agency
BD	Soil bulk density
CA	Conservation Agriculture
CAADP	Comprehensive Africa Agriculture Development Programme
CA-CoEs	Conservation Agriculture Centres of Excellence
CASI	Conservation Agriculture-based Sustainable Intensification
CASPA	Conservation Agriculture Service Providers Association
CBA	Cost–benefit analysis
CC	Climate change
CC	Cover crop
CCAFS	Climate Change, Agriculture and Food Security
CFGB	Canadian Foodgrains Bank

CFU	Conservation farming unit
CGIAR	Consultative Group on International Agricultural Research
CIMMYT	International Maize and Wheat Improvement Center
CIRAD	Agricultural Research Centre for International Development
CM	Collaborative-managed
CMS	Course management systems
CMT	Collaborative-managed trial
CNTA	Centre for No-Till Agriculture (Ghana)
CoP	Community of practice
CP	Conventional practice
CSA	Climate smart agriculture
CT	Conventional tillage
CTRC	Conservation Tillage Research Centre (China)
DAFF	Department of Agriculture, Forestry and Fisheries
DM	Dry matter
DT	Drought tolerant
ECAF	European Conservation Agriculture Federation
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FAW	Fall army worm
FFS	Farmers Field Schools
FIP	Farmer Innovation Programme
FISP	Farm Input Subsidy Programme
FMNR	Farmer managed natural regeneration
GACSA	Global Alliance for Climate-Smart Agriculture
GDP	Gross domestic product
GHG	Greenhouse gas
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
HCA	Hierarchical cluster analysis
HSHT	Haney soil health tests
ICAAP-Africa	International Conservation Agriculture Advisory Panel for Africa
ICARDA	International Center for Agricultural Research in the Dry Areas
IFAD	International Fund for Agricultural Development
IFPRI	International Food Policy Research Institute
IFSM	Integrated Soil Fertility Management
IITA	International Institute of Tropical Agriculture
IPCC	Intergovernmental Panel on Climate Change
IPM	Integrated pest management
ISFM	Soil fertility management
ISs	Innovation systems
IT	Information technology
IWM	Integrated weed management
JFFS	Junior Farmer Field School
KALRO	Kenya Agricultural and Livestock Research Organization
LDN	Land degradation neutrality
M&E	Monitoring and evaluation
MDF	Mahlathini Development Foundation
MFM	Maize–fallow–maize
MFS	Maize–fallow–soybean
MOOC	Massive open online course
MWM	Maize–wheat–maize
MWS	Maize–wheat–soybean

NARS	National Agricultural Research System
NCATF	National Conservation Agriculture Task Force
NDC	Nationally determined contributions
NEPAD	New Partnership for Africa's Development
NGO	Non-governmental organizations
NORAD	Norwegian Agency for Development Cooperation
NPV	Net present value
NT	No-tillage/no-till
PAW	Plant available water
PCA	Principal component analysis
pH	Scale to specify the acidity or basicity of an aqueous solution
PIAs	Participatory impact assessments
PIP	Programme improvement plan
PLFA	Phospholipid fatty acid
POM	Particulate organic matter
R&D	Research and development
RECs	Regional Economic Communities
RICA	Rwanda Institute of Conservation Agriculture
RUFORUM	Regional Universities Forum for Capacity Building in Agriculture
SADC	Southern African Development Community
SAM	Sustainable agricultural mechanization
SAMA	Framework for Sustainable Agricultural Mechanization for Africa
SARI	Selian Agricultural Research Institute
SCAP	Smallholder Conservation Agriculture promotion project
SDGs	Sustainable Development Goals
SFIP	Smallholder Farmer Innovation Programme
SG2000	Sasakawa Global 2000 programme
SHT	Southern highlands of Tanzania
SIMLESA	Sustainable Intensification of Maize–Legume Cropping Systems for Food Security in Eastern and Southern Africa
SLM	Sustainable land management
SMAF-SQI	Soil Management Assessment Framework-soil quality index
SOC	Soil organic carbon
SPAD	Soil plant analysis development
SQI	Soil quality index
SSA	Sub-Saharan Africa
STISA	Science Technology Innovation Strategy for Africa
TARI	Tanzania Agricultural Research Institute
TLC	Total LandCare
TLU	Tropical livestock units
UNCCD	United Nations Convention to Combat Desertification
UN-CUMA	Union Nationale des Coopératives d'Utilisation De Matériel Agricole
UNECA	United Nations Economic Commission for Africa
UNFCCC	United Nations Framework Convention on Climate Change
Vision 25×25	Malabo Declaration vision to have 25 million smallholders in Africa adopt climate smart agriculture by 2025
VMP	Versatile multi-crop planter
VSLAs	Village savings and loan associations
VSSD	Versatile strip seed drill
WAICSA	West African Initiative for Climate-Smart Agriculture
WANTFA	West Australian No-Till Farmers Association
WUE	Water use efficiency
WT	Wheeled tractor (as in 2WT and 4WT)

Keywords

Numbers indicate Chapter(s) in which keywords are used.

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1 The Malabo Declaration and Agenda 2063: Making Climate Smart Agriculture Real with Conservation Agriculture in Africa

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Abstract

The African Union (AU) has provided the vision and even a hint of the future through *Agenda 2063: The Africa We Want*, to be achieved, in part, through accelerated agricultural growth and transformation, leading to shared prosperity and improved livelihoods. The promulgation is contained in the Malabo Declaration of the AU Summit held in Malabo, Equatorial Guinea, in June 2014. Attaining the ambitious commitments of ending hunger, doubling productivity, halving post-harvest losses and poverty, enhancing resilience in livelihoods and production systems to climate variability and other shocks, and reducing child stunting to 10% and numbers of underweight children to 5% by 2025 requires a definition of the strategies and the operative paradigms. The Declaration also calls for African agriculture to become climate smart. This chapter presents the strategic positioning of Conservation Agriculture (CA) in making climate smart agriculture (CSA) real in Africa and harnessing partnerships, informed by science and analyses of lessons from past interventions. We conclude that investing US$50 per household, in a capacity development programme in CA for 25 million households, has the potential to increase land productivity, produce food surpluses and transform livelihoods, thus attaining the Malabo Declaration targets. The investment in and adoption of CA-based CSA to that magnitude will not only move Africa's agriculture to a new level, where a significant proportion of agricultural land is managed with CA systems, but also supply competitively priced raw materials for transformative industrial and economic growth in Africa.

Keywords: Resilience, development, economic growth, African Union, Vision 25×25, livelihoods

1.1 The Malabo Declaration and Agenda 2063: Africa's Vision for Conservation Agriculture-based Climate Smart Agriculture

1.1.1 Agriculture, Livelihoods and Wealth Creation

Agricultural development is one of the most powerful tools to overcome extreme poverty in Africa, boost shared prosperity and meet the nutritional needs of a projected 2 billion people by 2050. Growth in the agriculture sector worldwide is two to four times more effective in raising real incomes among the poorest compared to other sectors (Townsend, 2015). Agriculture employs 65%–70% of the African workforce and supports the livelihoods of 90% of Africa's population while contributing 15% of total gross domestic product (GDP). In a number of

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countries agriculture has the potential to contribute more than 25% of GDP. Taking all the related sectors together, and including food processing, manufacturing and services, the total GDP contribution can be much higher. Agriculture is a major provider of jobs when there is no other employment opportunity. Given the central role of agriculture in relation to food security, employment, livelihoods and economic growth – particularly for Africa where a large majority of the poorest make a living from farming and in related sectors – agriculture remains, therefore, the most effective way to lift people out of poverty and meet the food needs of the increasing urban populations in the non-agricultural sectors. Sustainable and higher output smallholder and medium-scale agriculture is a necessary and effective way to combat poverty and hunger for the foreseeable future.

Agriculture in many low- and middle-income countries is facing a threefold challenge: needing to meet growing food security and nutrition goals, being environmentally adapted and sustainable, and contributing to improving livelihoods and national economic growth. Currently, agriculture, forestry and land use change are responsible for about 25%–30% of greenhouse gas (GHG) emissions. Furthermore, traditional forms of agriculture account for 70% of water use and generate unsustainable levels of pollution and waste. The conventional tillage-based agriculture also leads to a downward spiral of environmental and natural resource degradation (erosion, pollution, soil mining, loss of biodiversity, etc.). Tillage-based farming reduces soil organic matter accumulation, destroys soil structure and debilitates soil biodiversity, all of which are important elements in ecosystem functions that create healthy, productive soils and deliver sustainable production and ecosystem services. Therefore, a shift to climate smart agriculture (CSA) that contributes to reducing the adverse climate and environmental impacts to meeting Agenda 2063 and the Sustainable Development Goals (SDGs) is not just urgent, but imperative for Africa.

1.1.2 The Malabo Declaration: Transforming Africa's Agriculture

At the African Union (AU) Summit in Malabo, Equatorial Guinea, in June 2014, heads of state and government adopted a remarkable set of concrete agriculture goals to be attained by 2025. *The Malabo Declaration on Accelerated Agricultural Growth and Transformation for Shared Prosperity and Improved Livelihoods* was, for Africa, a renewal of the continent's resolve and commitment to the Comprehensive Africa Agriculture Development Programme (CAADP) Decision (AUDA-NEPAD, 2003). The Malabo Decision articulated commitment to a new set of goals showing a more targeted approach to achieve the vision of agriculture-driven economic growth, improved livelihoods and shared prosperity for all. The Malabo Summit reconfirmed that agriculture should remain high on the development agenda of the continent and is a critical policy initiative for African economic growth and poverty reduction.

The call for action was to establish an expedient process to translate these commitments into results. This included calling upon the AU Commission and New Partnership for Africa's Development (NEPAD) Planning and Coordinating Agency (NPCA) (now the AU Development Agency) to develop an implementation strategy and roadmap that facilitates translation of the 2025 targets of Africa accelerated agricultural growth and transformation into concrete results and impacts. Commitment Six of the Malabo Declaration calls for AU Member States to 'enhance resilience of livelihoods and production systems to climate variability and other related risks'. AU Member States are expected to 'ensure that at least 30% of farm, pastoral and fisher households are resilient to climate and weather-related risks'. In Malabo, African leaders and member states also adopted the Africa Climate Smart Agriculture Vision 25×25 which aims to support at least 25 million farm households to practise CSA by 2025 (AUDA-NEPAD, 2014).

1.1.3 Agenda 2063: Framework for The Africa We Want

Agenda 2063 is Africa's blueprint and master plan for transforming Africa into a global powerhouse. It is the continent's strategic framework that aims to deliver on its goal for inclusive and sustainable development and is a concrete manifestation of the pan-African drive for unity,

The 2014 Malabo Declaration made seven specific commitments to achieve accelerated agricultural growth and transformation for shared prosperity and improved livelihoods:

1. Recommitment to the principles and values of the Comprehensive Africa Agriculture Development Programme (CAADP) process
2. Commitment to enhance investment finance in agriculture
    - Uphold 10% public spending target
    - Create and enhance policy and institutional conditions for investment in agriculture, agribusiness and agro-industries
    - Operationalize the African Investment Bank
3. Commitment to ending hunger by 2025
    - At least double productivity (focusing on inputs, knowledge & skills, irrigation, mechanization)
    - Reduce post-harvest losses by at least 50%
    - Increase agricultural productivity with social protection for vulnerable groups
    - Nutrition: reduce underweight to 5% and stunting to 10%
4. Commitment to halving poverty by 2025 through inclusive agricultural growth and transformation
    - Sustain annual growth of at least 6% in agricultural sector GDP
    - Establish and/or strengthen inclusive public–private partnerships for at least five priority agricultural value chains with strong linkage to smallholder agriculture
    - Create job opportunities for at least 30% of youth in agricultural value chains
    - Preferential entry & participation by women and youth in gainful and attractive agribusiness
5. Commitment to boosting intra-African trade in agricultural commodities & services
    - Triple intra-Africa trade in agricultural commodities and services
    - Fast-track continental free trade area and transition to a continental common external tariff scheme
6. Commitment to enhancing resilience in livelihoods and production systems to climate variability and other related risks
    - Ensure that, by 2025, at least 30% of farm/pastoral households are resilient to climate- and weather-related risks
    - Enhance investments for resilience-building initiatives, including social security for rural workers and vulnerable social groups, as well as for vulnerable ecosystems
    - Mainstream resilience and risk management in policies, strategies and investment plans
7. Commitment to mutual accountability to actions and results
    - Conduct a biennial agricultural review process through the CAADP results framework, involving tracking, monitoring and reporting on progress
    - Strengthen national and regional institutional capacities for knowledge and data generation and management that support evidence-based planning, implementation, monitoring and evaluation

self-determination, freedom, progress and collective prosperity pursued under pan-Africanism and an African renaissance (AUC, 2015). As an affirmation of their commitment to support Africa's new path for attaining inclusive and sustainable economic growth and development, African heads of state and government signed the 50th Anniversary Solemn Declaration (AU, 2013) during the Golden Jubilee celebrations of the formation of the OAU/AU in May 2013. The Declaration marked the re-dedication of Africa towards the attainment of the pan-African vision of 'An integrated, prosperous and peaceful Africa, driven by its own citizens, representing a dynamic force in the international arena' and Agenda 2063 is the concrete manifestation of how the continent intends to achieve this vision within a 50-year period from 2013 to 2063. The Africa of the future was captured in a letter presented by the then Chairperson of the AU Commission, Dr Nkosazana Dlamini Zuma (AU, 2013).

Agenda 2063: The Africa We Want has seven aspirations (AUC, 2015), the first being 'A prosperous Africa based on inclusive growth and sustainable development'. The ten elements of this first aspiration, summarized in Table 1.1, identify and prioritize inclusive growth and sustainable development using Africa's resources as the basis of prosperity.

Table 1.1. The ten elements of the first aspiration: a prosperous Africa based on inclusive growth and sustainable development. From AU Commission, 2015 (http://creativecommons.org/licenses/by/4.0/, accessed 30 June 2021).

1. Eradicate poverty in one generation and build shared prosperity through social and economic transformation of the continent.
2. Aspire that, by 2063, Africa shall be a prosperous continent with the means and resources to drive its own development, with sustainable and long-term stewardship of its resources and where:
    a) African people have a high standard of living and quality of life, sound health and well-being;
    b) presence of well-educated and skilled citizens, underpinned by science, technology and innovation for a knowledgeable society is the norm and no child misses school owing to poverty or any form of discrimination;
    c) cities and other settlements are hubs of cultural and economic activities, with modernized infrastructure, and people have access to affordable and decent housing with all the basic necessities of life such as water, sanitation, energy, public transport and ICT;
    d) economies are structurally transformed to create shared growth, decent jobs and economic opportunities for all;
    e) modern agriculture for increased production, productivity and value addition contributes to farmers' and national prosperity and Africa's collective food security; and
    f) Africa's unique natural endowments, its environment and ecosystems, are healthy, valued and protected, with climate-resilient economies and communities.
3. By 2063, African countries will be among the best performers in global quality of life measures. This will be attained through strategies of inclusive growth, job creation and increasing agricultural production; investments in science, technology, research and innovation; and gender equality, youth empowerment and the provision of basic services including health, nutrition, education, shelter, water and sanitation.
4. Africa's collective GDP will be proportionate to its share of the world's population and natural resource endowments.
5. Africa's agriculture will be modern and productive, using science, technology, innovation and indigenous knowledge. The hand hoe will be banished by 2025 and the sector will be modern, profitable and attractive to the continent's youth and women.
6. Africa's human capital will be fully developed as its most precious resource, through sustained investments based on universal early childhood development and basic education, and sustained investments in higher education, science, technology, research and innovation, and the elimination of gender disparities at all levels of education. Access to post-graduate education will be expanded and strengthened to ensure world-class infrastructure for learning and research, and to support scientific reforms that underpin the transformation of the continent.
7. Africa's blue/ocean economy, which is three times the size of its landmass, shall be a major contributor to continental transformation and growth, through knowledge of marine and aquatic biotechnology, the growth of an Africa-wide shipping industry, the development of sea, river and lake transport and fishing; and exploitation and beneficiation of deep sea mineral and other resources.
8. While Africa at present contributes less than 5% of global carbon emissions, it bears the brunt of the impact of climate change. Africa shall address the global challenge of climate change by prioritizing adaptation in all its actions, drawing upon skills of diverse disciplines with adequate support to ensure implementation of actions for the survival of the most vulnerable populations, including islands states, and for sustainable development and shared prosperity.
9. Africa will participate in global efforts for climate change mitigation that support and broaden the policy space for sustainable development on the continent. Africa shall continue to speak with one voice and unity of purpose in advancing its position and interests on climate change.
10. Africa shall have equitable and sustainable use and management of water resources for socio-economic development, regional cooperation and the environment.

The AU's Agenda 2063 sets both the vision and the action plan for the development of the continent over the next 50 years. Adopted in June 2014, the first 10-year implementation plan (2015–2025) covers seven priority areas aligned with the SDGs. These priorities are defined in the 2014 Malabo Declaration on Accelerated Agricultural Growth and Transformation for Shared Prosperity and Improved Livelihoods, and positioned CSA as a priority on the continental development agenda.

Accordingly, African heads of state and government pledged, among other goals, to end hunger by 2025, focusing on the triple targets of increased production, reduced losses and waste and improved nutrition. Commitment Six of the Malabo Declaration calls for AU Member States to 'enhance resilience of livelihoods and production systems to climate variability and other related risks'. AU Member States are expected to 'ensure that at least 30% of farm, pastoral and fisher households are resilient to climate and weather-related risks'.

Elements 2 (e and f), 3, 5 and 9 comprise, to a large extent, action points relating to the realization of a prosperous Africa based on inclusive growth and sustainable development. These include: (i) modern and productive agriculture using science, technology, innovation and indigenous knowledge for increased production, productivity and value addition; (ii) banishing the hand hoe by 2025; ensuring that the sector will be profitable and attractive to the continent's youth and women; (iii) ensuring that Africa's natural endowments, environment and ecosystems are healthy, valued and protected, with climate-resilient economies and communities; (iv) development of strategies for inclusive growth and job creation; increasing investments in science, technology, research and innovation; gender equality and youth empowerment; and (v) addressing the global challenge of climate change by prioritizing adaptation in all actions, drawing upon the skills of diverse disciplines.

Based on the scientific and empirical evidence from around the world, including Africa, the development community in Africa is convinced that Conservation Agriculture (CA) has a unique role to play in making these action points a reality.

1.1.4 Operationalization of the Malabo Declaration and Agenda 2063: The ACCA Process

The First and the Second Africa Congresses on Conservation Agriculture (1ACCA and 2ACCA) were held to bring together expert knowledge, information and insights from practitioners from across different sectors and interest groups from the public, private and civil sectors under one platform. Here they discussed and strategically agreed upon scaling CA as an integral part of the growing food and agriculture systems in Africa. The 1ACCA, held in Lusaka, Zambia, in March 2014, led to the Lusaka Declaration where stakeholders committed to have 25 million smallholder farmers in Africa practising CA by 2025. This is popularly known as Lusaka Vision 25×25 (ACT, 2015). In summary, the support to the realization of the 1ACCA Declaration was anchored on ten interventions (Table 1.2).

The 2ACCA (https://www.africacacongress.org/, accessed 30 June 2021) was held in Johannesburg, South Africa, in October 2018 (outcomes summarized in Chapter 30, this volume). The congress participants resolved to foster and bring to scale the practising of CA, thereby making tangible contributions towards the attainment of Africa's development goals in Agenda 2063 in general; and, specifically, in the Malabo Declaration on Agriculture Transformation, including the 25×25 target. The Statement of Actions was summarized under the following categories:

1. Appeal to governments and other public institutions, organizations and partner institutions, civil society players as well as the private sector, at all levels, to intensify locally adapted actions aimed at fostering the enabling environment and empowering human capital in scaling up the practicing of CA.
2. Continued commitment by public, private, farmers and farmer organizations, civil society and development partners to embrace and build on the gains and lessons from implementation of the outcomes of the first Africa Congress on CA.
3. Reaffirm that the Africa Congress on CA is an important event with essential value in providing a platform for sharing, networking and linking up for potential collaborations. Therefore, urge ACT to continue in mobilizing all concerned stakeholders and championing the hosting of the Congress.

1.2 Conservation Agriculture and Climate Smart Agriculture

1.2.1 What is Conservation Agriculture?

CA is a systems approach to farming based on the application of three interlinked principles as defined by the Food and Agriculture Organization

Table 1.2. The ten Declaration points of the 1ACCA. Courtesy African Conservation Tillage Network (ACT).

Resolutions to achieve the Comprehensive Africa Agriculture Development Programme (CAADP) goal of 6% growth of the agricultural sector
Policy, political commitment and leadership
1. We call for commitment from all national and international stakeholders in the public, private and civil sectors to support the up-scaling of CA as a climate smart technology to reach at least 25 million farmers across Africa by 2025
2. Governments are called upon to create a conducive environment for the adoption and development of CA by investing more in CA education and extension; integrating CA training in educational curricula; and supporting CA farmers and their organizations
3. Governments are called upon to create an enabling policy environment to allow investment financing and technological development including private sector involvement in CA-related value chains
4. Development partners are urged to increase support to CA programmes under the CAADP agriculture climate agenda
Private sector engagement
5. Urge the private sector to proactively support up-scaling of CA through further innovations and increased investments financing appropriate CA technologies and related services
Training, extension, research and innovation, and knowledge support
6. ACT is to establish a quality-assurance system for accredited agricultural training institutions to provide CA training certificates. ACT will also collaborate with relevant stakeholders for the harmonization of CA training curricula
7. Farmers who have adopted CA should be supported to be champions and educators for their counterparts. Furthermore, they should establish locally relevant collaborations, innovation platforms and associations that can engage with government and other CA actors
8. Agricultural training institutions are requested to take up CA as an integral part of their training programmes and to take part in farmer sensitization and training efforts
9. Urge all concerned including Forum for Agricultural Research in Africa (FARA) and the Consultative Group on International Agricultural Research (CGIAR) to ensure research and extension on CA is farmer-focused and responsive to the needs of farming communities. Research findings should be communicated more effectively to inform decision making at different levels, as well as to support knowledge management systems, including extension and training
10. ACT, in collaboration with FAO and Regional Economic Communities (RECs) are called upon to support knowledge management by stakeholders, including the CA task forces.

of the United Nations (FAO, www.fao.org/ag/ca, accessed 30 June 2021), namely:

- Continuously avoiding or minimizing mechanical soil disturbance: sowing seed or planting crops directly into untilled soil and managing weeds without tillage to maintain soil organic matter (which is essential to promote soil biological processes; protecting soil structure, porosity, and overall soil health; and enhancing productivity, system efficiency, resilience and ecosystem services).
- Enhancing and maintaining a permanent mulch cover with crop biomass on the soil surface: using crop biomass (including stubble) and cover crops to protect the soil surface; conserving water and nutrients; supplying organic matter and carbon to the soil system; and promoting soil biological activity. This will enhance and maintain soil health including structure and aggregate stability; contribute to integrated weed, pest and nutrient management; and enhance productivity, system efficiency, resilience and ecosystem services.
- Diversification of species: using diversified cropping systems with crops in associations, sequences or rotations that will contribute to enhanced crop nutrition; crop protection; soil organic matter build-up and productivity; system efficiency and resilience; and ecosystem services. Crops may include annuals, trees, shrubs, nitrogen-fixing legumes and pasture, as appropriate.

These three CA principles, when put into practice together through locally formulated and adapted practices, should be implemented in combination with ‘other good practices and technologies’ related to integrated crop, soil, nutrient, water, pest and energy management by farmers to obtain full productivity, socio-economic and environmental benefits from CA for themselves and for society. The other good practices and technologies cover a large range of expertise from equipment and machinery to soil management, residue management and cover crops to pest (weeds, insects, pathogens) management and nutrient and water management including crop and cropping system management (FAO, 2011). It is also important that the practising of CA and related crop and input choices provides a viable business for the farm. In addition, each country and sub-region in Africa has its own unique resource endowment, socio-economic conditions, range of production and farming systems, and agricultural and economic development opportunities. Likewise, each country and sub-region will have its own particular measures and patterns for adaptation into the local circumstances as well as adoption and spread of CA in space and time.

This state of affairs calls for flexibility and adaptability in the practice and operation of CA systems according to the specific biophysical and socio-economic situation in each country and sub-region. Given this understanding, therefore, the CA principles need to be translated into locally adapted practices that can work systematically in defined crop–soil–water–nutrient–pest–ecosystem management at a variety of scales to provide for optimal and sustainable agricultural productivity.

CA has been shown to be appropriate for small- and large-scale farmers at all levels of farm power and mechanization, from manually operated hand tools to equipment drawn by animals to operations performed by motorized equipment and mechanization. Its adoption in Africa, although now growing at an exponential rate, needs to be accelerated in all countries. As noted in several chapters in this volume, some reasons for this lower-than-desired adoption rate and spread of CA can be attributed to, among others: (i) inconsistent policies that continue the promotion and support of tillage-based agricultural systems; (ii) weak policies, regulatory frameworks and institutional arrangements to support the promotion and mainstreaming of CA; (iii) inadequate awareness, knowledge and expertise around CA systems and the process of their adoption and spread among policy makers, academic, research, extension and technical staff; (iv) inadequate research into the development of off-the-shelf CA practices and technologies, leading to inappropriate CA technology packaging and dissemination; (v) inadequate CA-based enterprise diversification and integration in farming systems; (vi) inadequate skills and competencies among farmers and other CA practitioners; (vii) poor availability and access to the required CA equipment, machinery and inputs; and (viii) absence of strong continental institutions and strategic policy framework to guide the promotion and mainstreaming of CA across Africa.

1.2.2 Where is CA Practised in Africa and by Whom?

According to Kassam *et al.* (2019), in 2015/16 it was estimated that CA was practised globally on more than 180 million ha of cropland, representing some 10 million ha per year in the period 2008/09 to 2015/16. Recent estimates (see Chapter 4, this volume), puts Africa’s cropland under CA at about 2.7 million ha, an increase of 458% over the past 10 years with 2008/09 as a baseline. The large proportion of this spread has been by smallholder farmers. Although CA adoption figures are not available for all the countries in Africa, South Africa has the greatest area (1,176,200 ha), followed by Zambia (552,667 ha), Mozambique (289,000 ha), Ghana (235,000 ha) and Malawi (211,000 ha) (Fig. 1.1). Other notable countries include Zimbabwe, Kenya, Tanzania, Tunisia, Morocco and Sudan. In terms of percentage cropland under CA, the greatest proportion of land under CA is in Zambia (14.4%), followed by South Africa (9.5%), Malawi (5.6%), Ghana (3.2%), Mozambique (3.1%) and Zimbabwe (2.4%). In all, a large community of farmers, scientists and extension workers, as well as many public and private sector stakeholders in more than 25 countries, are now promoting research and participatory extension activities to facilitate CA adoption by smallholder farmers. Several countries, including South Africa, Namibia, Mozambique, Zambia and Morocco, have

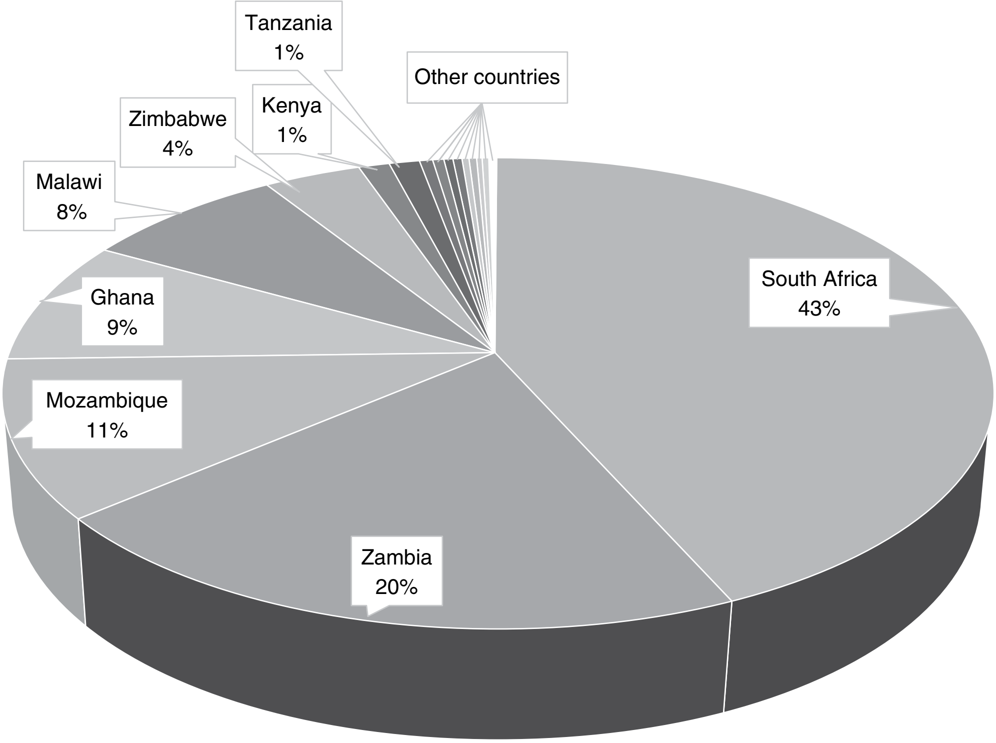

Fig. 1.1. Adoption of conservation in Africa, percentage by country. Other countries are detailed in Table 4.1. Authors' own figure.

adopted CA as the best option for achieving sustainable agricultural intensification.

Many large-scale farmers have been able to adopt profitable, mechanized CA in several countries such as South Africa, Zambia, Zimbabwe, Kenya, Tanzania, Morocco and Tunisia. However, in much of Africa, agriculture is dominated by smallholder farmers. They have different sets of drivers and challenges compared to large-scale farmers and they need greater support to adopt and practise CA (Derpsch *et al*., 2014). Unlike the highly mechanized large-scale farmers, the smallholders in Africa mainly use manual labour and animal traction, with less than 15% accessing tractor power (Mkomwa *et al*., 2017). Several participatory approaches to enhance CA adoption and scaling-up have been tested successfully. These include farmer field schools, lead farmer networks and no-till CA associations. Where mechanization is introduced, a service provider model, a group ownership approach or a combination may be suitable. The choice will depend on local constraints and the nature of the overall development support, including training, and on access to technical expertise, affordable supply chains and markets.

The introduction and promotion of CA for smallholder agricultural and livelihood development in Africa has been championed by a number of donor agencies, especially Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), the Norwegian Agency for Development Cooperation (NORAD) and individual farmers and extension agronomists since the 1980s, and research into CA practices began to be tested in the 1970s (Kassam *et al*., 2020). The FAO has also been championing CA since the late 1990s in partnership with NGOs, bilateral donors, national governments and research and development partners (Mkomwa *et al*., 2017). Some of the earlier countries where the FAO technical cooperation projects (TCP) with GIZ, NORAD and Department for International Development (DFID, UK) funding were implemented in partnership with national governments are: Burkina Faso, Kenya, Tanzania, Uganda, Ghana, Sudan, Zambia, Swaziland, South Africa, Zimbabwe, Mozambique, Lesotho, Eritrea and Egypt. ACT was conceived in 1998 at a GIZ-funded FAO regional workshop in Harare, Zimbabwe, and was set up in 2000 with GIZ and FAO support (Kassam *et al.*, 2000). The soil fertility initiative launched by FAO and the World Bank in 1996 supported CA in several African countries. In the late 1990s and early 2000s, West Africa – especially Ghana, Ivory Coast, Burkina Faso and Mali – was very advanced and active in CA promotion. ACT organized several international field visits to these countries in the period 2001–2004. The main players were those farming less than 1 ha (semi-subsistence).

In 2005 ACT and partners, with participation from national governments, NEPAD and international collaborators, organized the Third World Congress on Conservation Agriculture in Nairobi, Kenya (Mkomwa *et al.*, 2008). The Congress was sponsored by FAO, the French development agency AFD, the Agricultural Research Centre for International Development (CIRAD), GIZ and the Swedish International Development Agency (SIDA). The event created much-needed awareness about CA for policy makers, research and development practitioners, farmers and the private sector across Africa. This led to several FAO- and ACT-supported sustainable agriculture and rural development (SARD) projects in East (Tanzania, Kenya) and West (Burkina Faso) Africa, with funding from the Government of the Federal Republic of Germany and the International Fund for Agricultural Development (IFAD), respectively.

Promotion and spread of CA in Africa has relied mainly on donor funding and support through specific, time-bound projects. One of the exceptionally longer-term programmes that has made remarkable achievements since 1996 has been the Royal Norwegian Government-initiated CA support programme in Zambia with the Conservation Farming Unit (CFU). The key development partners who have supported CA in the recent past are: NORAD, IFAD, European Union (EU), GIZ, FAO and DFID. The majority of the programmes targeted countries in southern and eastern Africa under the Common Market for Eastern and Southern Africa (COMESA), Southern African Development Community (SADC) and the East African Community (EAC). West Africa-focused interventions include IFAD-financed country programmes in Ghana, Burkina Faso, Guinea and Niger; and the EU-funded ACT-implemented agroecology-based aggradation CA project (ABACO) which also covered Burkina Faso as one of the targeted countries. New entrants to the support of CA, mainly in West Africa, are the initiatives supported by African Development Bank (AfDB) under the Technologies for African Agricultural Transformation (TAAT) programme, with technical support from the Argentinian No-Till Farmers Association (AAPRESID). The initial interventions are in Ghana, Guinea, Ivory Coast and Sierra Leone. Their target is not the typical 1- or 2-ha smallholder farmer but medium- and large-scale farmers managing 100 ha and above, with soybean and maize being priority crops.

Other prominent international NGOs and development organizations that are or have been involved in promoting CA in Africa include Concern Worldwide, Canadian Food Grains Bank, CARE International, Total Landcare, Howard Buffett Foundation, Aga Khan Foundation, and Gates and Rockefeller Foundations (through the Alliance for a Green Revolution in Africa, AGRA). Several national-level NGOs are also promoting CA: Kwa-Zulu Natal No-till Association in South Africa, CFU in Zambia, Foundation for Development in Zimbabwe and Association pour la Promotion d'une Agriculture Durable (APAD) in Tunisia.

The focus of most CA initiatives has been on food security and livelihood development; participatory adaptive research with smallholder farmers for technology development for sustainable production; and advocacy for public and private sector support. Such initiatives are bound to have significant implications for the adoption and spread of CA in the region and need to be supported and encouraged.

The private sector has also contributed significantly to the current status of CA in Africa. The main stakeholders include the large-scale farmers (e.g. in South Africa, Kenya, Tanzania, Zambia and Zimbabwe) and CA equipment manufacturers, distributors and agricultural input suppliers. Their successful implementation of CA, especially in marginal and diverse conditions, has provided useful learning platforms for other farmers, policy makers and development organizations. Some large-scale farmers have even introduced outreach programmes to support neighbouring smallholder farmers.

Engagement of regional economic communities (RECs) across Africa in the promotion and uptake of CA is considered to be essential to attract greater investments across all stakeholder institutions. The RECs can help to sustain the existence of a conducive development environment for all stakeholders to play their respective roles. A good policy environment, commitment of national governments, and public and private sector institutional support is key to successful implementation of CA and CSA programmes in Africa. It is, therefore, necessary to have a regional platform where regional bodies can share evidence-based CA information to enable the formulation and implementation of policies and institutional strategies that can attract significant long-term investments to support the introduction, adoption and spread of CA as a core component of CSA initiatives.

1.3 Climate Smart Agriculture: What is it?

CSA is defined by FAO (2013) as an approach that helps to guide actions needed to transform and reorient agricultural systems to effectively support development and ensure food security in a changing climate. CSA aims to tackle three main objectives: sustainably increasing agricultural productivity and incomes; adapting and building resilience to climate change; and reducing and/or removing GHGs where possible. It addresses inclusive development through improving adaptive capacity at multiple levels from farm to nation and accelerating progress towards meeting the SDGs and the Paris Agreement ambitions.

1.3.1 Conservation Agriculture-based Climate Smart Agriculture

The importance and role of CA in sustainable agricultural growth and economic development has been clearly documented and can, therefore, be considered as the most appropriate entry point in transforming agricultural production in Africa. The benefits of CA include harnessing ecosystem services to society as well as benefits related to productivity; and building and enhancing resilience and system self-recuperation (Kassam *et al.*, 2017). The ecosystem services include providing fresh water supplies, biological nitrogen fixation, biological products, groundwater and streamflow regulation, and runoff and erosion control. The benefits are at multiple levels in the landscape (at field, farm and local community), the watershed/basin and in the greater society. The adoption and spread of CA in Africa is increasing exponentially but can be accelerated by more systematically addressing the challenges and constraints outlined above (and in other chapters in this volume). Addressing these challenges and constraints requires interventions at all levels, but particularly at the higher levels, to ensure development of appropriate policies and regulatory frameworks to support adaptation, adoption, up-scaling and mainstreaming of CA, and to attract the national and international private sector to invest in and develop CA-supportive businesses around agricultural commodity value chains and input supply chains.

Chapter 2 notes that the largest existing model of CSA worldwide in terms of surface area is that of CA (as noted earlier, covering about 180 million ha of cropland in 2015/16, and more than 2.7 M ha in Africa in 2018/19; see Chapter 4, this volume). In addition, the rationale for CA to serve as the core of CSA is its ability to contribute to all three of its objectives while also rehabilitating degraded lands. Worldwide, scientific evidence from research and empirical evidence from farm practice shows that CA is an effective strategy for achieving all the CSA dimensions (Kimaro *et al.*, 2015; Kassam *et al.*, 2020). However, the transformational power of CA systems and related technologies at the paradigm level of sustainable agriculture and ecosystem management depends on the economic and political context, the needs of the farming communities and society at large and a country's socio-economic and institutional conditions.

1.4 State of Conservation Agriculture and Climate Smart Agriculture in Africa and Opportunities

1.4.1 State of CA and CA–CSA Activities in Africa

Several initiatives are being undertaken by the multi-stakeholder Africa Conservation Agriculture

Community of Practice (Africa CA-CoP) to support operationalization of the 1ACCA Declaration, the Malabo Declaration, CSA Vision 25×25 and Agenda 2063. Some of the prominent initiatives include:

- **Africa Climate-Smart Agriculture Alliance (ACSAA)**: a pan-African multi-stakeholder platform for facilitating peer exchange and learning, building a common understanding of contributions to CSA, and aligning and harmonizing various climate change and agriculture programmes being undertaken across Africa and at multiple scales. ACSAA also provides the coordination platform needed to take stock of progress towards the AU Vision 25×25 on CSA. The alliance is hosted by the AU Development Agency (AUDA–NEPAD) and draws its membership from AU Member States, private sector, civil society and other non-state players such as learning and research institutions. Initial efforts leveraged on the interest of international NGOs wishing to improve livelihoods in Africa using CA. The international NGOs targeting 6 million households out of Africa's Malabo target of 25 million are Care, Oxfam, World Vision, Catholic Relief Services (CRS) and Concern Worldwide.
- **Research Program on Climate Change, Agriculture and Food Security (CCAFS)**: the purpose of the CCAFS of the Consultative Group on International Agricultural Research (CGIAR) is to marshal the science and expertise of CGIAR and partners to catalyse positive change towards CSA, food systems and landscapes. This will enable CGIAR to play a major role in bringing to scale practices, technologies and institutions that enable agriculture to meet the triple goals of food security, adaptation and mitigation. Of the CGIAR centres, the International Maize and Wheat Improvement Center (CIMMYT) and the International Center for Agricultural Research in the Dry Areas (ICARDA) have made longstanding and significant contributions to CA research in southern Africa and northern Africa, respectively.
- **Adaptation of African Agriculture (AAA or Triple A)**: an initiative launched at the United Nations Framework Convention on Climate Change (UNFCCC) Conference of the Parties (COP) 22: this was launched and promoted by Morocco during COP 22 held in Marrakesh from 7 to 18 November 2016. AAA aims to raise more funding for the adaptation of small-scale African agriculture while supporting transformation, structuring and acceleration of agricultural development (more information in Chapter 2, this volume).
- **African Conservation Tillage Network (ACT) – Conservation Agriculture Centres of Excellence (CA-CoEs)**: with the support of NORAD, ACT has initiated the establishment of CA-CoEs in Africa. The CA-CoEs concept (see Chapter 25, this volume, for more detail) has the expected impact to deliver coordinated demand-driven CA-based agricultural technologies, information services and knowledge to farmers and other stakeholders, for increased agricultural productivity, profitability, competitiveness and sustainable use of natural resources. The CA-CoEs key thrusts are research, outreach, linkages, information technology and training. This is attained by developing infrastructure of services and human capacities to include support for research and development, development of standard curricula for the training of farmers and key actors along the value chain, mainstreaming CA in agricultural training institutions, and capacity building of existing and potential CA-based mechanization service providers. Others include establishing strategic linkages of farmers with key support services such as financing, crop insurance, machinery suppliers and information. The CA-CoEs model builds around a selected public agricultural research or tertiary academic institution. The model is coordinated by an advisory panel comprising key thematic professionals from national ministries of agriculture, academia, research, farmers' organizations, private sector, value chain, youth and women, development partners and organizations carrying out best practice. With an initial establishment of six CA-CoEs, ACT plans to set up 25 such centres by 2025.

- **Other institutions involved in CA-based CSA research and development include**:
    - The RECs of COMESA, SADC, EAC and Economic Community of West African States (ECOWAS) have had the support of NORAD, DFID, the EU and the United States Agency for International Development (USAID) at different times to support the development and research of CA. In their leadership roles, the RECs have also in turn engaged CGIAR, Food, Agriculture and Natural Resources Policy Analysis Network (FANRPAN) and international NGOs such as ACT. Another intervention is the West African Initiative for Climate-Smart Agriculture (WAICSA), a West Africa-led blended finance fund with a specific focus on increasing the uptake of CSA practices by smallholder farmers. WAICSA has the potential to improve the food security of 90,000 smallholder farming households in the region and to convert over 185,000 ha to CSA.
    - The Forum for Agricultural Research in Africa (FARA) is the apex continental organization responsible for coordinating and advocating for agricultural research for development (AR4D). It has several regional affiliated partners supporting CSA research at the REC level. These include the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA), the Centre for Coordination of Agricultural Research and Development for Southern Africa (CCARDESA), the West and Central African Council for Agricultural Research and Development (CORAF/WECARD) and the North Africa Agricultural Sub Regional Organization (NAASRO).

1.4.2 Conservation Agriculture – What if 25 Million Households Adopted Conservation Agriculture-based Climate Smart Agriculture?

The adoption by 25 million smallholder and medium-scale farming households of CA-based CSA in Africa will permanently transform their livelihoods, which will become more productive and resilient, with improved soil health as the catalyser. This will require the transformation of a number of institutions in the public and private sector to provide the required support to the value chains to sustain the mainstreaming processes involved. Key outcomes of the transformation and CA systems optimization include: doubling of yields of staples, even in the semi-arid systems, with similar or reduced production costs; significant improvement in mother and child nutrition from the increased production of surplus food and crop diversification with nutrient-rich legumes; more equitable inputs markets creating rewarding employment in agribusiness and services; better rural employment created for rural farmers, mechanization service providers and processors; enhanced CA and related value-chain machinery production businesses and employment; significant contribution to GHG emission reductions and carbon sequestration from reduced fuel consumption for agricultural production, carbon sequestration from no-till and reduced use of nitrogen fertilizers offset by biological nitrogen fixation with leguminous cover crops (Fig. 1.2).

CA has the potential to transform farming into a new normal where it is the conventional way of farming, with the sustainability benefits defined under the three interlinked CA principles and described as follows.

Diversification of crops through rotations and associations has been reported to replenish soil fertility. This is particularly so when crops are rotated and/or intercropped with nitrogen-fixing legumes which transform atmospheric nitrogen through nitrogen-fixing bacteria in root nodules into biological forms of nitrogen compounds that are usable by plants. Keeping the soil covered, with cover crops or crop residues (a fundamental principle of CA), leads to improvement in soil properties, a stable CA system and increased biodiversity in the agro-ecosystem. CA also leads to an increase in soil organic matter in a process known as recarbonization. This is the foundation for improved soil health and results in numerous benefits including enabling crops to use the nutrients in the soil more effectively; helping to control weeds, diseases and pests by breaking their life cycles through the introduction of new crop species in the cropping system;

What does it mean to have
25 million households
adopt CA?

Doubling of cereal yields (e.g. 1.5 to 3 tonnes per hectare, even in semi-arid areas); thus an increase of 37.5 million tonnes annually worth 6.375 billion USD, and a capacity development cost of USD 1.25 billion (USD 50 per farmer).

Significant improvement in mother and child nutrition, contributing to the Malabo Declaration targets to reduce underweight to 5% and stunting to 10% from increased production and access to legumes and oil seeds. Intercropping and relaying of legumes (lablab, beans, peas, soya beans) and oil seeds (sunflower, simsim, canola, etc.) is a pre-requisite under CA systems, thus resulting to more consumption due to the improved access and support on awareness.

Surplus cereals, legumes and seed cake form the basic ingredients for expansion of women controlled small-stock (e.g. poultry, goats, aquaculture, etc.) livestock feeds and other agro-industries as well as other income generating enterprises that will efficiently utilize time saved from adopting CA.

An open but organised market of crop production inputs (e.g. crop and cover crop seeds, fertilizers, and agro-chemicals) worth USD 10 billion (USD 400 each farmer) annually.

Decent rural employment for at least 500,000 farmers as CA mechanisation service providers (contractors), agro-dealers and processors serving the 25 million households.

USD 25 billion worth of CA equipment market is an opportunity for locally adapted designs, manufacturing, importation and the distribution industry. Weather related crop insurance premiums of USD 1.25 billion annually (USD 50 per farmer or ha)

Climate smart agriculture. Not ploughing saves 16 litres of diesel per hectare, i.e. a saving of 200 million litres of diesel for 50% of the 25 million farmers using tractors, equivalent to USD 200 million annually. At 2.62 kg of carbon dioxide emissions per litre of diesel, 524,000 tonnes of CO_2 are saved annually in addition to sequestered CO_2 from no-till, cover crops and stubble retention.

Fig. 1.2. What does it mean to have 25 million households in Africa adopt conservation agriculture? Authors' own figure.

and reducing the risk of total crop failure in cases of drought and disease outbreaks.

Women in many countries in Africa generally fare worse on most social and economic indicators than their male counterparts. Their unequal status is shaped by the interlocking factors of poverty and discriminatory treatment in family and public life. Various studies have indicated that CA reduces labour requirements compared with conventional practices, and so it is attractive to women, who constitute a large proportion (40%) of small-scale farmers and of the farm labour force. Women engaged in CA have increased involvement in decision making at household level, from agricultural practices and crop use to household expenditure. Social status is heightened among women engaged in CA because of improved, reliable production and income (Owenya *et al*., 2011), with a larger proportion reporting self-confidence and an elevated status in their community and within their extended families (Reid and Chikarate, 2013). A clearer gender equality perspective in CA and CSA investments gives women the same access to production resources as men, leading to effective poverty reduction and an increase in both sustainability and productivity in agriculture.

At a higher level, adoption of CA at the magnitude of 25 million households will enable the AU to attain the ambitious Malabo Declaration goals described in section 1.1.2 and the SDGs, at an investment of US$50 per household.

1.4.3 Safe and Efficient Use of Agrochemicals to Reduce Their Environmental Impact

Recent research findings show that CA systems are successful and profitable while using fewer external inputs and expending less energy, resulting in 40% and 50%–90% reductions in energy and labour needs, respectively (detailed in Chapter 7).

Smallholder agriculture in low- and medium-income countries in Africa is often relatively resource efficient and less chemical intensive. The need for a shift towards increased environmental sustainability is considered prudent and not in conflict with the poverty reduction agenda. On the contrary, such environmentally adapted agriculture can yield increased productivity and a number of other gains in the form of ecosystem services such as clean water and natural pest control, and also provide animal feeds, increased resistance to extreme weather and much more to benefit the smallholder. The objective is not to preserve smallholder agriculture, but to give it scope to develop, including into more biological forms of CA systems that minimize or avoid the use of chemicals.

1.4.4 Mechanization and Commercialization of Smallholder Farming

Smallholder farming in Africa is largely subsistence, with little or no market integration for most farmers, and very few farmers satisfy their living requirements from their farming income alone. When farmers do not generate surpluses/profits from farming, they are unable to invest in acquisition of support services (such as mechanization or irrigation) or improved production inputs. The land holdings of many smallholders, however, could be sufficient to generate income if used efficiently, but many farmers are not able to increase production and productivity without major capital investments, which keeps their farm operations at low levels. Through CA, even resource-poor farmers can improve production and productivity drastically and without capital requirements; this not only increases the output but also offers an opportunity to enter into viable market linkages as production becomes more reliable. Thus, CA offers low-cost entry into commercial farming, without the need for unaffordable capital investments, giving farmers an ideal opportunity to commercialize their farming.

Commercialization of farming requires organized responses not only to the challenges of climate smart agricultural production, but also to the issues involved in larger value chains – input/output markets, financing, etc. In the past these were a shared responsibility between farmers, government, financial institutions and, in some cases, the market. The recent history of commercial industry in Africa has, however, eroded the trust of smallholders owing to the failure of farmer cooperatives. There are 'islands' of success with some contract farming models, savings and credit cooperative societies (SACCOS) and producer organizations. While these business models provide lessons to inform designs for interventions of the next generation of support to smallholders, African governments have to overstretch to prove their commitment to re-establish the technical capacity, infrastructure and financing to enable farmer cooperatives or organizations to commercialize.

1.5 The Second Africa Congress on Conservation Agriculture and This Book

The Second Africa Congress on Conservation Agriculture (2ACCA; https://africacacongress.org/, accessed 30 June 2021) provided an opportunity for CA stakeholders in Africa and elsewhere to come together and review the progress in the transformation of traditional agriculture into CA; to discover what new knowledge was available to improve the performance by farmers and service providers; and to learn what further actions were needed from all stakeholders to catalyse the implementation of CA initiatives in the context of Agenda 2063.

As this book makes clear, a growing community of stakeholders is now working seriously to enhance the adoption of CA in Africa, so bringing tangible CSA benefits and hope to millions of farmers, their households, youth and society at large. The stakeholders come from the public and private sectors and from civil society, and they continue to innovate and experiment. New approaches are being examined, including in science and technology; development strategies; mechanization along the value chain; service provisioning; education and training; and in mobilizing greater investments for longer-term agricultural and economic development needs.

The materials presented in this book are essentially based on the outputs/outcomes of the Second Africa Congress, which also reaffirmed the role of CA in making CSA with Agenda 2063 a reality. The knowledge sharing and discussions at the congress, and which are documented in this book, focused on several critical areas:

1. Why and how CSA can be made a reality in Africa through the use of CA, highlighting evidence-based examples of progress in countries in all regions of Africa.
2. What necessary conditions need to be established for institutions and policies to create an enabling environment for scaling and mainstreaming. This discussion drew on global evidence, as well as on evidence from countries in Africa where significant progress in CA uptake is occurring.
3. Scientific and empirical evidence. This was based on research and innovation shared and discussed in depth to provide a guiding base for CA uptake and spread in different farming systems and in different agroecological zones, with particular attention to smallholder farmers.
4. The efforts that are needed and being applied in the area of education and training and in capacity development for CA uptake; this issue attracted considerable attention and discussion.
5. The investments that must be directed across agricultural sectors and institutions to drive agricultural transformation in the coming decades. In light of the information shared and exchanged, and the ensuing discussions, congress issued a stakeholder statement on the critical importance of CA in the implementation of Agenda 2063, and on the need to continue to direct greater attention and investments in the development of CA-based CSA across Africa.

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2 Development of Climate Smart Agriculture in Africa

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Abstract

Climate change, food system complexity and changing international demands are creating new realities, challenges and opportunities. In this respect, unlocking Africa's agricultural potential is both a vital and a daunting aspiration to achieve commitments to the climate and development of the visionary and optimistic framework of Agenda 2063. In response to these challenges and drivers, climate smart agriculture (CSA) was promoted by governments and international organizations to functionally contribute to reducing vulnerability and increasing adaptation to climate change while ensuring sustainable progress in living standards, value chains and mitigation capacities of farming systems. Remarkable benefits in terms of increased productivity and performances of farming systems, enhanced farmers' resilience, environment and value chain sustainability, and developments of CSA in Africa and lock-in barriers exclusion are under way. These are because of investment in policy formulation and planning, approaches, alliances, incentives, capacity development, research, knowledge sharing, networking and engagement in bold regional and local initiatives. Side benefits from CSA are numerous for Africans in general and for producers and growers in particular. They include poverty alleviation through green growth, just and ethical transformation, gender equity and empowerment, shared prosperity and entrepreneurship via innovation. Overall, investing in CSA and particularly in Conservation Agriculture may greatly enhance a country's strategic thinking and capacity to meet the Sustainable Development Goals (SDGs).

Keywords: SDG, food security, climate change

2.1 Introduction and Background

Over the past decade, Africa has witnessed significant economic growth. However, food and nutrition security and climate security are twin crises that may delineate the future of the continent. In other concerns, eradicating hunger, alleviating poverty and sustaining economic growth are among the highest transnational priorities of decision makers and political leadership (FAO, 2017a). In addition, these challenges are the daily concerns of farmers and citizens at large, who are forced to adapt to their impacts and stresses.

None of the global challenges stands alone (Connolly-Boutin and Smit, 2016). Chronic drivers for these threats are scale dependent, interlinked and complex, and include poverty, environmental shocks, poor market access, social vulnerability of communities, economic

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drawdown and food price volatility. The impact of economic slowdowns on food production and prices has exacerbated such challenges.

Throughout the continent, the cycle of degradation is interlinked with rampant food insecurity and declining livelihoods, and associated with a downward spiral of environmental degradation (erosion, pollution, soil mining, etc.). The annual costs of land degradation at the global level were found to equal about US$300 billion, while the annual funds needed for climate change adaptation are estimated to be US$20–30 billion per year for the next 10 to 20 years (FAO, 2017b). Sub-Saharan Africa (SSA) accounts for the largest share (22%) of the total global cost of land degradation (Nkonya *et al.*, 2016).

In 2015, the world witnessed the adoption of two major transformative policies: the UN Agenda 2030 on SDGs and the Paris Agreement on Climate Change. In this framework, SDG 2 is intended to 'End hunger, achieve food security and improved nutrition, and promote sustainable agriculture,' while SDG 13 pleads for us to 'Take urgent action to combat climate change and its impacts.' To unlock the agriculture sector in Africa, achieve these goals and satisfy inclusive development, differential paths are needed for profound transition and transformation of food value chains and farming systems. As such, sustainable intensification is gaining greater importance in discussion fora and can be a game changer for desertification control (van Ittersum *et al.*, 2016; Rockström *et al.*, 2017; Caron *et al.*, 2018). In other words, Africa needs to find more sustainable ways to engage with its natural environments while satisfying its food security and human development obligations (Appiah *et al.*, 2018).

Reducing trade-offs and capturing the synergies (and nexus) between climate change mitigation, food security strengthening and inclusive development will certainly help to alleviate poverty and contribute to economic growth through nationally determined contributions (NDCs), as clearly claimed by the Paris Agreement. Such a framework will also ease the interlinkages among sectors (i.e. food, energy and water) and scales, and detect and consolidate co-benefits (Liu *et al.*, 2018).

Food security is critically threatened by climate change, soil mining, degrading resources, rapid population growth, limited household assets and agricultural expansion at the expense of pastures and forest lands (FAO, 2019a, c). To stem these impacts on farmers, governments have enacted emergency measures to provide funding and other institutional support. However, the quantum, speed and tenor of the response by African governments have not yet been impressive (Mbow, 2020). On the other hand, since 2014 the African Union (AU) has launched several continental and regional programmes and plans to end hunger, alleviate poverty and globally to achieve the SDGs (FAO, 2017b).

In 2016, the Sustainable Development Goals Centre for Africa (SDGC/A) was created to support governments, civil society, businesses and academic institutions in accelerating progress towards the achievement of the SDGs in Africa (SDG Centre, 2019). However, according to a report by the Alliance for a Green Revolution in Africa (AGRA, 2018a), more than half the countries in Africa are not on track to meet the Malabo targets to which they all subscribed. In this regards African governments are operationalizing CSA as their pursuit of the SDGs but a deep understanding of governance, synergies, trade-offs and co-benefits of simultaneous implementation is still needed (Newell *et al.*, 2019).

Sustainability is tightly linked to changes in innovation and systemic transformation of agriculture (Appiah *et al.*, 2018). According to Springmann *et al.* (2018) in the absence of changes in technologies and mitigation measures, the negative environmental effects of current food systems will increase by 50% to 90% by 2050, reaching levels that are beyond planetary boundaries. Hence, to achieve food security while increasing the adaptive capacity and resilience of agricultural systems and mitigating climate change, it is necessary to rethink the whole basis of food and farming systems and develop a synergetic combination of mitigation measures (FAO, 2017b).

Climate smart agriculture (CSA) is seen as a key strategy for decision makers to capture these paradigms and for farmers to strengthen their households and businesses in Africa (FAO, 2013; IPES-Food, 2016, 2017). In fact, concerns about the sustainability of conventional and traditional agriculture have promoted interest in CSA that includes various traditional conservation-minded farming methods blended with modern and hi-tech farming technologies. This includes the Comprehensive Africa Agriculture

Development Programme (CAADP) (2015–2025) results framework, which targets at least 25 million smallholder households for practising CSA by 2025, led by the AU Development Agency-New Partnership for Africa's Development (AUDA-NEPAD). However, so far African farmers have either been slow to adopt or failed to sustain the use of CSA.

Because of the scale and complexity of farming systems in Africa (Dixon *et al.*, 2020), responding to demands for transformed farming practices requires new forms of system thinking, knowledge exchange, sharing and diffusion. The adoption of starting points and pathways varies considerably, depending on the type and interactions of agriculture, environment and socio-economic contexts. Such interactions merit serious investigation which should make CSA solutions and their benefits more accessible to all partners in value chains.

This chapter aims to clarify the major issues and the role that CSA can play in unlocking agricultural potential and ensuring agricultural development and transformation in Africa. It provides examples of international and regional initiatives and innovative approaches (such as frontline implementation, policy alignment, research and advocacy) to drive and support the extension of CSA practices in Africa. It is also intended to promote the development of Conservation Agriculture (CA), a key CSA strategy, across the continent and address the barriers and growing challenges to implementing CSA and CA. It illuminates potential drivers to its rapid upscale and secure spread. On-going programmes and initiatives are also of prime importance to developing CSA on the continent and should be strengthened. The chapter is intended for a wide audience from producers to policy makers and also to CSA specialists and government, non-government and international organizations.

2.2 Food Security and Climate Change: Major Drivers of Agricultural Transformation

Africa has a population of 1.27 billion; it has increased 4.6 times from 1960 to 2019, and represents 18.3% of the world's population (UN Reports, 2017; FAOSTAT, 2020). The population is projected to increase to about 2.5 billion by 2050 and 4.4 billion by 2100 (Niang *et al*, 2014; UN Reports, 2017). Hence, food production must increase by at least 70% before 2050 to support population growth and rapid urban development (Smit, 2016). In particular, the demand for cereals in SSA will approximately triple.

Forty countries in Africa have poverty levels exceeding 40% (AfDB, 2020a). In SSA, the numbers of people in extreme poverty are not falling, but rather are persistent (approximately 48% of Africa's population – 450 million people – are living on less than US$1.25 per day) (The World Bank, 2015; Roser and Ortiz-Ospina, 2020).

Hunger is rising in almost all Africa's sub-regions. According to FAO *et al.* (2019), the prevalence of undernourishment reaches 22.8% in SSA, 26.5% in Central Africa and 30.8% in Eastern Africa. Such high undernourishment has an adverse impact on gender inequalities, population health and economic conditions and is inversely correlated to gross domestic product (GDP) (AfDB, 2020a). The main causes of increased hunger and food insecurity are climate change, population growth, social deprivation, deforestation, overgrazing, urbanization and mismanagement of agricultural lands. In other terms, the multiple food system challenges remain vast, suggesting unsustainable forms of intensification in much of the region (Tittonell and Giller, 2013; Dury *et al.*, 2019). Food-insecure households may increase in coming decades because of the high population numbers and low per capita income growth (Thome *et al.*, 2019).

Climate change is a unique global challenge in terms of magnitude, scale, urgency and complexity of action. In many areas droughts will become more frequent, more intense and last longer. In others, new patterns of rainfall will cause flooding and soil erosion. Such extreme events may also occur in the same locality or watershed (Awojobi and Tetteh, 2017).

African agriculture is the most affected sector as 95% of cultivated area is rainfed. The continent will lose between 2% and 7% of agricultural GDP annually from climate change (Niang *et al.*, 2014). According to FAO (2011b; 2019d), around 30% of the food produced was lost in SSA due to drought and extreme weather during the period 2000–2017.

Africa confronts a growing scarcity of water and land, and of soil fertility depletion (Barbier and Hochard, 2016; Mekonnen and Hoekstra, 2016), which result in insecure livelihoods for marginalized and vulnerable farmers. According to The Montpellier Panel (2013), soil degradation affects 65% of croplands, 30% of grasslands and 20% of forest lands in Africa and the situation could be worse by 2050 due to the negative impact of climate change. In fact, African societies have nearly reached a level of abrupt and even irreversible changes in terms of social and environmental degradation (Steffen *et al.*, 2015) and, without decisive and rapid action, the lives of those living in Africa will be devastated.

Food insecurity is not driven solely by population growth and climate change, but also by the rising urbanization of Africa, as about 40% of the population is living in urban areas and the process of urbanization will reach 56%–60% by mid-century (UN, 2019). Competition from cities for resources (food, water, energy, land, food) will exacerbate the problems of agricultural growth.

Per capita food consumption in Africa has been rising ten times faster than per capita food production. By 2030, meat and milk consumption is projected to increase by 2.8% and 2.3% per year, respectively, while the annual demands for cereals, fruits and vegetables are anticipated to grow by about 2.1%. To satisfy the dietary energy requirements of the African population, food imports have grown consistently over time (FAO, 2017b). They are estimated at US$35 billion yearly and are projected to reach US$110 billion by 2025. At the same time, the value of Africa's food market is projected to increase from US$313 billion in 2010 to US$1 trillion in 2030, of which a non-marginal share will come from the livestock sector (AGRA, 2018b; https://agra.org/our-strategy/, accessed 30 June 2021). This dependence of Africa (and especially of the Sub-Saharan region) on imports and hence on international trade, however, may accentuate food insecurity when restrictions, crises and disturbance in food supplies and local production occur (Bren d'Amour *et al.*, 2016). Such issues, which impact Africa's trading position, should be considered in the decisions of AfCFTA (African Continental Free Trade Area) (https://au.int/en/cfta, accessed 30 June 2021).

2.2.1 Farming Systems and Natural Resources: Diversity and Fragility

The total land area of Africa is about 30 million km^2, and represents 22% of the global area. SSA is a large region of 24.6 million km^2 where forests and woodlands occupy 6.7 million km^2; arable land is estimated at 8.1 million km^2, of which only 2 million km^2 is cultivated (UNEP, 2016).

Land is a critical component of the climate system and its degradation disturbs the flows of water, carbon, nitrogen and oxygen that are essential building blocks in all farming systems (Fuchs *et al.*, 2019). Farming systems in Africa are characterized by a high degree of diversity and heterogeneity, livelihood resources, typologies and strategies, social and population pressures, access to markets, institutions and agroecological conditions (Dixon *et al.*, 2020). Hence, such high diversity implies that farmers may respond differently towards any development support or policy initiative (Tittonell *et al.*, 2011; Kansiime *et al.*, 2018). On the other hand, decision makers are confronted with sustainable ways of targeting investments and developing policies and programmes to maximize rural and agricultural growth, taking in account socio-economic and ecological variability within farming systems (Tittonell, 2014).

The agriculture sector is critical to the African economy, representing 25% of its GDP and roughly 20% of its total exports, yet it faces severe challenges – low soil productivity, stringent water restrictions, low investment in terms of mechanization and input, and recurrent drought and floods. Agriculture and food systems are resource intensive, using 70% of available water, 30% of total energy demand and 60% of the labour force (FAO, 2015). Most African countries are dependent on agriculture, and a high prevalence of hunger coincides with resource scarcity and low crop yields.

Farmers are the stewards of our planet's precious soil but are at the mercy of diverse threats (weather extremes, pests, diseases, market, trade). Of the 608 million farms, 12% are located in SSA and less than 3% in North

Africa (Lowder *et al.*, 2019). Eighty percent of Africa's farms are small and family operated (Eastwood *et al.*, 2010; Livingston *et al.*, 2011; Lowder *et al.*, 2019). The average farm size is 1.6 ha in SSA (excluding South Africa) and 3.6 ha in North Africa (Lowder *et al.*, 2019). In addition, women are the backbone of African agriculture (Altieri *et al.*, 2012; FAO, 2017b).

Agriculture is a mix of rainfed and irrigation farming. However, in Africa, rainfed agriculture produces 90% of staple food needs and the irrigated supply provides only 5%. This continent suffers the most from water scarcity, which can be explained by a precipitation deficit in more than two-thirds of the continent (Masih *et al.*, 2014) and by the lack of conveyance, storage and distribution infrastructures in regions endowed with water. For example, in the Southern African Development Community (SADC) only 6.6% of the cultivated area is equipped for irrigation, which is a very small percentage of the irrigation potential of the region (SADC, 2014). In terms of geographic distribution, Central Africa and West Africa have the largest water resources (51% and 23%, respectively), as opposed to only 3% in North Africa. However, the irrigable potential area for the continent stands at 25% of arable land, taking into account both irrigable land and the available renewable resources (FAO Aquastat Database, 2021). The opportunities for increased water use efficiency should be prioritized throughout Africa (Turral *et al.*, 2011).

The majority of soils in Africa are under cycles of weathering, erosion, leaching, continued nutrient mining and degradation (Lahmar *et al.*, 2012; Bidogeza *et al.*, 2015; FAO and ITPS, 2015). Only 8% of land is of high-quality soil with no significant constraints for agriculture, 34% is of medium to low potential with at least one major constraint for agriculture and 55% is unsuitable for any kind of agriculture except nomadic grazing (Ussiri and Lal, 2020). Over 60% of the soil types represent hot, arid or immature soil assemblages: Arenosols (22%), Leptosols (17%), Cambisols (11%), Calcisols (6%), Regosols (2%) and Solonchaks/Solonetz (2%). A further 20% or so are soils of a tropical or subtropical character: Ferralsols (10%), Plinthosols (5%), Lixisols (4%) and Nitisols (2%) (Dewitte *et al.*, 2013; Jones *et al.*, 2013). The majority of African soils are associated with local soil-forming factors such as volcanic activity, accumulations of gypsum or silica, or waterlogging.

Aridity and desertification affects around half the continent while more than half of the remaining land is characterized by old, highly weathered, acidic soils with high levels of iron and aluminium oxides (hence the characteristics colour of many tropical soils) that require careful management if used for agriculture (Jones *et al.*, 2013). Estimates have shown that 35% of Ghana, 70% of Ethiopia, 80% of Kenya, between 49% and 78% of Swaziland and 3,500 km^2 of Nigeria is threatened by desertification (UNECA, 2007). More than one-third of the territory of Burkina Faso, Burundi, Lesotho, Rwanda and South Africa are severely degraded. Hence, there is a clear need to restore the degraded land in Africa and to preserve productive land.

Africa is one of the world's lowest consumers of agricultural inputs such as improved seeds, fertilizers and pesticides (FAO, 2015). Overall, Africa uses only 3% (4 million tonnes of fertilizers) of the world's total consumption while SSA uses less than 2% of global fertilizer demand (The World Bank, 2006; AGRA, 2018a). Although the 2006 Abuja Declaration on Fertilizer for the African Green Revolution pledged to raise fertilizer use to 50 kg/ha by 2015 (from less than 10 kg/ha in 2006), average fertilizer use in SSA remains significantly below that level at around 18 kg/ha, and far below the 132 kg/ha global average (Roy, 2020). Only Botswana, Egypt, Kenya, Morocco and South Africa satisfied the Abuja fertilizer use threshold. In fact, 70% of fertilizers are consumed by Egypt, South Africa, Nigeria, Morocco, Ethiopia and Kenya. The reduced use of fertilizers by smallholder farmers is due to limited domestic production, affordability, availability, access, logistics costs and rainfed-type agriculture, and also to lack of technological progress in the production system, which influences whether a farmer decides to adopt and use fertilizer.

In addition, annual nutrient loss in African soils is estimated at 30–60 kg of nutrients per hectare per year (Henao and Baanante, 2006). Thus, not surprisingly, nutrient limitation is the major bottleneck for increasing yields in Africa. It is estimated that the continent loses over US$4 billion worth of soil nutrients each year (Chianu *et al.*, 2008), severely eroding its ability to feed itself. However, nutrient depletion rates vary significantly spatially, depending on the overall crop productivity level and farmers' access to fertilizer.

At the 29th session of the FAO Regional Conference for Africa (Addis Ababa, 11 April 2016), the United Nations Economic Commission for Africa (ECA) reiterated the need for an adequate use of fertilizers for sustained productivity in the continent's agricultural practices (UNECA, 2021). To reach this goal, agricultural productivity and growth policy should favour sustainably intensified systems (i.e. CSA) and set in place instruments such as macroeconomic, monetary and trade policies, and investment in national and transnational public infrastructure and services. It is also very important to strengthen participatory research and advisory services on soil fertility mapping and fertilizer management with paradigm shifts through integration of ecological and sustainability metrics. Agricultural mechanization is another vital driver for boosting fertilizer adoption and use by farmers. Hence, profitable and sustainable nutrient management is necessary to rebuild soil capacities in sustaining farming systems. In this regard the Abuja Declaration emphasized that farmers need to shift from low-yielding, extensive land practices to more intensive, higher-yielding practices, with increased use of improved seeds, fertilizers and irrigation.

2.2.2 Climate Change and Variability in Africa: Challenges and Impacts

In Africa, climates are diverse and variable owing to three dominant processes: tropical convection, the alternation of the monsoons and the El Niño Southern Oscillation of the Pacific Ocean. The interaction of the processes and effects of climate change still merit further studies (Masih *et al.*, 2014). The four major agroecological zones are: arid, semi-arid, sub-humid and tropical humid (Peel *et al.*, 2007). Approximately 26% of Africa, mostly in SSA, is vulnerable to the desertification process and nearly 47% of Africa is characterized as desert (Jones *et al.*, 2013).

Climate shocks can be either acute (e.g. extreme weather events such as heatwaves, extreme droughts, landslides, hurricanes, cyclones, floods, wildfire, hail) or chronic (e.g. increasing temperatures, sea-level rise, desertification, loss in biodiversity, land and forest degradation). Masih *et al.* (2014) indicated that droughts have intensified in terms of their frequency, severity and geospatial coverage.

IPCC assessment reports suggest that the warming of Africa is very likely to be greater than the global annual mean warming throughout the continent and in all seasons. Annual rainfall is likely to decrease across much of Mediterranean Africa and in the Northern Sahara region. It is reported that rainfall in southern Africa is likely to decrease in much of the winter rainfall region, and there is likely to be an increase in annual mean rainfall in East Africa (Pachauri *et al.*, 2014).

GHG emissions from agriculture, forest and other land uses (AFOLU) in Africa account for 15% of global emissions, with an annual increase of 1.6% (FAO, 2016a), although the share in global emissions is only 3.6% for the whole of Africa (Tubiello *et al.*, 2015). Demissew Beyene and Kotosz (2019), in particular, concluded that the economic activities in East African countries do not lead to CO_2 emissions.

Crops, lands, biodiversity, forests and livestock are highly affected by rising temperatures and by variable and intense extreme events (droughts, floods, hot winds, etc.). Biomass productivity has declined significantly in Africa, and especially in North Africa, the region with extensive irrigated agriculture (Le *et al.*, 2016).

Over 80% of the African population depends on firewood and charcoal for cooking, which can threaten carbon sequestration (Neufeldt *et al.*, 2015). Africa had the largest annual rate of net forest loss in 2010–2020, estimated at 3.9 million ha; this was due to conversion to agriculture, use as fuelwood, timber harvesting, and urban and rural development (FAO, 2020). The FAO Global Forest Resources Assessment showed a continuous loss of forest cover at a rate > 0.6% a year in West and Central Africa and > 0.4% in East and Southern Africa. The rate of net forest loss has increased in Africa in each of the three decades since 1990. African forest is also highly threatened by human management, fire, disease and pests.

Food availability in SSA has increased by nearly 12% over the past two decades (FAO, 2017b). Notably, cereal production has increased by 125% and cultivated land by 70% in 30 years (FAOSTAT, 2020). In SSA, agricultural production increased at an average annual rate of 2.6% between 1961 and 2008, as measured by gross agricultural output (Fuglie and Rada, 2013) but has stagnated in recent years (FAO, 2017b). However, yield gaps are still high in most of Africa and for most crop and livestock products.

Lal (2017; 2019b) reported that crop yields in Africa have stagnated since 1960s for cereals at 1–1.5 Mg/ha and for grain legumes (pulses) at 0.2–0.5 Mg/ha. Globally, Africa's crop yields are only 56% of the international average.

Neumann *et al.* (2010) estimated that crop yields are between 50% and 64% of their maximum potential, which translates to potential yield improvements of between 56% and 100%. In another study, Tittonell and Giller (2013) estimated that observed yields on moderately fertile soils were between 36% and 61% of what could be attained under local conditions, which suggests that yields could be increased by between 64% and 178%. Henderson *et al.* (2016) reported both crop and livestock yield gaps from six Sub-Saharan countries, ranging from 16% to 209% and from 28% to 167%, respectively. The authors also found reduced gaps through higher efficiencies with decreased environmental impact and mainly reduced GHG emissions from mixed farming systems.

A report by van Ittersum *et al.* (2016), based on yield statistics from ten Sub-Saharan countries, found that rainfed maize yields during the period 2003–2012 ranged from 1.2 to 2.2 t/ha, which represented only 15%–27% of the water-limited yield potential. They also found that, to satisfy consumption demands, the yield gap closure was not sufficient. It is imperative to increase cropping intensity and expand irrigated areas.

Climate change is also predicted to reduce yields for most major crops and livestock (Schlenker and Lobell, 2010; Knox *et al.*, 2012; IPCC, 2019; Lal, 2019a), while growing demand for food will accentuate the pressure on food systems and land resources. Consequently, most countries still rely on international aid to supplement production deficits (Nhamo *et al.*, 2019).

Across Africa, mean yield reductions of 17% (wheat), 5% (maize), 15% (sorghum) and 10% (millet) were predicted by Knox *et al.* (2012). These authors did not detect a mean change in yield for rice. Maize production, the staple cereal of the region, is anticipated to suffer production reductions of between 12% and 40% by 2050 due to climate change (Roudier *et al.*, 2011; Calzadilla *et al.*, 2013; Ramirez-Villegas and Thornton, 2015). Other studies report that yields of maize and beans, the most widely planted crops in SSA, may decrease by 25% to 50% by 2050 (Challinor *et al.*, 2014). Sultan *et al.* (2014) found that yield losses due to climate change varied between 16% and 20% depending on the sorghum cultivar used in West Africa. Using robust models, Schlenker and Lobell (2010) found that, by mid-century, the mean estimates of aggregate production decline in SSA would be 22%, 17%, 17%, 18% and 8% for maize, sorghum, millet, groundnut and cassava, respectively. Rhodes *et al.* (2014) valued yield reduction of between 5% and 25% of maize and sorghum in West Africa if no action is taken over the next decades.

The IPCC reports anticipated losses of between 27%–32% in the production of maize, sorghum, millet and groundnut for a warming of about 2°C above pre-industrial levels by 2050 (Porter *et al.*, 2014; Niang *et al.*, 2014; Mbow *et al.*, 2019). Estimates from previous studies also show that crop and fodder growing periods in southern Africa would shorten by an average of 20% by mid-century, causing a 40% reduction in cereal yields and a decline in cereal biomass for livestock (Calzadilla *et al.*, 2013; Niang *et al.*, 2014). The empirical evidence of the impacts of climate change in southern Africa indicate extensive and direct consequences for agriculture if no mitigatory measures are put into practice.

Biodiversity, an essential resource for agriculture and food and feed production, is threatened by climate change, deforestation, land use conversion, diet changes, urbanization, pollution and mismanagement of lands (IPBES, 2019).

In rural areas of Africa, the majority of households are livestock keepers and are impacted by climate change. Increased temperature and water scarcity would reduce animal efficiency as well as fodder production and digestibility. Increase in vector-borne diseases is observed due to the increased vector population and decreased resistance in livestock (Grossi *et al.*, 2019; Nicola, 2019).

Although crop production is steadily increasing in the region, the anticipated losses in GDP, coupled with population growth and climate change, mean that agriculture would not be able to feed the growing population if no action is taken to mitigate the challenge and reduce yield gaps (Kotir, 2011; Jury, 2013; van Ittersum *et al.*, 2016). In fact, climate change should spur countries to lower carbon gaps and invest in sustainable agricultural development pathways. Hence, Africa cannot afford a low level of ambition in tackling and mitigating climate change and rising sustainable economic benefits to farmers.

2.2.3 High Commitment to Ambitious and Sustainable Agricultural Transformation

Farming systems have changed profoundly throughout human innovation and are constantly evolving as a consequence of developments and changes in technologies, policies, societies, diets, preferences, income generation, markets, energy sources, etc. (Tittonell, 2014). However, these changes and developments are not all desirable owing to heavy costs in terms of negative externalities and hence adverse impacts on environment, households and economy (Poore and Nemecek, 2019). If left unchecked and remaining in a 'business as usual' model, farming systems will decline further in productivity, leading to mass hunger and undermined development (FAO, 2017b). These trends will close the window of opportunity for avoiding climate change threats. It was estimated that to feed the continent's ballooning population, crop production will need to increase by 260% by 2050 (FAO *et al.*, 2019). van Ittersum *et al.* (2016) showed that, by closing production gaps, intensification options may allow accelerated yield growth, greater cropping intensity and an increased irrigated area. It is clear that Africa should invest in ecologically intensifying production systems to close production gaps without jeopardizing and disrupting ecosystem functioning (Pradhan *et al.*, 2015).

Keeping global warming within or below the 2°C threshold above pre-industrial levels demands that the agriculture sector should be transformed and relationships with development rethought (IPCC, 2018). In addition, technologies, ingenuity and resources exist to break the link between agriculture and land degradation (IPCC, 2019; Smith *et al.*, 2019). Policies and political leadership – and intensified transnational cooperation – are still lacking in Africa. Agenda 2063 is, however, giving great impetus and aspiration for closing these political and institutional gaps and is supported by strong commitment and strategies from governments and international organizations (i.e. FAO, African Development Bank (AfDB), World Bank).

In developing countries, about 80% of the required increase in food and feed production will need to come from higher yields and increased cropping intensity, and only 20% from expansion of arable land. Africa has tremendous comparative advantages, potentials and resources in terms of soils, biodiversity, water, local knowledge and renewable energy that can lead to sustainable intensification and climate-resilient agriculture. According to NEPAD (2016), while 40% of the land in Africa is potentially arable, only 9% is actually cultivated. In fact, FAO projections are that most arable expansion will be in SSA and Latin America (Livingston *et al.*, 2011). Sixty percent of the planet's unexploited arable lands (800 million ha) are found in SSA, but land must be protected from degradation and exhaustion (The McKinzy Global Institute, 2010; Livingston *et al.*, 2011). To reduce production and efficiency gaps in agriculture, CSA must be increased in both rainfed and irrigated regions.

National agricultural research systems in Africa continue to face numerous challenges, including low levels of public investment, dependence on external donors and volatility of funding flows (Beintema and Stads, 2017). Research pathways are still resistant to change, given that most incentives (e.g. funding timeframes, institutional specialization and career opportunities) favour conventional, specialized approaches (Pardey *et al.*, 2016; Beintema and Stads, 2017). Research and innovation (R&I) are key drivers in accelerating the transition to sustainable, healthy and inclusive food systems from primary production to consumption (Herrero *et al.*, 2020). Sustainable soil management, improvements to local and specific seed varieties, increase in use of fertilizers and expansions in irrigation could dramatically improve yields (NEPAD, 2016).

Stringent transversal challenges should also be tackled and relieved to promote the transformation process; these mainly include land tenure, market, finance, gender, youth and equity. There is a wide awareness of the fact that, through effective institutional development and with South–South collaboration and communication – as well as by sharing experiences and insights – African agriculture will certainly be revitalized. In addition, widespread science-centred CSA will enable African farming systems to turn from generating misery and food insecurity to creating prosperity and food security. Caron and Treyer (2016) concluded that science should help structure the political debate and effective international coordination.

2.3 Climate Smart Agriculture (CSA): Well-sequenced Strategy for Transformation

The fact that large-scale industrialized agriculture is not yet the norm in much of Africa has been highlighted as a major opportunity for embarking on a de-risking agricultural investment strategy and engagement in carbon neutral and agroecological transition.

2.3.1 Evolving Concepts

Several linked concepts have been proposed to establish new approaches and frameworks for agricultural transformation, including Save and Grow (FAO, 2011a), sustainable intensification (Pretty, 2008; Pretty *et al.*, 2011; Garnett *et al.*, 2013; Rockström *et al.*, 2017), agroecology (Altieri, 2002; Tittonell *et al.*, 2012; AFSA, 2016; Nicholls *et al.*, 2016; Saj *et al.*, 2017), eco-efficiency (Keating *et al.*, 2010; Hershey and Neate, 2013), nutrition-sensitive agriculture, regenerative agriculture, ever-green agriculture and CSA. HLPE (2019) presented the differences, drivers and challenges of these approaches. CSA is distinct from other approaches by the climate change–food security nexus and especially by its emphasis on food security as compared to agroecology and sustainable intensification (Moussadek and Mrabet, 2017; Liu *et al.*, 2018). The critical and underlining distinction for CSA as compared to the other practices is that it is not about more or better use of a specific technology or set of technologies. CSA is fundamentally about changing the way farming is conducted across all farming systems and including arable, livestock and forestry. CSA is not sustainable unless it is extended beyond a critical land size and so can impose and enforce agricultural transformation (Steenwerth *et al.*, 2014).

Climate smart agriculture

The CSA concept is open, emphasizing outcomes and impacts rather than means. It focuses on human sustainability and needs in terms of food, nutrition and well-being, environmental integrity and climate risk reduction (Steenwerth *et al.*, 2014). In addition, diversity and heterogeneity in food production/farming systems and household resources, pathways and scales towards CSA adoption are diverse but should be flexible, site-specific and specific to farmers' circumstances (adapted to local social and biophysical contexts) (Steiner *et al.*, 2020).

The CSA concept was first proposed in 2009 by FAO and defined in 2010 (FAO, 2009a,b; 2013). During the same period, the World Bank introduced CSA in its 2010 'World Development Report: Development and Climate Change' (The World Bank, 2010).

CSA has been differently defined (Rosenstock *et al.*, 2016; Chandra *et al.*, 2017) but is mostly founded upon the three pillars of strengthening food security, climate change mitigation and adaptation (Fig. 2.1) (FAO, 2013; Lipper *et al.*, 2014). It addresses inclusive development through improving adaptive capacity at multiple levels from farm to nation and accelerating progress towards the SDGs and the Paris Agreement. Food security cannot be interpreted as a simple quantitative production requirement, which would lead to productivist drifts. Affordability, nutritional quality and regular access to a diversified diet are equally essential requirements.

Agenda 2063 is addressing simultaneously the three dimensions of CSA to modernize African agriculture while contributing to collective prosperity and resilient economies. It also aspires to banishing the hand hoe by 2025, and

Fig. 2.1. Climate smart agriculture pillars and objectives. Adapted from FAO, 2013.

both science-based technologies and indigenous knowledge will be intensively used to successfully ensure a people-centred modern and resilient agricultural sector (AUC, 2015).

Accordingly, CSA makes the best use of nature-based, technological, digital and space-based solutions to deliver better climate and environmental results, increase climate resilience, and reduce and optimize the use of inputs (e.g. seeds, pesticides, fertilizers and energy). According to Neufeldt *et al.* (2013), any innovation or practice that liberally meet any set of the objectives addressed in Fig. 2.1 can be designated as climate smart (Chandra *et al.*, 2017).

CSA can be applied at different scales and contexts from farmers' fields, landscape and food value chains to a country's food systems and supply-side policy (De Pinto *et al.*, 2020). It also includes enabling policies and institutions as well as the identification of financing mechanisms (Saj *et al.*, 2017). CSA seeks not only to preserve and maintain natural resources and livelihood capitals, but also to develop them, as future generations will make more quality and quantity demands on agricultural and food products. The ability of CSA to reach the objectives of the three pillars simultaneously has been queried (Neufeldt *et al.*, 2013; Chandra *et al.*, 2017). It is an opportunity to fuse farming systems with the needs and aspirations of the continent for healthy, equitable and environmentally friendly food. Distinctively, CSA reconciles trade-offs between farmers' agricultural profits and environmental benefits for society at large, as found by De Pinto *et al.* (2020).

Public policies based on the requirement of simultaneity between the three pillars of the CSA would have the merit of leading to a renewal of practices promoting agriculture compatible with the stakes of climate change and capable of nourishing the planet (Frank *et al.*, 2017; Saj *et al.*, 2017). Caron (2016) proposed to develop a scientific framework for CSA to guarantee evidence to stakeholders, as it lies at the interface between science and policy making. De Pinto *et al.* (2020) requested a useful framework to tackle multi-objectives associated with CSA across scale. According to Neufeldt *et al.* (2013), agriculture and food systems are climate smart when it can be shown that they bring humanity closer to safe operating spaces (balancing needs to outcomes within planetary boundaries). Chandra *et al.* (2017) urged for a rethinking of political and institutional dimensions of the CSA discourse and enhancing knowledge production. Taylor (2018) proposed an alternative 'climatic-wise' framework to focus on the inherently political dimensions of food and agriculture in an era of climatic change.

An analysis of CSA concepts and contexts by Chandra *et al.* (2017) concluded that, for transformative CSA agenda to be effective, conventional top–down and scientific-led research should be complemented with the inclusion of non-experts and community- and farmer-led organizations. The authors claimed also to focus on vulnerable farmers and their associations and networks.

Conservation Agriculture

The term Conservation Agriculture (CA) was first used in late 1990 but CA principles were introduced in the mid 1950s to counter the Dust Bowl in the USA. CA is among the operational strategies of CSA and has a history of being both contentious and pragmatic (Powlson *et al.*, 2014).

There is considerable diversity in what constitutes CA throughout Africa (Brown *et al.*, 2017; Mtakwa *et al.*, 2020). CA has different incarnations depending on stakeholders, including scientists, extension and communication officers, government managers, farmers and producers. It can, however, be defined as the link between three components or principles: (i) elimination of mechanical seedbed preparation and soil disturbance; (ii) permanent soil cover through retention of crop residue mulch and cover crops; and (iii) adoption of diversified crop rotations along with other complementary good agricultural production and land management practices (i.e. use of quality seeds, and integrated pest, nutrient, weed and water management). Each component requires interpretation (Stevenson *et al.*, 2014). Complementary practices are enablers for farmers to increase CA feasibility and narrow yield gaps (Thierfelder *et al.*, 2018). CA was not initially developed to harness biodiversity, and optimizes ecosystem services through implementation of its underlying principles (Palm *et al.*, 2014).

The amount of research devoted to CA has increased significantly and in 2015/16 cropland under CA had extended considerably to reach 180 million ha worldwide (Kassam *et al.*, 2020). Prestele *et al.* (2018) showed that the process of CA adoption can be speeded up while alleviating institutional, social and economic barriers, and that the potential of CA can be in the range of 533–1130 M ha (38%–81% of global arable land). Presently CA represents 1.5 million ha in Africa. The five leading countries are South Africa, Zambia, Mozambique, Malawi and Zimbabwe, representing 90% of the CA acreage. Prestele *et al.* (2018) showed that the potential CA area ranges from 28.41 to 124.40 million ha (12%–53% of arable land in Africa).

2.3.2 Climate Smart Agriculture (CSA) Imperatives and Synergies for Sustainable and Inclusive Growth in Africa

Strategic reports agree that CSA unifies the agendas of the agriculture, development and climate change communities under one category, even though these often overlap and interact (Chandra *et al.*, 2017). Several CSA approaches and frameworks have been proposed to sustain the decision-making process in the agricultural sector by taking into consideration the three primary principles and by copiously accounting for the synergies and trade-offs among the outcomes (FAO, 2019b; AfDB, 2020b).

Sustainable development is a challenging goal for Africa and depends on the pursuit of pathways of development (Caron *et al.*, 2018; FAO, 2018; Mbow, 2020). CSA interventions should not be focused only on technologies and measures but also on transformation across the personal, practical and political spheres, and on the dynamics (including drivers of risks) and interactions among these spheres (O'Brien *et al.*, 2015). In other terms, the feasibility and scalability of CSA depend on interplay of the three dimensions. In this respect, CSA contributions and operationalization are not restricted to biophysical and environmental factors, and achieving the SDGs is critical and fundamental (FAO, 2019b; Mbow, 2020).

To reach the agreed SDGs, Africa as whole and countries individually need mechanisms, legislation, guidelines and plans for a high and sustainable rate of CSA adoption by farmers. The essence of CSA lines up with several SDG targets (Rabobank, 2018; Roy *et al.*, 2018). Rabobank (2018) sees CSA as directly supporting SDGs 2, 8, 9, 12, 13, 15 and 17 and indirectly supporting SDGs 1, 2, 5, 7, 8, 9, 10, 13, 15 and 16.

FAO has proposed a five-step implementation process for CSA: (i) expanding the evidence base; (ii) supporting enabling policy frameworks; (iii) strengthening national and local institutions; (iv) enhancing financing options; and (v) implementing locally appropriate and context-specific practices and technologies for CSA on the ground (FAO, 2019b).

There is no single generalizable model of CSA to achieve the three core principles or dimensions. CSA promotion should be based upon coordinated actions from farmers, researchers, private sector, civil society and policy makers towards climate-resilient pathways through four main action areas: (i) building evidence; (ii) increasing local institutional effectiveness; (iii) fostering coherence between climate and agricultural policies; and (iv) linking climate and agricultural financing (Stevenson *et al.*, 2014).

Because conditions vary extensively across geographies, economies and societies in Africa, any enhanced CSA should avoid ‘one size fits all’ and ‘business as usual’ approaches and consider key characteristics of a country’s agriculture sector (HLPE, 2019). This includes an examination of national production and consumption trends of crops and livestock, as well as the types and sizes of producers. In other words, the legitimacy and durability of CSA should account for and integrate diverse perspectives, needs and priorities. CSA differs from business as usual approaches by emphasizing the capacity to implement flexible and context-specific solutions through its attractivity to value chain policy support and investment financing action (Lipper *et al.*, 2014).

Drivers for small-scale farmers are diverse and dependent on site-specific socio-economic situations, resource endowment, mechanization level and biophysical challenges. Establishing and supporting enabling policy environment and coherence is foundational for CSA alignment with a country’s development model.

Bringing about change in social contexts and mindsets is often very difficult and involves long periods of awareness raising to engage farmers and policy makers in parallel. Equitable benefit sharing and inclusive governance are extremely important to build resilience and enhance adaptation of the agricultural sector in any country. CSA could not be scaled up without such critical changes, in addition to eliminating inequalities.

2.4 Climate Smart Agriculture (CSA) and Development Initiatives: Supporting Bottom-up Alliances

2.4.1 Land Degradation Neutrality (LDN)

Most agroecological zones in Africa have high levels of vulnerability to climate change because they are affected by significant on-going processes of degradation and desertification (Spinoni *et al.*, 2015; Prăvălie, 2016) and high levels of poverty and food and nutrition insecurity (FAO, 2017b; von Grebmer *et al.*, 2017). Prevalence of severe food insecurity varies across sub-regions in Africa with the lowest in North Africa (9.23%) and the highest in Middle Africa with an average for SSA of 25.7% (FAO, 2017b). The same report noted that the average per capita income was three times lower in SSA than it was in other regions of the world in 2014, although it saw a 30% increase between 1990 and 2014.

Land degradation has been speeded up by human activities and mismanagement and uses of natural resources. To curb this scourge and its disastrous consequences, the United Nations Convention to Combat Desertification (UNCCD) launched the concept of LDN. LDN represents a paradigm shift in land management policies and practices and is an approach that counterbalances the expected loss of productive land with the recovery of degraded areas. It strategically places the measures to conserve, sustainably manage and restore land in the context of land use planning (Cowie, 2020).

Cowie *et al.* (2018) explained that management of land degradation has co-benefits for climate change mitigation and adaptation and for biodiversity conservation, in addition to enhancing food security and sustainable livelihoods. In other words, achieving LDN targets would decrease environmental footprints, support food security and sustain human well-being (Stavi and Lal, 2015). These are the founding objectives of CSA. In fact, the UNCCD considered that the problems of slow adoption of CSA could be addressed by inclusion of LDN as a SDG (Lal *et al.*, 2012). LDN is a key element of SDG target 15.3, and is recognized as an accelerator for achieving several other SDGs by 2030, including those on reducing hunger and poverty and tackling climate change. Accordingly, CSA is one of the main mechanisms to achieve LDN (Sanz *et al.*, 2017). CSA advances LDN as it endeavours to minimize the risks of land degradation, rehabilitates degraded lands and ensures the optimal use of land resources through improvement in soil quality (Lal *et al.*, 2012).

2.4.2 Enhanced Nationally Determined Contributions (NDC)

According to UNEP (2019), there should be a reduction in global emissions by 7.6% and 2.7% every year for the next decade to meet the Paris Agreement targets of 1.5°C and 2°C, respectively. The UN report showed that even if all current unconditional commitments under the Paris Agreement are implemented, temperatures are expected to rise by 3.2°C. Hence, collective ambition (mainly from developed countries) must increase more than fivefold over current levels to deliver the cuts needed in the period 2020–2030.

In support of the Paris Agreement implementation, NDCs were intended to set out the ambitions of governments, in both developing and developed countries, for a transition to a growth-oriented, climate-resilient and low-carbon development model. For African countries, NDCs provide opportunities to reduce GHG emissions and present policies that promote growth while developing an agricultural sector based on the three dimensions of sustainability. They are also prospects for international cooperation and funds (FAO, 2016b). However, according to IPCC (2018) and UNEP (2018), current commitments in the NDCs are inadequate to close the emission gap in 2030. It has been proposed that all countries should substantially increase their ambition and to triple their NDCs to get on track to 2°C and increase fivefold to align with 1.5°C (Fransen *et al.*, 2017; NDC Partnership, 2019).

Enhancing and investing in NDCs through CSA was claimed by several African countries to tackle climate change impacts. Other solutions have also been mentioned or associated with CSA, such as sustainable land management (SLM) and agroforestry, to optimize natural resource use and avert climate change loss and damage (Richards *et al.*, 2016). Many countries in Africa included fertilizer use, soil fertility management and agricultural inputs as part of their contributions to the Paris Agreement. Plans and policies are in progress for widening appropriation by farmers of such resilience-based systems (FAO, 2018). IPCC (2019) reported that increased soil carbon using SLM systems and CSA are the most cost-effective options for climate change adaptation and mitigation, and to combat desertification, land degradation and food insecurity.

2.4.3 Climate Smart Agriculture (CSA) Central to Gender and Equity

Agriculture and women's empowerment are central to the new SDGs. It is well known that gender inclusion through gender diversity and equality contributes enormously to economic growth. However, women and youth are in the front line of climate and land challenges. In a recent study by the World Food Programme, a set of indicators across 17 countries indicated a clear relationship between gender inequalities and food insecurity, to the detriment of women (WFP Gender Office, 2020). It was also found that hunger cannot be reduced or eliminated solely through provision of adequate food, but rather through women's empowerment and gender equity.

Across the continent, women tend to have less access to resources, capital and services compared to men (IFPRI, 2020). CA development in North Africa differs from that in SSA in that the 'tillage mindset' is difficult to change in most North African farmers. The other issue of singular importance is gender vulnerability, as hand hoe-based Sub-Saharan agriculture is led by women (FAO, 2017b). Women from marginal households face greater workloads and are more vulnerable to climate change (WFP Gender Office, 2020). In addition to migration and health issues, rural women have increased roles and tasks (United Nations, 2015).

Enhancing opportunities and benefits for women and men in the agricultural sector is vital for promoting gender equity and enhancing well-being in SSA. The specific needs, realities and priorities of women and men should be recognized and adequately tackled. Immediate benefits include reduced labour time, access to subsidies, training and markets as well as use of inputs and technologies. Opportunities are linked to sustainable results from CSA and may give women access to cash, spending and investing ability, resource use and management, and access to and control of land.

Several CSA programmes and projects were designed to include gender and labour productivity analysis and be gender sensitive (Murray *et al.*, 2016). To scale-up CSA in Africa, it is imperative that women get access to resources and inputs, and avoid differential impacts or co-disadvantages that burden women's labour and productivity (Kaczan *et al.*, 2013; Nyamangara *et al.*, 2014; Thierfelder *et al.*, 2015). Women bring new skills and capabilities when male-to-female employment is reduced. However, to rely on women for CSA adoption, the gaps in significant knowledge, technology, energy and capacity building should be bridged and closed (MICCA programme by FAO; http://www.fao.org/climatechange/micca, accessed 1 July 2021). This approach will allow the progress of CA adoption to be assessed and monitored, based on gender-sensitive indicators. In addition, gender-based barriers should be relieved and women should not be taken away from opinion- and decision-making processes, and should receive equal opportunities for financial instruments, skill development and empowerment (Lipper *et al.*, 2014). Education, training, information technology and digital development should resolve the gender gap and awareness deficit within African societies and consequently be used to strengthen the equal access of women and men to CSA solutions, benefits and opportunities.

All three pillars or dimensions of CSA are gender sensitive and hence gender impact should be included or augmented. If CSA systems are to be sustainably adopted and tangible benefits realized, it is imperative to raise the level of leadership evenly, and engage women and men in supervising and managing agricultural projects and enterprises. Policy orientations should be developed to allow gender parity and productivity, and to acquire for women the rights to access and control resources, information and get involved in farmer-led organizations and public institutions linked to agricultural services (Collins, 2018).

2.5 Fostering and Enhancing Conservation Agriculture (CA) Science and Technology as a Foundation for Climate Smart Agriculture (CSA)

The largest existing model of CSA worldwide in terms of surface area is that of CA (about 180 million hectares of cropland in 2015/16). In addition, CA as a CSA core objective is to mitigate climate change while regenerating land degradation in order to reduce food gaps. In fact, worldwide scientific evidence from research and empirical evidence from farmers' practice shows that CA is an effective strategy for achieving CSA dimensions (Kimaro *et al.*, 2015; Kassam *et al.*, 2020). However, the transformational power of CA systems and related technologies depends on the economic and political context, the needs of the farming communities and society at large and a country's socio-economic and institutional conditions. CA is much concerned with farming and production systems, while CSA is broader as it deals with entire agricultural value systems; that is, from production, processing (agro-industry) and storage through to consumption. However, CA impacts can be sensed through the value chains and any technological development will certainly increase its acceptance, adoption and scale-up.

In Africa, soil erosion in SSA is considered one of the root causes of stagnating or declining agricultural productivity. Hence, the relevance of CA has been emphasized through research on soil erosion control and soil surface management at IITA since 1976 (Lal, 1975; 1979). Research into CA has also been conducted in the dry areas of North Africa by the International Center for Agricultural Research in Dry Areas (ICARDA) and national research institutes (Mrabet *et al.*, 2012; El Gharras *et al.*, 2017); in subtropical regions of southern Africa (Thierfelder *et al.*, 2014; Wall *et al.*, 2014) by the International Wheat and Maize Improvement Center (CIMMYT) (Wall, 2007); and by ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) in southern and West Africa. An increasing number of countries and regions are adopting CA systems, but the dynamics, scale and pace should be enhanced (Kassam *et al.*, 2020).

The FAO report on regional overviews of food security and nutrition suggests that increasing the resilience of agricultural livelihoods, and promoting and financing CSA practices, would be a powerful lever to reach the pledge of the SDGs 'to leave no one behind' (FAO, 2019b). Translation of commitments and declarations into effective programmes and plans is both urgent and mandatory, in addition to fundamental reformatting of the values, trade-offs, regulations, policies, markets and governance related to CA systems.

The transformative potential of CA in its ability to raise agricultural productivity and resilience, and to improve livelihoods and empower communities, has increasingly been recognized. There has been growing appreciation and documentation of CA's potential to increase and stabilize long-term production in Africa by optimizing biological regulation processes, recycling nutrients and promoting diversified agroecosystems (Pretty *et al.*, 2011), as well as providing a buffer against environmental and economic risks and accelerating climate adaptation (IPES-Food, 2016). CA is an opportunity for each country to unveil an ambitious plan for 'a resilient and robust food system', with emphasis on sustainability, resource optimization and socio-ecological resilience (Pisante *et al.*, 2020).

Thornton *et al.* (2018a) proposed a framework for setting priorities for CA research and development in order to set metrics of benefits at contrasting scales and in time and space. The framework also recommended adding iterative and long-term research on CA to cycles of evaluation and learning. Such a framework necessitates appropriate resources, funds and capacities as well as support from farmers, private sectors and organizations, and policy makers.

2.6 A New Legacy of Sustainability

Kassam *et al.* (2017) have stated that tillage, irrespective of whether it is mechanized, animal or human drawn, has caused widespread degradation of croplands. Such degradation has affected crop productivity and enhanced the impact of climate change, particularly in developing countries. Cycles of unsustainability and vulnerability have led to falls in the stability of farming systems owing to increased yield gaps and reduced farmers' incomes (Lal, 2020b).

To be sustainable a farm must satisfy four major goals: productivity and quality, financial feasibility and viability, environmental sustainability, and human welfare and security. Most CA practices indigenous to SSA merit development and enhancement following historical success (Zai pits, half-moons, tassa water harvesting, agroforestry parklands). CSA practices are linked to biodiversity conservation, forest management and integrated livestock with crops and trees.

For recovering and (re)building resilient food systems in Africa, it is important to leverage the power and dynamism of CSA in shifting concepts to sustainability and resilience. Mainstreaming CA in Africa will allow the balancing of farmers' goals and countries' challenges and hence support the interaction between food and ecosystem security.

Across Africa, growing evidence from many studies has revealed better performance of CA than of conventional systems on various sustainability metrics: crop productivity, soil microbial species richness and abundance, soil fertility, nitrogen uptake by crops, water infiltration and holding capacity, energy use and efficiency, and many other ecosystems services (Thierfelder *et al.*, 2013c; Boulal *et al.*, 2014; Nana *et al.*, 2014; Ndah *et al.*, 2014; Wall *et al.*, 2014; Thierfelder *et al.*, 2015; 2016; Mupangwa *et al.*, 2016). CA helps to enhance below- and above-ground ecological interactions through integration of crop residue, soil and pest management practices, which constitutes a robust and sustainable path for optimizing a farming system's functions and productivity. CA also ensures ecosystem services and hence the creation of healthy ecosystems.

2.6.1 Doing More with Less by Leveraging and Harnessing Technology

Under traditional farming systems, the benefit–cost ratio is often too low to encourage farmers to apply fertilizer and pesticides, because of the relatively high prices at the farm gate, the low market price of food crops like maize and the high year-to-year variability of the agronomic efficiency of applied inputs. Such unsustainable farming systems should be redesigned for increased profitability and efficiency, and accompanied by innovative policy measures. Sommer *et al.* (2013) considered CA, integrated soil fertility management and N-fixing legume-based rotations as proven alternative options for profitable and sustainable nutrient management for smallholder farming systems in East and southern Africa.

A variety of CA practices are used in Africa, ranging from hand planting with pointed sticks and digging permanent narrow planting basins with specialized hoe and rippers to animal- and tractor-mounted seed drills (Thierfelder and Wall, 2012; Thierfelder *et al.*, 2015). However, research for development and technology transfer programmes, projects and other interventions are still struggling to make CA innovations go to scale in Africa. In fact, asymmetric or limited access to CA technologies and practices, knowledge, information and advice leads to inequality in farmers' decision making, reaching benefits and reducing trade-offs (Holden *et al.*, 2018).

To secure sustained CSA success, CA technologies have developed and improved substantially over the years but their use and integration in farming systems differ considerably according to farm size, crop type, geography, investment availability, advisory systems and farm assets. CA technologies comprise a vast range of applications including farm management (soil, cover crops, quality seed, crop health, pest monitoring), seeding and spraying as well as integrated pest and weed management, crop residue management, harvesting and post-harvest management. Investing in seed and machinery innovations through private sector and research institutes will have a considerable impact on African agriculture and enable several SDGs to be reached.

Development of the seed sector is of immense importance to fully benefit from CA outcomes. Cultivar adjustment is an important strategy to climate change adaptation. Climate smart varieties with adaptations to new climatic conditions such as drought and heat tolerance, or the ability to withstand floods, are needed. The seed system (i.e. the institutions and policies) involved in the breeding, delivery and adoption of these new generations of varieties should be renovated and upgraded (Challinor *et al.*, 2014; Porter *et al.*, 2014).

In advanced CA, technology solutions may also involve satellite imagery and sensors, edge computing, robotics and automation, digitalization and big data, as well as biological therapeutics. The young generation of farmers, emerging start-ups and crowdfunding in rural areas are instrumental and should play a role in attracting CA technologies.

Unsurprisingly, technology heavyweights and industries are supporting and developing CA across the world and in Africa. Machinery, seed, fertilizer and herbicide companies have long been instrumental in advancing and adopting CA. Such companies and industries should develop farming ecosystems and maintain their support to increase rates of attraction, adoption and spread of CA in Africa. The use of advanced technologies such as artificial intelligence, machine learning and blockchain in CA ecosystems should be further developed, enabling farm management and operations to be more integrated and facilitated. These technologies will become less risky in the future, although they were more costly in the early phase of adoption. CA systems, with opportunities from digital technologies, should also help to tackle Africa's pressing agricultural development challenges (The World Bank, 2019). Stringent investments are required in digital green and precision agriculture to realize the potential benefits of CA systems and to address the multiple constraints and barriers faced by farmers, mainly those managing smaller and vulnerable farms. Policy improvements are needed to convey CA to farmers through networking, e-extension, start-ups, incentives, financial services, etc. (Rasoanindrainy, 2017; HLPE, 2019).

2.6.2 Rising Crop Productivity and Reducing Yield Gaps During Climate Variability

Crop yields in developing countries are stagnating or the growth in yield rates are lower than required to meet global food demand (Ray *et al.*, 2013). In addition, the perception by farmers of high risks in adopting and applying advanced technologies (e.g. CA) has been the major driver for crop yield gaps (Tittonell and Giller, 2013; George, 2014).

Numerous individual studies have compared crop yield and quality differences between CA and conventional systems. These data have been synthesized in several meta-analyses or reviews. Most of these studies support the CA principles and showed that CA either out-yielded or had similar yields to conventional systems. In particular, it was found that CA helped to close yield gaps in dry years, permitting higher yields than conventional tillage owing to the higher water-holding capacity of CA-managed soils

(Mrabet, 2011a; Altieri *et al.*, 2012; Bayala *et al.*, 2012; Kutu, 2012; Thierfelder *et al.*, 2013b; Boulal *et al.*, 2014; Swanepoel *et al.*, 2017). In a meta-analysis study, Lamanna *et al.* (2016) showed that, among CSA practices applied in East Africa, CA doubled the yields of maize.

Steward *et al.* (2019) showed that crops in CA systems expressed higher resistance to climatic stress and increased in overall adaptive capacity to enhanced risks due to global warming. In a review summarizing results from eight countries in East and southern Africa, Wall *et al.* (2014) showed marked maize yield benefits under CA systems compared to conventional tillage practices (CT) in both research and farmers' fields. The same authors reported that sorghum, cotton, wheat, cowpea and teff yielded comparable results under CA and CT. Assessments by Mrabet (2011a), Boulal *et al.* (2014), El Gharras *et al.* (2017) and Bahri *et al.* (2019) revealed that grain yields of annual crops outyielded in CA systems and that the benefits were higher and with greater crop residue retention. Reduced yields under CA compared to CT systems were mostly explained by partial adoption of CA components (Guto *et al.*, 2011; Erenstein *et al.*, 2012; Wall *et al.*, 2014; Bahri *et al.*, 2018; Souissi *et al.*, 2018; Stevenson and Vlek, 2018) or by the need for a transition phase for soil recovery and yield improvement vis-à-vis rainfall variability (Loke *et al.*, 2012; Pittelkow *et al.*, 2015; Brown *et al.*, 2017).

Intercropping, crop rotations and diversification (i.e. using pulses/food and oilseed legumes; forage crops) are, overwhelmingly, the main management practices that CA farmers should use. These influence input use efficiency, grain and forage production and quality, and soil fertility building, and are an integral part of weed, pest and disease management strategies (Wall *et al.*, 2014; Steward *et al.*, 2019). Optimal crop/animal assemblages and integration, skillful crop residue maintenance, cover cropping and well-planned rotations are instrumental for successful CA design and implementation, and allow the farming system – over time – to sponsor self-enrichment of soil nutrient pools, crop protection and yields. Farmers' awareness and perceptions of the function of legumes in crop rotations and intercropping systems should further be emphasized (Muoni *et al.*, 2019).

It is extremely important to examine crop varieties and the seed sector in Africa (Muoni *et al.*, 2019). Crop rotations should be enforced by use of improved varieties that carry genetic attributes boosting the success of CA. The varieties used should enable resistance to biotic and abiotic stress, and allow water and nutrient use efficiency and adaptation to climate variability and extremes.

Crops cannot produce in environments stressed by weeds and pests. Integrated weed/pest management strategies and practices are needed to guarantee higher and stable performance from CA systems.

2.6.3 Recarbonization and Enhancing the Resilience of African Soils

At the national scale, carbon benefits are primarily concerned with improved food security and agricultural sustainability, while at the global level the anticipated benefits from improved soil carbon management are mainly enhanced biodiversity, increased carbon offsets and climate change mitigation (Banwart *et al.*, 2015). International and national research has revealed that agroecological farming and livestock systems can both sequester and reduce direct agricultural GHG emissions (Abdalla *et al.*, 2016). Climate solutions that enhance land-based carbon sinks cluster around food waste and diets, ecosystem protection and restoration, improved agricultural practices and prudent use of degraded land (Smith *et al.*, 2016; Griscom *et al.*, 2017; IPCC, 2018). It is estimated that the land-based mitigation potential is 265 million tons CO_2 per year up to 2030 through cropland management, grazing land management and the restoration of degraded lands (Smith *et al.*, 2013; Smith *et al.*, 2014; Mbow, 2020). In addition, 812 million t CO_2/year can be mitigated by reducing deforestation and promoting forest conservation combined with sustainable intensification practices (Mbow, 2020). Applying and adopting climate smart agricultural production systems has the potential to mitigate or curb climate change trends.

To limit global warming to 1.5°C, the world – including Africa – should shift and/or adopt a technique of removing CO_2 from the atmosphere or implement negative emission technologies (NET) (Fuss *et al*., 2016; Williamson, 2016; Fuss *et al*., 2018). However, for these techniques to deliver such targets and at the scale needed, depends on efficiency, viability, feasibility, acceptability, safety and costs/benefits (Wezel *et al*., 2014; Kartha and Dooley, 2016). In addition, the options should both assure CO_2 removal or storage and non-climatic impacts such as healthy ecosystems, biodiversity protection, food security and environmental sustainability (Wezel *et al*., 2014; Smith *et al*., 2016; IPBES, 2019).

In Africa, long-term investments in upscaling soil fertility and carbon management are critical for food security and essential instruments for climate change mitigation (Garrity *et al*., 2017; Wiesmeier *et al*., 2019). Soil carbon sequestration is one of a few strategies that could be applied at a large scale and low cost (Paustian *et al*., 2016). Most reviews and research support the view that CA systems are more energy efficient and environmentally friendly, and particularly useful in reducing land erosion and degradation, restoring soil functions and storing soil carbon (Baggs *et al*., 2006; Mchunu *et al*., 2011; Thierfelder *et al*., 2012; 2013a, b; Swanepoel *et al*., 2017).

González-Sánchez *et al*. (2019) conducted a meta-analysis on potential sequestration by CA in Africa and estimated the amount as being 143 Tg of carbon/year; that is, 524 Tg of CO_2/year. This figure represents about 93 times the current sequestration figures. It is also almost threefold that found for Europe by González-Sánchez *et al*. (2017), which amounted to 189 Tg CO_2/year.

A meta-analysis by Powlson *et al*. (2016) found that, in SSA, increases in carbon stocks were between 0.28 and 0.96 Mg C ha^{-1} yr^{-1}, but with much greater variation and a significant number of cases showed no measurable increase. Thus, increasing net soil carbon storage by even a few percentage points represents a significant carbon sink potential for the tropical region of Africa.

Recarbonization is essential for all soil processes that impact agronomic productivity and the environment (FAO, 2019d). Persistence of a soil carbon pool as an ecosystem property depends on a range of environmental and biological controls (e.g. nutrient availability) (Mrabet *et al*., 2017). While nitrogen is the most limiting nutrient for crop production, many agricultural soils in Africa are deficient in phosphorus, potassium, sulfur and micronutrients (Sommer *et al*., 2013), which makes balanced nutrient inputs critical to carbon sequestration in soils. Integrated plant nutrient management is a challenge for low-capacity soils in Africa, and the 4R approach proposed by the International Plant Nutrition Institute (IPNI) can be used to maximize fertilizer use efficiency, reduce N_2O emissions from fields and, at the same time, guarantee better production and environmental stewardship (IPNI, 2012; Johnston and Bruulsema, 2014). Improving fertilizer management under CA is one of the most effective strategies that farmers can adopt to both increase crop yields (Mrabet *et al*., 2001b; Kimaro *et al*., 2015; Kabirigi *et al*., 2017) and reduce GHG emissions (Mrabet *et al*., 2012; Shcherbak *et al*., 2014; Powlson *et al*., 2016). Locally blended fertilizers should be encouraged to reduce the costs of fertilization associated with incorporating nitrogen-fixing crops, cash crops and manure. It is extremely important to shift from monocropping (e.g. maize) to diversified crop sequences.

Carbon storage and sequestration are widely recognized to permit co-benefits for the soil and environment, such as improvements in hydrological processes and the soil–water balance (infiltration, runoff and evaporation control, water conservation and soil water-holding capacity, etc.) (Mrabet *et al*., 2012; Wall *et al*., 2014; Mtakwa *et al*., 2020). It has also been reported that efforts to sequestrate carbon in agricultural land, to reduce climate impact below 1.5°C, may even reduce calorie loss by 65% and so limit undernourishment (Frank *et al*., 2017).

The review by Wall *et al*. (2014) showed that infiltration improved by 67% under CA compared to CA in 39 sets of data from East and southern Africa. The review also outlined that, in erosion studies from Ethiopia, Kenya, Zimbabwe and South Africa, CA helped to reduce runoff by 51% (range 14%–95%) and erosion by 71%. Such benefits are confirmed in North Africa by Mrabet (2011a), Moussadek *et al*. (2011a) and Mrabet *et al*. (2012). Corrections and enhancements in soil biological and hydrological processes of this kind enable resilience in farming systems.

2.6.4 Livestock Performance and Synergistic Integration with Crops

Livestock use 30% of the entire land surface of the Earth as permanent pasture and 33% of arable land is used to produce feed for the livestock (FAO, 2006). In Africa the livestock sector is highly dynamic but, globally, has negative impacts on production efficiency and environmental sustainability (Lal, 2020a). Mixed farming systems contribute to the livelihoods of a large population by providing most of the staples consumed by many millions of poor people in Africa: between 41% and 86% of the maize, rice, sorghum and millet; 90% of the milk; and 80% of the meat (Thornton and Herrero, 2015). In addition, demand for livestock products is expected to increase due to population growth, shifts in living standards and diets, and urbanization. On one hand, the African livestock sector has been hit by climate change owing to its impact on the quality of feed crops and forage, water availability, animal and milk production, livestock diseases and outbreaks, animal reproduction, composition and productivity of pasture and rangelands, and biodiversity (Grossi *et al.*, 2019).

On the other hand, in Africa, livestock-related GHG emissions from enteric fermentation and manure contribute nearly two-thirds of the agriculture sector's emissions (about 69%). Manure left on fields itself contributes about 28% (FAO, 2016a). Sustainable livestock systems should find a point of balance between stable production and a good income for farmers, build-up of resources, ecological and climate change benefits and demands for more animal health and welfare (Thornton and Herrero, 2015). These systems provide 15% of the nitrogen inputs for crop production via manure amendments (Thornton and Herrero, 2015).

Livestock is characteristically integrated with cropping systems through weedy fallows, residue and stubble grazing, and the use of woodlands and rangelands. Crop–livestock integration means durable relationships between the animal component through health and feeding, plants in terms of productivity and performance, and soil for its quality and resilience. Synergistic integration is needed for CA systems to be adopted at stable rates in Africa.

Numerous reports and studies have pointed to the problems of crop residue retention and the trade-offs between different uses in crop–livestock farming systems (Palm *et al.*, 2014; Valbuena *et al.*, 2012). Crop stubbles and residues are important forage for ruminants and sources of income for farmers (Mueller *et al.*, 2003). In addition, animal manure is the most important soil fertility amendment. Owing to low biomass production, returning crop residues to soils is the major barrier for CA adoption in Africa. Main benefits from CA are due to crop residue management which improves the functioning of the soil–water–plant system (Wall *et al.*, 2020), which allows farmers to understand the system and so make sound and relevant decisions. Adopting CA does not mean uncoupling grain and livestock but ensures simultaneous production and ecological efficiencies (reduced erosion, increased carbon storage, etc.). Crop residue management is a long-term engagement and should be resolved and agreed upon at the community level to ensure benefits to soils, crops and farmers. In addition, enabling policies and effective communication on residue management under CA are prerequisites for CA uptake and adoption.

Improved skills and options are needed for synergistic crop–livestock integration under CA systems to minimize financial risks, improve livestock performance and regenerate degraded soils. Such integration would be enhanced mainly through the feed (fodder and grain) supply from encouraging the use of diversified or multi-cropping cropping systems. Other alternate options are spatial management and control of grazing, livestock mobility and agricultural insurance to avoid yield penalties through excessive residue removal and associated adverse effects on soils (De Leeuw *et al.*, 2019). Further options are explained in Box 1 (Mrabet, 2008b; Thornton *et al.*, 2018b; Lal, 2020a).

2.6.5 Knowledge Economy

The knowledge economy is driven by innovation and creativity. While developed nations have benefited from advanced CA technologies since the early to middle 1900s, many subsistence and traditional farmers across Africa are suffering from soil mining techniques using stage 1 agricultural mechanization (human and animal

Box 1. Conservation Agriculture options for climate-resilient integrated crop–livestock systems

- Policies for preventing/reversing rangeland degradation.
- Revaluing competition for crop residues and stubbles.
- Replacing (weedy) fallow with fodder crops to produce a greater quantity of higher-quality feed for livestock.
- Introducing forage legumes and dual-purpose crops.
- Partially removing crop residues, ensuring that enough residues are left for soil protection and enrichment.
- Flexibly controlling seasonal grazing on stubble with appropriate stocking rates.
- Establishing perennial forages for direct grazing and for cut-and-carry (use of fodder trees, shrubs and cactus).
- Introducing row crops (cash crops) for generating higher returns to guarantee feed purchase, especially if supplementary irrigation is possible.
- Improving food resources and nutritious diet supplements.
- Using silage and feed blocks to give more efficient use of a wide range of agro-industrial by-products.
- Temporarily displacing animals to pastures; soil physical condition of degraded lands may recover faster under CA conditions when animals are excluded for a period of time.
- Increasing crop biomass yields and soil quality through integrated soil fertility management and best management practices.
- Producing better-quality (more nutritious) straw through genetic improvements and crop nutrition.
- Managing manure for nutrient soil supply and resilience.
- Improving livestock diets and using feed additives to mitigate methane emissions.
- Substituting livestock species and changing breed strategy.
- Developing index-based livestock insurance.

tools) to grow food and raise livestock (FAO & AUC, 2018; de Araújo *et al*., 2020). In addition, CA depends more on knowledge than on labour. Hence, disruptive pathways to the CSA revolution, and specifically to CA, are needed for Africa's food security and climate change mitigation. These should generate the co-benefits of increased agricultural production and efficiency, reduced environmental footprints, enhanced economic returns and farmers' well-being.

Investing in intellectual capital through education, training, skills and communication development is critically important for changing paradigms and closing knowledge gaps on CA systems. The entire system of education and training should be enhanced in terms of resources, capacities and competences. NEPAD's Agricultural Education and Skills Improvement Framework 2015–2025 will certainly allow such dynamism and development.

CA has changed the way knowledge is shared, developed and spread, as resource- and profit-dependent paradigms are being replaced by sustainable development paradigms. At the same time, adopting and promoting CA systems requires the continuous production of scientific knowledge and the development of skills and training by CA users so they can face and explain emerging challenges and address farmers' evolving concerns. CA development entails strengthening knowledge for all stakeholders and the creation of information-sharing mechanisms and channels to replace the usual research–extension systems (Altieri *et al*., 2012). More public–private investment and farmer engagement in CA research and information sharing should be encouraged and valued, and investment in national research and education systems can help revitalize sustainable agriculture.

The potential of information communication technology (ICT) to support access to and exchange of information and knowledge of CSA for smallholder farmers is huge. ICT, and especially mobile technologies and social media, can enhance and expand the networking of farmers, non-governmental organizations (NGOs) and agribusiness. It can also facilitate the provision of services such as weather information and forecasts, advice and financial payments. ICT will also reduce the literacy and gender gap and allow community learning, awareness and development by improving the access of women and youth to information and knowledge of CSA and CA. ICT is of paramount importance in facilitating up-to-date knowledge and continued information generation and documentation, as well as farmer-to-farmer communication and real-time information sharing. It also reduces barriers to CSA adoption related to local language and forms of communication in remote rural areas. To facilitate access to ICT and its services, public–private partnership is essential, mainly to expand network and electricity coverage. ICT-based platforms include VERCON developed by FAO (Treinen, 2010), ESOKO (http://www.esoko.com, accessed 1 July 2021), Prolinnova (http://www.prolinnova.net, accessed 1 July 2021) and CropLife (http://www.croplifeafrica.org/, accessed 1 July 2021).

2.6.6 Economic and Social Benefits for Green Growth

Since the turn of the millennium, the African continent has been one of the fastest-growing regions of the world. However, recycled green revolution cannot sustain and boost food production while permitting food and nutrition security and eliminating hunger against climate change for small holder farmers in Africa (Turral *et al*., 2011). Publications indicate that the economic and social benefits from CSA are wide and include savings in inputs, labour, time, fuel and machinery wear; more machinery productivity; timely sowing; and less drudgery (Wall *et al*., 2020).

Most agricultural land in Africa is currently producing below its capacity. Using CA systems to increase the productivity of its fragile soils is cost effective, resource use-efficient and implies closing the whole-farm performance gaps (Wall *et al*., 2020). Pretty *et al*. (2011) concluded that the impact of CSA on domestic food budgets, social infrastructure, business development and the well-being of both the rural and the urban populations can be huge.

Large-scale farmers are better positioned to take advantage of economies of scale and size. The adoption of CA systems (either reduced tillage or no-till) represent opportunities for all farmers to reduce machinery investment and lower their cost of production. Griscom *et al*. (2017) found that CSA solutions (agroforestry, CA and crop nutrient management) are the most cost-effective land-based climate options in mitigating climate change and addressing issues related to water and air quality and biodiversity protection.

In a recent study, De Pinto *et al*. (2020) showed that widespread adoption of CSA practices can increase production and lower the world prices of wheat, maize and rice under future unfavourable climatic conditions. It was also found the reduction in prices is projected to make food products more accessible to millions of people, thereby lowering the number of people at risk of hunger and that of undernourished children. These gains can be obtained while improving soil fertility and with a reduction in GHG emissions.

The level of mechanization in Africa is dominated by hand tools (65%) with animal and engine power sources contributing 25% and 10%, respectively. To increase agricultural and labour productivity, alleviate poverty and raise employment in rural areas, it is imperative to modernize farming systems through mechanization. The development of the agricultural machinery sector in Africa is critically important to fuel farming systems, increase financial growth and act as a vehicle for CA up-scaling for both small-scale and modernized farmers (Collier and Dercon, 2014). In other words, the viability of CA depends on farmers shifting from outdated, traditional methods to modern, well-tested and knowledge-based methods of land use. A policy framework for sustainable agricultural mechanization has been developed (FAO & AUC, 2018) and deployment of mechanization should be along the complete value chain including seeding, fertilizer application, weed and pest control, harvest and post-harvest activities. African farmers should then benefit from technological development and diversity in drills, tractors, harvesters, sprayers, etc. Governments should develop local industry and service providers. In this way both small and large-scale farmers engaged in CA could improve their crop yields and profits while achieving more efficiencies in labour, water, input and energy. CA systems will also confer natural resource conservation and mainstream ecosystem services.

A market systems approach should be also developed to boost adoption of CA technologies and outcomes by farmers. Access to modern and structured markets is essential to improve CA uptake, lower the costs of inputs and guarantee that farmers innovate. The higher returns achieved by converting to CA systems should allow increased investment and use of credits and available funds, as well as providing an economic incentive for adoption. Entrepreneurship is then possible in rural areas as well as in off-farm services and benefits.

2.7 Barriers Impinging on Adoption and Diffusion of Conservation Agriculture (CA)

In Africa, CA was first introduced in large farms in Zimbabwe in the late 1960s (Andersson and D'Souza, 2014). Hence, in the history of CA, the difficult part is not the innovation itself but the changing of perceptions, habits and paradigms. The effort to adopt and promote CA across the agroecologies has been under way for five decades but it is only recently that technologies are being accepted by farmers and producers. Despite the many successes of CA across Africa, adoption is still low (1.5 million ha; Kassam *et al.*, 2020) compared to other regions with a similar climate and soils (e.g. Asia). Monitoring failures and successes is critical to guide the CA transition towards sustainable food and agricultural systems.

Mainstreaming the 'triple win' of CSA in Africa faces diverse types of challenges and barriers (James *et al.*, 2015; Shilomboleni, 2020). It can be hypothesized that the barriers for the implementation of CA are related to technological, ecological, institutional, economic and socio-cultural aspects. However, one of the major barriers to CA adoption by communities is the difficulty in fully understanding the tensions, relationships and synergies among the three CA dimensions or principles in both the research and farmers' communities. It is necessary to shift from the 'damage and fix' type of approach to systemic and inclusive approaches. CA farmers should not simply correct deficiencies and repair damage caused by mismanagement or use of CA practices and principles and imposed by recurrent environmental stresses.

Two of the most prominent lock-in factors identified were both social and institutional. Challenges to CA adoption in Africa include the retention of sufficient crop residues, crop rotation, weed control, pest and diseases, farmer perception and economic limitations, including poorly developed markets (Wall *et al.*, 2020). According to Lahmar *et al.* (2012), the organic resources are the most limiting factor in Sahelian agroecosystems owing to low biomass productivity and the multiple uses of crop residues, chiefly to feed livestock. The authors proposed to first enhance soil fertility and nutrition, develop alternative sources of biomass and integrate traditional farming methods and cereal intercropping in CA systems.

African farmers, and especially smallholder and vulnerable farmers, make decisions in complex and variable contexts within which are factors such as markets, policies and programmes, and other social institutions are critically important. Such contexts may facilitate or constrain adoption decisions by farmers and impact their behavioural change. Farmers and their organizations need to develop strong networking and permit social learning in order to get the best determinants of CA adoption and receive state-of-the art knowledge and the skills they need.

It was concluded that CA is not a 'one size fits all' solution and often needs significant adaptation and flexibility when it is implemented across farming systems (Holden *et al.*, 2018). However, CA may potentially reduce a future decline in soil fertility and the effects of seasonal dry spells, and may have a large impact on food security and farmers' livelihoods if the challenges can be overcome (Thierfelder *et al.*, 2015; El Gharras *et al.*, 2017).

The ambitious objective of limiting climate change while ensuring food security and environmental sustainability through CSA triggered profound changes in the food and farming systems in the continent (Mbow *et al.*, 2019) and more space should be allowed for debate and discussion (Taylor, 2018). In this respect, CA adoption and diffusion in Africa needs to be rethought, and based upon a systemic but concerted change involving all stakeholders (farmers, land managers, researchers, NGOs, businesses, decision makers, communication media and citizens) (Glover *et al.*, 2016). Extensive cooperative networks and a high level of international collaboration exists in Africa and should facilitate and implement such changes and developments.

Building trust among the actors and stakeholders is central to pan-African adoption and spread of CA. Such trust requires broad-based partnership and collaboration as well as shared values and insights into the acceptability and appropriateness of CA. Developing policy experience and research–training–linkages expertise in relation to CA ecosystems is of paramount importance in changing paradigms within the complex sphere of stakeholders. This will open space for transformation.

Barriers should be replaced by CA adoption accelerators in a way that mind-sets and attitudes are changed and transformed among stakeholders. CA mainstreaming and decision-making abilities are mainly improved and accelerated through public awareness, social license and stakeholder dialogue, knowledge and information sharing intensive mechanisms, stable funding and investment. Other facilitators can be better problem-solving capacities, regulations, encouragements and incentives for value chain actors and risk repulsion against undesirable and indirect effects. Failure to engage in such systemic change will keep CA at an embryonic stage of adoption and a spiral of degradation will begin. Research into CA adoption should use comprehensive theoretical lenses and examine factors at both individual and structural level.

2.8 International Cooperation, Political Statements and Bold Initiatives: Shift Towards Long-term Funding Models

African agriculture is at a crossroads and transforming at a breathtaking pace owing to climate change, demography, hunger, urbanization, pandemics, youth, innovation, etc. Interventionist policies to solve emergencies are not efficient and durable in the face of such complex and pressing challenges. As early as 2010 CSA received the support of several countries and institutions, international organizations and development agencies, in particular the World Bank and FAO (Chandra *et al.*, 2017).

In 2002 the CAADP, prepared jointly by FAO and NEPAD, was launched in Abuja (Nigeria) as Africa's policy framework for agricultural transformation, wealth creation, food security and nutrition, economic growth and prosperity for all. A year later, in Maputo, Mozambique, the AU Summit made the first declaration on CAADP as an integral part of NEPAD (NEPAD, 2003). In addition to an agricultural growth target of at least 6%, the CAADP also aimed for at least 10% of government budgets to be allocated to agriculture (Maputo Declaration, 2003).

The AU Agenda 2063 set both the vision and the action plan for the development of the continent over the next 50 years. Adopted in June 2014, the first 10-year implementation plan (2015–2025) covers seven priority areas aligned with the SDGs. These priorities are defined in the 2014 Malabo Declaration on 'Accelerated Agricultural Growth and Transformation for Shared Prosperity and Improved Livelihoods' and positioned CSA as a priority on the continental development agenda.

Accordingly, African heads of state and government pledged, among other goals, to end hunger by 2025, focusing on the triple targets of increased production, reduced losses and waste and improved nutrition. Commitment 6 of the Malabo Declaration calls for AU Member States to 'enhance resilience of livelihoods and production systems to climate variability and other related risks'. AU Member States are expected to 'ensure that at least 30% of farm, pastoral and fisher households are resilient to climate and weather related risks'.

At a Dakar conference in October 2015, while defining a roadmap for the transformation of agriculture in Africa, five priorities were established: (i) set up multiple nutrition programmes; (ii) improve agricultural productivity; (iii) develop agricultural activities (value chain approach); (vi) increase funding for agriculture; and (v) support the inclusion of women and young people.

In April 2016, the Abidjan Declaration aimed at ensuring resilient agricultural development in Africa through three opportunities for action: (i) build government capacities; (ii) develop climate-resilient agricultural policies; and (iii) reinforce financial and technical support to adaptation.

The same year the AfDB, echoing the commitments made under the CAADP as articulated in the Maputo and Malabo Declarations, adopted the 'Feed Africa' strategy (2016–2025) to enhance a competitive and inclusive agribusiness sector that creates wealth, improves lives and protects the environment. The strategy, which is one of the main five priorities of the AfDB, aims to end hunger and rural poverty in Africa in that decade by focusing on transformation, scaling-up agriculture as a business through value addition (led by the private sector and enabled by the public sector) and using innovative financing mechanisms. It also seeks to bring to scale existing and successful initiatives across Africa and beyond. The strategy clearly states that, owing to the escalating challenge of climate change, CSA is no longer an option but a core necessity. The AfDB then intends to promote and finance the use of CSA practices and better prepare farmers and other vulnerable populations for climate risks.

African countries have made efforts to improve agricultural adaptation to climate change through engagements at various levels and in different fora. These include the Ministerial Declaration on food security and the agriculture sectors in the changing climate at the 29th FAO Regional Conference for Africa, and the Adaptation of African Agriculture (AAA, or Triple A) initiative discussed and launched during COP22.

The West African Initiative for Climate-Smart Agriculture (WAICSA) is the only West Africa-led blended finance fund with a specific focus on increasing the uptake of CSA practices by smallholder farmers. WAICSA has the potential to improve the food security of 90,000 smallholder farming households in the region and convert over 185,000 hectares to climate smart agriculture. The fund can also contribute to mitigating up to 2 million tons of CO_2 emissions a year (Table 2.1).

Over the last 10 years, CSA, in its various models, has attracted international cooperation and mobilized partnerships and resources to reduce tensions on the agricultural sector, households and farmers. To promote and scale-up CSA, and secure investment in it, several strategies, programmes and initiatives have been launched to guarantee planning, coordination and investment. A range of new Africa-based initiatives and non-profit organizations has emerged quite recently, and NGOs in particular play an increasingly important role in promoting the increased adoption of CSA (Dinesh *et al.*, 2015; 2017).

Seeking increased agricultural productivity, enhanced adaptive capacity, improved soil security and carbon sequestration, organizations such as the Food and Agriculture Organization of the United Nations (FAO), the World Bank and the research programme on Climate Change, Agriculture and Food Security (CCAFS) of the Consultative Group on International Agricultural Research (CGIAR) employ a 'climate smart agriculture' framework in various countries and sub-regions of Africa (FAO, 2013; Neate, 2013). These organizations, with a country's institutions, have implemented various initiatives and programmes on CSA (including CA) to curb the spiral of degradation, recarbonize soils, impede climate change and improve livelihoods and food security. The Green Climate Fund (GCF) named CSA in Africa and Asia as one of its five priority investment areas, and the Global Environmental Facility GEF) has a focal area on CSA and food security in Africa (Rosenstock *et al.*, 2016; Dinesh *et al.*, 2017).

The United Nations climate summit in 2014 saw the launch of the Global Alliance for Climate-Smart Agriculture (GACSA), a platform for knowledge exchange and inter-regional cooperation on CSA with over 465 members including multilateral agencies, governments, research institutions, farmers' organizations, the private sector and NGOs (GACSA, 2016; 2020; Dinesh *et al.*, 2017). The aim of GACSA is to support the scaling-up of CSA around the world, as well as to maximize the impact of the CSA approach, accelerate its implementation, identify financing mechanisms, and create and catalyse partnerships (http://www.fao.org/gacsa/en/, accessed 2 July 2021). It is intended that this partnership will empower 6 million smallholder farmers in SSA by 2021.

There is no blueprint for CSA, and the specific contexts of sub-regions, countries and communities would need to shape how it is ultimately designed, planned and implemented. CSA plans for selected countries are presented in Table 2.1. CSA initiatives and projects for other countries are presented by Nyasimi *et al.* (2014). This growing CSA momentum should be better acknowledged in high-level decision-making

Table 2.1. Selected CSA strategies, initiatives and programmes globally and in Africa. Authors' own table.

Programme/initiative	Partnership	Goals	References/URL
Global			
Global Alliance for Climate-Smart Agriculture (GACSA)	Over 140 members including governments, research institutions, farmers' organizations, the private sector and NGOs	GACSA is an inclusive, voluntary and action-oriented multi-stakeholder platform on climate smart agriculture (CSA) hosted by FAO	UN (2014) GACSA (2016) http://www.fao.org/gacsa/en/, accessed 2 July 2021
Research Program on Climate Change, Agriculture and Food Security (CCAFS)	East–West Africa, Latin America and South-east and South Asia	Overall goal of CCAFS: to catalyse positive change towards climate smart agriculture, food systems and landscapes	https://ccafs.cgiar.org, accessed 2 July 2021 https://ccafs.cgiar.org/ccafs-phase-ii, accessed 2 July 2021
4 per 1000 initiative	Global	Ambition of the initiative is to encourage stakeholders to transition towards a productive, highly resilient agriculture, based on the appropriate management of lands and soils, creating jobs and incomes, hence ensuring sustainable development	Chabbi *et al*. (2017) Minasny *et al*. (2017) https://www.4p1000.org, accessed 2 July 2021
NDC Partnership	Hosted by World Resource Institute & UN Climate Change. Supported by World Bank, UNDP, Inter-America Development Bank. 104 countries, 35 international institutions and 23 associate members work together to deliver the world's commitments and goals under the Paris Agreement	Works directly with developing country governments on NDC implementation, helping mainstream climate action into domestic sustainable development agendas, enhancing countries' climate ambitions and mobilizing finance for transition to low-carbon, climate-resilient economies	http://ndcpartnership.org/caep NDC Partnership (2019)
IFAD: Adaptation for Smallholder Agriculture Programme (ASAP)	8 million smallholder farmers from 13 countries in Asia, Sub-Saharan Africa and Latin America	Multi-year and multi-donor financing window for mainstreaming climate change for resilience and food security and promoting adaptive technologies such as agroforestry, Conservation Agriculture and water harvesting	IFAD (2014) www.ifad.org/climate/asap, accessed 2 July 2021

Continued

Table 2.1. Continued

Programme/initiative	Partnership	Goals	References/URL
World Business Council on Sustainable Development - WBCSD CSA Initiative	WBCSD convened companies from the food and agriculture sectors to address the dual challenges of climate change, and the need to satisfy the nutritional requirements of a growing global population	Building smallholder/family farmer resilience; scaling-up investment in CSA; improving business ability to trace, measure and monitor CSA progress	WBCSD (2015) https://www.wbcsd.org/Programs/Food-and-Nature/Food-Land-Use/Climate-Smart-Agriculture, accessed 2 July 2021
Food Security Climate Resilience Facility (FoodSECuRE)	World Food Programme, IRI and financed by Norway and Luxembourg	For countries in Africa, South Asia and Latin America	https://www.wfp.org/publications/foodsecure, accessed 2 July 2021
Inter-Agency Working Group on Climate Smart Agriculture in International Development	Since 2010 the CSA working group seeks to strengthen integration of environment and climate change considerations into the implementation of Feed the Future, the US government's flagship food security initiative	CSA working group's goal is to improve the effectiveness and sustainability of food security programmes by promoting climate smart agriculture policies and practices	https://rmportal.net/groups/csa/about-csa, accessed 2 July 2021
Africa			
Feed Africa strategy (2016–2025)	African Development Bank	Enhancing a competitive and inclusive agribusiness sector that creates wealth, improves lives and protects the environment	https://www.afdb.org/fileadmin/uploads/afdb/Documents/Policy-Documents/Feed_Africa-Strategy-En.pdf, accessed 2 July 2021
The African Agriculture Adaptation Initiative (AAA Initiative)	Initiative developed as a foundation to serve Africa as a whole	Launched upstream of COP22 organized in Morocco, AAA aims to reduce the vulnerability of Africa and its agriculture to climate change. Promotes and fosters the implementation of specific projects to improve soil management, agricultural water control, climate risk management and capacity building and funding solutions. An important response to climate change and food insecurity. Objective is to place AAA at the heart of climate debates and negotiations, and to attract a substantial share of climate funds. Aims to contribute to the roll-out of specific agricultural projects	Badraoui *et al*. (2018) Lal (2019b) http://www.aaainitiative.org, accessed 2 July 2021

Alliance for a Green Revolution in Africa (AGRA)	Committing grants across all 11 priority countries and in support of continental agencies	Strategic focus on (i) policy and state capacity to strengthen agricultural sector leadership; (ii) systems development to ensure functional inputs and off-taker systems; (iii) partnerships to ensure value and alignment with government priorities through improved coordination	https://agra.org, accessed 2 July 2021 AGRA (2018b)
Technologies for African Agricultural Transformation (TAAT)	Being implemented in 22 countries; focuses on nine priority commodity agricultural value chains (maize, wheat, rice, sorghum/millet, cassava, high-iron bean, orange-fleshed sweet potato, aquaculture and small livestock) with the support of enablers	Funded by the AfDB. A knowledge- and innovation-based response to the need to scale-up proven technologies across Africa, to boost productivity and make Africa self-sufficient in key commodities	https://www.afdb.org/fr/news-keywords/technologies-african-agricultural-transformation-taat, accessed 2 July 2021
Sustainable Development Goals Center for Africa (SDGC/A)	Began in July 2016 to serve all Africa	An international organization that supports governments, civil society, businesses and academic institutions to accelerate progress towards the achievement of the SDGs in Africa	https://sdgcafrica.org, accessed 2 July 2021
Pilot Programme for Climate Resilience (PPCR)	AfDB in Niger, Zambia and Mozambique for three priority areas: agriculture and landscape management, water resources management, and climate information services and disaster risk management	Funded by the Strategic Climate Fund (SCF), one of the two climate investment funds (CIF). Designed to demonstrate ways that developing countries can make climate risk and resilience part of their core development planning. Helps countries build on their national adaptation programmes of action (NAPA) and helps fund public and private sector investments identified in climate-resilient development plans	PPCR (2016) https://www.afdb.org/en/topics-and-sectors/initiatives-partnerships/climate-investment-funds-cif/strategic-climate-fund/pilot-program-for-climate-resilience-ppcr, accessed 2 July 2021
The African Soil Health Consortium (ASHC)	Coordinated by CABI in partnership with international and national research and development organizations, supported by the Bill & Melinda Gates Foundation	Works with initiatives in SSA to encourage the uptake of integrated soil fertility management (ISFM) practices, primarily by supporting development of down-to-earth information and materials designed to improve understanding of ISFM approaches	https://africasoilhealth.cabi.org/, accessed 24 September 2021

Continued

Table 2.1. Continued

Programme/initiative	Partnership	Goals	References/URL
TerrAfrica	African member countries; bilateral development partners Norway, France, Netherlands, European Union; multilateral development partners World Bank, AU, IFAD, FAO, AfDB, UNDP and UNEP; UNCCD) (secretariat and global mechanism), GEF; civil society	A regional initiative to enable governments of SSA, the international development community and other global, regional and national stakeholders to better coordinate efforts to scale-up the financing and mainstreaming of effective and efficient country-driven sustainable land and water management (SLWM)	https://www.nepad.org/programme/terrafrica, accessed 2 July 2021
African Fertilizer and Agrobusiness Partnership (AFAP)	Since 2012 has implemented projects/programmes and advised public, private sector clients, NGOs and donors in Ghana, Tanzania, Mozambique, Malawi, South Africa, Ivory Coast, Nigeria, Senegal, Rwanda, Kenya, Ethiopia, Democratic Republic of Congo and Uganda	Adds value to agriculture inputs and agribusiness value chain by building capacity and linking African hub agrodealers and smallholder farmers to global inputs and output market companies, promoting use of high-quality and affordable balanced crop nutrition products, partnering with technology and equipment providers and facilitating trade finance for fixed assets and inventory via the Agribusiness Partnership Contract (APC) mechanism	https://www.afap-partnership.org, accessed 2 July 2021
AfricaFertilizer.org	Run by the AFAP, the International Fertilizer Industry Association (IFA), FAO and the AU Commission	Supports dissemination of information on the fertilizer sector for the public and private sectors, including fertilizer industry, distributors and farmers	AfricaFertilizer.org, accessed 2 July 2021
The R4 Rural Resilience Initiative	World Food Programme and Oxfam for pilot countries Ethiopia, Kenya, Malawi, Senegal, Zambia and Zimbabwe	To enable vulnerable rural families to increase their food and income security by managing climate-related risks	https://www.wfp.org/r4-rural-resilience-initiative, accessed 2 July 2021
FertiMap	In use in several African countries as part of South–South cooperation	Concerned with the fertility of cultivated soils in Morocco; an on-going partnership project between the Moroccan Ministry of Agriculture and the OCP Group since 2010. Work is carried out by a consortium of Moroccan research and agricultural education institutions led by the National Institute of Agricultural Research (INRA Morocco)	http://www.fertimap.ma/, accessed 24 September 2021
AFS4Food	Coordinated by CIRAD and funded by AU and EuropeAid in Cameroon, Kenya and Madagascar	Enhancing food security and well-being of rural African households through improved synergy between agroforestry systems and food crops	https://afs4food.cirad.fr/en, accessed 2 July 2021

West African Initiative for Climate-Smart Agriculture (WAICSA)	Initiated in 2015 and led by the Commission of the Economic Community of West African States (ECOWAS) and funded by the European Union, World Bank and the AU's NEPAD in 15 countries in West Africa	Builds climate resilience among smallholder farmers by providing financial and technical support to incentivize the adoption of climate smart agriculture and increasing local financial institutions' capacity for climate smart lending	https://climatepolicyinitiative.org/wp-content/uploads/2019/10/WAICSA-v16_18092019-_Final.pdf, accessed 2 July 2021
VUNA (climate smart agriculture programme)	UK-Aid–DFID-funded programme, implemented by Adam Smith International; aimed to transform agricultural systems in five countries in East and southern Africa to be suitable for the changing climate from 2015 to 2018	Support to smallholder farmers to adapt to climate change, and supporting achievement of national and regional priorities to transform agriculture in the face of climate change (aligns with the CAADP pillars)	https://adamsmithinternational.com/projects/building-smallholder-farmers-climate-resilience-in-east-and-southern-africa/, accessed 6 December 2021
Soil Carbon Network for Sustainable Agriculture in Africa (CaSA)	An open scientific group for a better consideration of CSA in Africa. Network mainly driven by four research teams from the South and the IRD. Comprises 21 research teams from 11 African countries	Mobilization of African and European researchers to promote soil carbon sequestration for sustainable management of soil fertility and productivity	https://www.reseau-carbone-sol-afrique.org, accessed 2 July 2021
Partnership for Agricultural Water for Africa (AgWA)	Hosted by FAO at its sub-regional office for Eastern Africa (SFE) in Addis Ababa. AgWA main partners are AfDB, AMCOW, FAO, IFAD, IWMI, NEPAD/NPCA, and World Bank	To increase investment in agricultural water management that is socially equitable, profitable at the farm level, economically viable, environmentally friendly and sustainable, while contributing to implementation of the CAADP national process, in particular to its Pillar 1 on sustainable development of land and water and the achievement of the SDGs	
ACT (African Conservation Tillage) network	Premier pan-African network of excellence in promoting sustainable natural resource management for improved livelihoods and wealth creation in Africa and beyond	To enhance agricultural productivity, sustainable land management (SLM) and environmental conservation through promotion of CA principles and practices in Africa	http://www.act-africa.org, accessed 2 July 2021
Platform for an Africa–Europe Partnership for Agricultural Research for Development (PAEPARD)	Supported by European Commission and co-managed by FARA and AGRINATURA	Aims to facilitate multi-stakeholder Africa–Europe partnerships in agricultural research for development (ARD) to contribute to the achievement of the Millennium Development Goals (MDGs, now SDGs)	https://faraafrica.community/paepard, accessed 24 September 2021

Continued

Table 2.1. Continued

Programme/initiative	Partnership	Goals	References/URL
West Africa Agricultural Productivity Program (WAAP/PPAAO)	World Bank	Objective was making agriculture more climate smart across 16 West African countries so the agriculture sector remains sustainable for future generations	http://www.waapp-ppaao.org/en/content/who-we-are, accessed 2 July 2021
Africa Climate Business Plan (ACBP)	World Bank	Aims to raise awareness and accelerate resource mobilization for priority climate-resilient and low-carbon initiatives in Africa	https://www.worldbank.org/en/programs/africa-climate-business-plan, accessed 2 July 2021
CSA Framework Programmes (CSA-FPs)	Joint initiative supported by CCAFS, the World Agroforestry Centre (ICRAF), the International Centre for Tropical Agriculture (CIAT), NEPAD and COMESA. It concerns Kenya, Uganda, Tanzania, Botswana and Namibia	Aim to support countries to synergize their national agricultural investment plans (NAIPs) and agricultural sector programmes with national climate change strategies and action plans to ensure a common and holistic approach	https://ccafs.cgiar.org/blog/ready-take-east-african-countries-develop-climate-smart-agriculture-frameworks#. X3Je1y17TxsCSA Framework Programmes (CSA-FPs), accessed 2 July 2021 Girvetz *et al*. (2017)
National Agricultural Resilience Framework	Nigeria	Seeks to minimize climate risks associated with Nigeria's ambitions to promote rural development through export-led agriculture	Vermeulen *et al*. (2014)
National CSA and food security action plan	Ghana (2016–2020)	Aims to translate the national goals and objectives on CSA into action on the ground through sound implementation of programmes in agroecological zones and various districts	Essegbey *et al*. (2015)
Climate Resilient Green Economy (CRGE) initiative	Ethiopia	Supported by Green Economy Strategy (GES) and the Climate Resilience Strategy (CRS); focuses on improving crop and livestock production practices for greater food security and better income for farmers, while reducing emissions	CRGE (2011) https://www.undp.org/content/dam/ethiopia/docs/Ethiopia%20CRGE.pdf, accessed 2 July 2021
Climate Smart Agriculture Programme 2015–2025	Uganda	Jointly implemented by Ministry of Agriculture, Animal Industry and Fisheries, and Ministry of Water and Environment	Eriksen *et al*. (2019)

IRD, Institut de Recherche pour le Développement; IRI, International Research Institute for Climate and Society; NDC, nationally determined contributions.

spaces and more reflected in farmers' fields across the continent.

2.9 Africa Climate Smart Agriculture (CSA) Vision 25×25 and the Adaptation of African Agriculture (AAA) Initiative

2.9.1 Africa Climate Smart Agriculture (CSA) Vision 25×25: Turning Challenges into Balanced Motivation and Concrete Opportunities

Overcoming barriers to adoption and up-scaling of CSA technologies while releasing farmers' constraints to sustainably produce field crops is a lengthy process and requires a clear and long-term vision. At the same time, the ambitions of Agenda 2063 from the agricultural sector to attain higher levels of production of safe and high-quality food while preserving natural resources and mitigating climate change, should make adoption of CSA highly feasible.

In its 31st AU Summit in Malabo in 2014, African leaders and Member States adopted the Africa Climate Smart Agriculture Vision 25×25 which aims to support at least 25 million farm households in practising CSA by 2025. Several countries, such as Kenya, Uganda, Namibia, Botswana and Tanzania, drafted country programmes that set national agendas on CSA (CANA, 2020). In North Africa, several projects were mainstreaming CA as a climate smart solution for alleviating climate change impacts on agriculture and food security (Cheikh M'hamed *et al.*, 2018). In particular, the recent Green Generation Plan (2020–2030) clearly showed a vision based on CSA including CA, agroforestry and organic farming systems. Across Africa, several million smallholder family members are already benefiting from CA land uses and this number may increase many fold with the CSA vision and support from government initiatives, international organizations, NGOs, civil societies and grassroots organizations. It is expected that the vision will serve as an engine of growth while assuring a continuous food supply for growing populations under climate change.

2.9.2 Adaptation of African Agriculture (AAA) Initiative for Scaling-up/out Climate Smart Agriculture (CSA)

Most Africans derive their livelihoods from natural resource-based occupations, including agriculture, livestock, pastoralism and fishing. Low productivity, low efficiency and policy weaknesses prevail and continue to challenge food security for both the rural and urban populations. In order to remedy to such inefficiencies, AAA (which is now a foundation), was launched and promoted by Morocco during the COP22 summit held in Marrakesh, Morocco, from 7 to 18 November 2016. AAA aims to raise more funding for the adaptation of small-scale African agriculture while supporting transformation, structuring and acceleration of agricultural development, based on four mega-programmes: (i) sustainable and resilient soil management; (ii) improved and efficient agricultural water management; (iii) climate risk aversion and management; and (iv) solidarity financing of small project holders (Fig. 2.2).

The initiative concerns all agricultural systems in Africa (rainfed, irrigated, agroforestry and rangelands) to which scientifically and technically based adaptation measures, technologies and innovations are applied. The aim is to simultaneously improve and diversify production and incomes to farmers while protecting natural resources (soil, water and biodiversity).

The initiative provides assistance, advice, expertise, assessment, audit and inspection services related to the AAA on climate change, food security and mitigation through carbon sequestration (Badraoui *et al.*, 2018). Its aim is to put AAA, food security and poverty alleviation at the heart of climate debates and negotiations. The initiative contributes to the attainment of SDGs, mainly SDGs 1, 2, 13 and 15; directly SDGs 3–6, 8–12 and 16–17; and indirectly SDGs 7 and 14 (Lal, 2019b).

Novel projects include but are not restricted to agroecology, agroforestry, CA, soil fertility stewardship, water-energy efficient systems and improved rangeland management. Increased resilience and climate risk management systems will be ensured through early-warning systems, contingency plans and insurance. In addition, payment for ecosystem services will be an important measure to

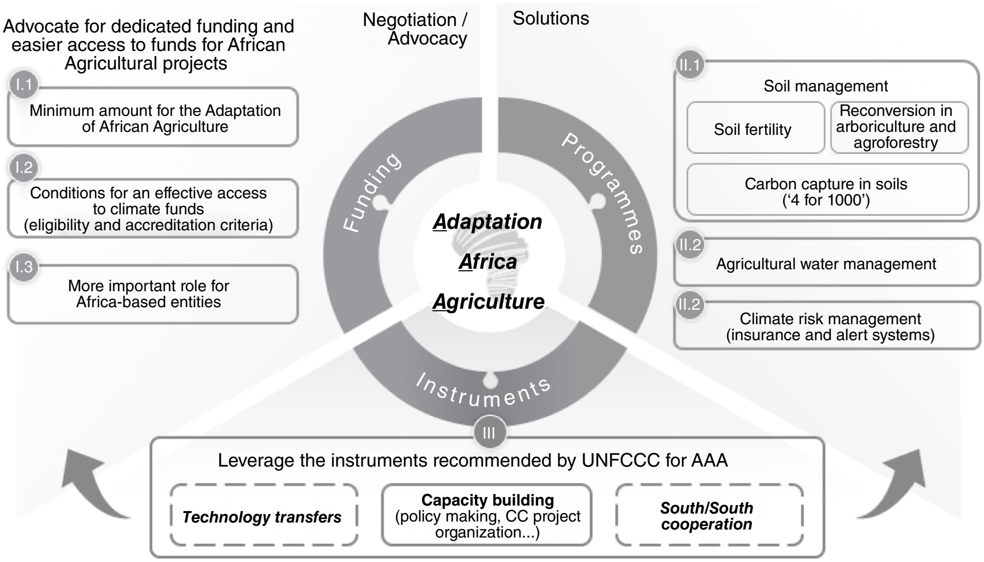


Fig. 2.2. Adaptation of African Agriculture (AAA) initiative: solutions, instruments and funding programmes. Courtesy of Mohamed Ait Kadi, 2015.

ensure adoption of adaptation actions. The AAA initiative is also integrating cross-cutting issues such as nutrition, gender and youth to develop sustainable food value chains.

The initiative also plans to limit GHG emissions through adoption of mitigation schemes (carbon management and sequestration, use of solar energy in agriculture, resource use efficiency, improved feed management, etc.).

Three instruments are used to boost implementation of the AAA goals: (i) technical expertise, knowledge sharing and technology transfer; (ii) capacity building, empowerment and development; and (iii) South–South cooperation.

Key international organizations involved in the design and promotion of AAA, contributing internal expertise and resources, include: Islamic Development Bank, FAO, AfDB, the World Bank, UNCCD, (Global Mechanism, land degradation neutrality (LDN) fund), International Fund for Agricultural Development (IFAD), Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), French Development Agency (AFD), GEF and Adaptation Fund. The initiative is also supported by scientific and education institutions (Institut National de la Recherche Agronomique INRA Morocco, CGIAR, Institut national de recherche pour l'agriculture, l'alimentation et l'environnement (INRAE), Agricultural Research Centre for International Development (CIRAD), Ohio State University, Massachusetts Institute of Technology (MIT) and Wageningen University) in addition to the private sector, civil society and NGOs. It is a global alliance that is supported by 33 African countries and also by the USA, France, Spain and other countries.

2.10 Suitability of Conservation Agriculture (CA) in Morocco

CA systems based on no-till (NT) technologies were introduced into Morocco by INRA in the 1980s, when long-term research trials began; and later, in 1990, field demonstrations were implemented (Mrabet *et al.*, 2012). Moroccan farmers in general have yet to adopt these practices (Mrabet, 2017). CA systems have been applied across approximately 20,000 ha in various cereal-producing regions with contrasting soils, climates and land features. The promotion of CA requires a clear understanding of its relative suitability, costs and benefits. Much of the research conducted in the country has shown the large environmental, economic and production benefits of CA (Mrabet, 2000; 2002; 2008a, b, c; 2011a, b, c; Mrabet *et al.*, 2001a, b; 2010; 2017; Moussadek *et al.*, 2011a, b; 2014). It is, therefore, important to complete this by developing a suitability study of CA. INRA and ICARDA launched a pilot study in central Morocco (the largest cereal basin in the country) using a 'target' area and 'match' location to better assess which areas in Morocco could be optimized for CA. A land suitability approach is used, based on biophysical factors including soil properties, regional climate and land use, which are compared and analysed.

Soils with a fine texture, well drained and with low salinity are more adapted and hence suitable (S1) for NT in cereal systems. Moderately suitable lands for NT (S2) have soils with a fine texture but with drainage problems. Unsuitable soils for NT (N1 and N2) are saline and poorly drained with sub-compaction problems (plough pan). Use of reduced tillage is more recommended for shallow soils and those with a high gravel content (less suitable to NT, S3) (Fig. 2.3).

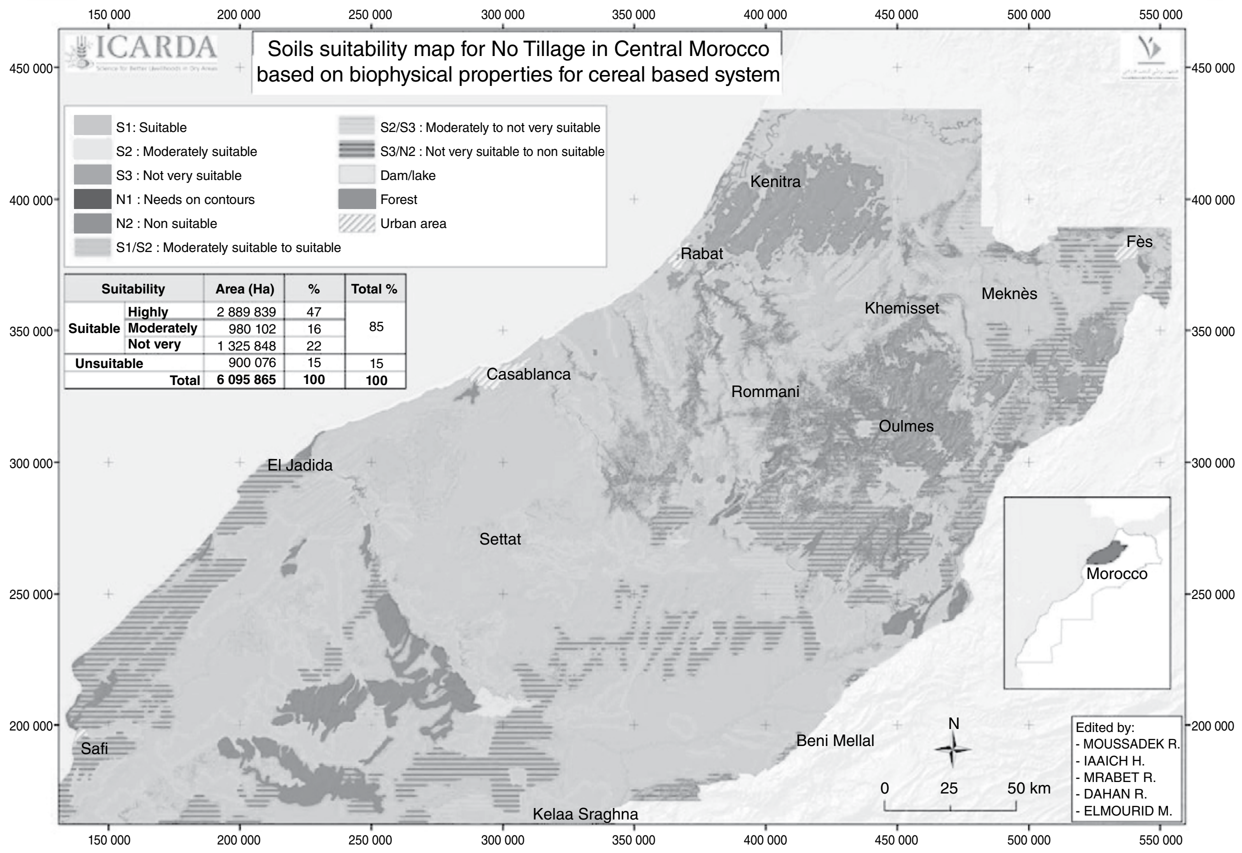
According to suitability map analysis (Fig. 2.3), 63% of total arable land in central Morocco is highly to moderately suitable for CA, and could benefit nearly 10 million people if adopted and scaled up.

Additional data – including, for example, the number of farmers and households in a region, and the machinery available – could make the technology an excellent tool in facilitating greater CA adoption in the region. A pilot study was funded through the Conservation Agriculture for North Africa (CANA) Project, the Australian Centre for International Agricultural Research (ACIAR) and the INRA-ICARDA Program III-Integrated Natural Resource Management (INRM).

2.11 Conclusion: Riding the Wave of Greater Success

In Africa, farming systems are at a critical juncture, and economies and livelihoods are bearing the brunt of climate shocks and disrupted by land challenges (Mbow, 2020). In addition, increased use of (relatively abundant) land, rather than improved technical efficiency, has been the main driver of agricultural production growth in Africa. The African population has increased more than in any other place in the globe and is putting excessive stress on land resources (soil fertility, water resources and biodiversity). Smallholder cropping systems experience chronic low productivity due to lack of investment in sustainable soil management, input use efficiency and management strategies to cope with droughts and other externalities. Consequently, transformation in Africa's agriculture will happen only when innovation (including technology) gets to the end users. Countries should develop sound policies that enhance the research capacities of Africa to develop and promote innovation in agricultural and agribusiness sectors.

Conventional views of agricultural transformation (e.g. the Green Revolution in Asia and Latin America) have often focused on the introduction and spread of adoption of new technologies to increase productivity and to feed the growing population. For Africa, and in the case of CSA and especially of CA, transformation of farming systems requires inclusive and participatory forms of innovation, governance, networking, knowledge production, co-sharing mechanisms and platforms, and social and societal actions including issues of equity and gender (Collins, 2018; Karlsson *et al.*, 2018). Incremental transitions in the short term, and structural changes to institutions and norms in the medium and long term, need to take place in a harmonized and integrated way to achieve the expected transformation of farming systems (De Pinto *et al.*, 2020). CSA should be implemented and developed in a continuum of scale: global (e.g. international public goods, climate agreements, SDGs), regional (e.g. agendas, declarations, development mechanisms and transnational pacts including pan-African trading), national (e.g. enabling environments, policies and incentives) and local (e.g. capacity and skill development, market opportunities, empowerment, gender-responsive and farmer-based innovation platforms and networks). A large array of strategies, policies, partnerships and investments exist for CSA development in Africa; however, they should be complemented with targeted implementation on the ground, sustainable financing, institutional coordination and metrics to assess the efficacy of interventions (Dinesh *et al.*, 2017).



Suitability		Area (Ha)	%	Total %
Suitable	Highly	2 889 839	47	85
	Moderately	980 102	16	
	Not very	1 325 848	22	
Unsuitable		900 076	15	15
	Total	6 095 865	100	100

Fig. 2.3. Central Morocco: suitability for the Conservation Agriculture (CA) system. Authors' own figure.

Robust agricultural growth is highly dependent on urgently regenerating soil fertility and health (Garrity *et al*., 2017). Sustainable intensification based upon CSA solutions aims to unlock the potential of land for productivity and resilience and to increase farmers' incomes and reduce upfront costs. CSA permits smart and optimal use and management of resources including fertilizers, pesticides, seeds, energy and labour, and enables conservation and recarbonization of soils. Notably, CA practices optimize water use efficiency either in rainfed or irrigated systems, and maximize crop productivity and livestock performance.

Through the construction of resilient and inclusive food systems, CSA can help to create a wide range of benefits and opportunities for downtrodden and resource-poor smallholder farmers. In addition, innovative pathways are possible through implementation of CSA to break intergenerational cycles of poverty and hunger. Governments and international organizations, as well as grassroots farmer organizations and NGOs, are paving the way for sound, evidence-based CSA programmes and policies.

The adaptation of existing indicators of agronomic and economic performance, as well as the development of integrative indicators adapted to the African context through science-based, bottom-up participatory approaches, will be critical to assess the overall performance and benefits of CSA (and especially CA) in its multiple dimensions of action and impact.

The limited coverage of CA in Africa is likely to be the result of insufficient policy advocacy, and the lack of enabling policies, technical support, financial assistance and private sector involvement, and of incentives for vulnerable farmers working on fragile soils to produce sustainably. Hence, more ambitious policy mechanisms are needed to create incentives for farmers to shift to CA at a large scale. However, this ambition must be met with financial, research, technological, institutional and capacity-building support. Stable funds from both national budgets, and from institutions and development agencies, should be maintained to out-scale CSA and CA.

To advance and indemnify the adoption of CSA (CA) in Africa, each country should expand its macroeconomic objectives and also develop supply-side policies to improve the long-term structural performance and productivity of its economy, including incentives, market, labour and capital productivity, research capacity and innovation, employment and job creation, entrepreneurship and risk management vis-à-vis externalities.

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3 Climate Smart Agriculture for Africa: The Potential Role of Conservation Agriculture in Climate Smart Agriculture

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Abstract

To achieve the challenges raised in Agenda 2063 and the Malabo Declaration, new agricultural techniques need to be promoted. Practical approaches to implement climate smart agriculture and sustainable agriculture, able to deliver at field level, are required. These include sustainable soil and land management that allows different user groups to manage their resources, including water, crops, livestock and associated biodiversity, in ways that are best suited to the prevailing biophysical, socio-economic and climatic conditions. The adoption of locally adapted sustainable soil management practices is needed to support climate change mitigation and adaptation from the agricultural perspective. In this sense, Conservation Agriculture (CA) can be adapted to local conditions, and help achieve the key objectives.

The application of CA principles brings multiple benefits, especially in terms of soil conservation, but also for mitigating climate change. In fact, CA has the ability to transform agricultural soils from being carbon emitters into carbon sinks, because of no-tillage (NT) techniques and the return to the soil of diverse crop biomass from above-ground parts of plants and from diverse roots systems and root exudates. Similarly, fossil energy use decreases due to the reduction in agricultural operations, and so less CO_2 is emitted to the atmosphere. Lower greenhouse gas (GHG) emissions in CA also result, because of reduced and more efficient use of inputs.

Scientific studies confirm the sequestration potential of increased soil organic carbon (SOC) stocks on croplands in Africa on each of the continent's major bioclimatic areas. Coefficients of SOC sequestration for Africa are presented in this chapter.

Keywords: No-till, climate change mitigation, coefficients, greenhouse gas, soil organic carbon, soil organic matter

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3.1 Introduction

Greenhouse gas (GHG) emissions occur naturally in the Earth's atmosphere. However, the atmospheric concentrations of CO_2, CH_4 and N_2O have increased significantly since the industrial revolution began. In the case of CO_2, the average concentration has risen from 316 parts per million (ppm) in 1959 to 410 ppm in 2019 (WMO, 2020). Additionally, since the 1970s, CO_2 emissions have increased by about 90%, with emissions from fossil fuel combustion and industrial processes contributing about 78% of the total GHG emissions increase from 1970 to 2016 (EPA, 2016).

The Paris Agreement seeks to hold the increase in the global average temperature to well below 2°C above pre-industrial levels while pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels. At 1.2°C above the pre-industrial (1850–1900) levels, the global average temperature in 2020 was already approaching the lower limit of temperature increase the Paris Agreement seeks to avert. There is at least a one in five chance of the average global temperature temporarily exceeding 1.5°C by 2024, according to World Meteorological Organization's (WMO) Global Annual to Decadal Climate Update, led by the United Kingdom's Met Office.

The lockdown due to COVID-19 has cut emissions of many pollutants and GHG, such as CO_2. But any impact on CO_2 concentrations – the result of cumulative past and current emissions – is in fact no bigger than the normal year to year fluctuations in the carbon cycle and the high natural variability in carbon sinks like vegetation. The Met Office annual global temperature forecast for 2021 (Fig. 3.1) suggests that it will once again enter the series of the Earth's hottest years, despite being influenced by the temporary cooling of La Niña, the effects of which are typically strongest in the second year of the event (WMO, 2021).

3.1.1 Impact in Africa, in brief

Africa has been the lowest emitter of GHGs in the world; however, the continent is the most vulnerable to the impacts of climate change. Indeed, the Intergovernmental Panel on Climate Change (IPCC) has alerted that temperatures across Africa are expected to increase by 2–6°C within the next 100 years (IPCC, 2014a). The effects will not be limited to a rising average temperature and changing rainfall patterns, as an increasing severity and frequency in droughts and floods is expected (Niang *et al.*, 2014; Hummel, 2015).

Ecosystems are known to play an important role in climate change adaptation processes, since some of the services they provide may reduce the impacts of extreme events and disturbance, such as wildfires, floods and droughts. This role is especially important in regions vulnerable to climate change such as the African continent, whose adaptation capacity is limited by many geographic and socio-economic constraints (Leal Filho *et al.*, 2021).

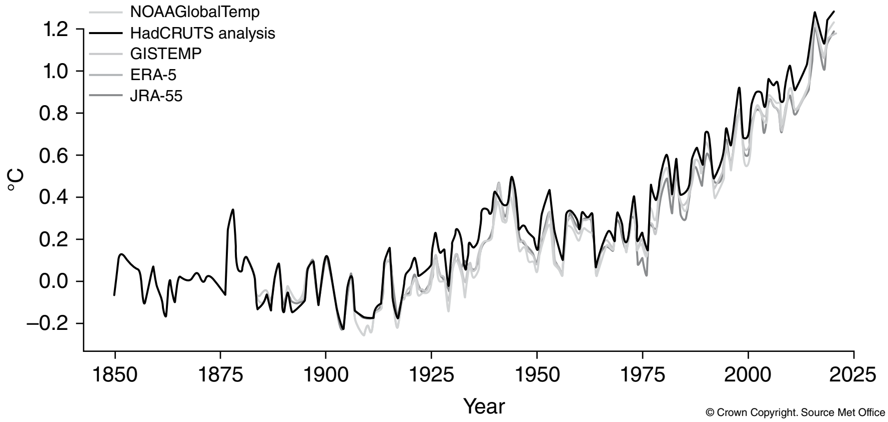

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Fig. 3.1. Global mean temperature difference from 1850 to 1900 (°C). From Met Office, 2021.

It is expected that climate change will lead to a reduction in food production due to changes in rainfall patterns and temperature in Africa (Awojobi and Tetteh, 2017). Changing weather patterns in recent years are producing a detrimental impact on food security. There is evidence of impacts such as flooding, drought, deforestation and land degradation leading to migration in Africa (Abebe, 2014; Science for Environmental Policy, 2015). There is also increasing evidence that climate change is affecting forests and forest ecosystems in Africa, as well as the livelihoods of the forest-dependent communities (Chidumayo *et al.*, 2011).

Africa has a limited capacity to deal with further disasters from climate change. Around 90% of people depend on agriculture for their livelihoods. Therefore, any decrease or change in rainfall patterns could mean crop failure and, consequently, produce serious food shortages or even famine. There is a strong correlation between climate change and East African livelihoods (Worldwide Fund for Nature, 2006). Records show a reduction in rainfall in the period 1996–2003 of 50–150 mm for each season, and a correlated reduction in maize and sorghum production across most eastern African countries (Funk *et al.*, 2005).

African countries will be among the worst affected by climate change, where it is an increasing threat (UN, 2020). High levels of poverty and underdevelopment combined with insufficient infrastructure exacerbate the already severe impact of global warming on resources, development and human security. Tangible actions are needed to allow adaptation to and mitigation of the effects of climate change.

3.2 Climate Change and Agriculture

Global GHG emissions were estimated to be 49 (±4.5) Gt CO_2 -eq in 2010 (IPCC, 2014a), with approximately 24% (10.3–12 Gt CO_2-eq) of emissions coming from agriculture, forestry and other land use (AFOLU) (IPCC, 2014a; Tubiello *et al.*, 2015). Annual non-CO_2 GHG emissions, primarily CH_4 and N_2O from agriculture, were estimated to be 5.2–5.8 Gt CO_2-eq yr^{-1} in 2010 (FAOSTAT, 2014; Tubiello *et al.*, 2015), with approximately 4.3–5.5 Gt CO_2-eq yr^{-1} attributable to land use and land-use change activities (IPCC, 2014a) (Fig. 3.2).

Agriculture both contributes to and is affected by climate change. The food we consume has been produced, stored, processed, packaged, transported, prepared and served. In each of these phases, GHGs are released into the atmosphere. GHG emissions from agriculture come mostly from the cultivation of crops and livestock, and from deforestation (IPCC, 2014a). In addition to CO_2 agriculture, in particular, releases significant amounts of CH_4 and N_2O, two potent GHGs. CH_4 is produced by livestock during digestion, due to enteric fermentation, and is released by belching. It can also be released by manure and organic waste stored in landfills. N_2O emissions are an indirect product of organic nitrogen and mineral fertilizers. Poorly drained soils tend to have higher levels of CH_4 and N_2O emissions.

Agricultural practices regulate soil nitrogen and carbon dynamics and thereby affect the fluxes of GHGs like N_2O and CO_2 (Adviento-Borbe *et al.*, 2007; Mutegi *et al.*, 2010). Natural factors also affect or interact with farming practices, thereby influencing N_2O, CH_4 and CO_2 emissions (Chatskikh *et al.*, 2005; Jansen, 2009; Gu *et al.*, 2013; Vidon *et al.*, 2016). In recent decades, many site-specific studies have been conducted to explore the impacts of fertilization (Yan *et al.*, 2015;

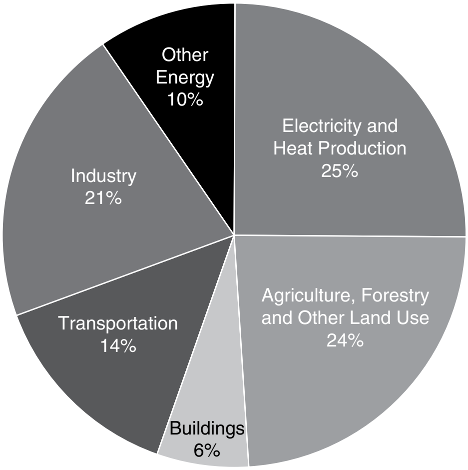

Fig. 3.2. Global greenhouse gas emissions by economic sector. This estimate does not include the CO_2 offsets from soils. Courtesy of IPCC (2014a); based on global emissions from 2010.

Tan *et al.*, 2017), tillage (Wei *et al.*, 2012) and crop residues (Hu *et al.*, 2013; Huang *et al.*, 2013).

Land-use changes such as deforestation, overgrazing and burning of vegetation – particularly in Africa – not only add to the carbon load but also cause a change in energy and moisture fluxes, with noticeable consequences on weather and climate patterns at local and regional levels (Ngaira, 2003). GHG fluxes in Africa play an important role in the global GHG budget (Bombelli *et al.*, 2009; Hickman *et al.*, 2014; Valentini *et al.*, 2014). In recent years, conversion rates of African natural lands (including forest, grassland and wetland) to agricultural lands have increased (FAO, 2010; Gibbs *et al.*, 2010). The dominant type of land-use change has been the conversion of forest to agriculture with average deforestation rates of 3.4 million ha yr^{-1} (FAOSTAT, 2014). This land-use conversion results in an estimated release of 0.32 ± 0.05 Pg C yr^{-1} (Valentini *et al.*, 2014) or 157.9 ± 23.9 Gt CO_2-eq from 1765 to 2005 (Kim and Kirschbaum, 2015), higher than fossil fuel emissions for the continent (Valentini *et al.*, 2014).

Even if agriculture were not the only productive sector affected by global warming, the impacts on it would definitely have negative effects on food security and social welfare. Crops need adequate land, water, sunlight and heat to grow and complete their production cycles. Global warming has already altered the duration of the growing season in some areas. The periods of flowering and harvest of cereals are already several days ahead. It is foreseeable that these changes may continue to occur in many regions (EEA, 2015).

Changes in temperature patterns and precipitation, and an increase in the concentration of atmospheric CO_2, will significantly affect crop development. Global climate variabilities are now estimated to be responsible for 32%–39% of yield variability (Ray *et al.*, 2015), so even higher CO_2 levels may affect crop yields even more.

Elevated CO_2 levels can increase plant growth. However, other factors, such as changing temperatures, ozone, and water and nutrient constraints, may counteract these potential increases in yield. For example, if the temperature exceeds a crop's optimal level, and if sufficient water and nutrients are not available, yield increases may be reduced or reversed. Also, elevated CO_2 has been associated with reduced protein and nitrogen content in alfalfa and soybean plants, resulting in a loss of quality.

The flow of the impacts of climate change on the agricultural sector are illustrated in Fig. 3.3. The impacts of climate change on crops include the change in flowering and harvesting seasons, quality change and shift in areas suitable for cultivation (Kim *et al.*, 2009). Climate change affects the agricultural ecosystem, giving rise to blights and pests, and causing population movement and change in biodiversity.

Among the positive impacts of global warming include the increase in crop productivity due to the fertilization effect caused by the increase

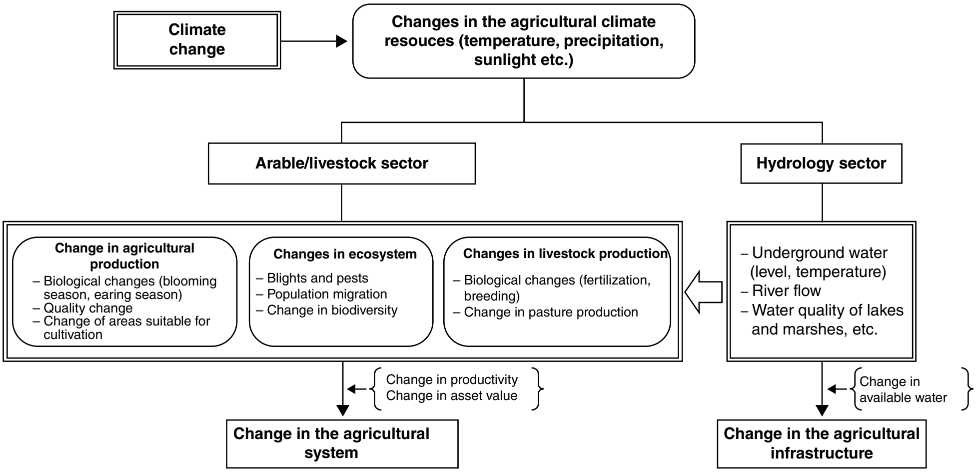

Fig. 3.3. Flow of the climate change impact on the agricultural sector. Courtesy of Kim *et al*. (2009).

Table 3.1. Comparison of relative production changes for a variety of African crops under climate change in different regions. The results are probabilistic projections of production impacts in 2030 as a percentage of 1998–2002 yields. From: Pereira (2017).

Region	Projection	Wheat	Rice	Maize	Sorghum	Groundnut
Northern Africa	worst	−14.53	−6.62	−6.79	−15.33	−9.19
	median	−7.71	−1.73	−1.11	−4.29	−0.38
	best	−2.72	3.7	7.42	6.18	8.77
Western Africa	worst	−11.03	−5.92	−9.64	−5.51	−16.6
	median	−1.26	−1.91	−3.51	−0.19	−7.32
	best	9	0.75	1.09	4.65	−2.01
Central Africa	worst	−8.33	−6.52	−4.18	−16.69	−8.14
	median	−1.76	−1.9	−1.39	−4.02	−2.54
	best	4.82	1.23	0.7	5.56	1.51
Eastern Africa	worst	−4.75	−3.24	−5.78	−7.17	−2.52
	median	5.45	3.31	−0.97	0.84	2.9
	best	17.73	12.27	4.42	6.23	10.72
Southern Africa	worst	−32.34	0.39	−46.56	−16.86	−8.09
	median	−15.79	5.23	−28.49	−1.49	2.21
	best	−4.78	12.05	−12.27	14.66	13.2

in CO_2 concentration in the atmosphere; expansion of the areas available for production of tropical and/or subtropical crops; expansion of two-crop farming due to the increased cultivation period; reduction in damage to winter crops by low temperature; and reduction in heating costs for agricultural crops grown in protected cultivation facilities. Fig 3.4 shows the positive and negative impacts of global warming on the agricultural sector.

Negative impacts of global warming include reduced crop quantity and quality due to the reduced growth period following large temperature rises; reduced sugar content, bad coloration and reduced storage stability in fruits; increase in weeds, blights and harmful insects in agricultural crops; reduced land fertility due to the accelerated decomposition of organic substances; and increased soil erosion due to increased rainfall. However, according to the IPCC (2014a), more regions will be negatively impacted by climate change than will benefit. Feeding a growing global population in a changing climate presents a significant challenge to society.

According to a UN Environment report, no continent will be struck as severely by the impacts of climate change as Africa. Given its geographical position, the continent will be particularly vulnerable as its adaptive capacity is very limited, and this will be exacerbated by widespread poverty. Climate change is a particular threat to continued economic growth and to the livelihoods of vulnerable populations (UN, 2020). In addition, African countries would be more affected by climate change because of their reliance on agriculture as well as their lower financial, technical and institutional capacity to adapt to it (Huq *et al.*, 2004; Nordhaus, 2006; Singh and Purohit, 2014; Rose, 2015). Eastern African countries (Burundi, Eritrea, Ethiopia, Kenya, Uganda, Tanzania, Rwanda and Somalia) are among those countries vulnerable to the effects of drought because of their dependency on rainfed agriculture. Feyssa and Gemeda (2015) reported that climate change mainly affects the rainfed agricultural sectors in technological and economically less developed countries in Africa. By 2100, drought is expected to result in the expansion of arid and semi-arid lands (ASALs) of Africa by 5%–8%, or 60–90 million ha, resulting in agricultural losses of between 0.4% and 7% of gross domestic product (GDP) in North, West Central and southern Africa (IPCC, 2007).

3.3 Climate Smart Agriculture, Agenda 2063 and the Malabo Declaration

As defined by FAO (2021), climate smart agriculture (CSA) is an approach that helps to guide

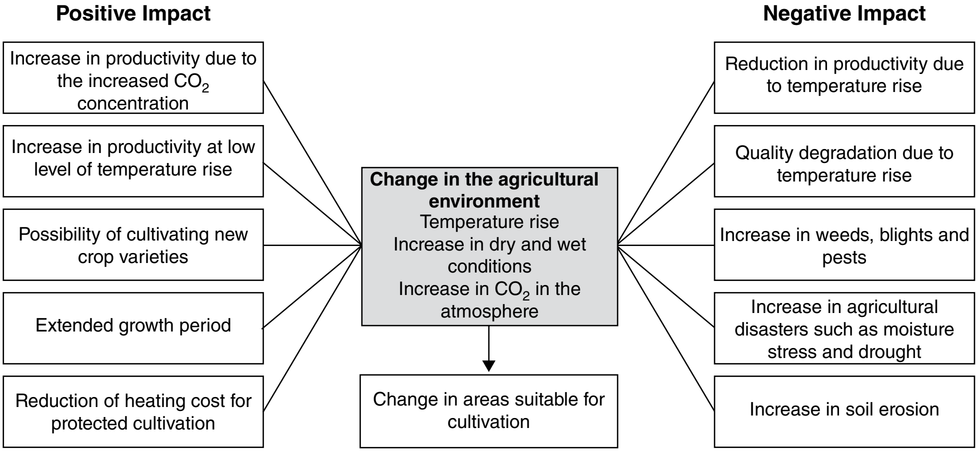

Fig. 3.4. Potential impacts of global warming on the agricultural sector. Courtesy of Kim *et al*. (2009).

actions needed to transform and reorient agricultural systems to effectively support development and ensure food security in a changing climate. CSA aims to tackle three main objectives: sustainably increasing agricultural productivity and incomes; adapting and building resilience to climate change; and reducing and/or removing GHG emissions, where possible.

Agenda 2063 is Africa's blueprint and master plan for the sustainable development and economic growth of the continent. It is an affirmation by African heads of state and government of their commitment to transforming Africa into a global powerhouse. The Ten-Year Implementation Plan (2014–2023) is the first in a series that aims to fast-track implementation of Agenda 2063 over 50 years. The Agenda 2063 funding needs and related sources of funding identifies as Goal number 7 the environmentally sustainable and climate resilient economies and communities. The Africa Union (AU) informed about the establishment of an African Climate Fund by 2025, where the potential sources of funds could be AU's member states by the creation of carbon credits; namely through implemented carbon emission/climate change mitigation projects, where CSA based plans should be at heart of the agricultural initiatives. CSA objectives also directly contribute to achieving the 2014 Malabo Declaration goals, which include commitments to: (i) end hunger in Africa by 2025; (ii) halve poverty by 2025 through inclusive agricultural growth and transformation; and (iii) enhance the resilience of livelihoods and production systems to climate variability and other related risks. These linkages underscore the importance of including CSA in country and regional plans to achieve overarching development objectives in Africa, in particular food security and poverty reduction.

The 2014 Malabo Declaration made seven specific commitments to achieve accelerated agricultural growth and transformation for shared prosperity and improved livelihoods. Commitment 6 relates to enhancing resilience in livelihoods and production systems to climate variability and other shocks. Its aim is to ensure that, by 2025, at least 30% of farm/pastoral households are resilient to shocks; that investments for resilience building initiatives are enhanced, including social security for rural workers and other vulnerable social groups, as well as for vulnerable ecosystems; and that resilience and risk management in policies, strategies and investment plans is mainstreamed.

New agricultural techniques should be promoted to meet these challenges. Practical approaches to implement CSA and sustainable agriculture, able to deliver and aligned with the Agenda 2063 objectives and the Malabo commitments at field level, are required. In particular, sustainable soil and land management should allow different user groups to manage their resources (including water, crops, livestock and associated biodiversity) in ways that are best suited to the prevailing biophysical, socio-economic and climatic conditions (FAO, 2021). The adoption of locally adapted sustainable soil management practices is needed to support climate change mitigation and adaptation from the agricultural perspective. In this sense, Conservation Agriculture (CA) can be adapted to local conditions, and help achieve the above objectives.

3.4 Conservation Agriculture: The Three Principles

CA is an alternate paradigm of agricultural production and land use that is applicable to all land-based agricultural production systems in rainfed and irrigated farming, including annual, perennial and mixed systems; orchards; agroforestry and plantation systems; crop–livestock systems; and pasture and rangeland systems. According to FAO (http://www.fao.org/conservation-agriculture), CA is an ecosystem approach to regenerative sustainable agriculture and land management based on the practical application of three context-specific and locally adapted interlinked principles, namely:

1. Continuous no (or minimum) mechanical soil disturbance: this principle is implemented by the practice of no-till seeding or broadcasting of crop seeds; direct placement of planting material into untilled soil and no-till weeding; and causing the minimum soil disturbance possible from any cultural operation, harvest operation or farm traffic. Sowing seed or planting crops directly into untilled soil reduces erosion; reduces the loss of soil organic matter (SOM) and disruptive mechanical cutting and smearing of pressure faces; promotes soil biodiversity and microbiological processes; protects soil structure and connected pores; avoids impairing movement of gases and water through the soil; and promotes overall soil health and functions including improved retention of soil moisture, plant nutrients and soil carbon; reduces labour and energy requirements and reduces GHG emissions; and contributes to integrated weed, insect pest, pathogen and nutrient management as well as overall resilience and sustainability.
2. Permanent maintenance of a vegetative mulch cover on the soil surface: this principle is implemented by retaining crop biomass, root stocks and stubbles and biomass from cover crops and other forms of biomass from *ex situ* sources. Use of crop residues (including stubbles) and cover crops reduces soil erosion; protects the soil surface; increases water infiltration rates, reducing run-off; conserves water and nutrients; supplies organic matter and carbon to the soil system; promotes soil biodiversity and microbiological activity to enhance and maintain soil health and functions including structure and aggregate stability (resulting from glomalin production by mycorrhiza), improved capture and retention of water, plant nutrients and soil carbon; and contributes to integrated weed, insect pest, pathogen and nutrient management as well as to overall resilience and sustainability.
3. Diversification of species in cropping system: this principle is implemented by adopting economically, environmentally and socially adapted crops in rotations, and/or sequences and/or associations involving annual and perennial crops, including a balanced mix of legume and non-legume crops and cover crops. Use of diversified cropping systems contributes to diversity in rooting morphology and root composition; enhances soil biodiversity and microbiological activity; builds up SOM; enhances crop nutrition and crop protection through the suppression of pathogens, diseases, insect pests and weeds; and contributes to integrated weed, insect pest, pathogen and nutrient management as well as to overall resilience and sustainability. Crops can include annuals, short-term perennials, trees, shrubs, nitrogen-fixing legumes and pastures, as appropriate.

The above principles and associated reference core practices are applied, along with other complementary good agricultural production and land management practices of integrated crop, soil, nutrient, water, pest (weeds, insects, pathogens) and energy management, to optimize the whole production system at the farm level. At the landscape and watershed levels, CA systems enable the harnessing of a range of ecosystem functions and societal services including clean water; carbon sequestration; carbon, water and nutrient cycling; surface and groundwater regulation; control of erosion; increased biodiversity and food webs; and pollination services. CA systems are present in all continents and across a wide range of agroecologies in temperate, subtropical and tropical regions.

The application of CA principles brings multiple benefits, especially in terms of soil conservation, and also for mitigating climate change. In fact, CA has the ability to transform agricultural soils from being carbon emitters into carbon sinks, because of no-tillage and the return to the soil of diverse crop biomass from above-ground parts of plants and from diverse roots systems and root exudates. Owing to the reduction in agricultural operations, fossil fuel energy use also decreases, thus less CO_2 is emitted to the atmosphere. Lower GHG emissions in CA also arise from reduced and more efficient use of inputs.

3.5 The Role of Agricultural Soils in Climate Change Mitigation; Consequences of Tillage

The '4 per Thousand' and 'Adapting African Agriculture' are bold and innovative initiatives adopted at COP21 in Paris and COP22 in Marrakesh, respectively. These initiatives are soil-centric and based on adoption of soil-restorative and improved agricultural practices (Lal, 2019). Indeed, soil is one of the most relevant natural resources for combating climate change. It is broadly accepted in the literature that improved soil management practices can help reduce GHG emissions from agriculture. Soil's potential for capturing CO_2 from the atmosphere and incorporating it in the form of organic carbon makes it a powerful climate change mitigation tool. Proof of this is that soil is the greatest reserve of carbon in terrestrial ecosystems (Lal, 2008) and the second in the world behind the oceans, accumulating three times more carbon than the atmosphere (Smith, 2004) and aerial biomass (Sommer and Bossio, 2014).

Improving SOM in agricultural soils is essential for sustainable crop production. Organic matter is composed of soil microbes including bacteria and fungi, and decaying material from once-living organisms (such as plant and animal tissues) and products formed from their decomposition. Organic matter is a heterogeneous mixture of materials that range in stage of decomposition from fresh plant residues to highly decomposed material known as humus (Table 3.2).

Even if organic matter is just 2%–10% of the mass of most soils, it has an important role in the physical, chemical and biological function of agricultural soils. In fact, it contributes to nutrient retention and turnover, soil structure, moisture retention and availability, degradation of pollutants, carbon sequestration and soil resilience.

Conversely to conventional agricultural systems that are based on tillage, and which lead to a reduced organic carbon content and higher CO_2 emissions, improved soil management

Table 3.2. Size, turnover time and composition of soil organic matter fractions. Source: Griffin and Edwards, 2020.

Fraction	Size	Turnover time	Composition
Dissolved organic matter	< 45 µm (in solution)	Minutes to days	Soluble root exudates, simple sugars and decomposition by-products. It generally makes up less than 5% of total SOM
Particulate organic matter	53 µm–2 mm	2–50 years	Fresh or decomposing plant and animal matter with identifiable cell structure. Makes up 2%–25% of total SOM
Humus	< 53 µm	Decadal (10s to 100s of years)	Older, decayed organic compounds that have resisted decomposition. Can make up more than 50% of total SOM
Resistant organic matter	< 53 µm–2 mm	100s to 1000s of years	Relatively inert material, such as chemically resistant materials or organic remnants (e.g. charcoal). Can be up to 10% of SOM

SOM, soil organic matter.

systems have a great deal of mitigation potential. There is a general agreement in the literature that soil disturbance from tillage is one of the major causes of losses of soil organic carbon (SOC) (Balesdent *et al*., 1990; Six *et al*., 2000; Olson *et al*., 2005). Indeed, scientific studies confirm that intensive farming contributed to a loss of between 30% and 50% of organic carbon in agricultural soils (Reicosky, 2011). Kinsella (1995) estimated that, in only 10 years of tillage, 30% of the original organic matter was lost.

Taking into account soil's carbon storage capacity and the ongoing systematic loss of carbon over decades, any strategy aimed at increasing the organic carbon content of soil, however small those increases may be, will have a positive impact on mitigating climate change. At this point, it is worth bearing in mind that the soil's capacity to store carbon is limited and that a point comes when a balance is reached between the carbon captured and the carbon released through decomposition of organic matter (Ogle *et al*., 2019). Given the low SOC in many regions of the world, that balance in agricultural ecosystems will not be reached in the short term. It will take a considerable time to even reach a plateau, and more than 10–15 years before a deceleration in the rate of carbon increase is observed (González-Sánchez *et al*., 2012).

Another consequence of tillage-based agriculture is higher CO_2 emissions. Tillage has a direct influence on soil CO_2 emissions both in the short term (immediately after tillage) and in the long term (during the growing season). It stimulates the production and accumulation of CO_2 in the porous structure of the soil through the processes of mineralization of organic matter. The mechanical action of the tillage involves a breakdown of the soil aggregates, with the consequent release of CO_2 trapped inside the soil; this is then emitted into the atmosphere. Among the first studies of CO_2 emissions during tillage are those carried out by Reicosky and Lindstrom (1993) and Reicosky (1997) in the central area of the USA. These authors showed that the increase in CO_2 observed just after tillage was the result of changes in soil porosity and, therefore, it is proportional to the intensity of the tillage (generated by the depth and roughness of the soil).

Different agricultural practices (tillage, application of fertilizers and amendments, irrigation, plant protection treatments, etc.) are mostly carried out with the use of fossil fuels, especially diesel, implying energy consumption and unavoidable GHG emissions. Thus, conventional tillage implies high consumption of fossil fuels, which leads to higher atmospheric pollution due to the emissions of CO_2, with the consequent negative effect on climate change. It is well known that all energy processes lead to the emission of CO_2.

Agricultural soils can also play a relevant role in relation to the adaptation of agrarian ecosystems to climate change. The IPCC, in its fifth evaluation report (IPCC, 2014a), warns of the increase in the occurrence of episodes of extreme rainfall, the presence of new pests and diseases, and the lower availability of water resources for crops. Soils of higher quality are needed to achieve a more resilient ecosystem, which means they must have more organic matter and be better structured, with a greater capacity for water retention and with a greater degree of biodiversity. There is a broad consensus that conventional farming systems, based on intensive tillage, have adverse environmental effects, with the potential to put natural ecosystems at risk (Duru *et al*., 2015). Some of the main risks of such systems are depletion of water sources, pollution of soil and water resources, air pollution, GHG emissions, depletion of SOC, erosion of the fertile soil layers by wind and water, and soil salinization (Horrigan *et al*., 2002).

These considerations mean that mitigation measures in the agricultural sector should involve fixing the carbon found inside the oxidized compound in the soil while reducing GHG emissions in general. In turn, if – as well as mitigating climate change – the measures also improve water balance and soil quality, as well as increasing biodiversity, they will help crops adapt to future climate scenarios involving lower availability of water resources, higher incidence of extreme weather conditions that increase the risk of erosion and the incidence of new pests and diseases.

3.6 Climate Change Mitigation with Conservation Agriculture: Climate Smart Agriculture

CA can be seen as a system that mitigates climate change and contributes to the adaptation of crops to the effects of global warming. In its fifth assessment report, the IPCC defines climate change mitigation as 'a human intervention to reduce the sources or enhance the sinks of greenhouse gases' (IPCC, 2014b). In this context, CA could be understood as a mitigation measure, by fulfilling the double premise set out by the IPCC of reducing sources and enhancing sinks. For this reason, CA can be considered a system that enhances soil's carbon sink effect. On the other hand, the drastic reduction in soil tillage and the non-mechanical alteration of the soil means lower CO_2 emissions resulting from the energy saved and the reduction in organic matter mineralization processes (Fig. 3.5).

SOM and SOC are closely linked. Organic matter is made of organic compounds that are highly enriched in carbon (Ontl and Schulte, 2012), and so carbon is the main component of organic matter. As an indicator for soil health, SOC is important for its contributions to food production, mitigation and adaptation to climate change, and the achievement of the Sustainable Development Goals (SDGs) (FAO, 2017).

While organic matter is difficult to measure directly, SOC is a measurable component of SOM, and so laboratories tend to report SOC. SOC refers only to the carbon component of organic compounds. The concentration of SOC is generally considered an indicator of soil quality because of its agronomic and ecological functions. Factors that influence SOC content include land use, soil properties, rainfall, temperature, crop characteristics (such as the amount and fate of crop residues or root distribution) and soil management practices like no-tillage (Carbonell-Bojollo *et al.*, 2011).

Thus, organic matter stock can be estimated from SOC. Considering that about 58% of the mass of organic matter can be counted as carbon, we can estimate the percentage of organic matter from the percentage of carbon by using the Van Bemmelen conversion factor 1.724 (obtained from the relation 100/58) (Tabatabai, 1996). This conversion factor can vary in different soils, but 1.724 provides a reasonable estimate of organic matter for most agricultural purposes (Eqn 3.1):

$$\text{SOM (\%)} = \text{SOC (\%)} \times 1.724. \qquad (3.1)$$

If a quantity is needed rather than a percentage, we would need to convert percentage to weight for a given depth and area (Eqn 3.2):

$$\text{SOC stock in tonnes (t) of carbon per hectare (t C/ha)} = (\text{SOC\%}) \times (\text{mass of soil in a given volume}). \qquad (3.2)$$

For example, a soil with a SOC of 1.2% (0.012) and a bulk density of 1.25 g/cm^3 (equivalent to 1.25 t/m^3) would have SOC to a depth of 20 cm (0.2 m) per hectare (10,000 m^2) (Eqn 3.3) of:

$$(0.012\ \text{C}) \times (1.25\ \text{t/m}^3 \times 0.2\ \text{m} \times 10\,000\ \text{m}^2\text{/ha}) = 30\ \text{t C/ha}. \qquad (3.3)$$

Using the conversion factor of 1.724, the amount of SOM would be: 30 × 1.724 = 51.72 t.

Tebruegge (2001) stated that, through the processes of microbiological oxidation which occur in the soil, 3.7 t of CO_2 are generated from 1 t of carbon decomposition. From the increases in organic matter observed in CA management systems in comparison with conventional tillage management systems, it is possible to determine, based on organic carbon, what these increases mean in terms of CO_2 amounts. This makes it possible to provide a range of values on the potential of CA with regard to atmospheric carbon fixation compared to tillage agriculture.

3.6.1 Soil as a Carbon Sink in Conservation Agriculture

Recent modelling approaches confirm the positive effect of CA with carbon sequestration (Valkama *et al.*, 2020), which has been broadly studied in fieldwork. This is due to the soil management in CA, that leads to alterations in the dynamics of carbon in the soil, increasing both amount and concentration. There are two reasons for this. First, by leaving crop residues on top of the soil, and root biomass in the soil, CA produces a dynamic in the organic matter that is similar to how natural ecosystems behave. The result of these practices is an increase in organic matter accumulation in the vertical dimension. This carbon accumulation is used as the recovery index in the quality of agricultural soil degraded by tillage (Franzluebbers, 2002; Moreno *et al.*, 2005). A significant part of this surface organic matter is incorporated into the soil by earthworms which are, incidentally, more abundant in CA than in tillage systems (Cantero *et al.*, 2004; Bescansa *et al.*, 2005). Second, the less the soil is tilled, the more carbon it absorbs. As a

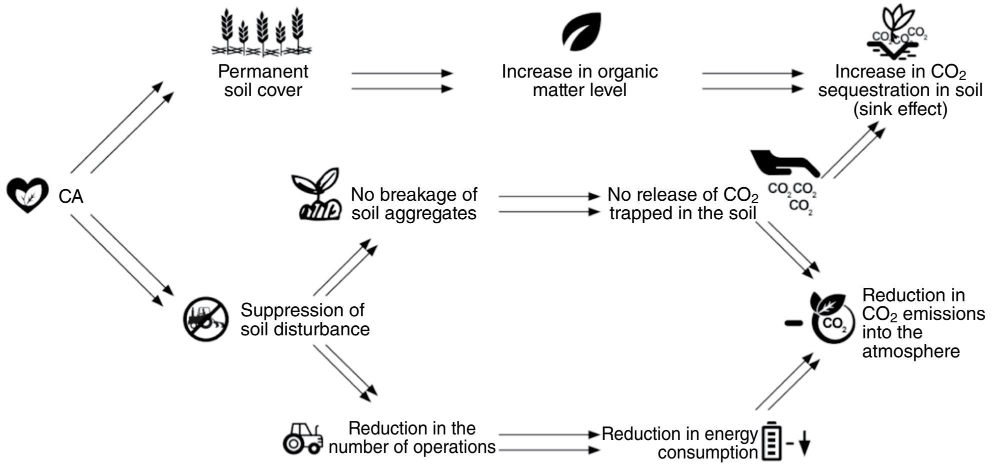

Fig. 3.5. Climate change mitigation mechanisms used in Conservation Agriculture (CA). Courtesy of González-Sánchez *et al*. (2017).

result it synthesizes more organic matter, which in the long term increases its productive capacity, while also reducing the CO_2 released into the atmosphere.

It is important to consider that the magnitude of response of CA systems to carbon sequestration varies considerably depending on the soil and weather conditions of the region, the amount of crop biomass left on the ground and how long the CA system has been in place. There are studies that suggest that the organic carbon content of the soil rapidly increases over the first 10 years of CA practice, after which it slows down until reaching almost zero growth, as the soil reaches a new equilibrium (Franzluebbers and Arshad, 1996; Puget and Lal, 2005).

CA promotes sequestration of CO_2 into the soil owing to the presence of stubble and root biomass, and reduces CO_2 release as there is less tillage, which in turn results in an increased sink effect. Many articles in the literature demonstrate how CA effectively boosts the soil's capacity to sequester atmospheric carbon in agricultural soils in CA. Ranaivoson *et al.* (2017) found that the organic carbon in soils under CA increased by 0.38 t ha^{-1} yr^{-1}. In a meta-analysis studying the carbon capture capacity of different crop management systems, Aguilera *et al.* (2013) obtained carbon sequestration rates of 0.44 t ha^{-1} yr^{-1} in the case of no-till systems in herbaceous crops, and 0.27 t ha^{-1} yr^{-1} in the case of groundcovers in woody crops, an increase in soil carbon content of 11.4% and 10%, respectively, compared with conventional farming methods. In Europe, the increase in SOC sequestration of no-till fields in comparison with conventional tillage was found to be 0.4 t ha^{-1} yr^{-1} (Freibauer *et al.*, 2004; Smith *et al.*, 2005). For woody crops, groundcovers are permanent grass or grass–legume cover crops between rows of woody crops. In this case, Vicente-Vicente *et al.* (2016) determined that groundcovers improve the SOC contents by 1.1 t ha^{-1} yr^{-1} in olive groves, 0.78 t ha^{-1} yr^{-1} in vineyards and 2.0 t ha^{-1} yr^{-1} around almond trees. Carbon sequestration values may vary, depending on the pruning residue management in woody crops; if residue is spread over the soil, higher carbon sequestration can be expected than in the case of grasses alone.

Several studies confirm the sequestration potential of increased SOC stocks on croplands in Africa on each of the continent's major bioclimatic areas. Thus, in an equatorial climate, Barthès *et al.* (2004) obtained mean rates of carbon capture in no-till CA soils of 1.50 t ha^{-1} yr^{-1}. In a tropical climate, mean carbon increase rates in no-till CA soils range from 0.33 t ha^{-1} yr^{-1} obtained on farms in Kenya (Okeyo *et al.*, 2016) to 2.76 t ha^{-1} yr^{-1} obtained on farms in Zimbabwe (Gwenzi *et al.*, 2009). Gonzalez-Sanchez *et al.* (2019), using the results of peer-reviewed papers, provided coefficients of SOC sequestration for Africa (Fig. 3.6) and addressed the high potential of CA for the continent,

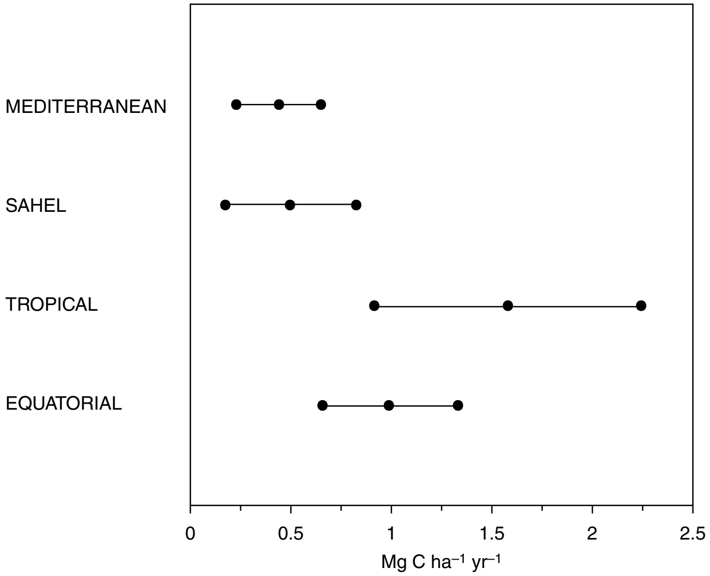

Fig. 3.6. Carbon sequestration rates in no-tillage for Africa's climate regions. Figure represents the 95% confidence intervals. Authors' diagram, based on Gonzalez-Sanchez *et al.*, 2019 and Zomer *et al.*, 2017.

which may be almost 100 times higher than current sequestration.

Table 3.3 summarizes results for the sequestration potential of increased SOC stocks on croplands for Africa (Zomer *et al.*, 2017). In the study the authors identified where carbon might be sequestered and by how much, if (through improved practices and management) SOC could be improved on agricultural land by a generally accepted (as attainable) moderate to optimistic amount, based on the medium and high sequestration scenarios of Sommer and Bossio (2014).

However, some studies stress that low carbon input, as a result of limited biomass production, may limit soil carbon increase (Cheesman *et al.*, 2016). This is an interesting and ongoing topic of research. Best results are most probably achieved where no stubble is retained for feeding animals, and minimal soil disturbance takes place; poor results may be found where tillage is reduced and residues are removed. It is important to reinforce the need to standardize no-tillage and CA research. Although no-tillage suggests merely the absence of tillage, in reality several components need to be applied to a CA system to guarantee equal or higher yields and better environmental performance than with conventional tillage systems. Broad understanding is lacking of what CA systems research means. This has led to a situation of conflicting research results because different technologies, methodologies and definitions of CA systems have been applied (Derpsch *et al.*, 2014).

3.6.2 Saving CO_2 Emissions with Conservation Agriculture

There are many factors involved in the release of CO_2 emissions from the soil, such as the type of soil management, SOM, soil temperature and moisture conditions, crop phenological stage, weather conditions and residue management. Adopting CA means a drastic reduction in or complete elimination of any mechanical actions that alter the soil profile. This reduction affects the volume of CO_2 emissions produced because on the one hand there is less fracture of soil aggregates and the subsequent gas exchange that occurs following tillage and, on the other, the reduced consumption of fuel required for the land to be tilled.

To quantify GHGs in agriculture and forestry Ogle *et al.* (2014) use 100-year global warming potentials reported in the IPCC (2014a). A positive CO_2-eq flux indicates a net increase in GHG

Table 3.3. Regional analysis of available soils. Soil organic carbon (SOC) for all available cropland soils by region (i.e. those not excluded from the analysis as high SOC or sandy soils), showing both the regional totals and the regional averages per hectare, at current status (T_0), and after 20 years for both the medium and high sequestration scenarios, and their annual increment. Adapted from Zomer *et al.*, 2017.

	Soil organic carbon					Average soil organic carbon					
Cropland soils (30 cm depth)	Current	After 20 years		Annual increase		Current	After 20 years		Annual increase		
Scenario	T_0	Medium	High	Medium	High	T_0	Medium	High	Medium	High	Cropland area
Region		Pg C		Pg C yr^{-1}			t C/ha		t C ha^{-1} yr^{-1}		km^2
East and southern Africa	5.64	6.80	8.02	0.06	0.12	53.00	64.00	76.00	0.55	1.13	1,055.461
North Africa	1.51	1.83	2.17	0.02	0.03	58.00	71.00	84.00	0.63	1.28	258,602
West and Central Africa	4.83	6.35	7.95	0.08	0.16	37.00	49.00	61.00	0.58	1.19	891,532

	Soil organic carbon					Average soil organic carbon					
Cropland soils (30 cm depth)	Current	After 20 years		Annual increase		Current	After 20 years		Annual increase		
Scenario	T_0	Medium	High	Medium	High	T_0	Medium	High	Medium	High	Cropland area
Region		Pg C		Pg C yr^{-1}			t C/ha		t C ha yr^{-1}		km^2
East and southern Africa	5.64	6.80	8.02	0.06	0.12	53.00	64.00	76.00	0.55	1.13	1,055.461
North Africa	1.51	1.83	2.17	0.02	0.03	58.00	71.00	84.00	0.63	1.28	258,602
West and Central Africa	4.83	6.35	7.95	0.08	0.16	37.00	49.00	61.00	0.58	1.19	891,532

emissions from the soil to atmosphere, while a negative flux indicates a net CO_2-eq decrease from atmosphere. Therefore, a positive (increasing) SOC change represents a negative CO_2-eq flux (Eqn 3.4):

$$\begin{aligned}&CO_2 \text{ flux (kg } CO_2\text{-eq ha}^{-1}\text{ yr}^{-1}) = -1 \times \\ &\text{dSOC} \times 44 \text{ kg } CO_2/12 \text{ kg C} \times \text{GWP}_{CO_2}, \\ &N_2O \text{ flux (kg } CO_2\text{-eq ha}^{-1}\text{ yr}^{-1}) = N_2O\text{–N} \times \\ &44 \text{ kg } N_2O/28 \text{ kg N} \times \text{GWP}_{N_2O}, \\ &CH_4 \text{ flux (kg } CO_2\text{-eq ha}^{-1}\text{ yr}^{-1}) = CH_4\text{–C} \times \\ &16 \text{ kg } CH_4/12 \text{ kg C} \times \text{GWP}_{CH_4} \qquad (3.4)\end{aligned}$$

where dSOC is the average annual SOC change in kg C ha^{-1} yr^{-1}; N_2O–N is average annual N_2O emissions in kg N ha^{-1} yr^{-1}; CH_4–C is average annual CH_4 soil fluxes in kg C ha^{-1} yr^{-1}; and GWP is the 100-year global warming potential of CO_2 (GWP = 1), N_2O (GWP = 165) and CH_4 (GWP = 28). GWP is an index measuring the radiative capacity of a GHG over a given time horizon relative to that of CO_2. It represents the combined effects of the different lengths of time that the gases remain in the atmosphere, and the relative effectiveness of the gases at absorbing infrared radiation.

There is ample scientific evidence that tilled soils emit a greater amount of CO_2 than CA soils. In research carried out in the USA, Sainju *et al.* (2008) observed that tillage-based practices increased the CO_2 emissions in comparison with no-till systems from 62% to 118%. Reicosky and Archer (2007) assessed the short-term effects on CO_2 emissions of two soil management systems, one based on the use of mouldboard ploughing and the other using no-till methods. The result was higher emission levels from tilled plots than from no-till plots, in both the short and medium term, with values ranging from emissions 3.8 times higher for shallow tillage (10 cm) to 10.3 times higher for deep tillage (28 cm) compared with no-till plots. The research was also able to quantify the emissions associated with the different types of equipment used in each of the assessed soil management systems. These results are in agreement with other studies in Europe by Carbonell-Bojollo *et al.* (2011), who studied not only the reduction in CO_2 emissions in soil when changing the management system, but also the behaviour of these emissions after each operation. In all of these operations, an emission peak was observed 2–4 h after tillage, with the maximum difference between the two management systems (no-till versus conventional tillage) occurring during that period. This difference was greater the more deeply the soil was altered in the operation, indicating how tillage intensity has a direct relationship with the level of CO_2 emissions, although other edaphoclimatic factors such as soil humidity, temperature and incidence of rainfall can also have an influence. Several studies have also addressed the effect of energy consumption in operations to prepare the soil for sowing in terms of equivalent carbon emissions. Some studies have estimated carbon emissions equivalent to 35.3 kg ha^{-1} in conventional tillage, 7.9 kg ha^{-1} in minimum tillage using a chisel plough and 5.8 kg ha^{-1} in no-till farming, making for a reduction of 84% of emissions in comparison with conventional agriculture (Lal, 2004). Similarly, in studies conducted over 20 years in an irrigated wheat and rice rotation on the Indo-Gangetic plains, reductions of CO_2 emissions linked to lower fuel consumption due to no-till farming reached 67% a year (Grace *et al.*, 2010).

In Africa, O'Dell *et al.* (2020) – after over 3 years of measurement – found that the mean and standard error (SE) of CO_2 emissions for the plot with the most consistent CA practices was 0.564 ± 0.0122 g CO_2 m^{-2} h^{-1}, significantly less (−61%) than 0.928 ± 0.00859 g CO_2 m^{-2} h^{-1} for the conventional tillage practice. Overall, the CA practices of no-till with the use of cover crops produced fewer CO_2 emissions than conventional tillage and fallow.

3.7 Conclusions

The impact of human activities, such as the burning of fossil fuels, tillage-based agricultural land use, burning of agricultural biomass and deforestation are increasing the levels of GHGs in the atmosphere, causing global warming and climate change. Africa has been the lowest source of GHG in the world, but is the most vulnerable continent to the impacts of climate change. It is expected that climate change will lead to a reduction in food and agricultural production owing to changes in rainfall patterns and temperature regimes in Africa.

Soil management of agricultural land has a direct effect on climate change. Appropriate soil management is one of the best tools for climate change mitigation and adaptation. CA transforms soils into an important pool of active carbon and plays a major role in the global carbon cycle that may contribute to changes in the concentration of GHGs in the atmosphere. Our research has found that, even if carbon sequestration rates differ depending on the agroclimatic region considered, promising results for CA in Africa with regard to climate change may be achieved.

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4 Mainstreaming of the Conservation Agriculture Paradigm in Africa

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Abstract

This chapter provides a justification for mainstreaming Conservation Agriculture (CA) in Africa. It describes the rationale for total transformation of agriculture that is needed in the future. Mainstreaming CA requires not only nation-wide adoption of the new paradigm of agriculture but also the necessary policy and institutional alignment to ensure that CA maintains its quality and full range of benefits to the farmers and to society. CA is a core component of climate smart agriculture and has been endorsed by the Malabo Declaration and Agenda 2063 for agricultural development. Thus, it is essential that everything possible is done by all stakeholders to support the implementation of Agenda 2063 with CA at its core. The chapter elaborates five major areas of change that are necessary to create the appropriate conditions for mainstreaming CA in Africa.

Keywords: adoption, political economy, climate smart agriculture, Malabo Declaration, Agenda 2063, champion

4.1 Introduction

There are two words in the title of this chapter which require some elaboration. The first is *mainstreaming*, which in the agricultural development context refers to the establishment of an ongoing national development process aimed at making the application of Conservation Agriculture (CA) by farmers and their communities the new normal, and for all relevant institutions and stakeholders to support this transformation. Such a change requires that the change process also involves aligning and mobilizing the support of all the key institutional stakeholders in the public, private and civil sectors to work together for this common objective.

The second word is *paradigm*, which means a new way of thinking and acting about an important area of human endeavour. It calls for a different mindset and behaviour compared to what was in place before; for example flat earth versus round earth, or monarchy versus republicanism. In the case of CA, it requires shifting from the tillage and high chemical input mindset to the CA and high biological input mindset by all concerned individuals and institutions, and building a new ecological foundation for best practice and knowledge as well as a policy environment and institutional services.

It has been said that preparing an effective article on the subject of mainstreaming anything requires the courage to be candid about the past and the present, and to make some bold statements about the future. We would like to offer our personal views about some of the issues related to mainstreaming an alternative agricultural

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paradigm such as CA, based on what we have observed, experienced and learnt over the past five decades or so.

Looking back over these 50 years, it is simply amazing and exciting to see the breadth and depth of developmental changes that have occurred everywhere in the world in the quality of our material life, in the growth of public, private and civil institutions, and in our abilities to generate new knowledge and invent and apply all kinds of technologies and skills to advance national economies, reduce poverty, improve livelihoods and quality of life. It is also amazing that within our lifetimes, during which much of the European colonial rule came to an end, agriculture and land use systems have developed to a point where, at the global level, enough food is being produced to feed more than 10 billion people (Holt-Gimenez *et al.*, 2012).

Alongside this global phenomenon of excessive primary production, however, we have unequal access to food and nutrition so that 820 million people are chronically hungry and undernourished while 2 billion are obese or overweight and 150 million children are stunted (FAO, 2019). Globally, more than 50% of the grain is used to feed livestock and some 150 billion land-based animals and 2 trillion aquatic creatures are killed every year. Two-thirds of the global agricultural land is used for animal production, causing losses in biodiversity and natural vegetation, and land degradation (Kassam and Kassam, 2020a). It has been reported that some 30%–40% of the food produced is wasted. In addition, some 90% of global ecosystems are degraded (MEA, 2005), two-thirds of them severely; and up to 0.5 billion hectares (ha) of agricultural land have been lost since the end of WWII, owing to intensive tillage-based industrial production practices in the industrialized world and to tillage-based, low-output agriculture based on mining natural fertility.

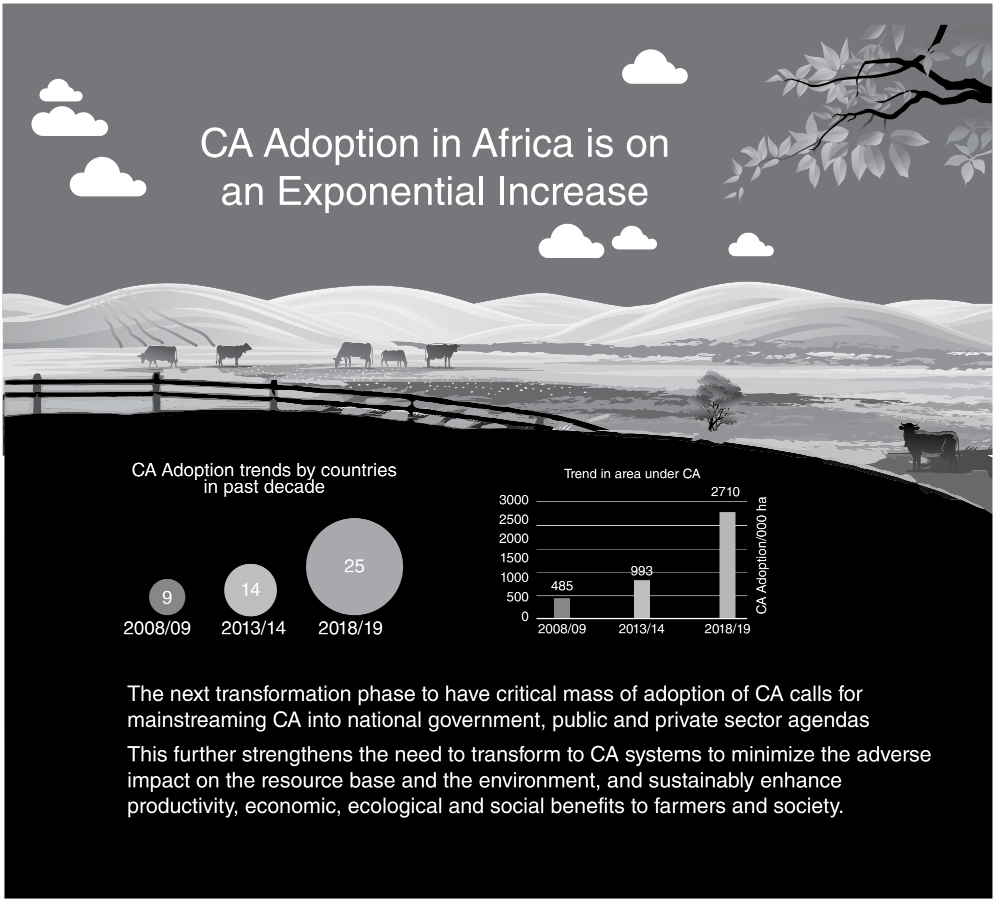
Thus, the unprecedented increase in global agricultural output and economic wealth over the past 70 years has been accompanied by equally unprecedented widespread malnutrition and food insecurity, as well as by degradation of agricultural land resources, biodiversity and the environment. The latter has resulted in the abandonment of up to some 0.5 billion ha of agricultural lands globally (Montgomery, 2007) and degradation of many of the ecosystem functions and land-mediated societal services such as clean water; carbon, water and nutrient cycling; regulation of streams and rivers; control of erosion, runoff and floods; pollination; and control of insect pests and pathogens (MEA, 2005; Juniper, 2013; Nkonya *et al.*, 2016).

According to researchers such as H.E. Dregne, David Pimentel and David Montgomery, over the last 70 years – in addition to the abandoned agricultural land globally – we have severely degraded even more land due to the way our farming and agricultural systems have evolved, particularly since WWII. This process of degradation has been clearly described by David Montgomery in his book *Dirt* (Montgomery, 2007), which shows that tillage is the root cause of soil and land degradation and erosion, and loss of soil health and its functions, physical structure and ecological productivity. In modern agriculture, as well in traditional agriculture, tillage is accompanied by maintenance of bare soils and low or no return of vegetative biomass to physically protect the soil surface and feed soil microorganisms. Tillage is also accompanied with cropping systems that are poor in diversity and therefore vulnerable to biotic and abiotic stresses. Under the dominant Green Revolution agriculture, intensive tillage is also accompanied by excessive application of fertilizer and pesticides, and high use of fossil energy and heavy investment in mechanization for on-farm operations.

Indeed it is known that, in many parts of the world (including in the industrially advanced nations of Europe), cereal yields have plateaued at a suboptimal level for the past three decades (Brisson *et al.*, 2010) and inefficiency in the use of fertilizer has increased (Carvalho *et al.*, 2012). The continent of Africa also suffers from its own share of severe agroecosystem degradation, and loss in crop and land productivity, even in areas where tillage is performed using hand hoes or animal-drawn ploughs.

So, in this chapter, we will not focus on 'doom and gloom' stories about the state of our planet's and continent's agroecosystems, or on the out-of-date knowledge and support services that are maintaining the suboptimal status quo (Kassam and Kassam, 2020a). We would rather focus on another – and much richer and inspiring – set of stories to tell with confidence and pride, and to be reflected upon. These stories are about the innovative and sustainable agricultural achievements that have been occurring internationally and especially in the Africa region. The number of countries in Africa choosing to adopt CA as a core production component of climate smart agriculture (CSA) has been increasing exponentially, from 9 to 14 to 25 in 2008/09, 2013/14 and 2018/19, respectively. Likewise, the area under CA has also increased exponentially from 485,230 ha to 993,440 ha to 2,712,203 ha over the same period, an increase of more than fivefold over a period of 10 years (Fig. 4.1 and Table 4.1). These achievements in sustainable production intensification can also be seen over large areas in South and North America; Australia; more recently in Asia including in Iran, India, Pakistan, Kazakhstan and China; and in Europe including in Spain, the UK, France, Germany, Italy, Poland and Romania (Kassam *et al.*, 2019). The stories of such achievements, which are not regularly found in the mainstream agricultural and environmental policy discourse, should be replacing the fear and ignorance with hope, excitement and commitment for the future development of agricultural systems in the Africa region and around the world (Kassam *et al.*, 2020).

The above notwithstanding, there have also been the development of effective responses over the years by farmers and concerned stakeholders in a growing number of countries, which are providing the international community with successful examples and models to emulate. Several countries in all continents have now successfully shown that it is possible, using the new



The next transformation phase to have critical mass of adoption of CA calls for mainstreaming CA into national government, public and private sector agendas

This further strengthens the need to transform to CA systems to minimize the adverse impact on the resource base and the environment, and sustainably enhance productivity, economic, ecological and social benefits to farmers and society.

Fig. 4.1. The number of countries and area under Conservation Agriculture in Africa has been increasing exponentially. Authors' own figure.

Table 4.1. Countries that have adopted Conservation Agriculture (CA) and cropland area (ha) under CA. Authors' own table.

No.	Country	Area (ha) 2008/09	Area (ha) 2013/14	Area (ha) 2018/19
1	South Africa	368,000	368,000	1,176,200
2	Zambia	40,000	200,000	552,667
3	Mozambique	9,000	152,000	289,000*
4	Zimbabwe	15,000	90,000	100,000*
5	Kenya	33,100	33,100	33,100*
6	Tunisia	6,000	8,000	14,000
7	Morocco	4,000	4,000	12,826
8	Sudan	10,000	10,000	10,000*
9	Lesotho	130	2,000	2,000*
10	Ghana		30,000	235,000
11	Malawi		65,000	211,000*
12	Tanzania		25,000	32,600*
13	Madagascar		6,000	9,000*
14	Namibia		340	800
15	Uganda			7,800*
16	Algeria			7,000
17	Swaziland			800
18	Ethiopia			7,500
19	Niger			5,000
20	DR Congo			2,060
21	Cameroon			2,000
22	Burkina Faso			1,000
23	Guinea			400
24	Rwanda			250
25	Burundi			200
	Total	**485,230**	**993,440**	**2,712,203**
	Increase since 2008/09 (%)		105	459

*Data for 2015/16.

sustainable agriculture paradigm of CA, to reverse the trends in agricultural land degradation and destruction of biodiversity and the environment. They have also shown how, with this reversal, rural communities and nations can become economically thriving, thus offering decent and dignified livelihoods to hundreds of thousands of farming families and the families of their service providers, and for the environment to be managed sustainably.

During the past two decades or so, farmers in Brazil, Argentina, Paraguay, Uruguay, the USA, Canada, Australia, Russia, Ukraine, Kazakhstan, Iran, Syria, China, India, and also in countries of the Africa region such as Morocco, Tunisia, Algeria, Ghana, Tanzania, Kenya, Zimbabwe, Zambia, Mozambique, Malawi, South Africa and Madagascar have demonstrated that a different kind of agricultural intensification and development paradigm is possible (Kassam *et al.*, 2019). This paradigm is available to all nations and peoples and allows them to build a more efficient, resilient, affordable and equitable food and agriculture system.

The story of the journey of global agricultural transformation began in the 1950s and 1960s in North America, and in the 1970s and 1980s in South America, Australia and New Zealand, with pioneer and champion farmers working with champion technical experts. This also occurred in Africa in the 1970s and 1980s. These pioneers and champions showed that a very different and much improved way of farming was possible by all types of farmers.

This new and alternate paradigm is CA. It offers higher, more stable and sustainable productivity and output, and greater economic, environmental and social benefits than the conventional tillage farming with its poor soil health management and limited crop diversity. This innovation has been applied in all continents to production systems in rainfed and irrigated agriculture involving annual cropland systems, perennial systems including orchards and plantations, agroforestry systems, mixed crop–livestock–tree systems, rice-based systems, grassland and rangeland systems, and organic systems. It is being practised by smallholder farmers and large-scale farmers, by rich and poor farmers and by women and men farmers with production systems relying on manual labour, animal traction or motorized power.

As a result of the spread of this new paradigm of CA, we have also come to know that a productive and sustainable agriculture system can also simultaneously deliver large-scale ecosystem services to farming communities and to societies from landscapes comprising large watersheds and whole provinces. It is simply impossible to achieve these soil-mediated services with conventional, intensive tillage-based agriculture, including tillage-based organic farming or tillage-based agroecology.

This chapter elaborates the justification for mainstreaming CA within the guiding framework of Agenda 2063 in terms of: (i) the political economy of CA; (ii) why Africa should adopt and promote CA as the core of its preferred paradigm for CSA; (iii) the enabling environment for mainstreaming; and (iv) the development of institutional capacity and policy support for mainstreaming.

4.2 Agenda 2063: Justification for mainstreaming Conservation Agriculture (CA) in Africa

Agenda 2063 now provides the guiding framework for the mainstreaming of CA and confirmation of political goodwill from the African continent. The Malabo Declaration and Agenda 2063 provide the justification to move away from the other agricultural paradigms that have been promoted earlier – including the Green Revolution – and which have not worked. This section elaborates on the political economy of CA and the adoption status of CA across Africa.

4.2.1 Political Economy of Conservation Agriculture (CA)

Given the history and nature of the political economy of agriculture development globally, and particularly in Africa, most of the inherited national and international institutional and policy support strategies still continue to push forward agricultural development strategies based on the conventional tillage-based Green Revolution agricultural paradigm, with its inherently poor soil health management practice and limited crop diversity. We consider this to be ‘business as usual’ agriculture. Applying CA practices essentially means altering generations of traditional farming practices, including the use of mechanical implements, which have determined the social and cultural fabric of African rural societies. CA must be understood in the context of change in farming and livelihood systems that is much more fundamental than just a change in a crop production technique. This largely explains why the adoption and spread of CA as the foundation for CSA, as well as the institutional mainstreaming of CA, cannot be expected to occur automatically in any country in Africa. Indeed, the full potential of CA to address issues ranging from poverty alleviation and food insecurity to global climate change cannot be fully realized until the constraints to increasing CA’s wide-scale uptake across Africa are resolved. Experience from countries that now have a significant extent of agricultural land under CA systems, both outside Africa such as Brazil and Paraguay, or in Africa such as South Africa and Zambia, shows that there can be a long gestation period of some 15 years or more. In this period pioneer farmers, extension agronomists and researchers are able to champion the cause and generate the needed proof of concept and application models to lay the foundation for effective expansion and exponential growth in the uptake and spread of CA. This is because time is a necessary resource required to establish critical levels of research activities, farmers’ engagement and private sector involvement to generate the mainstreaming drive and momentum with government support and with all stakeholders working together.

Farmers, researchers and extension agronomists in Africa have also been working on CA since the early1970s, particularly in eastern and southern Africa and in North Africa. There is now substantial accumulated empirical and scientific evidence to show that CA systems adapted to local biophysical and socio-economic conditions and supported by service providers work profitably and sustainably on all farm sizes and with different farm power sources. This is in line with the global scientific and empirical evidence and experience which has led the global CA area since 2008/09 to increase at an annual rate of 10.5 M ha of cropland to 180 M ha in 2015/16, corresponding to about 12.5% of the global cropland area (Kassam *et al.*, 2019). There is also a substantial area of CA-based perennial systems such as orchards, plantations and agroforestry in all continents, but the exact extent is not known.

4.2.2 Adoption of Conservation Agriculture (CA) in Africa

The African Union (AU), through its Malabo Declaration and Agenda 2063, plans to end hunger in Africa by 2025 by aiming for 25 million households to be practising CSA (Vision 25×25) by the same date. CA systems that include multi-purpose trees are increasingly considered to be a 'foundational practice' for use on all farms in the dryland regions of Africa, since they complement all other improved farming practices and cropping and livestock systems, and add about US$200 to the value of each household (Garrity, 2017). The value of CA cropping systems with trees is reinforced by the fact that they require relatively little cash investments by farmers and thus have enormous advantages compared with the costs and establishment risks of producing monocrops on their own in semi-arid and dryland environments. The UN Convention on Combating Desertification (UNCCD) is championing the goal of attaining a land degradation-neutral world. The restoration of degraded agricultural land is a major part of this effort and the incorporation of trees into CA cropping systems is now becoming recognized as an important vehicle to achieving this goal.

The CA cropland area in Africa in 2008/09 was 0.48 M ha spread across nine countries. Over the next 5 years the area doubled to 0.99 M ha in 2013/14, an increase of some 105% spread across 14 countries. Over the following 5 years the area increased to 2.71 M ha in 2018/19, an increase of 174%, corresponding to an increase of 459% since 2008/09, spread across 25 countries (Table 4.1). As the CA cropland areas in several countries could not be updated, the total area of 2.71 M ha is a conservative figure. In addition, CA cropland systems with trees are reported to cover several million hectares across the semi-arid areas of Sub-Saharan Africa[1] (Garrity *et al.*, 2010; Garrity, 2017; Kassam *et al.*, 2020). There has been a considerable increase in the area under CA cropping systems since 2015/16. Taking into account the crop production systems with trees in the semi-arid and Sahel areas, as well as possible similar systems in the humid areas, it now appears that the total area of cropland under CA in Africa may be closer to 10 M ha, or some 10% of the total cropland area. This has brought productivity, economic, environmental and social benefits to several million smallholder family members in some 25 countries across Africa.

Furthermore, there are mixed systems in humid areas in countries of West and Central Africa in which annual crops are grown in association with perennial crops such as coffee, cocoa and oil palm. Such systems also appear to be applying CA principles, but their area extents are not known.

The rate of adoption of CA systems in Africa and globally is expected to continue to increase in coming years as more policy and institutional attention, and public and private sector support, is directed towards their promotion at the grassroots level. African governments must now make a firm and sustained commitment to encourage and support the CA paradigm, through contextualized CA systems in the different climatic zones, as the desired CSA for achieving the agricultural development vision of the Malabo Declaration (specifically, Vision 25×25) and the goals set by Agenda 2063. This should be expressed in government and institutional policies that are consistent and mutually reinforcing across the spectrum of government responsibilities, including mainstreaming CA in public advisory, research and education services, and sufficiently flexible to accommodate variability in local ecological and socio-economic characteristics. Any financial and structural assistance and incentives needed by farmers can be justified by the recognition of the public goods value of environmental and socio-economic benefits generated by CA-based land use.

4.2.3 Conservation Agriculture (CA) as a Core Component of Climate Smart Agriculture (CSA)

CA represents a different 'paradigm' of agriculture, comprising a fundamental operational change in agricultural production systems management, both technically and managerially. It requires a deeper awareness of ecosystem functions, and the societal services they offer in agricultural landscapes, so that they are least disrupted when landscapes are altered or used for agricultural production. A large range of productivity, economic, environmental and social benefits that accrue from CA land uses, most of which are not possible in tillage-based agriculture, provide an indication of why so many farmers globally, as well as in Africa, have adopted CA systems. They also provide a justification of why CA deserves greater attention from the development community, including government, corporate and civil sectors. Studies in Africa and globally have indicated that CA can facilitate the development of CSA because, at the production level, it has the ability to adapt and mitigate climate change and also contribute to enhancing food security (Kassam *et al.*, 2017; Gonzalez-Sanchez *et al.*, 2019; Kassam, 2021). The promotion of CA needs, therefore, to be based not merely on the commercial value of farm produce, but also on the transformative yet unseen ecosystem- and sustainability-enhancing societal services CA provides in addition to the regenerative and climate smart nature of CA systems.

Analysis of the global empirical and scientific evidence, including that from Africa, shows conclusively that conventional tillage-based agriculture (at any level of development or type of farm power) is unable to maintain soil health and functions in crop fields and over agricultural landscapes (Kassam *et al.*, 2017; Kassam, 2021). Because of continuous mechanical soil disturbance (which leaves soils bare and without a biomass substrate to feed the soil life) and poorly diversified cropping, all tillage-based agricultural systems lead over time to soil erosion and land degradation, loss of soil and ecosystem health, increased biotic and abiotic stresses and damage, and poor adaptability to climate change. These weaknesses contribute to a significant loss in attainable agroecological land and crop potentials; suboptimal actual crop yields, factor productivity and profit; and poor system resilience. There is also a loss in ecosystem functions and societal services such as clean and regulated water supply; carbon sequestration in soils; nutrient, carbon and water cycling; and pollination services. According to a recent preliminary continental assessment, the carbon sequestration potential of Africa with annual and perennial CA systems is considerable (Gonzalez-Sanchez *et al.*, 2019).

CA systems, underpinned by the three interlinked principles of continuous no or minimum mechanical soil disturbance; permanent soil mulch cover; and diversified cropping, are known to be regenerative in terms of soil health and capable of reversing land degradation and minimizing soil erosion. They also offer greater resilience to biotic and abiotic stresses and are climate smart. Thus, established CA systems generally confer a range of productivity, economic, environmental and social benefits to all land-based production systems and to producers (whether they operate on a small or on a large scale) and to society at large. These include: (i) higher stable production, factor productivity and profitability with lower production input and capital costs; (ii) greater capacity for climate change adaptation and reduced vulnerability to extreme weather conditions such as drought, leading to more reliable harvests and reduced risks; (iii) enhanced soil and landscape health as well as ecosystem functions and services; and (iv) reduced greenhouse gas (GHG) emissions and increased soil carbon sequestration (Kassam, 2021).

In the case of the last two benefits, we are referring to the two well-known examples of large-scale harnessing of ecosystem services in Brazil. The first example is the Cultivating Good Water (Cultivando Água Boa) programme in Parana Basin III whose water drains into the reservoir of the Itaipu Dam, which generates hydroelectric power for Brazil, Paraguay and Argentina (Mello *et al.*, 2020). The second example is the carbon offset trading scheme operated by the Alberta Government in Canada, where farmers are paid 24 Canadian dollars per tonne (t) when the sequestered carbon offsets are purchased by industries that are releasing carbon emissions greater than their maximum allowable amounts (Swallow and Goddard, 2016). The two ecosystem service programmes in Brazil and Canada are worth many millions US$ to those nations and their peoples, and were made possible only because of the successful integration of the new paradigm of CA into their national and provincial agricultural systems. These programmes have succeeded under the stewardship of hundreds of thousands of small and large farmers and their local no-till (NT) associations, supported by many public and private institutions.

The Cultivating Good Water Programme in the Parana Basin III led to adoption of CA systems and their improvement, leading to reducing levels of soil erosion, land degradation, chemical and sediment water pollution, and improvements in the quality of the water draining into the Itaipu Dam and passing through the hydroelectric generating turbines. This has led to a considerable increase in crop yields and significant increase in the operating life of the Itaipu Dam complex (Mello *et al.*, 2020).

In 2007 the Government of Alberta, Canada, amended its earlier climate change policy that required large final emitters to reduce their annual GHG output. To reach their compliance targets, facilities had options, including one of purchasing offset credits from Alberta sources using government-approved protocols. One of the agricultural opportunities at the time was the development and application of a CA-based NT annual cropping protocol that recognized the increase in soil carbon sequestration with the adoption of NT cropping systems (Goddard *et al.*, 2008). The updated version, now named the Conservation Cropping Protocol (CPP), also includes a provision for reduction in summer fallow.

Possibilities of operating such ecosystem service programmes in African countries, based on CA land management, have been reported over the past two decades. With regard to improving water resource management or soil and water conservation, work has been done in several countries in southern Africa (e.g. Thierfelder *et al.*, 2015; Wall *et al.*, 2020), eastern Africa (e.g. Lanckriet *et al.*, 2012; Assefa *et al.*, 2018) and North Africa (e.g. Mrabet *et al.*, 2012) that shows substantial benefits offered to farmers and communities. The potential of carbon sequestration is substantial, as shown in the preliminary study conducted by the African Conservation Tillage Network (ACT) and the European Conservation Agriculture Federation (ECAF) (Gonzalez-Sanchez *et al.*, 2019; 2020) and other studies (e.g. Simone, 2018). Pilot schemes involving payment to farmers for carbon sequestration have been tested (e.g. Lufafa, 2013). As more research evidence becomes available, schemes involving payments for ecosystem services, such as for the provision of clean water and increased carbon sequestration, are likely to appear. Constraining factors are not always concerned with difficulties in overcoming biophysical or agronomic aspects, but may involve setting up enabling mechanisms (e.g. Demenois *et al.*, 2020).

The wider global bioeconomic impact of the CA paradigm has been that countries that have adopted and are mainstreaming CA at the national level have a thriving agricultural and rural economy, and have become competitive ‘bread baskets’, contributing to national and international food security and to economic growth. Their agricultural sectors are generating employment and livelihoods, offering hope to youngsters and opportunities to stay in the farming sector, and establishing a wide range of professional and business careers in the rural sectors.

The colossal success of CA land use programmes has not made these nations and their agricultural stakeholders complacent, nor have the scientific research and development communities and the NT farmers lost any of their original enthusiasm and commitment to sustainability. In fact, nations such as the USA, Canada, Brazil, Argentina, Paraguay, Uruguay, Spain, Russia, Kazakhstan, India, China and Australia, that have significant areas under CA systems, have continued to improve the quality, richness and profitability of NT farming systems, including the development of mixed and diversified CA systems. In Africa, countries such as South Africa, Zambia, Mozambique, Malawi, Zimbabwe, Kenya and Morocco have been providing effective leadership during the past two decades, but much remains to be accomplished.

4.2.4 Enabling Environment for Mainstreaming Conservation Agriculture (CA)

So, what have we learnt from those countries that have moved towards mainstreaming the CA paradigm of sustainable intensification in the context of CSA?

Perhaps one way to the answer is to highlight the underlying criteria for success drawn from these diverse experiences (Kassam *et al.*, 2014) that highlight the necessary conditions that need to be present to establish the sufficient conditions for mainstreaming.

There are obviously many issues and factors involved in making any fundamental change of the kind we are talking about, but we will mention five key criteria which appear to us to be the most crucial for changing completely the way we approach the business of taking care of our agricultural lands and natural resources, and which can serve to mainstream CA and reconnect people, land and nature. They also serve to help achieve a paradigm change from a degrading and vulnerable tillage-based agricultural land management system to a sustainable system of CA that is more productive and profitable, efficient and resilient, delivers societal ecosystem services and is regenerative and self-repairing – a system that is not only climate smart but also smart in many other ways.

The five critical ‘criteria of success’ for mainstreaming CA, where the agricultural paradigm is shifting successfully towards CA, are:

1. The presence of champions and pioneer farmers, and champion institutions and champion institutional leaders.

In the Africa region there are champions and pioneer farmers but not as many as in the countries where CA is dominant. Similarly, there are champion institutions such as ACT and conservation farming units (CFUs), and institutional leaders, but to nowhere near the extent found in the countries where CA is widely spread. Without adequate numbers of individual and institutional pioneers and champions, including farmers and extension agronomists and engineers, there will never be enough momentum to achieve and sustain uptake of CA or to address the challenges that can be expected to arise. Thus, a major effort must be made to inspire new generations of farmers, graduates, scientists, extensionists, institution heads and stakeholders in the private, public and civil sectors to become engaged at all levels in generating the momentum for change and CA-based transformation and agricultural development.

2. The presence of farmers coming together to form powerful farmer organizations for proactive actions and greater self-reliance.

There are some NT or CA farmer organizations[2] across the Africa region but not as many as in the countries where CA is dominant. Fortunately, this is beginning to change, but little will happen to spread quality CA if farmers themselves do not work together, empower themselves, and find a strong voice and visibility to accelerate the mainstreaming of CA in each country and across Africa. Governments can provide support in enabling farmers to come together and establish associations to capture economies of scale in many areas within the value chains; these would generate momentum and efficiency in bringing about the needed agricultural transformation. Increased levels of government support in terms of development investment could enable farmers to establish associations; work together and improve their capacities to gain or generate new knowledge; apply new methods including mechanization; and improve market access and returns. When working together, farmers can deliver public goods to society more effectively in response to incentives, including payments for environmental services where extra costs to farmers may be involved. Such public goods include clean water supplies, reduction in flood risks, carbon sequestration, and reductions in soil erosion and biodiversity loss.

3. The presence of education, research and innovation systems supported by new communication technologies that have aligned themselves to promoting the new paradigm.

Throughout the Africa region there are universities offering courses on sustainability, environment, soil, climate change adaptability and mitigation, CSA, global food security, how to feed the world and how to reduce wastage. Only a few universities in the Africa region teach CA. The same lack of emphasis on CA systems and practices applies to research and innovation and to new communication technology. This is why

ACT and its partners have launched pan-African curriculum development and quality assurance initiatives to ensure that CA and development standards are maintained at the best possible level. CA requires users to embrace and internalize new knowledge and skills that can be built in partnership with other knowledge systems. The skills, insights and abilities of teachers and learners need to be raised at all education levels, and these efforts should be linked with wider global and national social movements to empower local, self-reliant CA development efforts.

It is thus important to establish long-term CA demonstration sites at field scale (e.g. over approximately 50 ha) in such areas to generate evidence that regenerative and more productive community-based crop–livestock management is possible, and would benefit both crop farmers and livestock owners, as well as reduce land degradation and improve the overall environment.

4. The presence of governance that creates policies and institutional support for CA paradigm change.

The Africa region struggles with policies and institutional strategies to support a more sustainable way of farming. Only a handful of countries such as South Africa, Namibia, Zambia, Zimbabwe, Mozambique, Namibia, Kenya, Tanzania, Ethiopia and Morocco have attempted to develop a governance structure that supports the promotion, adoption and spread of CA, and the public and private institutional support it needs to improve its quality, generate graduates with CA knowledge and promote CA participatory research and training. But there is good news because:

- ○ The Food and Agriculture Organization of the United Nations (FAO) continues to expand its support for CA in Africa and launched the CA-based Sustainable Agricultural Mechanization for Africa initiative at the Second Africa Congress on Conservation Agriculture (2ACCA) with ACT as its strategic partner to assist in operationalizing the initiative.
- ○ The African Development Bank (AfDB) is promoting a pan-African initiative based on CA to develop agriculture in the Guinea Savannah region.
- ○ The International Fund for Agricultural Development (IFAD) is increasingly including a CA component into its loan programmes as it mainstreams climate change resilience approaches through the Adaptation for Smallholder Agriculture Programmes (ASAPs).
- ○ The Rwanda Institute for Conservation Agriculture (https://www.rica.rw/, accessed 8 July 2021) was established in 2018.
- ○ The Government of Morocco launched the Adaptation of African Agriculture (AAA) initiative at COP 22 in 2016.
- ○ ACT has established an initiative to create a network of 25 CA Centres of Excellence across Africa; each complex will comprise a group of collaborating institutions from the education, research, extension and private sectors, all working closely with farmers on CA adoption and uptake.

5. There is effective capacity to partner with the private sector in ways that benefit farmers, communities and society at large, including nature.

If we look at the Africa region in terms of partnering with the private sector for sustainable agriculture, all we have to do is ask why birds and bees are disappearing; why deforestation, erosion, land degradation, droughts and desertification are occurring; and why farmers must be forced to use more than 200 horsepower tractors when 50–120 horsepower would be sufficient in most cases. There is hardly any meaningful dialogue with the corporate-dominated agricultural private sector. This is why it is exciting to note the recent launch of a sustainable agricultural mechanization initiative for Africa led by FAO, ACT and partners, under the auspices of the AU, to accelerate the modernization and development of agriculture with CA. However, similar initiatives are needed to help minimize the use of agrochemicals while intensifying productivity and ecosystem services with CA. It is generally true that established CA systems use considerably less seed, water, nutrient, pesticide, energy and time than do tillage systems and, with increased productivity, they generate employment along the value chain. These five criteria are useful in examining the prospects for success in changing from conventional agriculture to CA. They may enable us to see where the gaps or weak points are, directing our attention to where we need to focus our energies for change.

The models of countries such as Brazil, Argentina, Paraguay, Uruguay, the USA, Canada, Australia and, more recently, Kazakhstan, China, India, South Africa, Zambia and Morocco show that that the policy and institutional environment in the public and private sector in African countries needs a fundamental reform to allow transformation of conventional tillage farming to CA.

These five core criteria, which seem to us to be the key drivers or conditions for agricultural change in each country and region across Africa, together constitute the sufficient conditions. They can be used to monitor and evaluate where we need to focus our attention and where we need to make a faster, bigger difference in shifting to the CA paradigm. All five work together and create a foundation for maintaining and enhancing the momentum for change, innovation and impact.

Finally, by promoting the adoption of CA systems across Africa in each country and region, a foundation for creating the much-needed harmony between nature and humankind will be laid. Also, the adoption of CA is a response to underpin the development of sustainable food and agricultural systems ecologically and biologically in African nations, to meet future human needs in line with the Malabo Declaration and Agenda 2063.

4.2.5 The Africa Conservation Agriculture (CA) Congresses

It is in recognition of the dire consequences outlined above that all the regional and global congresses on CA are extremely important because they are providing an opportunity to mainstream the CA paradigm as a core component of CSA. They also serve to counterbalance and challenge the attachment to the idealized version of conventional tillage-based industrial Green Revolution agriculture. Congresses on CA, including the 2ACCA held in October 2018 in Johannesburg, South Africa, provide a clear way forward, as reflected in the following quotation from the statement justifying the need for 2ACCA for Africa:

> Conservation Agriculture (CA) is an alternate paradigm for sustainable agriculture system that is agro-ecological, productive and profitable, and regenerative. CA is also climate smart, as well as smart in many other ways, in serving economic, environmental and social needs of societies worldwide. CA is transforming the way farmers practice agriculture worldwide and has replaced conventional agriculture (in 2015/16) on more than 180 million ha of cropland, corresponding to 12.5% of ‘global arable’ lands. Since 2008/09, the global rate of CA expansion has been some 10.5 million ha per year. During the past 10 years, CA area in Africa has more than doubled to about 1.5 million ha, benefitting several million farming households. Increasing numbers of governments as well as public and private institutions in Africa are supporting climate smart agricultural development based on CA systems.
>
> ACT is a leading pan-African institution dedicated to the promotion of CA systems as an essential core component of investment in agricultural development in Africa through: institutional capacity building; mechanization and commercialization of value chains; participatory research and innovation, education and extension; knowledge management and communication; national and international partnerships; and technical assistance support to governments and regional organizations.

The direction of 2ACCA, in support of the Malabo Declaration and Agenda 2063, is grounded in the experiences of NT CA systems which many farmers in many countries began in the 1970s and 1980s in North and South America, Europe and Africa, and which have continued in ever-increasing numbers in all continents and in all land-based agroecologies.

Production systems of significance in the Africa region such as orchards, plantations and agroforestry systems, and mixed production systems including crop–livestock–forestry systems, can all be converted to NT CA systems as is happening in other continents. All these CA systems – annual, perennial and mixed – are applying an ecosystems approach to sustainable production intensification that is regenerative and which is also becoming increasingly recognized as a core production component of CSA envisaged in the Malabo Declaration and Agenda 2063.

Congresses such as 2ACCA are essential in providing much-needed fora for all CA stakeholders, including farmers, to meet face-to-face periodically to share experiences, exchange information and put greater energies and resources into supporting the adoption and mainstreaming of CA.

4.2.6 Institutional Capacity and Policy Support for Mainstreaming

Despite all the known advantages of CA systems and the known disadvantages of conventional tillage-based agriculture, currently most of the knowledge and development service institutions in the public and private sectors in Africa tend to align themselves in supporting the conventional tillage-based production systems. There is also limited policy experience and research–training–linkages–expertise to assist the small-scale and large-scale farmers in the different ecologies and national contexts in the transformation of conventional tillage systems to CA systems. Consequently, a concerted effort is needed to create and sustain an enabling policy and institutional environment in each country to be able to promote the adoption and spread of CA across Africa more effectively.

Without this strategic policy and institutional alignment to support the spread of CA, mainstreaming CA across Africa will not be possible. There is now an urgent need to move away from the current situation, dominated by NGO-driven pilot projects, and from research experimentation on CA and CA test scaling, which will not provide an adequate basis for meaningful pan-African adoption even in 40–50 years. We must move to government-supported CA capacity development strategies, plans and programmes involving all CA stakeholders in the public, private and civil sectors. This requires systematic CA capacity development within the governments and their institutions and in the private sectors in terms of: (i) structures, systems and roles; (ii) staff and facilities; (iii) skills; and (iv) tools that would include the R&D, training, and extension/outreach departments of all national governments.

Key limiting factors that constrain CA adoption and up-scaling are: the paucity of knowledge across agricultural and related sectors including farmers, expertise, inputs (especially machinery and equipment), adequate financial resources and infrastructure, and poor policy and institutional support. Where a country is not currently generating the knowledge needed for transforming tillage production systems towards CA systems, it must rely on successful experience from outside its borders and support a network of on-farm operational research conducted by pioneer farmers, backed by public and private sector advisory services, NGOs and research establishments. Given the limited involvement of national research establishments in CA, NGOs and networks (such as ACT) have had significant contributions in capacity development, knowledge management and information sharing.

The engagement of the agricultural machinery sector is necessary to facilitate the supply of needed equipment. Commercial CA farming for the smallholder African farmers is possible, but with a prerequisite investment in farmer organization and linkages to markets. This is not of initial interest to the private sector dealing with production inputs. Also, social capital development in terms of CA farmer associations is seen as an important prerequisite to the large-scale adoption of sustainable behaviours and technologies. Where such social capital is high in formalized groups, people have the confidence to invest in collective activities, knowing that others will also do so. Farmer participation in technology development and participatory extension and innovation approaches has emerged as a response to such new thinking.

Policy support and cohesion to meet these aims is critical, as most governments have a variety of institutions involved in natural resource management (e.g. agriculture, forestry, national parks, energy, water). The fragmented nature of their mandates often inhibits full effectiveness. On the other hand, a commonality of underlying concern with the care of land, underpinning policy cohesion, will facilitate the needed interdisciplinary collaborations to be undertaken with farmers and other land users. An agricultural development policy should, therefore, have a clear commitment to CA as a basis for sustainable CSA; many nations have now done this, and more are beginning to do so.

All agricultural development activities dealing with agricultural production 'intensification' and commercialization should be assessed for their compatibility with ecosystem functions and their desired societal services. The necessary policy driver is the promotion of smallholder CA as a sustainable livelihood programme, incentivized for the good of the planet, by government strategies, programmes, policies and skills, and involving public–private–producer sectors. Any environmental management schemes for agriculture (e.g. certification protocols, payments for environmental services) that do not promote the integration of CA principles and practices into farming systems are unlikely to be economically, environmentally and socially sustainable in the long run.

4.3 Conclusions

Conventional tillage agriculture is no longer fit for purpose and should no longer be considered appropriate as a basis for sustainable intensification in Africa. The focus of all governments in Africa should be on agricultural development investment and policy efforts to mainstream CA-based CSA within all agricultural institutions, across all agricultural sectors and in all government systems to support agricultural development, as envisaged by Agenda 2063 and the Malabo Declaration.

At the practical development level, mainstreaming CA means that all relevant stakeholders, comprising agricultural development institutions, sectors, and government systems, must:

1. strategically align themselves to provide effective support for promoting the adoption and spread of good quality CA systems;
2. develop and sustain capacity for CA research, education and extension, including that of CA service providers along the value chains across agriculture sectors; and
3. mobilize government systems policy support for investment, infrastructure development, mechanization and incentives for the commercialization of CA-based CSA.

These are major tasks for all CA stakeholders across Africa within the context of the Malabo Declaration and Agenda 2063 implementation. If they are not taken seriously, and with a long-term political commitment, there will be disastrous economic, environmental and social consequences at all levels of development.

As noted earlier, the new paradigm of CA is now spreading across all continents, at an annual rate of 10.5 M ha, an area the size of Portugal. In the Africa region an area of probably more than 10 M ha is already being managed under CA, mainly in rainfed lands across all agroecologies, and benefitting several million people. In Africa, estimates show that the area of CA has increased exponentially since 2008/09 and is approaching 3 M ha of cropland, with several additional CA areas growing trees. This is a source of hope and confidence that we are winning the battle to change the agricultural paradigm.

The need for change is urgent everywhere. Change is possible because, as other countries have shown, solutions to the constraints of implementing the spread of the new paradigm are being applied. Knowing that the change to CSA is inevitable and possible is a tangible source of hope and confidence.

All stakeholders, including many farmers, development experts, researchers and academics, private and public sector leaders, government and political officials, donors and philanthropists have shown themselves to be courageous and persistent, innovative and bull-headed in promoting and implementing the shift of paradigm to NT CA in all types of production systems. They have kept the goal of making a better future for African farmers in front of them at all times. This is a source of hope and confidence to keep them going and allocate even greater investment into this change process across Africa.

Finally, by promoting the adoption of CA systems across Africa in each country and region, a foundation for creating the much-needed harmony between nature and humankind will be laid. The adoption of CA is also a response that underpins the development of sustainable food and agricultural systems ecologically and biologically in African nations, to meet future human needs, in line with the Malabo Declaration and Agenda 2063.

Notes

[1] Garrity (2017) reports that in the semi-arid regions in Africa, CA-based cropping systems with sorghum and pearl millet include *Faidherbia* and other indigenous tree species at low to medium densities across more than 5 M ha in Niger and across undreds of thousands of hectares in Mali, Burkina Faso, Senegal and Ethiopia. In Zambia, the conservation farming unit (CFU) has promoted the incorporation of *Faidherbia* trees into CA-based maize production systems. In 2014, some 68,000 farmers are estimated to have *Faidherbia* trees on their farms. Similarly, through support from government and International Centre for Research in Agroforestry (ICRAF) activities, Malawi has many farmers who intercrop maize and pigeon pea with nitrogen-fixing trees such as *Faidherbia*, *Gliricidia* and *Sesbania*. In the West African Sahel from Mali to Ethiopia, crop production in combination with *Faidherbia* and the indigenous shrub *Guiera* is practised with the Zai practice of soil–water management or with minimum soil disturbance over large areas.

[2] These include the KwaZulu-Natal no-till club and the association for sustainable agriculture in Tunisia (Association pour la Promotion d’une Agriculture Durable, APAD).

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5 Challenges and Approaches to Accelerating the Uptake of Conservation Agriculture in Africa and Europe

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Abstract

Over the past few decades the concept of Conservation Agriculture (CA) has spread globally, and almost exponentially, with an adoption rate of around 10 M ha per year in the past few years. This uptake has, however, been experienced rather unequally throughout the different regions. Whereas in the Americas and Australia the share of cropland under CA is considerable, in Africa and Europe both the area under CA and its share of total cropland lag far behind. This chapter provides an overview of the most recent figures available on CA adoption for Africa and Europe, and identifies the major challenges faced by the spread and adoption of CA. Different reasons are identified for the lagging behind of these two continents as a result of huge contrasts between Africa and Europe in terms of agroecological conditions, infrastructure, education and agriculture. Other challenges, however, such as farmers' mindsets, missing or inadequate policy frameworks and institutional support, are common. Yet encouraging opportunities do exist, namely with regard to the political agenda that, if followed up subsequently, could result in concerted efforts towards the expansion of truly sustainable agriculture, including the concept of CA. To be successful in the two continents, however, approaches to mainstream CA need to be tailored to the different regions, and even locally.

Keywords: No-tillage, out-scaling, climate smart agriculture, policy and institutional framework, opportunities

5.1 Introduction

Conservation Agriculture (CA) developed as a farming system approach as a response to the negative impacts of conventional and traditional (and often highly mechanized) agriculture, and is founded on the quality of key natural resources such as soil, water, landscape, biodiversity and the associated ecosystem services provided by natural ecosystems (Montgomery, 2007; Kassam *et al.*, 2013). Its origins go back to the desperate need for soil and water conservation as a consequence of devastating dust bowls in the Canadian prairies and in the mid-western and northern USA in the so-called 'dirty thirties' during the 1930s (Awada *et al.*, 2014), caused by intensive tillage and the subsequent bare and disaggregated soils (Basch *et al.*, 2015). As a result, conservation tillage systems started to develop from the middle of the 20th century and to

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gradually replace conventional plough tillage, which for many centuries was seen as the most effective way to guarantee satisfactory weed control, nutrient mineralization and seed bed preparation. This development, described thoroughly by Lindwall and Sonntag (2010) in their book *Landscapes Transformed*, did not, however, occur simultaneously – nor to a similar extent – in the different regions of the world. Conservation tillage and direct seeding or no till (NT) started in the USA and Canada and was introduced gradually into South America, Australia and New Zealand during the 1980s. Even in Europe, early attempts were made in the 1960s to introduce direct-drilling techniques in the UK, based on the availability of the herbicide Paraquat to control weeds. However, the increase in grass weeds and a straw burn ban led to the end of this practice and its further development (Christian, 1994).

The early development of conservation tillage was based mainly on any form of reduced tillage when compared to the conventional disc or mouldboard plough. Soon, however, the importance of protective soil cover, through crop residues at the soil surface, started to be recognized as key element for soil conservation and to help control wind erosion (Chepil, 1944). At the turn of the millennium, and after already using the concept of residue-based zero tillage in Brazil (Sorrenson and Montoya, 1989), the term 'Conservation Agriculture' was coined in a meeting sponsored by the Food and Agriculture Organization of the United Nations (FAO) in 1997 (Reicosky, 2015). This took place a few years before the 1st World Congress on Conservation Agriculture held in Madrid in 2001, organized by FAO and the European Conservation Agriculture Federation (ECAF). The key elements of this concept were the simultaneous application of minimum soil disturbance, permanent organic soil cover and the practice of crop rotation and diversification. A few years later FAO established an official definition for CA, based on the known, following principles (FAO, 2014):

- Continuous no or minimal mechanical soil disturbance (implemented by the practice of NT seeding or broadcasting of crop seeds, and direct placing of planting material into untilled soil; and causing minimum soil disturbance from any cultural operation, harvest operation or farm traffic).
- Maintenance of a permanent biomass soil mulch cover on the ground surface (implemented by retaining crop biomass, root stocks and stubbles, cover crops and other sources of *ex situ* biomass).
- Diversification of crop species (implemented by adopting a cropping system with crops in rotations, and/or sequences and/or associations involving annuals and perennial crops, including a balanced mix of legume and non-legume crops).

Today, FAO also describes each of these principles in quantitative terms, which can be retrieved from the current FAO CA website (FAO, 2020a).

At the very beginning of conservation tillage development the key driver for reducing tillage intensity was clearly the threat of soil erosion by wind and water. Soon, however, the economic benefits of reduced and NT crop production systems became as relevant as the concern for soil conservation. Lower production costs associated with machinery, fuel, time and labour, apart from severe erosion problems, are considered to have been the main driver for the adoption of NT in Brazil in the early 1970s (IAPAR, 1981). Today, the full range of benefits that can be harnessed through the successful implementation of the principles of CA is well known and documented, and is the reason for CA being promoted by FAO as a farming system approach allowing for sustainable production intensification (FAO, 2011), while being an important element of climate smart agriculture.

Globally, in 2015/16 CA was practised on 180 M ha of cropland, with the three regions of North and South America and Australia (including New Zealand) accounting for around 85% of cropland under CA. In absolute terms of area under CA the continents of Europe and Africa are lagging far behind, with 3.56 M ha and 1.51 M ha under CA, respectively (Kassam *et al.*, 2019). Despite the huge differences between Africa and Europe in terms of agroecological conditions, infrastructure, education and agriculture, both continents can be considered as developing regions in terms of the adoption of CA. Therefore, this chapter tries to analyse the reasons for these two continents lagging behind. The following sections describe the current CA situation in them both, and try to identify the main challenges, opportunities and promising approaches to mainstream CA adoption in terms of its implementation.

The Malabo Declaration and Agenda 2063 call for the accelerated uptake of CA systems across Africa. Similarly, in Europe, the European Common Agricultural Policy (CAP) increasingly calls for sustainable production systems that are climate smart, productive and profitable, and greener. This is leading to greater attention being paid to CA systems and practices. This chapter reviews the challenges and approaches to accelerating the uptake of CA in Africa and Europe.

5.2 Current Status of Conservation Agriculture (CA) Spread and Adoption

5.2.1 Africa

The application of at least one of the principles of CA, mainly the use of minimum soil disturbance, has been practised for many decades due the widespread lack of animal power for ploughing the land, and thus the reliance on pointed sticks or simple hoes to loosen the soil surface and cover the seeds. Crop rotations and/or associations were also a common feature of traditional farming in Africa during precolonial times (Page and Page, 1991). Later, colonial powers and missionaries introduced mechanization and tillage implements, with extensionists and learning institutions promoting the deep hoe, ridging and ploughing (Thiombiano and Meshack, 2009); this continued even after independence, through agricultural development projects (Starkey, 2000). Practices seen today as able to improve soil fertility, such as crop rotation and reducing tillage intensity, were perceived by colonial science as backward (Elkins, 2005). Today, people are pushed to reacquire old practices once recommended to be abandoned, and farmers using tillage are now portrayed as backward (Sousa *et al.*, 2020).

In Africa, the simultaneous application of the three principles of CA started recently in several regions, and South Africa, Zambia, Mozambique, Malawi and Zimbabwe were the most noteworthy adopters. Other countries, such as Kenya, Tanzania and Ghana, also have areas of 30 kha and more (Table 5.1) (Kassam *et al.*, 2019). There is also a concentration of annual cropland under CA in the southern and south-eastern part of the African continent. Among the northern countries of Africa only Morocco and Tunisia have some areas under CA, although this has seen some increase in recent years.

5.2.2 Europe

In northern European countries, the combined negative effects of excessive tillage (particularly in wet soils), the decline in the rural population and the increased costs of machinery, led many researchers to consider a reduction of tillage and to start experiments in Germany (Bäumer, 1970), the Netherlands (Van Ouwerkerk and Perdok, 1994) and the UK (Christian, 1994). The first real attempts to introduce conservation or zero tillage (i.e. NT) were triggered by economic objectives: to reduce the production costs associated with tillage, namely machinery, fuel and labour (Basch *et al.*, 2015). These early attempts were assisted by the availability of recently discovered plant growth regulators and herbicides (Phillips and Phillips, 1984). After an initial take-off of NT, mainly in the UK where the area of adoption reached almost 300,000 ha in the early 1980s, increasing problems with weed control and volunteer cereals and the straw burn ban practically stopped its use (Christian, 1994). Before the period represented in Table 5.2 only a few European countries reported noteworthy areas under CA. It was not by chance that these were among the founding members of ECAF: Spain, the UK, France, Germany, Italy and Portugal. Other countries like Finland (2008/09) and Romania and Poland (2015/16) joined the list of countries practising CA that already had astonishing areas under this system.

In western and central European countries, with the exception of the Netherlands, it was mainly scientists who believed and insisted in NT-based crop establishment, and visionaries like Tebrügge (2003) engaged themselves in showcasing NT as a viable option in annual cropping systems. Publication of workshop proceedings of a EU project on the ‘Experience with the Applicability of No-tillage Crop Production in the West-European Countries’ provided a credible testimony of these efforts (Tebrügge and

Table 5.1. CA adoption (000 ha) in Africa: recent evolution (adapted from Kassam *et al.*, 2019).

Country	2008/09	2013/14	2015/16
South Africa	368	368	439
Zambia	40	200	316
Mozambique	9	152	289
Malawi	n.d.	65	211
Zimbabwe	15	90	100
Kenya	33.1	33.1	33.1
Tanzania	n.d.	25	32.6
Ghana	n.d.	30	30
Tunisia	6	8	12
Morocco	4	4	10.5
Sudan	10	10	10
Madagascar	n.d.	6	9
Uganda	n.d.	n.d.	7.8
Algeria	n.d.	n.d.	5.6
Lesotho	0.13	2	2
Swaziland	n.d.	n.d.	1.3
Namibia	n.d.	0.34	0.34
	491.23	1001.44	1526.84

n.d. = no data available. For equal figures in different periods, no changes were reported.

Böhrnsen, 1994; 1995; 1996; Tebrügge and Böhrnsen, 1997a; 1998). Whereas some countries show a recent steady increase in their area under CA, others stagnate or show declining figures. Surprisingly, in Germany, where very positive research findings would support strong adoption, the area between 2008/09 and 2015/16 decreased by almost 60%. In Spain, where we found the greatest area under CA, the first studies on CA in annual crops date back to 1976 and were performed in the 'Haza del Monte' farm in Seville. These studies aimed at anticipating the sowing date of a second crop, which was NT soybeans sown into the residues of a previous winter crop (Fernández-Quintanilla, 1997). In February 1995, a group of farmers, technicians and scientists, many of them participants of the above-mentioned experiments, founded the Spanish Association for Conservation Agriculture and Living Soils. Thanks to the development of European-funded projects such as LIFE 99ENV/E/308 and LIFE 96ENV/E/338, and the support of manufacturers of NT machinery and the industry of plant protection products, a number of activities that required technical–scientific knowledge were conducted with a high degree of regularity, and these are still currently in place.

Table 5.2. CA adoption (000 ha) in Europe: recent evolution (adapted from Kassam *et al.*, 2019).

Country	2008/09	2013/14	2015/16
Spain	650	792	900
Romania	n.d.	n.d.	583.82
Poland	n.d.	n.d.	403.18
Italy	80	380	283.92
Finland	200	200	200
France	200	200	300
Germany	354	200	146
United Kingdom	25	150	362
Slovakia	10	35	35
Portugal	28	32	32
Switzerland	9	17	17
Hungary	8	5	5
Ireland	0.1	0.2	0.2
Moldova	n.d.	40	60
Greece	n.d.	24	24
Netherlands	n.d.	0.5	7.35
Belgium	n.d.	0.27	0.27
Estonia	n.d.	n.d.	42.14
Czech Republic	n.d.	n.d.	40.82
Austria	n.d.	n.d.	28.33
Lithuania	n.d.	n.d.	19.28
Croatia	n.d.	n.d.	18.54
Bulgaria	n.d.	n.d.	16.5
Sweden	n.d.	n.d.	15.82
Latvia	n.d.	n.d.	11.34
Denmark	n.d.	n.d.	2.5
Slovenia	n.d.	n.d.	2.48
Luxembourg	n.d.	n.d.	0.44
Cyprus	n.d.	n.d.	0.27
	1564.1	2075.97	3558.2

n.d. = no data available. For equal figures in different periods, no changes were reported.

The considerable areas under CA in Romania and Poland, reported for the first time in 2015/16, are likely to be the result of the restructuring of land tenure, creating large-scale conditions for the implementation of CA. They were applied to rather drought-prone conditions when compared to western and central European countries, under which CA shows an enhanced resilience. Also, in the initial phase of adoption – and still today – the spread of CA in Europe was strongly influenced by the existence or absence of specific subsidies, whether in the form of investment subsidies (e.g. NT seeders in Spain and Portugal) or on an area basis (Basch *et al.*, 2015). This may explain, at least partially, different adoption rates throughout Europe.

5.3 Challenges and Approaches to the Adoption of Conservation Agriculture (CA)

CA has been proven to work and to be feasible under the most diverse agroecological conditions, being applicable in all agricultural cropping systems, but needs to be adapted to the specific crop requirements and the local conditions of each agricultural region (ClimateADAPT, 2019). Global empirical evidence, documented in several recently published books (Jat *et al.*, 2014; Farooq and Siddique, 2015; Kassam, 2020a, b), and the fact that CA is practised today on over 180 M ha of annual cropland, corroborate this conclusion.

Furthermore, CA has been described as a crop management and farming systems' approach that can contribute decisively to climate change mitigation through soil carbon sequestration, especially in warmer climates that are both arid and humid (Sá *et al.*, 2014; Moreno-García *et al.*, 2020; Sun *et al.*, 2020), and adaptation through higher infiltration, reduced evaporation losses and more water retention, thus alleviating drought stress conditions under increasingly erratic rainfall patterns (Thierfelder and Wall, 2009; Ussiri and Lal, 2009; Verhulst *et al.*, 2010; Basch *et al.*, 2012; Dendooven *et al.*, 2012).

Yet, despite the well-documented benefits, the applicability of CA farming systems under different agroecological conditions, and – above all – the need to mitigate and to adapt to climate change, the adoption of CA in Africa and Europe lags far behind the adoption rates in other regions of the world. This calls for an analysis of the specific challenges and drivers existing in these two continents so approaches to overcome those challenges can be formulated. The challenges, opportunities and approaches for both continents are summarized in Tables 5.3 and 5.4 in the respective sections.

5.3.1 Africa

While analysing the challenges for CA adoption in Africa, an important reality to take into account, especially in Sub-Saharan Africa (SSA), is the predominance of smallholder farms with around 80% of farms being below 2 ha in size (Nagayets, 2005). Furthermore, these farms can be considered as resource poor, resulting, obviously, in a reduced capacity or motivation to experiment and to risk even a part of their available land. Testing new technologies may represent a considerable risk to short- and medium-term household food security (Pannell *et al.*, 2014), especially if the new technologies do not necessarily provide immediate benefits in term of productivity, and even may require additional initial inputs such as in the case of specific CA planting equipment and eventually herbicides. For resource-poor farmers the immediate costs and benefits considerably outweigh those that might incur in the future (Pannell *et al.*, 2014). Benefits from the practice of CA are often not experienced right from the first year of implementation (Rusinamhodzi *et al.*, 2011), which is no surprise considering the absence of experience, advice, and adequate equipment and inputs, and where farmers are often starting on degraded land with poor soil conditions (Mbow, 2020).

Another, widely experienced trade-off with the correct implementation of CA, and a strong handicap for harnessing the full benefits of CA, is competition for the use of crop residues. These serve multiple purposes such as fencing, thatching, bedding in kraals, fuel and, above all, fodder for livestock. In many regions of Africa livestock plays an essential role even for smallholder farmers, as it can be used as draft power, but also represents cash income or at least risk insurance and a form of investment into an uncertain future (Herrero *et al.*, 2013; Ndah *et al.*, 2017). In sub-humid and semi-arid regions in particular animal feed is often short and crop residues are a welcome source to complement any shortages in critical times, thus very little biomass remains as mulch soil cover. Pathways for enabling implementation of CA that is not in conflict with other goals of farmers' livelihoods (e.g. livestock farming) need to be identified (Ndah *et al.*, 2017). Another threat to maintaining reasonable amounts of crop residues on cropland are grazing systems where communal use or free-grazing livestock, whether of herders or other crop farmers, is tradition. In many regions, crops are only 'protected' until harvest, allowing crop residues to be grazed by animals belonging to other members of the community. Even fencing of plots to protect the crop residues as mulch would need

Table 5.3. Challenges, opportunities and approaches for the adoption of CA in Africa. Authors' own table.

Challenges

Smallholding/farm size:
- ○ Resource-poor (limited opportunities for mechanization and other inputs) (Grabowski and Kerr, 2014; Pannell *et al*., 2014)
- ○ Benefits often limited to improved food security, not necessarily to improved farm income (Harris and Orr, 2014)
- ○ Lack of equipment

Willingness to try (Pannell *et al*., 2014)
Livestock/competition for crop residues for soil cover (Ganou, 2012; Lamantia, 2012; Herrero *et al*., 2013)
Labour demand for weeding if no herbicides (Ouédraogo, 2012; Zerbo, 2012)
Lack of and access to markets (Dorward, 2009; Giller *et al*., 2009; Ndah *et al.,* 2015)
Missing or inadequate policy framework (Boulal *et al*., 2014; Djamen *et al*., 2014)
Conflicts with other agricultural development strategies (Devèze, 2006)
Extremely poor soil conditions that may cause yield penalties (Lal, 2007; Thiombiano and Meshack, 2009; Ganou, 2012)
Land tenure system (Boahen *et al*., 2007; Ganou, 2012)
Education and extension (Ganou, 2012)
Mindset: CA is for the poor, also because labour-intensive (ECAF, 2020)

Opportunities/Approaches

Potential to address shortage of labour and production cost (ECAF, 2020)
Aligned with sustainable land management strategy (Thiombiano and Meshack, 2009)
Mechanization framework in progress (FAO and AUC, 2018; FAO, 2020b)
International and African frameworks in place to support transition
Response to soil degradation and climate change
Targeting promotion of CA to adoption-prone agroecological conditions and farm types (Corbeels *et al*., 2015)
Involvement of all major stakeholders (policy makers, donors, private sector, education and research such as academia, extensionists, trainers)
Build-up of infrastructures and markets along the value chain (Wall *et al*., 2014)
Identification of pathways and implantation of strategies to allow livestock raising and crop residue retention (Ndah *et al*., 2017)
Promotion based on truthful information on CA, including advantages and disadvantages (ECAF, 2020)
Implementation of participatory and transformative learning strategies for thorough engagement in CA (Probst *et al*., 2019)

negotiation within the community to overcome traditional rules (Brown *et al*., 2017).

Despite not ploughing the entire field, thus allowing for the timely planting of crops, labour demands through the practice of CA have been reported to eventually outweigh the savings gained by direct planting. The higher requirements for labour may result from increased needs for weeding in case no herbicides are used. Nevertheless, the practice of crop associations instead of crop rotations may also increase the demand for labour as they require more time for planting, weeding and harvesting operations. In addition, sowing crops by hoe into a mulch cover of 4 t ha^{-1} has been reported to increase labour by 54% (Ouédraogo, 2012; Zerbo, 2012). By using appropriate direct seeding equipment such as a jab planter or animal-drawn direct seeder, however, improvements in labour productivity have been reported (M'Biandoum *et al*., 2010; Bougoum, 2012).

Economic and market-related challenges also play a decisive role in hampering the adoption of CA. Poorly functioning or inaccessible markets often complicate the investment in inputs such as quality seeds, fertilizers, herbicides and NT equipment, essential for CA performance (Giller *et al*., 2009). Depending on the farm type and its livelihood strategies, missed credit opportunities and lack of access further aggravate

Table 5.4. Challenges, opportunities and approaches for the adoption of CA in Europe. Authors' own table.

Challenges
Mindset and cultural entrenchment of tillage practices (Friedrich *et al*., 2014)
Crop residues (excess and lack) (Basch *et al*., 2008; Friedrich *et al*., 2014)
Lack of condition-specific machinery, equipment and inputs (Friedrich *et al*., 2014; Basch *et al*., 2015)
Productivity rather than economist approach
Reduced economic pressure through considerable income support to farming
Lack of policy commitment towards effective soil conservation
Economic limitations to diversify crops and their rotation
Mismatch between academic and problem-driven and solution-oriented CA research
Weed, insect pest and disease issues (Soane *et al*., 2012)
Widespread rejection of commercial, highly productive agriculture and inputs of agrochemicals
Potential ban on glyphosate, even for pre-seeding weed control
Opportunities/Approaches
Soil recognized as key element to achieve climate action (EU, 2019)
Soil quality and its recovery and protection highly ranked in the political agenda (EC, 2020)
EU member states to propose eco-schemes for enhanced environmental protection and climate action (ENRD, 2020)
Push and pull policies to enhance and create opportunities for CA adoption
Shift towards subsidies for ecosystem services delivering farming practices
Establishment of an educational, institutional and policy framework to mainstream the perception of effective soil conservation (living labs) (EC, 2020)

the shift of resource-poor farmers to CA (Dorward, 2009).

Changing from conventional, traditional practices and technologies to new ones, often breaking completely with deeply rooted convictions and habits, requires tremendous efforts and acquisition of new knowledge and skills by those applying the innovations as well as by those assisting and supporting the transformation. Therefore, the shift to a knowledge-intensive CA is a major challenge in an environment characterized by low education and literacy standards of the farming community, and a clear lack of information and technical support through official extension services (Erenstein *et al.*, 2012).

These challenges are far from providing the full picture of issues hampering the uptake of CA on a regional scale and even less on a local scale in the diverse African agroecological, socio-economic, cultural and institutional contexts. However, they summarize the key challenges acting throughout the African continent as forces hindering the use of CA as the solution to the major concerns African agriculture is facing. Many other challenges have been described and discussed in more detail in numerous papers and are also referred to in Table 5.3 (Wall, 2007; Giller *et al.*, 2009; Erenstein *et al.*, 2012; Ndah *et al.*, 2012; Corbeels *et al.*, 2014; Ndah *et al.*, 2014; Thierfelder *et al.*, 2014; Wall *et al.*, 2014; Ndah *et al.*, 2018; Probst *et al.*, 2019; Ndah *et al.*, 2020).

CA has been demonstrated throughout Africa to have a considerable potential to address the manifold aspects of sustainable land use and to provide increased agronomic, environmental and climate change-related outcomes (Boulal *et al.*, 2014; Ndah *et al.*, 2014; Thierfelder *et al.*, 2015; Mupangwa *et al.*, 2016; Thierfelder *et al.*, 2016; Thierfelder *et al.*, 2017). At the same time many scientific results prove the disastrous effects of tillage-based agriculture on soil degradation, soil organic matter and biological activity decline and – what matters most in water-deficit regions – water infiltration, retention, runoff and erosion (Holland, 2004; Montgomery, 2007; Pretty, 2008). It is well known that all profound changes in agricultural practices, including CA systems, may bear the risk of failure, especially in less favourable environments. The details of CA systems reported to have failed are often unclear and so, sometimes, are the reasons why they failed. Some authors prefer to stress and highlight these failures and pitfalls of CA systems in Africa, concluding they are inappropriate for resource-poor smallholder farmers (e.g. Giller *et al.*, 2009; Baudron *et al.*, 2012), which might suggest that business-as-usual soil management would be a better option under the given conditions in Africa. Others even consider that the achievements of successful CA adoption lack the necessary evidence, interpreting the low CA adoption rates as proof of the inappropriateness of CA principles to the African reality and suggesting that its promotion and insistence upon are inherently politically motivated (Whitfield *et al.*, 2015).

Fortunately, however, there are others who, seeing the undeniable and proven benefits of successfully implemented CA systems for soil and water conservation, climate change mitigation and adaptation, improved livelihoods in the medium and long term, etc., and the many cases of success from all around Africa (see above and also Mrabet *et al.*, 2012; Ngwira *et al.*, 2013; Thierfelder *et al.*, 2013; Kassam *et al.*, 2017; Lalani *et al.*, 2017), identify opportunities and search for approaches to improve systems based on the principles of CA. Politically supported initiatives can be very valuable, as the considerable adoption rates in Zambia, Zimbabwe, Mozambique and Malawi show, and where CA is today supported by government policy (Corbeels *et al.*, 2015). The Adaptation of African Agriculture (AAA) initiative aims to reduce the vulnerability of Africa and its agriculture to climate change. Launched upstream of COP22, to date this initiative is actively supported by 33 African countries, the United Nations Framework Convention on Climate Change (UNFCCC) and the FAO. In its proposals for soil management solutions, CA is mentioned as being supported in its development and implementation (Adaptation of African Agriculture, 2020), also Badraoui *et al.*, 2018; Lal, 2019.

Scaling up CA requires, in the first place, the identification and addressing of the main challenges encountered in each specific agroecological, socio-economic, cultural and institutional/political environment (Ndah *et al.*, 2014). In the second place, up-scaling approaches need to identify the specific demands of the different target groups to differentiate the approaches accordingly. For example, the needs and concerns of resource-poor smallholder farmers are completely different from those of medium- or even large-scale farmers; or the training of extension workers would need a different approach than the training of decision makers or private sector stakeholders (Corbeels *et al.*, 2014).

A third pillar on which up-scaling of CA must be based is the creation of an innovation-oriented enabling environment. Such an environment must include the involvement of all of the major stakeholders: policy makers, private sector, supply chain and markets, donors, extensionists, educational institutions, etc. In this context, the example of Zambia is often referred to as an approach to be followed in the up-scaling of CA (Baudron *et al.*, 2007). The access to inputs both in terms of market availability and capacity to invest is a crucial aspect for testing and implementing CA. Manual as well as mechanized CA requires specific implements such as jab-planters, animal-drawn or two-wheel tractor-drawn NT seeders, cover crop seed and other inputs (fertilizers, herbicides). There are often claims for initial incentives and subsidies for investments in equipment and inputs, particularly for small-scale/resource-poor farmers, and programmes have been put in place to facilitate the shift towards CA. Yet, in this context, the initial interest and further implementation of CA should be the result of its potential and perceived benefits, and not the result of a continuous financial expectancy (Brown *et al.*, 2018), unless successful CA farmers receive payments for environmental services generated. Otherwise, as observed by Pedzisa *et al.* (2015) in Zimbabwe, the initial adoption of CA during the period of active promotion could result in its abandonment in the absence of support from non-governmental organizations (NGOs).

Education and training of extension services to overcome cultural entrenchment and beliefs regarding traditional practices contribute to this enabling environment, as well as policies fostering directly or through private sector engagement the conditions for CA uptake. Today, numerous efforts throughout Africa are undertaken to promote participatory approaches to mainstream CA (Kassam *et al.*, 2019). These can envisage the development of supply chains for smallholders to access CA equipment, and also participatory learning approaches in the form of farmer field schools (FFS), networks of lead farmers (champions) and farmer to farmer extension (F2FE). These approaches have found to be helpful in creating awareness and familiarity with the CA system, but cannot replace other forms of agricultural extension (Fisher *et al.*, 2018). Further, other instruments such as the Qualitative Expert Assessment Tool for CA adoption in Africa (QAToCA) (Ndah *et al.*, 2012) and a Transformative Learning Approach (TLA) have been proposed to: (i) allow for a systematic evaluation of factors influencing the CA adoption process at the field, farm and regional scale in a variety of regional contexts in Africa; and (ii) stimulate and nurture a joint learning process around CA, to diagnose hindering and supporting factors for up-scaling CA and to develop options for changes in promotion (Ndah *et al.*, 2020).

Another important cornerstone for the adoption of CA is the flexibility and adaptability with which CA systems are promoted and being adopted, thus responding to the great diversity of agricultural practices and cropping systems in Africa. Underpinning the need for adaptability, Erenstein *et al.* (2012) insist that CA systems are best developed *in situ* through a multi-stakeholder adaptive learning process to create viable CA-based options that are technically sound, economically attractive and socially acceptable. This, of course, opens the door for criticism and the argument that CA adoption figures are just claims and far from corresponding to reality: that is, they do not represent the area in which the application of the three basic CA principles occurs. Brown *et al.* (2019) analysed a survey of 58 farmers in eastern and southern Africa showing interest in CA and concluded that progressing from interest to implementation of CA will need adaptation to fit within the contextual realities of the farmers, and that a more flexible and transitional promotion and pathway towards CA is needed and would benefit from greater community participation in research and extension. The respondents also highlighted that the major issues that needed to be addressed were financial viability, small-scale mechanization, information exchange and the competition for crop residues.

This latter aspect of reduced soil cover by crop residues has been an obstacle throughout Africa to the successful implementation of CA and to the harnessing of the benefits of soil and water conservation and improved soil structure that effective soil cover can provide. Identifying and implementing locally adapted options to produce additional forage, its conservation for times of shortage and the establishment of local agreements to limit the access of free-grazing livestock would be a breakthrough towards the performance of CA systems (Ndah *et al.*, 2017).

The mechanization efforts of CA systems obviously need to be tailored to site-specific conditions. It is hoped that the Sustainable Agricultural Mechanization Framework for Africa, established between FAO and the AUC (FAO and AUC, 2018), offers the necessary options to boost small-scale mechanization of CA systems.

Complementary practices to support CA systems, despite benefitting conventional systems as well, are suggested by Thierfelder *et al.* (2018). The authors stress equally the need for adaptation to local farmer contexts of what they call practices and enablers, and suggest that CA systems should be implemented either at small scale (and grow from there) or in a sequential approach. The latter, however, bears the risk that the benefits potentiated and harnessed only by the concomitant application of all three CA principles may not be revealed.

Finally, looking at the known performances of CA systems under different environments and its low but widespread implementation, it is argued that research efforts should now be targeted preferentially to adapt and improve CA-based systems rather than to compare them with conventional tillage systems. There is no further need to justify or legitimate CA for it to be acknowledged and recommended as a promising approach to address the needs of African agriculture (Wall *et al.*, 2014).

5.3.2 Europe

Adoption of new farming systems or agricultural practices are normally the response to driving forces or pressures to improve the current state, or to avoid or alleviate the impact (negative) of changes, whether of natural or other origin (technological, knowledge, etc.). The conservation tillage concept had its origin in disastrous events causing severe soil degradation mainly through erosion by wind and water in North and South America (see above). Elsewhere, the need for cost reduction was also an important driver to maintain feasible agricultural production. Western Australia, with almost 95% of CA on annual cropland (Rochecouste and Crabtree, 2014), is certainly a clear example of how only the shift to CA-based farming practices allowed annual cropping systems to survive. In most of Europe such extreme and adverse natural conditions and events are rarely experienced, thus the need for change is not triggered. In general, agroecological conditions, especially rainfall patterns and variability, and soil status, can be considered rather favourable when compared to other regions of the planet. However, the recognition and gradual perception that European soils are threatened, and that climate change is also having a growing effect on the European continent, may slowly increase the pressure to change. European agriculture continues to be strongly subsidized, however, and so there is currently no drive to adopt CA as a solution to work more cost-efficiently on farms.

Often, in Europe, the diversity of conditions is blamed for the resistance to adoption of NT or CA-based production systems, owing to difficulties in adapting the seeders. These systems have frequently been found not to be suitable for certain crops, timing of sowing (winter- or spring-sown cereals), soil types, variable seasonal conditions, etc. Such unfavourable conditions include spring-sown cereals, badly drained clay soils and crops not suited to NT in the rotation due to heavy soil movement at harvest (e.g. potatoes) (Soane *et al.*, 2012). Unstable, weakly structured soils, whether sandy or sandy loams, especially when low in soil organic carbon (SOC) (Ehlers and Claupein, 1994; Munkholm *et al.*, 2003) or even loams and clays (Van Ouwerkerk and Perdok, 1994) have been excluded from soils considered to be suitable for NT. However, CA can contribute to the rehabilitation of those type of soils, building a better structure and improving SOC owing to permanent organic soil cover (Neufeldt, 2005; Dal Ferro *et al.*, 2018).

The south-eastern European region was one of the cradles of agriculture and arable farming. Thus, history may play a role in the deep cultural entrenchment of ploughing and preparing a clean seedbed for sowing. Conventional tillage in modern European agriculture is still widely based on the mouldboard plough, which replaced the ancient Roman plough in the 18th century. The perfect inversion of the upper soil layer effectively controlled perennial grass weeds and the plough was therefore the preferred tillage implement. Yearly ploughing championships are still held in several European countries.

Another challenge frequently raised to the well-functioning of CA is the issue of crop residues. Some regions with low productivity levels (e.g. rainfed conditions in the Mediterranean region) do not even produce enough residues to provide a good soil cover for erosion protection and soil moisture conservation. Other regions, with quantities of residues of 10 t of straw ha^{-1} or more, often experience difficulties in warming and drying the soil sufficiently in spring, thus delaying crop emergence or initial development. While in former times the alternative uses for straw were for animal bedding and less for feed and only locally for other uses such as the mushroom industry, today the production of plants for producing bioenergy is an important competitor for straw, which is used as a carbon source for soil carbon sequestration. An additional challenge of excess residues is their adequate management (Basch *et al.*, 2008). Leaving high stubble where possible and uniform distribution of the chopped residues are key to facilitate the performance of the seeding equipment to establish the following crop (Friedrich *et al.*, 2014). Row cleaners in wide-row crops may also facilitate seed/soil contact, the warming up of the soil and overall emergence. In purely rainfed conditions in the drier regions of Europe an old recommendation of South American CA farmers ‘the grain for the man, the straw for the soil’ (Crovetto, 2006) would certainly be the best approach to achieve a satisfactory level of soil cover. But, here also, the economic value of the straw – even if small – is easier to be perceived as the added value it might have in the future through higher SOM levels.

Although highly and frequently over-mechanized, the European market for agricultural machinery and equipment lacks solutions for CA-specific implements, especially those capable of handling higher amounts of residues in the wetter regions of Europe. Most purely direct-drilling seeders available on the European market are brands from overseas. European manufacturers were long reluctant to focus on this type of equipment as it could reduce the sales of other tillage implements most of them were also producing. Only a strong demand could probably overcome this situation. Surprisingly, two European enterprises have focused almost exclusively on the manufacturing of NT seeders. In the 1990s a Finnish brand was quite successful in selling its equipment, boosting the uptake of CA in Finland quite early, to over 7% of the annual cropland under CA. More recently, a manufacturer in the UK appeared on the market with a strongly inclined disc-coulter-type NT seeder, which also seemed to help in boosting CA adoption in that country. For a long time the small average farm size in many European countries also limited the investment of individual farmers in the substantially more expensive NT seeding technology. Today, increasing farm sizes and the broader availability of service providers may overcome this challenge. A similar situation exists when it comes to other inputs that could improve the performance of CA-established crops. Varieties/genotypes of the main crops better adapted to the different NT conditions (lower temperatures, N dynamics, higher initial bulk density, etc.) as well as site- and rotation-specific cover crops may also help in creating more options and interest in CA adoption (Friedrich *et al.*, 2014).

In Europe, the evaluation and acceptance of new farming practices and technologies still strongly depends on their impact on yield performance of the crops and less on the overall performance of the system. Therefore, yields are compared on a productivity basis (production per unit of area), but rarely on a cost basis (costs per unit of produce). Also, the fear of potential yield losses, even if production costs are reduced considerably, weighs heavily in the process of deciding whether or not to try to shift towards what is perceived as the ‘unknown’. Several authors report some yield penalties in the first years after adoption, due to soil structural conditions, but with clear improvement after 3 years (Ball *et al.*, 1989; Christian and Ball, 1994; Six *et al.*, 2004; Anken *et al.*, 2006), yet others conclude that crop yields can be similar right after the shift to CA (Basch and Teixeira, 2002). Under drier climatic conditions the yields of CA-based systems are frequently higher than of conventional systems (Soane *et al.*, 2012). Yield reductions under CA have often been reported to have originated in problems related to weed control, compaction or residue management. In general, yield penalties can be avoided or minimized in the transition phase when good advice is available, or when soil structural deficiencies can be overcome and restored without the help of tillage. Over time, however, initial yield reduction disappears even under less favourable conditions (Soane *et al.*, 2012), or may improve and surpass conventional yields as soil structure, N availability and other soil physical, chemical and biological properties improve (Carvalho and Lourenço, 2014).

One of the major challenges frequently reported with pest or disease problems under CA is the higher incidence of slugs. Although manageable with molluscicides, increased costs and their detrimental effects on beneficial fauna that could help control this very problem recommend the restriction of this solution to very extreme cases. Recent studies, however, found that insect and slug pests were not more abundant in reduced-tillage systems than in high-disturbance tillage systems, and that foliar pests were more abundant in systems with more intense tillage practices (Rowen *et al.*, 2020). Slugs were found to be even more abundant in conventional plots than in conservation plots, possibly due to the lower presence of natural enemies such as ground beetles (Scaccini *et al.*, 2020). Regardless of the intensity of tillage adopted, which can result in higher or lower antagonistic pressure on different pests and diseases, multiple control mechanisms should be employed to avoid yield loss and the economic consequences (Leake, 2003). Crop residues remaining at the soil surface may bear the risk of carry-over of pathogens from one season to another (Mikkola *et al.*, 2005). On the other hand, concentration of organic matter at the soil surface was suggested to suppress some soil-borne fungal crop diseases (Ehlers and Claupein, 1994), and that residues at the soil surface favour the presence of beneficial polyphagous predators (Jordan *et al.*, 1997). Minimum soil disturbance, together with well-chosen crop rotations, has been reported to help develop disease-suppressive soils (Peters *et al.*, 2003).

A very specific and important challenge for the acceptance and adoption of CA in Europe is the widespread opinion that minimum soil disturbance is synonymous with increased herbicide use. Misinformation and misperception has led to a kind of distancing of the broad public, administration, decision makers and politicians, and even of farmers, that prevents them from considering CA as a promising farming approach. Especially critical in several central and northern European countries is the issue of glyphosate (Deutsche Welle, 2020). This became a 'red rag' to some environmentalists, as it was seen to represent all the evil modern agro-industry has brought about, although the need to care for the soil, to be resource efficient (water, nutrients, energy, etc.), to be the steward for entire landscapes and ecosystems, and to mitigate climate change and help adapt to it, still need to be addressed (Holland, 2004). A potential ban on glyphosate in Europe may have considerable impacts on weed management and more generally on farm operations (Mahe *et al.*, 2020). Although equally used in conventional agriculture, NT farming/CA would face severe problems without glyphosate to control weeds before sowing and to terminate cover crops (Kudsk and Mathiassen, 2020).

There is, however, enough scientific evidence that applying the principles of CA does not increase the need for more chemical weed control when compared to conventional farming (Friedrich and Kassam, 2012). At most, a shift from post-emergence to pre-emergence or pre-seeding application of herbicides may occur; but, over time, a reduction in herbicide inputs (number of applications and rates) is even being observed (Bräutigam and Tebrügge, 1997; Barros *et al.*, 2007; 2008; Calado *et al.*, 2010). While overall weed numbers normally decline under CA, certain weeds – mainly perennials and some grass weed species – may become more abundant (Basch *et al.*, 2015). Methods for their effective management in CA systems have been comprehensively described by Basch *et al.* (2020). In general, CA cropping systems facilitate the integration of several weed control strategies based on crop rotation, residue cover, cover crops (including the 'planting green concept'; Kassam *et al.*, 2019) and better timing of application, thus leading over time to less herbicide use. Knowing about the benefits of CA, some pioneer organic farmers succeed in carrying out CA without any chemical herbicide inputs (Peigné *et al.*, 2016).

Despite extensive pioneering research in Europe on NT, particularly during the period 1960–1990 and including long-term trials comparing different soil management systems (Tebrügge and Böhrnsen, 1997b), CA adoption did not follow the encouraging results obtained by most researchers in many parts of Europe. However, CA research is partly focusing on minimum tillage and many NT experiments have been conducted in monoculture cropping systems that have accentuated weed and pest problems (Derpsch and Friedrich, 2009). Long-term studies, including crop rotations, cover crops and the systematic monitoring of changes in soil properties, crop performance, etc. would be needed to capture the real potential of good and locally adapted CA systems. Such long-term efforts, however, are hardly compatible with most of today's short-cycle national and EU research programmes. On the other hand, it also appears that NT or CA research has mainly been driven by academic interest with little focus on practical and solution-oriented research; that is, top–down instead of bottom–up, demand-driven research. Only strong (CA) farmers' organizations could make this happen, demanding long-term support for the necessary applied research from decision and policy makers and administration; and, on the other hand, to call upon researchers and extension workers (where they still exist in Europe) to provide solutions to fine-tune and improve CA at the regional level. Good examples of the importance of farmers' organizations-driven bottom–up approaches could be found in South America some decades ago, but more recently also in Spain, where there is the largest area of annual crops under CA in Europe. This includes 1.3 M ha of CA in perennials (mainly olives) (AEAC/SV, 2020). In the UK, a promising grassroots initiative (Groundswell) started in 2016 and is having an impact on CA adoption rates in the UK.

For more than five decades European agriculture has been subject to the strong influence of the CAP framework. Until the early 2000s income support to the farming sector was mostly production oriented, favouring high productivity levels obtained with massive external inputs, instead of promoting competitiveness and sustainability. Since 2003 the so-called decoupling process led to the shift of income support to an 'area-based' support system through direct payments based on the historical income support of farms. Nevertheless, the enormous welfare transfer to the farming sector continues, justified by the high standards (environmental and animal welfare) European farmers have to comply with. On top of the direct payments, which supposedly oblige all farmers to respect minimum standards, with respect to soil conservation, some EU Member States (MS) promoted and still promote the practice of CA with additional payments from the rural development funds. In some MS or regions within MS these additional supports indeed resulted in increased CA adoption rates. However, there are examples (e.g. Portugal) where considerable initial adoption rates were triggered by attractive temporary support schemes, but which decreased substantially after the continuous support ceased. This clearly indicates that temporary financial support alone, with the objective of facing potential risks during the transition phase, may not sustain an enduring shift towards CA farming (Goddard *et al.*, 2020).

Despite the fact that awareness about threats to soil and the need for its conservation has clearly risen at European policy and administration levels, and numerous studies and research projects on soil quality and sustainable soil management have been financed, there appears to be little feedback and effect on the definition of clearly soil-oriented agricultural policy. However, unless the public in general and often even the farming community do not recognize clearly the extent of damage, loss of ecosystem services and costs of tillage-based agriculture (whether conventional or not) it will be difficult to convince politicians and decision makers to embrace CA as a preferred option to achieve the Sustainable Development Goals (SDGs), climate goals, ecosystem services, food security, competitiveness and many more objectives. Perhaps the newly created EU Mission Board for Soil health and food with its slogan ‘Caring for soil is caring for life’, and the objective of ensuring that 75% of soils are healthy by 2030, can make a difference through citizen engagement and finally result in actions – not just for the upcoming research agenda, but also for a sound, soil-oriented CAP.

5.4 Outlook

CA represents a fundamental change in production system thinking. It is counterintuitive, novel and knowledge intensive. Yet its roots lie in the farming communities, and its spread has been largely farmer driven. The shift from tillage-based to CA systems requires a large and long-term vision and effort. Both African and European farmers must find the right supportive environment to shift towards CA, and an institutional framework is an essential corner stone.

Adoption rates of CA in Africa and Europe are relatively low when compared to other regions and continents. The reasons behind this are manifold and the major challenges to adoption have been described in this chapter. Some are common to both continents; others are region specific. Owing to the great variety of agroecological conditions and different socioeconomic, cultural and institutional contexts (including land tenure), CA out- and up-scaling approaches have to take these different environments into account, identify the main local challenges and tailor strategies accordingly. Knowing that CA is working in different agroecological environments when applied correctly, it is up to the research community, administration and extension to help tailor and fine-tune the CA system and to provide solutions to whatever challenges may appear, rather than comparing the performance of CA with the obsolete conventional system.

Common to both continents is the issue of applying the three principles of CA concomitantly. Whereas minimum soil disturbance is generally the entry point in the shift towards CA, the principles of permanent soil cover plus crop rotation/diversity seem often to be more difficult to comply with. Whether alternative, apparently more rewarding uses of crop residues, including feeding livestock, (more common in Africa) or poor crop rotations due to missing economically interesting crops (Europe), it must be understood that failing one of the principles of CA may jeopardize the success of transition and lead easily to wrong conclusions regarding the applicability of CA as a system approach under the given conditions. Despite the necessity for flexibility and adaptation of CA to local needs and conditions, this understanding must be clearly addressed and alternatives found to guarantee minimum soil cover, crop diversity and minimum soil disturbance.

The adoption rates may lead to the conclusion that both continents have failed to create an enabling environment that helps to recognize and adopt CA as a promising response to the failures of conventional agriculture. Creating such an environment requires a multi-actor approach including the different sectors potentially involved in this process. Those sectors include: i) the civil society through education and awareness raising about what really matters; ii) the private sector by providing business opportunities and necessary means; iii) the administration level to reduce legal and institutional constraints and provide the necessary advice and training; iv) policy and decision makers to set the framework of incentives, restrictions and thresholds agriculture has to comply with and, finally; v) the farming community being aware of its most valuable resource and how to conserve/improve it, and being convinced to embrace CA for its benefits rather than an additional source of support/income through incentives or whatever subsidies are received.

Mechanization is key to the development of sustainable agriculture and for keeping younger people active in this sector. This is less the case in Europe, but more so in Africa. Bearing in mind what conventional tillage-based agriculture has done and is still doing to our major resource – the soil – all attempts to boost mechanization of African agriculture should be streamlined with the concept of CA, to avoid the global soil degradation caused by intensive mechanized tillage. It is hoped that the CA-based Sustainable Agricultural Mechanization for Africa framework, SAMA (FAO, 2020b), launched at the 2nd Africa Congress on CA and supported by AU, FAO and the African Conservation Tillage Network (ACT), will take the lead in this direction within the context of the Malabo Declaration and Agenda 2063.

There is no doubt that accelerating the adoption of CA would contribute to achieving many of the goals set out in past, current and upcoming initiatives, including the SDGs, CAP, 4 per 1000 initiative (4p1000, 2017) AAA, the African Union (AU) Green Transition, the European Green Deal and Farm to Fork, Carbon Neutrality 2050, Africa CSA Vision 25×25, FEED AFRICA: Strategy for Agricultural Transformation in Africa 2016–2025 and NDCs. Key to achieving all these objectives are soil-mediated deliverables. CA has been recognized by the European Commission as an effective practice to protect soil, and has been identified as a solution to serious environmental problems that affect European soils, and whose annual costs total EUR38 billion (Van-Camp *et al*., 2004). CA has also been demonstrated as being capable of contributing decisively to the AU's Green Transition objective by potentially sequestering tremendous amounts of carbon in both European and African soils (Smith, 2006; González-Sánchez *et al*., 2019).

It is hoped that the dialogue already existing between the EU and AU – and especially the Memorandum of Understanding between ECAF and the ACT network, signed in 2017 – can boost the effort to accelerate the uptake of CA in both continents. If both Africa and Europe could be described as 'CA-developed' instead of 'CA-developing', both the soils and people of both continents would benefit considerably.

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6 Conservation Agriculture in the Southern Highlands of Tanzania: Learnings from Two Decades of Research for Development

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Abstract

Since its introduction into the Southern Highlands of Tanzania by researchers 25 years ago, Conservation Agriculture (CA) has been well received, researched and the concept proven to be increasing productivity and incomes, enhancing resilience of livelihoods and contributing to reducing greenhouse gas emissions. CA research, as defined by the three interlined principles, was introduced into the Southern Highlands by the Tanzania Agricultural Research Institute (TARI) Uyole, formerly Agricultural Research Institute (ARI) Uyole around 1995. Research results showed a labour saving of up to 70% in CA compared to conventional tillage, yield increases of 26%–100% and 360% for maize and sunflower, respectively, partly attributed to higher moisture content (18%–24%) in CA systems. CA was also found to be much more effective in mitigating dry spells and increasing productivity in maize production in areas where average annual rainfall is less than 770 mm. Economic analysis of maize production showed that profits in CA were three times more than in conventional tillage production at US\$526.9 ha^{-1} and US\$ 176.6 ha^{-1}, respectively. Profits were twice as much for beans under CA at US\$917.4 ha^{-1} compared to US\$376.3 ha^{-1} for conventional practice. Studies confirm that 5% of farmers in the Southern Highlands have adopted CA. Increased uptake requires addressing challenges including resistance to change in mindset, inaccessibility of appropriate mechanization and cover crop seeds, traditions of free-range communal grazing of livestock (which makes it difficult for farmers to retain crop residue in their farms) and shortage of investment capital. A holistic value chain approach is recommended in CA interventions, bringing together various stakeholders including scientists, trainers, extension workers, administrators, policy makers, agro-inputs and machinery dealers, machinery service providers, agro-processors and financial institutions. The innovations adaptation set-up brings service providers closer to farmers for co-innovation. Long-term CA programmes are recommended, with farmers being taken through the complete learning cycle in testing CA technologies under their own farm environments. This should be complemented by entrepreneurial CA machinery hire services provision to increase the availability of farm power to smallholders unlikely to have the capital or skills to buy and manage their own machinery. The proof of application of the CA concept in the Southern Highlands has set the stage for further scaling the adoption of CA through support from national policies and programmes.

Keywords: cover crops, no-till implements, labour, productivity, adoption

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6.1 Introduction

Agriculture is the main economic activity in the Southern Highlands of Tanzania, with over 80% of the people depending on farming for their sustenance and livelihoods. Agriculture in the zone is dominated by smallholder farmers who cultivate between 0.2 and 2.0 ha, with an average per capita holding of only 0.2 ha per household. Farming generally is subsistence, characterized by low levels of technology use and poor management, leading to low crop yields.

The Southern Highlands of Tanzania comprise seven administrative regions (Ruvuma, Iringa, Njombe, Mbeya, Songwe, Rukwa and Katavi); has a total area of 245,000 km^2, equivalent to 28% of the area of mainland Tanzania; and an estimated population of 7.2 million (URT, 2012). The altitude ranges from 400 to 3000 m above sea level (masl); and rainfall varies from 750 mm per annum in lower altitude areas to 2600 mm in the mountains and along Lake Nyasa. Tropical and temperate climates are experienced in the zone, favouring livestock and crop production.

The Southern Highlands of Tanzania occupy approximately 26% of Tanzania's maize-producing area and account for nearly 50% of all the maize produced in the country. With a GDP growth greater than 7% p.a., and a vast and vibrant agricultural sector that contributes 23% to the gross domestic product (GDP) and employs more than 65% of the country's population, Tanzania has developed its new agricultural strategy (ASDP II) and is well positioned to transform its agricultural systems and increase the productivity and income of smallholder farmers. The country has high agricultural potential and increasing private sector interest to invest in agriculture.

However, the Tanzania agricultural sector still needs improvement to become more competitive and foster inclusive economic growth. There is growing concern over the decline in the productive capacity of soils (Mkonda and He, 2017) in the Southern Highlands and in Tanzania in general, caused by – among other factors – unsustainable land use practices. Conventional tillage agriculture, which is most commonly practised in the zone, involving continuous use of ox-drawn mouldboard ploughs (on 27% of the cultivated area) and tractor-drawn disc ploughs and harrows (on 20% of the cultivated area) at the same cultivation depth builds up layers of compacted soils leading to the formation of hardpans or plough pans 10–15 cm below the surface of the soil. The hardpans restrict root growth and reduce root capacity to extract water and nutrients from deeper layers. Hardpans also reduce water infiltration and percolation rates, which increases surface runoff, thus accelerating soil erosion. The major causes of land degradation are overgrazing (49%), deforestation (27%) and unsustainable agriculture practices (24%) resulting in declining soil fertility and hence low agricultural productivity (URT, 2011).

To help achieve Vision 25×25 of the African Union Malabo Declaration, the Africa We Want (Agenda 2063) and the core objectives of development (especially poverty reduction, food security and sustainable natural resource management), measures to stabilize and increase soil productivity need to be taken without delay. However, this cannot be achieved using conventional tillage methods, which promote soil degradation and thus reduce soil productivity. Therefore, best farming systems and practices such as Conservation Agriculture (CA) should be promoted in the country, adopted and scaled up. The economic appeal of no-till (NT) to farmers consists in the reduction of production costs, above all as a result of considerably lower expenditure on energy and labour. In the medium and long term, CA leads to appreciable increases in yield accompanied by reductions in the need for agricultural inputs (fertilizers, pesticides). As a consequence of the enrichment of surface soil organic matter (SOM) and of the reduced energy requirements, CA techniques exhibit a positive CO_2 balance. The soil becomes a CO_2 sink instead of a CO_2 source. CA enhances soil fertility and structure; facilitates better infiltration of rainwater and reduces soil erosion; and enhances desirable biodiversity, thus contributing to environmental conservation as well as to enhanced and sustained agricultural production.

6.2 Conservation Agriculture (CA) Initiatives in the Southern Highlands of Tanzania

6.2.1 Indigenous Practices and Mechanical Measures

Farmers in the Southern Highlands have been practising several traditional soil and water conservation techniques. Some of these techniques include the matengo pits (*ngoro*) in Mbinga district, mounding (*ntumba*) in Sumbawanga district, terracing in Mporoto in Mbeya district, and ridging and reduced soil disturbance (*kukomolea*) in most of the semi-arid areas. These techniques have shown immense benefits in terms of soil and moisture conservation for crops as well as fertility improvements (Temu and Bisanda, 1996). Under the *ngoro* system, for example, farm residues from the previous cropping season are arranged into square grids of around 1.5 m edge length and subsequently covered with soil dug up from the pits in the centre of the grids (Fig. 6.1). The residues increase soil fertility while the pits retain rainwater, thus considerably increasing soil moisture.

Overall, the system has succeeded in the control of erosion, maintenance of soil fertility and increase in productivity on the steep slopes of the Matengo Community in the Southern Highlands of Tanzania for more than a century. However, most of these traditional soil and water conservation practices, being hand-hoe based, are labour intensive and thus severely limit the cropped land area and scaling.

In the early 1970s the Tanzania Government, in collaboration with development partners, initiated various programmes to combat land degradation in most affected areas such as Kondoa, Usambara, Shinyanga, Arusha, Babati and Iringa. Some of the measures that were introduced included contour farming, terracing, afforestation/agroforestry, gully control, soil fertility restoration, reduced tillage, sub-soiling, green manures and crop rotation. One of the notable projects in the Southern Highlands was HIMA (*Hifadhi Mazingira*), which was implemented in Iringa rural district (Iringa region) and in Njombe and Makete districts in Njombe region. The major activities that were undertaken included afforestation, gully control, soil fertility restoration, crop diversification, protection of water catchments, institutional building and farmer training (Mkoga *et al*., 2001; Shetto *et al*., 2001).

6.2.2 Conservation Agriculture (CA) Research in the Southern Highlands

Conservation activities at the Agricultural Research Institute (ARI[i]) Uyole, serving the Southern Highlands of Tanzania, started way back in the late 1970s and up to the late 1990s. Research concentration was on reducing mechanical soil disturbance, mulching, and on contour and ridge experiments which aimed at addressing soil and water conservation.

Early efforts in soil conservation

A number of animal-drawn soil management implements such as tine rippers, ridgers and tie ridgers were evaluated in comparison to the conventional mouldboard plough, as animal traction was one of the main sources of power used by smallholder farmers, the main target group of ARI Uyole (Shetto and Mkomwa, 1996). The main parameters under observation included moisture retention, soil erosion control, grain yield, labour requirement, field capacity and implement draught requirement. Both on-station and on-farm trials were conducted, with replicated completely randomized block design treatments being laid. The trials started with two villages, Iyawaya and Njelenje villages in Mbeya district, and expanded to 18 villages in the early 2000s in Njombe, Mbarali and Sumbawanga districts (Table 6.1).

Research results showed that the ox-drawn tine ripper is cost effective, facilitates spreading

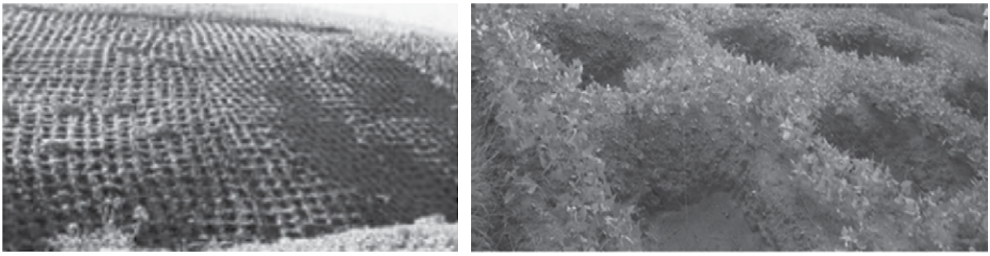

Fig. 6.1. Aerial view of Matengo pits (*ngoro*) (left); and enlarged view of beans planted on *ngoro* (right). Figure courtesy of Henry Mahoo, 2015.

Table 6.1. The effect of tillage implements on effective field capacity, ox-team hours, labour input and yield at Wanging'ombe in 2002/03 season. Authors' own table.

Treatment	Effective field capacity (ha h^{-1})	Ox-team hours (ha^{-1})	Labour input (person-h ha^{-1})	Maize grain yield (kg ha^{-1})
Mouldboard plough	0.07^{c}	14.64^{a}	21.87^{a}	3425
Magoye tine ripper	0.13^{a}	7.85^{c}	14.99^{c}	3619
Ridger	0.13^{a}	7.76^{c}	15.08^{c}	3322
Tie ridger	0.08^{b}	11.46^{b}	20.28^{b}	3126
Mean	0.10	10.43	18.06	3373 NS
CV (%)	11.5	8.33	11.76	20.0

^{a,b,c} Figures with the same letter in a column e.g. "^{a}" denotes the results are not statistically significant at the 0.05 level. NS, not significant; CV, coefficient of variation.

of the labour peak and reduces labour input by about 70% compared to the hand hoe. Maize yields in ripping treatments were always higher, although they were not significantly different. Farmers who continue practising ripping were perhaps encouraged by the reductions in the arduousness of labour and efficient utilization of saved labour for expansion of farmed land or other income-generating activities. In on-farm trials, farmers evaluated different tillage systems with respect to ease of operation, adjustment, durability, ease of penetration, moisture retention and effective soil erosion and weed control. The participatory research evaluation tools used included pairwise and matrix ranking. Field days were also organized yearly to allow farmers to make visual observation of the crop stand and test the implements.

Apart from animal traction-based trials, several other studies were carried out during that period to address basic needs of other segments such as tractor-powered technologies for the then National Agriculture and Food Corporation farms in Mbarali and Mbozi for paddy and maize production respectively, and the Tanganyika Wattle Company (TANWAT) in Njombe for maize and wheat. At TANWAT, tillage studies were done in response to reduced yields in maize and wheat production. It was observed that the production of maize declined from 5 tonnes (t) ha^{-1} to 1.2 t ha^{-1} in a period of 10 years consecutively from 1980 to 1989, despite using the same levels of fertilizers. The field trials conducted established that the main cause of the declined production was formation of hard pans (2–10 cm below the surface), formed as a result of conventional tillage continuously using heavy disc trailed harrows (Shetto and Kwiligwa, 1989). Other investigative studies undertaken in collaboration with ARI Mlingano confirmed the presence of tillage-induced hardpans in Njombe district and several other areas in the Southern Highlands zone (Ley *et al.*, 2003).

Development and evaluation of reduced soil disturbance implements

In 2000/2001 new dimensions on NT and vegetative soil cover were introduced as a follow-up to the International Workshop on Conservation Tillage which was held by the Food and Agriculture Organization of the United Nations (FAO) in June 1998 in Harare, Zimbabwe, and also due to new experiences acquired from Brazil. New CA implements were introduced, including jab planters and animal- and tractor-drawn knife rollers and direct seeders. Furthermore, in addition to the NT equipment exploration journey, the new regional networking initiative African Conservation Tillage Network (ACT) (www.act-africa.org, accessed 10 July 2021) was born in June 1998 at the International Workshop in Harare, Zimbabwe (ACT, 2018).

Work conducted at the ARI Uyole to evaluate the performance of different NT equipment concluded that there was considerable labour saving in tractor- and ox-drawn direct seeding compared to manual hand hoe or ploughing. While the labour requirement/input for the hand-hoe system was 143.7 person-h ha^{-1} for the 2001/02 season, it was 46.2 person-h ha^{-1} for the jab planter, 17.9 person-h ha^{-1} for the ox-drawn seeder system and only 0.55 person-h ha^{-1} for the tractor-drawn direct seeder system. Similar results were observed in the 2002/03 season (Table 6.2).

Table 6.2. Labour input and maize yield with various planting equipment treatments at TARI Uyole. Adopted from Mkomwa and Mkoga (2010).

	Effective labour input (person-h ha^{-1})		Maize grain yield (kg ha^{-1})	
Treatment	2001/02	2002/03	2001/02	2002/03
Hand hoe (pot holing)	143.7^{a}	113.1^{a}	1853^{a}	3469.5
Jab planter	46.2^{b}	46.6^{b}	108^{b}	3257.5
Ox-drawn direct seeder	17.9^{c}	6.88^{c}	1966^{a}	3446
Tractor direct seeder	0.55^{e}	0.56^{e}	2092^{a}	3344.9
Significance	*	*	*	NS
Mean	52.1	41.7	1700.5	3379.5
CV	39.30%	46.70%	64%	12.10%

*significant at $p \leq 0.05$.

[a,b,c] Figures with the same letter in a column e.g. "a" denotes the results are not statistically significant at the 0.05 level.

NS, not significant; CV, coefficient of variation.

Generally, no significant differences ($p > 0.05$) in the effects of different planting implements on the grain yield was observed (Mkomwa and Mkoga, 2010). It was also observed that, at 0.13 ha h^{-1}, the field capacity for rippers was higher than that of the plough (0.07 ha h^{-1}).

Cover crops

Cover crop screening trials were also initiated to capture the wider spectrum of CA in conjunction with minimum soil disturbance practice. About 59 cover crops, including legumes, grasses and leguminous shrubs, were locally sourced and an additional 26 cover crops were obtained from Brazil. Seeds of the imported cover crops were subjected to a rigorous laboratory test and were later screened in the field under strict open quarantine managed in collaboration with the Tanzania Pesticides Research Institute (TPRI) before they were released for on-station and on-farm trials.

The cover crops were evaluated on soil fertility improvement; agronomic establishment (biomass production and ground cover); weed management through smothering; susceptibility to pests and diseases; suitability as forage feed and edibility by humans; and ability to maintain a vegetative cover over a longer part of the dry season. On-farm trials were conducted in four villages representing different agroecological zones in the Southern Highlands with 21 participating farmers.

It was found out that canavalia (*Canavalia ensiformis*), vetch (*Vicia villosa*), lablab (*Lablab purpureus*), lupines and mucuna (*Mucuna pruriens*) had the highest biomass, greater than 15,000 kg ha^{-1}; while desmodium, mucuna, lablab, lupines and lucerne had the highest smothering or weed suppression effect (Table 6.3). The test results are from the ARI Uyole site at an altitude of 1850 masl and an annual rainfall of 965 mm. It was also established that pigeon peas and lablab penetrated plough pans or hard-set layers to a depth of up to 1 m in a period of 4 months, thus effectively improving the soil water storage and crop root development. It was also established that lablab and pigeon peas had higher soil moisture retention at different soil horizons compared to the plough at 1.60%, 1.43% and 1.27%, respectively (ARI Uyole, 2003; ARI Uyole, 2004).

6.2.3 Local Capacity Building and Promotion of Conservation Agriculture (CA)

Several institutions were involved in capacity building and promoting CA in the Southern Highlands, either in collaboration with ARI Uyole, or independently through a number of short-term projects (in most cases of 3 years or less).

Training of technical staff

Capacity building was undertaken through formal training of extension officers from the government and other institutions, and from

Table 6.3. Cover crop biomass yield and smothering effect. From Mkomwa, 2004.

Cover crop species	Biomass of maize + cover crop (kg ha^{-1})	Smothering effect weed weight (g m^{-2})
Mucuna pruriens	15,150^{c}	206
Lablab purpureus	19,210^{ab}	300
Canavalia ensiformis	14,610^{cd}	na
Vicia villosa	20,440^{a}	na
Local lupine	16,020^{bc}	517
Desmodium uncinatum	10,860^{defg}	432
Crotalaria ochroleuca	12,840^{cde}	554
Cajanus cajan	10,960^{defg}	na
CV (%)	17.43	63 NS

na, not available.

[a,b,c] Figures with the same letter in a column e.g. "a" denotes the results are not statistically significant at the 0.05 level.

NS, not significant; CV, coefficient of variation.

non-governmental organizations (NGOs), to broaden their knowledge of CA concepts, cover crops, weed management and implements. ARI Uyole trained some 200 extension workers by 2018 and various technicians in the fabrication of CA equipment including jab planters and animal-drawn rippers, rollers, subsoilers and direct seeders.

The Zambia Conservation Farming Unit, through its in-country partner Hanns R. Neumann Stiftung (HRNS), trained 52 MoA extension officers in Mbozi, Mbeya Rural, Rungwe and Ileje districts in Mbeya region in 2013–2015. ACT also trained 50 extension officers in the Southern Highlands and ten artisans/manufacturers on the fabrication of rippers, subsoilers, knife rollers, jab planters and direct seeders for use in CA. The Conservation Farming Unit Tanzania (CFU), in collaboration with the Agricultural Council of Tanzania, also trained 12 tractor-based mechanization service providers and 26 herbicide spray service providers. CFU is also supporting the establishment of ARI Uyole as a centre of excellence on CA in collaboration with ACT.

Workshops were also conducted in the Southern Highlands involving various stakeholders including policy makers, researchers, extension workers, trainers, agricultural machinery dealers and manufacturers, agro-inputs dealers, agro-processors and financial institutions to create awareness of CA, discuss arising opportunities and challenges, and to enhance networking and the capacity for providing CA services to advance the technology in the country.

In 2014 the Ministry of Agriculture Training Institute (MATI) Uyole, supported by ARI Uyole and ACT, developed a draft CA curriculum for students pursuing an Ordinary Diploma in Crop Production under the MATI system. The CA curriculum was formally approved in 2020 for inclusion in the National Council for Technical Education (NACTE).

Training of farmers

Local training was also provided to farmers through farmer field schools (FFS) where farmers were practically trained stage by stage on a 0.5–1-ha test plot in validating various CA options or treatments, from land preparation to harvesting in their own farm environment. The CA options tested include ripping, direct seeding or use of cover crops, etc., in comparison to conventional tillage practices. Groups of 15–25 farmers were formed in selected villages; these usually met weekly to practice, learn, observe crop development and discuss CA concepts, challenges, opportunities and options suitable to their own local environments. ARI Uyole trained about 400 farmers (22% female) on various CA technologies through FFS in 1998–2003 under both the FAO Technical Cooperation Project and the World Bank-supported Ministry of Agriculture soil fertility improvement project. ACT and ARI Uyole were also able to target and reach an additional 5000 farmers through radio programmes and through study tours to sites demonstrating the best field-level climate smart agricultural practices. The HRNS have trained 259 farmer groups (producer groups or FFS) involving 8331 farmers (17% female) and helped to link them with input suppliers for bulk purchase, credit links to commercial financial institutions and to mechanization service providers. Meanwhile the CFU, in partnership with the Tanzania Agricultural Partnerships II, trained 808 service providers on mechanization service provision.

The Sokoine University of Agriculture (SUA) used 25 FFS to train 116 farmers on planting basins in 13 villages in Njombe and Wanging'ombe districts. In April 2013 the Institute of Agriculture at the University of Iringa introduced 47 demonstration plots highlighting improved production practices (including CA) through a companion village project which enabled farmers to see increased yields in the improved production practices compared to conventional tillage practices. CARITAS also trained several farmers on planting basins with manuring and contour bunds in Iringa district.

Through the CA centre of excellence concept, in the period 2018 to date TARI Uyole has formed a new consortium with ACT and CFU-Tanzania to undertake CA demonstrations in nine villages of Mbeya and Wanging'ombe districts. They have jointly trained about 1000 farmers (46% female) on different aspects of CA technologies including land preparation, planting, basin making, animal-drawn implements and tractor service provision.

Promotion of CA

CA promotional events have been held in the Southern Highlands involving various actors such as ARI Uyole, ACT, HRNS and CFU. These included field demonstrations of CA implements and machinery, and field days and agricultural shows with 300–500 farmers participating in each event. A number of leaflets on CA have been prepared and distributed widely to create awareness of the technology. On-farm demonstrations have also been held to promote some CA components such as minimum soil disturbance, fertility improvement, crop rotation and cover crops, based mostly on farmers' requirements, to enable farmers to see for themselves and to monitor the crop through the cropping calendar.

ARI Uyole, in partnership with ACT as the Secretary of the National Conservation Agriculture Task Force (NCATF), have over the years organized several other CA promotional activities which are likely to have contributed to the achievements of CA in the region, including:

- Organization of Tanzania CA stakeholders' events.
- International CA training courses.
- NCATF members' awareness-creation study tours.
- Participation in the Zonal National Tanzania Agricultural Shows (*Nanenane*).
- Cover crop seed (mucuna, canavalia, crotalaria) exchange with an inorganic fertilizer programme intended to publicize biological soil fertility improvement options.

ACT, in partnership with FAO under the CA-SARD project, has promoted local CA equipment manufacturing. There is now a budding industry in Kenya and Tanzania as result of exposure to Brazilian equipment and specialist technical training of East Africans in Brazil and Paraguay. Machinery manufactured commercially includes Draught Animal Power (DAP) rippers and NT planters, manual jab planters and sprayers. In 2013 ACT initiated the formation of a community of practice of CA equipment manufacturers, to assist in the sharing of lessons in tackling the challenges of access to equipment. This was followed by the CA equipment manufacturers workshop held in Dar es Salaam, Tanzania, attended by 29 stakeholders from Africa, Asia and Brazil (ACT, 2013). Several donors have supported district councils in the Southern Highlands, including Finnish International Development Agency (FINNIDA), Norway, Sweden, the International Fund for Agricultural Development (IFAD), FAO, United Nations Children's Emergency Fund (UNICEF), the United States Agency for International Development (USAID), the Netherlands and the World Bank by funding some short-term projects that included training farmers and setting up demonstrations of various CA technologies.

6.2.4 Main Benefits of CA in the Southern Highlands

Several benefits of CA have been reported elsewhere in Tanzania and in the world in general. Some of these were observed in the Southern

Highlands and included increased crop yields, reduced on-farm costs in terms of savings in time, labour and machinery use at the farm level, increased soil fertility and protection from soil erosion.

Increased and stable crop yields

Increased yield in maize by 26%–100% and in sunflower of up to 360% have been reported in the Southern Highlands in CA compared to conventional tillage agriculture (Mkomwa *et al*., 2007; Shetto and Owenya, 2007; Mwakimbwala *et al*., 2013). Farmers in Mshewe Ward in Mbeya district observed that the yield of maize increased by 20% in 2–3 years in reduced tillage with cover crops (mucuna, lablab or pigeon peas), even without use of inorganic fertilizers (Banjarnahor, 2014). An increase in yield of 70% was observed in maize from 2.5 t ha in tractor-ploughed fields to 4.2 t ha^{-1} in tractor-ripped fields in Mbeya region in 2015 under the ZCFU project (ZCFU, 2015).

Experiments conducted in the Mkoji subcatchment of the great Ruaha river basin in Mbeya district in the 2007/08 season by ARI Uyole and SUA showed that ripped plots with crop residue yielded 3.8 t ha^{-1} of maize compared to 1.7 t ha^{-1} for conventional tillage treatments. This was an increase of 124% while the soil moisture was higher by 6%. The Agricultural Production Systems Simulator (APSIM) crop simulation model run over a 24-year period (1985/1986 to 2007/2008), to simulate long-term production series of soil moisture and grain yield based on the soil and weather conditions in the area, showed that maize yields were significantly higher with conservation practices than with conventional tillage practices by 22% at 4.4 t ha^{-1} and 3.6 t ha^{-1}, respectively, and the moisture content was higher by 18%–24%. It was established that, generally, conservation practices with tine ripping and surface crop residues are much more effective in mitigating dry spells and increasing productivity in maize production in areas where the seasonal average annual rainfall is less than 770 mm (Mkoga *et al*., 2010).

Apart from increased yields, farmers have observed more stable yields over the years when they practised CA compared to conventional tillage agriculture (Mkomwa *et al*., 2007). However, complementary good agronomic practices are essential to enable farmers to reap the benefits of CA. These include use of improved crop varieties, timely planting, good pest and disease control and use of fertilizer where soils are nutrient deficient, especially in the early years of transformation.

Reduced labour and smoothing labour peaks

Results from ARI Uyole indicate a labour saving of 57% with jab planters, 60% when animal-drawn rippers are used and 72% with the animal-drawn direct seeder compared to conventional flat cultivation using the ox-drawn mouldboard. Some farmers who have adopted tine ripping have gainfully utilized the time and labour saved to increase their cropped land by 20%–50% (Mkomwa *et al*., 2007). Tine ripping has brought forward the planting time to November in the Southern Highlands, just before the onset of the rains, thus productively utilizing the idle time and smoothing the labour peak for planting and weeding in December/January, as planting is done immediately after ripping in November. This has led to some farmers reducing their dependence on hired labour and hence lowering their production costs.

Economic benefits and improved livelihoods

Several studies have carried out comparative economic analysis of conventional tillage agriculture and CA in the Southern Highlands. Mlengera *et al*. (2018) showed that the profits in CA maize production were three times greater than in conventional tillage agriculture, at US$526.9 and US$176.6, respectively. For beans the profits in CA were twice as much, at US$917.4 compared to conventional practice profits of US$376.3 (Table 6.4). Such high profits were the result of reduced cost of production and increased yield under CA, as reported by most respondents who were interviewed in the survey.

Mkomwa *et al*. (2007) also reported that net benefits increased more than threefold for sunflower and fivefold for maize under CA compared to conventional tillage agriculture in Njelenje village, Mbeya district, as a result of increased yields in CA despite a 50% reduction in the use of inorganic fertilizer. Increased maize

Table 6.4. Costs of bean and maize production under conventional and Conservation Agriculture practices.

	Bean production cost (US$ha^{-1})		Maize production cost (US$ha^{-1})	
Operations	Conventional practice	CA practice	Conventional practice	CA practice
Land preparation	65.2	86.2	56.8	32.5
Ploughing	66.6	–	71.2	–
Ripping	–	33.8	–	25.6
Harrowing	41.4	–	45.5	–
Fertilizer	93.2	93.2	204.6	204.6
Seeds	113.6	142.1	47.7	54.6
Planting	80.5	80.2	75.1	93.9
Weeding	78.3	56.4	92.1	62.9
Control of insect pests	51.6	30.2	34.7	24.3
Harvesting	62.2	59.9	61.0	85.2
Total production costs	652.7	623.5	688.7	583.6
Yield (t ha^{-1})	1.5	2.3	5.6	7.1
Total revenue	1029.0	1540.9	865.2	1110.6
Profit	376.3	917.4	176.6	526.9

yield was attributed to improved soil fertility as a result of continuous use of soil-enriching cover crops such as mucuna, lablab and canavalia. Farmers using cover crops in Njelenje village reduced the use of inorganic fertilizers from 125 kg ha^{-1} to 60 kg ha^{-1}, while the maize yields increased from 1125kg ha^{-1} to 2250 kg ha^{-1}, leading to increased net benefits as a result of reduced maize production costs and more revenue accrued from the increased sales of maize.

6.2.5 Adoption of Conservation Agriculture (CA) in the Southern Highlands

CA adoption studies are scanty and hence it is difficult to generalize as most of them have been based on small localized areas only. However, they depict the general trend of CA adoption in the country. A study conducted in Mshewe Ward in 2014 indicated that, of the 43 households participating in CA FFS, only 5% were early adopters who practised CA on their own farms; 65% were at a ‘Try and Observe’ stage, including 37% who were trying reduced soil disturbance with cover crops on 0.1–0.4 ha only, with the rest of their farms being tilled conventionally with ploughs; 16% were testing reduced soil disturbance with tine rippers on 0.1–0.7 ha only; and 12% were trying use of cover crops only (mucuna, lablab or pigeon peas) on 0.1–1.2 ha, with the rest of their farms being tilled conventionally with ploughs (Banjarnahor, 2014).

Mkomwa *et al.* (2007) found that 20% of the 143 households that started practising CA in small plots of their farms when it was introduced in 1998 in Mshewe Ward were still practising in 2002; others had dropped out, probably because they were looking for quick returns, had difficulty using harvested cover crop seeds (especially mucuna) or had insignificant increase in maize yields as the rainfall was high in the area and there was less risk from drought as the average annual rainfall was 900–1200 mm. A baseline survey conducted by the ACT in the six districts of Mbarali, Njombe, Karatu, Kongwa, Bukoba Rural and Kwimba in 2011/12 indicated that only 3% of the interviewed households in Njombe implemented the three principles of CA (i.e. minimum soil disturbance or NT, soil cover and crop rotation or associations), while in Mbarali it was almost negligible (non-existent) and adoption in the other four districts was standing at 5% (Lugandu, 2015).

On the other hand, a study carried out in 2018 involving a survey of 58 (18 female) farmers out of 120 farmers who were farming around ARI Uyole revealed increased adoption rates of CA technologies (mainly reduced soil disturbance and crop rotation) at the rate of 52%, 55% and 65% for the 2015/16, 2016/17 and 2017/18 cropping seasons, respectively.

Farmers usually adopt the most 'doable' technology first and, with time, others follow as more tangible benefits unfold. Key entry points differ from one farmer to another; to one it might be reduced labour, to another it might be improved soil fertility, rainwater harvesting or compatibility with the intercropping system. The increased adoption rate of CA technologies around ARI Uyole was a result of the sharp increase in labour costs in conventional tillage agriculture in bean production. In Wanging'ombe Ward the animal-drawn tine ripper was adopted first, unlike the hand-powered jab planter, because farmers in the area have been using oxen for a long time and they felt that using the jab planter was retrogressive (Mkomwa *et al.*, 2007; Mlengera *et al.*, 2018).

6.3 Main Achievements and Challenges of Conservation Agriculture (CA) Adoption

6.3.1 Main Achievements

Among the achievements of the work undertaken by ARI Uyole and other organizations are CA-awareness creation in the farming community, administrators and policy makers in the Southern Highlands through both on-station and on-farm trials, field demonstrations, public or contact meetings and agricultural shows. Under the Common Market for Eastern and Southern Africa (COMESA) climate change project funded by Norwegian Agency for Development Cooperation (NORAD), for example, ACT invited the Mbeya District Authorities (District Executive Director and District Commissioner) to a CA study tour in Zambia and Zimbabwe, and to the first Africa Congress on Conservation Agriculture (1ACCA) held in Lusaka, Zambia, respectively.

Most farmers around ARI Uyole (79%) mentioned the institute as the main source of CA technologies and know-how; very few acknowledged that they obtained the information from other sources such as the internet (5%), printed or published materials (8%) and learning in school/college/universities (about 8%) (Mlengera *et al.*, 2018). Training of extension officers and lead farmers has been conducted; these have formed core teams for training farmers in their respective villages in a more continuous and sustainable manner. Other research centres in the country are involved, such as Selian Research Institute, TARI Mlingano and TARI Ilonga as a spillover effect from ARI Uyole. Various CA technologies have been tested and promoted by these institutions, including reduced soil disturbance, cover crops and crop rotation patterns.

Suitable cover crops for the Southern Highlands have been established after extensive screening of both locally available and imported cover crops. The farmer-preferred tropical cover crops are canavalia, pigeon peas, lablab, cowpeas, crotalaria and mucuna. The preferred temperate cover crops are vetch and lupines. It has also been established that some of the cover crops – like pigeon peas, canavalia and lablab – have the capability of penetrating hard pans, thus loosening the soil up to a depth of 1 m below the surface. This reduces the need for mechanical means such as subsoilers, and the effect becomes stronger with optimal spacing.

However, the use of mucuna was limited as it requires special processing – such as continuous boiling for 6 h – to detoxify it before it can be used as food or feed for livestock. Research carried out by SUA and ACT (Aboud *et al.*, 2010) on the detoxification of mucuna concluded that thermo-extrusion at 165°C and slow screw speed (10 rpm) reduces concentration of L-DOPA in mucuna seed to levels safe for human and animal consumption. Furthermore, in local chicken feeds, thermo-extruded mucuna seed meal can be incorporated in diets at up to 30% without any deleterious effects.

Related work was carried out in Muheza district, Tanga, Tanzania, by TARI Mlingano, to determine options for enhancing use of *Canavalia ensiformis.* The canavalia seed materials have been reported to contain appreciable levels of protein, desirable amino acids, fatty acids, starch and minerals. Despite the desirable nutritive features, the canavalia seeds are not extensively used as food/feed, mainly owing to the presence of certain anti-nutritional compounds. Limited information is available on the effect of the level of substitution of processed canavalia seeds as a protein source in common animal feeds. Maulaga *et al*. (2014) studied treatments containing varying combinations of soaked, boiled canavalia beans and soaked, toasted canavalia beans to replace sunflower seed meal and fish meal at 0, 25%, 50% and 100% levels as protein sources. Maize meal and maize bran were used as a source of energy. The study showed that the diets based on soaked and toasted beans at 25% and 50% substitution level gave good results, indicating that substitution of sunflower seed meal and fish meal with processed canavalia beans has potential in poultry diets. This was exhibited through its protein and basic amino acid content, relatively low fibre, good energy level and good mineral contents. The potential of canavalia beans as a human food has been demonstrated by Ndabikunze *et al.* (2014). Canavalia bean treatments have included soaking, treatment with trona and germination. Soaking had minimal effect on reducing phenolic compounds but germination of canavalia beans for 48 h had the highest (82%) reduction effect. Acceptability tests were performed on products prepared from composite flour made from canavalia beans germinated for 48 h. The products included breads, buns and porridges. Panellists liked the buns much more than the breads and porridges. These two studies sought to increase options for canavalia use that will overcome constraints to the adoption of green manuring and cover crop technologies.

There is also involvement of the private sector, including small-scale CA implement manufacturers like Intermech Engineering Ltd, Nandra Engineering and SEAZ Ltd; and agro-input dealers, agro-processors, medium- and large-scale farmers in the promotion or up-scaling of CA. Large-scale farmers like Otto Ulyette in Kilolo District, Iringa Region, manage 500 ha under CA. He is providing training and supply of agro-inputs such as herbicides, fertilizers and some ripping services to smallholder farmers around his farm. A number of agro-input dealers and agro-processors have been trained and are also supporting smallholders with supplies of agro-inputs. By facilitating this linkage to input suppliers, farmers can gain access to genuine inputs and the option to procure inputs on credit through their farmer group structures.

Medium-scale farmers owning tractors have been trained on CA and use tractor-drawn tine rippers and direct seeders to reduce soil disturbance, and provide direct seeding services to other farmers in their localities. The introduction of tractor-based mechanization service providers has increased accessibility of the very expensive CA equipment to a wide spectrum of smallholder farmers who do not have the capital or skills to buy and manage the implements. About 120 ha were put under minimum soil disturbance practice in the Southern Highlands in 2015 when this programme started serving about 90 smallholder farmers. Some local manufacturers – such as Intermech of Morogoro, Nandra Engineering of Moshi and SEAZ of Mbeya, and local artisans – have also acquired skills in the fabrication of CA equipment like jab planters and animal-/tractor-drawn rippers, subsoilers, knife rollers and direct seeders, thus increasing the availability of such equipment locally.

6.3.2 Challenges of CA Adoption

The adoption of CA in the Southern Highlands has been slow because of a number of challenges such as change in mindset; the difficulty of weed control particularly during the first 2 years; inaccessibility of appropriate mechanical equipment and cover crop seeds; crop residue use for livestock feed competing with soil cover needs; and lack of capital investment. It was observed that farmers in Mshewe Ward and elsewhere in Mbeya perceived that ploughing is necessary to loosen the soil for proper crop development and weed control. Thus, farmers could not mentally switch to tine ripping, especially when the availability of herbicides was questionable (Banjarnahor, 2014).

The limited use of introduced cover crops such as mucuna to improve their livelihoods, including edibility and marketability; free-range communal grazing of livestock which made it difficult for farmers to retain the crop residue on their farms; and lack of pronounced yield increment, especially in the first few years, made farmers more hesitant to adopt the technology. In the Southern Highlands, there were no established markets for cover crop seeds, such as lablab, unlike in the Northern Highlands where there was a ready market in neighbouring Kenya.

Lack of capital to purchase inputs such as cover crops, herbicides, improved seeds, fertilizers and CA equipment makes change difficult for cash-strapped smallholder families. These mostly depend on income from sales of their crops, which in most cases are not even enough to meet their household obligations and last only for a short time, probably 2–3 months a year. Further, limited opportunities in investing saved time from the adoption of CA to other economic productive activities, such as value addition or agro-processing, has made it difficult to spread the higher investment costs in CA over a number of enterprises and thus absorb the additional requirements.

It may be difficult for farmers who have been practising conventional tillage agriculture for many years to comprehend the new concept of CA easily, as it contradicts much of their conventional farming knowledge and traditions. Thus, more time is needed on the learning curve, including trying and observing for tangible benefits in farmers' small plots, before up-scaling. The duration of most CA donor-funded interventions has been short (3 years or less) which has not been enough to allow farmers to complete the learning cycle and allow them to make informed choices between the various introduced technologies. It has been reported that, when adoption occurs, farmers might apply the proposed CA practices in only a small plot of their land or adopt it partially and in a stepwise manner, adopting only the most relevant and doable components in their environments (Kassam *et al.*, 2009; Derpsch *et al.*, 2010; Nkala *et al.*, 2011; Umar *et al.*, 2011).

The fragmented project approach in the promotion of CA as practised by many donor-funded projects and NGOs has further exacerbated the situation, as they were location-specific and covering few farmers only in a district, and dealing only with specific aspects of CA such as training or skills development. Such interventions have been short lived and many activities were abandoned by farmers as the projects ended. Many farmer groups disintegrated after the project as sometimes farmers were motivated only by the package they were given, such as free seed or fertilizer.

6.4 Conclusions and Recommendations

6.4.1 Conclusions

CA is a promising sustainable system in smallholder farming in the Southern Highlands of Tanzania. It is cost effective, with net benefits that sometimes increase threefold, compared to conventional tillage agriculture involving use of animal- or tractor-drawn ploughs. High net benefits in CA are obtained as a result of reduced cost of production and increased yield.

The inclusion of other economic investment opportunities, apart from crop production, enable smallholder farmers to utilize more efficiently the time saved with CA interventions, which increases their household incomes and improves their livelihoods. The investment opportunities may include poultry farming, rearing of small ruminants or other investment opportunities in their localities.

The use of cover crops is important in improving soil fertility and increased yields. Some deep-rooted cover crops such as pigeon peas, canavalia, mucuna and lablab are useful in compacted soils as they penetrate the hard pans and break up the soil. This increases rainwater infiltration and improves *in situ* water harvesting. However, the extensive use of some cover crops such as mucuna, canavalia and lablab in the Southern Highlands has been hampered by lack of immediate tangible benefits such as edibility or marketability to improve household incomes. Options for treatment of these non-edible cover crops, such as extrusion, should be promoted.

The adoption of CA has been low in the Southern Highlands, like elsewhere in Tanzania, due to a number of challenges such as change in mindset; the difficulty of weed control particularly during the first 2 years; inaccessibility of appropriate mechanical equipment and cover crop seeds; crop residue use for livestock feed competing with soil cover needs; and lack of capital investment.

Inclusive discussions between farmers and CA researchers and promoters on the challenges of CA are important in seeking possible solutions suitable for and applicable to their own local environments. Many problems are localized and mostly site-specific, depending on the biophysical and socio-economic context, and no solution can cut across the diversified geographical and socio-economic conditions in the Southern Highlands.

Short-term interventions in CA, sometimes of less than 3 years by ARI Uyole researchers, NGOs, academic institutions and other donor-funded projects have been effective in creating CA awareness. However, farmers need more time in assessing and evaluating new technologies in their own farm environments as, to the majority, it is very difficult to be convinced abruptly that 'farming without ploughing' works compared to conventional tillage, a technology which has been inherited from ancestors and practised from time immemorial. More participatory approaches give farmers a free mandate in selecting and testing a technology of their choice in their small plots. In practice, farmers' ability or willingness to implement or partly adopt CA is based on their perception of what is feasible in their particular circumstances, as individual and site-specific potential constraints still play a role in the continuity and spread of CA.

The involvement of medium- and large-scale farmers and other private sector players like agro-input dealers, processors, machinery dealers, financial institutions and structured markets are important to bring closer services and ready markets for crops in the up-scaling of CA. Once convinced, medium- and large-scale farmers will practise the technology at a larger scale, demonstrating CA visually, and may facilitate smallholder farmers with support services like machinery hire and supply of agro-inputs closer to their localities. Medium-scale farmers owning tractors may also offer minimum soil disturbance seeding services to smallholder farmers, thus bringing closer the availability of the much-needed CA equipment.

6.4.2 Recommendations

A holistic value chain approach is recommended in CA interventions, bringing together various players including scientists, trainers, extension workers, administrators, policy makers, agro-input and machinery dealers, machinery service providers, agro-processors and financial institutions to bring services closer to farmers. A market pull approach should be emphasized, rather than the technological push approach which has commonly been practised. Business models such as contract farming should be encouraged, as they offer ready markets for farmers and provide support services such as agro-inputs, machinery hire, short-term credit and technical advisory services, which are important in propelling agriculture forwards in the country.

Collaborative activities among the various actors promoting CA should be emphasized, as more tangible results may be obtained through pooling of resources and expertise while avoiding duplication of efforts and sending different messages which sometimes may be conflicting. Champion organizations like ARI Uyole should be supported and the centre for excellence under development should be facilitated as it may become the hub for CA promotion and up-scaling in the Southern Highlands as the basic infrastructure is already established. CA knowledge management, information flow and networking should also be improved.

Long-term CA interventions or programmes are recommended and farmers should be taken through the complete learning cycle in testing CA technologies in their own farm environments. CA learning FFS plots should be worked first, such as breaking hard pans before treatments are imposed, as crop development may be hampered, especially when ripping does not go beyond the hard pan. In Brazil this is known as 'treating the soil'; and, together with breaking hard pans, liming is done in acidic soils. Aspects of financing such as promotion of savings and credit societies (SACCOS) and village community banks such as 'VIKOBA' should also be incorporated in FFS. These have been influential in supporting small businesses in the villages and may partly cover the financing of CA equipment procurement while ensuring sustainability and continuity of activities even after the end of projects.

Entrepreneurial CA machinery hire services should be promoted, especially to youth, as they increase the availability of power to the smallholders who do not have the capital or skills to buy and manage the machinery. Through this arrangement, smallholders will be required to meet only the machinery hire charge, which is affordable to the majority.

Note

[1] Until 2016 the Tanzania Agricultural Research Institute (TARI) Uyole was known as the Agricultural Research Institute (ARI) Uyole.

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7 Historical Review and Future Opportunities for Wider Scaling of Conservation Agriculture in Tunisia

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Abstract

In Tunisia, rainfed agriculture is facing the major challenges of low and irregular rainfall, as well as natural resources degradation. These are further accentuated by climate change. Changes in technical and management paradigms are needed to boost agricultural productivity. Since the early 1990s in Tunisia, a Conservation Agriculture (CA) system has been proposed as an adapted set of management principles to ensure more efficient and resilient agricultural production systems. In the last 20 years several research and development (R&D) projects have been implemented. Research findings in Tunisia show that the long-term adoption of CA allows increased crop yields and water use efficiency of cereals, enhanced soil biological life and soil organic carbon and reduced energy costs at farm level. Despite promising research results, adoption and up-scaling of CA in Tunisia has been rather modest (currently some 16,000 ha are managed under CA systems). The purpose of this book chapter is to summarize the previous R&D projects dealing with CA in Tunisia. It also aims to provide better insights into the complexity and potential ongoing solutions for integrating crops and livestock into CA systems. Crop–livestock systems dominate a large part of northern and central Tunisia where most of the rainfed field crops are produced.

Keywords: No tillage, adoption, crop–livestock integration, R&D projects

7.1 Introduction

Tunisia is a North African country with large semi-arid and arid areas marked by hot summers, cold winters and low annual rainfall. Average rainfall in the lowlands is between 200 mm and 400 mm per year in semi-arid areas, and below 100 mm per year for arid regions and desert. In the sub-humid highland areas average rainfall is higher, at up to 1000 mm per year. The annual rainfall is characterized by inter- and intra-annual variability and varies considerably from north to south (Nouaceur and Murarescu, 2016). Moderate temperatures from November to March, and periods of sunshine interspersed between relatively short rainy periods, are favourable for photosynthesis and efficient soil-moisture use. A very limited number of rainy days (fewer than 120 days per annum in general) and frequent droughts during the growing season combined with high temperatures are common constraints to plant growth, especially for cereal crops, which are strategic crops for the country. More than 90% of the 10 million ha agricultural lands is

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rainfed and is subject to these constraints. In addition, water resources are limited and below the water-poverty threshold at less than 500 m^3 per year per inhabitant (Jemmali, 2013). These constraints represent the major challenges faced by Tunisian agriculture and are accentuated by climate change (CC). It is expected that Tunisia will be highly affected by CC due to its critical location in the centre of the Mediterranean region (Verner and Breisinger, 2013; Zouabi and Peridy, 2015). The agricultural sector remains vulnerable to CC with an expected average increase in temperatures of +2.1°C by 2050. Within this context, the country is expecting an increase in the frequency and intensity of extreme dry years and a moderate decrease (10%) in precipitation. It is also expected that surface water will decrease by 5% in the same scenario, which will lead to a decline in agricultural water availability (Paeth *et al*., 2009; INDC, 2015). The expected increase in temperature will lead to greater evapotranspiration and therefore a decrease in water resources (INDC, 2015). Different analyses of the likely effect of CC on Tunisian agriculture have highlighted the vulnerability of rainfall production systems, especially in the central and southern parts of the country.

The second major challenge faced by the agricultural sector is related to soil degradation. More than 3 million ha are being eroded or under water erosion risk (DGACTA, 2017). Soil erosion is specifically important in the northern regions of Tunisia where most field crops and cereal areas are located. The effects of water erosion are expected to be exacerbated by CC (Raclot *et al*., 2018). Autumn rains contribute to erosion due to summer overgrazing of crop residues and absence of vegetation covering the soil. Furthermore, arable soils in Tunisia are increasingly degraded owing to the inadequate agricultural practices that are promoted, especially the dominance of conventional production systems based on intensive tillage (Mtimet, 2001). These practices have led to land degradation and depletion of soil fertility and soil water-storage capability. The introduction of inappropriate mechanization, especially heavy ploughs and tractors, has led to soil mining and degradation, particularly in arid and semi-arid regions.

Agriculture is an important sector in Tunisia, contributing to 8.7% of the national GDP and employing around 16.2% of the total work force in the country (The World Bank, 2013). It provides permanent income to 470,000 farmers and 60,000 fishermen. Total agricultural investment of TND1297 million (Tunisian dinar) in 2012 represented 8% of the total investment of the country. Private investment in the agricultural sector is about 52% compared to 48% for public investment. Crop production provides more than 80% of the value of the total agricultural and agrifood sector, while the remaining 20% is generated from livestock and fishery sectors. Tunisia mainly exports olive oil, fruits (date, orange, etc.) and seafood. Main imports are cereals, grain-oil and sugar. The added value of agriculture and fisheries almost doubled between 2005 and 2014, registering TND7226 million in 2014 compared to TND3722 million in 2005.

The Tunisian agricultural sector is characterized by an abundance of smallholder farmers (more than 80% of farms are less than 10 ha). In rainfed regions, agricultural production systems are mainly based on crop–livestock integration dominated by field crops, especially cereals (wheat: *Triticum aestivum* and *T. durum*; barley: *Hordeum vulgare*; and oat: *Avena sativa*) and small ruminant livestock (sheep, goats), with dominance of cereals monoculture. Livestock are considered by smallholder farmers as a primary asset that can be easily converted into cash in dry years. The main growing season, under rainfed conditions, generally extends from November to June. Cereals (mainly durum wheat and barley), are the dominant annual crops after olive trees. In Tunisia the government guarantees the market and prices of major cereals which make these crops less risky for farmers. Cereal monoculture, especially in areas where rainfall is less than 350 mm, has become common practice. In addition, the inadequate mechanization and the vulnerability of the market for pulses and oilseed crops are some of the main constraints for the practice of appropriate rotations. Similarly, the lack of appropriate forage seed production systems also affects the integration of forage crops into the crop rotation. Within this perspective, the sustainability of agricultural production under CC will be a real challenge. Upgrading agricultural production systems will require considerable effort for sustainable intensification accompanied with higher technical and economic efficiencies (Zouabi and Peridy, 2015). Conservation Agriculture (CA) is an ecosystem approach to sustainable agriculture and land management that can contribute to sustainable intensification of cereal-based systems in North Africa (Ben Hammouda, 2007; Jat *et al.*, 2014; Kassam *et al.*, 2018; Bahri *et al.*, 2019). CA is based on the practical application, in specific contexts, of three locally adapted and interlinked principles: (i) continuous no or minimum mechanical soil disturbance, i.e. no-till (NT) seeding/planting and weeding; (ii) permanent maintenance of soil mulch cover (crop biomass, stubble and cover crops); and (iii) diversification of cropping systems through rotations and/or sequences and/or associations (Kassam *et al.*, 2018).

In many cases, CA has been shown to reduce farming systems' greenhouse gas emissions and enhance their function as carbon sinks. Improved soil structure and health under CA thus holds the key to improving water use efficiency (WUE) which leads to improved farm profits and benefits the farm environment. Under CA, crop biomass retention on the soil surface leads to improved control of soil water (Bachmann and Friedrich, 2003) by decreasing soil evaporation and increasing infiltration and deep percolation. These characteristics lead to increased yields and WUE (Jat *et al.*, 2014; Parihar *et al.*, 2016).

Despite the introduction of CA since the late 1990s in Tunisia, the level of adoption by small holder farmers remains low, although many research and research for development (R&D) projects have been trying to tackle this low adoption level from different angles. However, technical constraints and a poor enabling policy environment appear to be constraining any significant progress with regard to scaling. The objective of this chapter is to review the historical and current status of CA, drawing on significant recommendations that can help leverage the scaling of this alternative system in Tunisia.

7.2 Historical Overview

In Tunisia, CA based on direct seeding (CA/DS) was initiated from 1970 to 1980 through acquisition of American NT seeders in the framework of a R&D project funded by USAID. The significant experience to promote CA began in 1999, following the CIRAD invitation of some Tunisian agronomists to participate in the workshop focused on NT, organized in Paris in March 1999. Following this workshop, Agence Française de Développement (AFD, the French Agency for Development) decided, with the French Ministry of Foreign Affairs and CIRAD, to promote CA/DS in Tunisia (Baccouri, 2008). Thus, an R&D programme of direct seeding and sowing under cover crop (semis sous couvert vegetal, SCV) funded by the International Fund for Agricultural Development (IFAD) and the French Facility for Global Environment (Fond Francais pour l'Environnement Mondiale, FFEM) has been implemented on-farm by the Technical Centre for Cereals (Centre Technique des céréales, CTC), with the collaboration of the Higher Agriculture School of Kef (ESAK), the National Institute of Agronomic Research of Tunisia (INRAT), the Integrated Agricultural Development Project in Siliana (Projet de Développement Rurale Agricole Intégré, PDRAI) and Cotugrain Company (a private company that supplies agricultural equipment and inputs).

The approach adopted for implementing this R&D programme was to work for farmers, with farmers and among farmers (Raunet *et al.*, 2004). Within this framework programme, the first on-farm demonstration plots under CA/DS were installed during the growing season 1999/2000 on 11 farms in northeastern Tunisia (Siliana and Kef governorates), using the American NT seeder acquired in the 1970s. The demonstration plots focused on comparing CA/DS and conventional agriculture (CovA). The first agronomic results reported from this period (1999–2002) were promising (Angar, 2010). Indeed, for cereal crops, results showed that the development of crops was improved under CA/DS compared to CovA. Furthermore, plots under CA/DS were distinguished by better tolerance to drought and better straw production. However, weed control for legumes under CA/DS remained a challenge (Raunet *et al.*, 2004).

From 2001 to 2004 FFEM funded the first phase of the Conservation Agriculture Development Support Project (Project d'Appui au Développment de l'Agriculture de Conservation, PADAC project), which has targeted the bigger farms in the north of the country. This first phase enabled logistical support for farmers through the provision of NT seeders for farmers who wished to test agricultural practices under CA systems, as well as technical supervision provided by CTC and ESAK with the support of CIRAD.

The second phase of the PADAC project was between 2007 and 2011. It was funded by FFEM and managed by AFD. The CTC/INGC, ESAK and the Tunisian Association for Sustainable Agriculture (Association Pour Agriculture Durable, APAD) were collaborators in the implementation of this project. This second phase of the project targeted the larger farms (> 100 ha) in the north, similar to the first phase.

Since 2006, in addition to the PADAC project focused on larger farms, interest has also focused on integrating small farms. This was first carried out through the Conservation Agriculture for Smallholders project funded by the Arab Authority for Agricultural Investment and Development (AAAID), and implemented by CTC and ESAK during 2006–2009. The project focused on CA for smallholders.

Two constraints were recognized as impeding the rapid adoption of CA, based on evaluation of two phases of the PADAC project: (i) stubble grazing during the summer period, which compromised permanent soil cover; and (ii) the non-availability of low-cost NT seeders. To resolve these two major challenges to CA adoption, several R&D projects were implemented in the following period. From 2012 to 2015 the CANA project Rapid Adoption of Conservation Agriculture in North Africa for Smallholders was implemented in Fernana region (a sub-humid region with annual rainfall of 750 mm year^{-1}, and a wet area with high vulnerability to water erosion). The project was funded by the Australian Centre for International Agricultural Research (ACIAR) and managed by INRAT, INGC and ICARDA. The implementation of the CANA project was based on the innovation platform concept where all the stakeholders are invited to participate and share their experiences and to contribute to the development and promotion of CA systems and agricultural practices.

From 2013 to 2016 a new project, Integrated Crop–Livestock under Conservation Agriculture for Sustainable Intensification of Cereal-based Systems in North Africa and Central Asia (CLCA) was implemented. This project was funded by IFAD and managed by INRAT–INGC–ICARDA. It focused on crop–livestock integration in CA systems. This project was implemented in Siliana governorate, which is a semi-arid region with annual rainfall of 450 mm year^{-1} and covers 400 ha that is farmed by more than 100 farmers (Angar, 2016; Cheikh M'hamed *et al.*, 2016). As a result of this project, the innovative stubble grazing model 30:30 was developed (Guesmi, *et al.*, 2019) to resolve the competition between livestock grazing (crop biomass and stubble grazing during the summer period) and maintaining some biomass on the soil surface as mulch. Development of this model was based on a stocking rate of 30 animals ha^{-1} during a period of 30 days of stubble grazing (Moujahed *et al.*, 2015; Guesmi *et al.*, 2019).

During 2015–2017 the AC Maghreb project was funded by the French Association for International Cooperation for Agricultural Development (Association Française de Coopération Internationale pour le Développement Agricole, FERT) in Tunisia and Morocco. The project aimed to develop innovative practices in CA systems, especially sowing under permanent living plant cover (semis sous couvert végétal vivant permanent, SCVP) through farmers' groups, and to raise awareness of the project among Tunisian national stakeholders. The project activities in Tunisia were implemented by FERT in collaboration with INGC and INRAT.

As a result of the good performance achieved during the first phase of CLCA project (see above), the project was allowed to carry on with a second phase as Use of Conservation Agriculture in Crop Livestock Systems (CLCA) in the Drylands for Enhanced Water Efficiency, Soil Fertility and Productivity in Near East and North Africa (NEN) and Latin America and the Caribbean (LAC) Countries. This phase of the project is funded by IFAD, managed by ICARDA and coordinated by INRAT in Tunisia, with the collaboration of INGC and the Office of Livestock and Pasture (l'Office de l'Elevage et des Paturages, OEP) for 4 years (2018–2022). The project aims to up-scale CLCA technologies in the semi-arid regions of the northern part of the country (Siliana, Kef, Beja and Zaghouan governorates).

Recently, three other research projects into CA were funded for 4 years (2019–2023) by the EU through the consortium Partnership for Research and Innovation in the Mediterranean Area (PRIMA) programme, in which Tunisia is a partner in all three projects. These projects implemented in Tunisia by INRAT are: (i) ConServeTerra project Overcoming the Physical and

Mental Barriers for Up-scaling Conservation Agriculture in the Mediterranean; (ii) 4CE-MED project Camelina: a Cash Cover Crop Enhancing Water and Soil Conservation in MEDiterranean Dry-farming Systems; and (iii) the CAMA project Research-based Participatory Approaches for Adopting Conservation Agriculture in the Mediterranean Area.

A descriptive summary of relevant CA projects and initiatives in Tunisia is presented in Table 7.1.

7.3 Current Status

The development of CA in Tunisia during the period 1999–2019 (20 years) can be divided into four phases: (i) initiation (1999–2003); (ii) experimentation (2003–2007); (iii) consolidation (2007–2010); and (iv) up-scaling (2010–2019) (Cheikh M'hamed *et al.*, 2019).

The CA areas (ha) increased considerably from 27 ha implemented on 11 farms in 1999 to 167 ha implemented by 30 farmers in 2000–2001, and to more than 2900 ha in 2005 (Richard, 2007). In 2007 more than 6000 ha distributed among 78 farms (Baccouri, 2008) were cultivated under CA. The areas under CA continued to increase considerably, reaching 12,000 ha in 2010 (Angar, 2010) and 14,000 ha in 2016, operated by almost 200 farmers and 107 NT seeders (Angar, 2016). Currently, the areas under CA are estimated at 16,000 ha (Fig. 7.1).

7.4 Characteristics of the Main Conservation Agriculture Systems

Most of the areas under CA in Tunisia are located in semi-arid regions. Production systems in these regions are mainly based on field crops and especially cereal production (wheat, barley and oat) combined with ruminant livestock. These systems can be different from the systems in other parts of the world where many typical CA farmers manage large and small land areas. Smallholder farmers practice CA collectively in Tunisia through their respective cooperatives. Mechanization service provision for CA (particularly zero-tillage seeding) is not yet strongly developed in the country.

From a system component perspective, it is remarkable that large-scale CA farmers, focusing on field crops, face no major constraint in terms of permanent land cover since biomass and stubble grazing is not usually practised by these types of farmers. They are also usually highly specialized, and they effectively produce forage feed for their livestock. However, small holder farmers usually practise both crop and livestock activity, and give preference to their livestock, as these are usually a primary source of income and risk management. For these farmers, it can be a challenge to manage the three CA interlinked core practices, with zero-tillage as the most adopted practice initially. These smallholder farmers also tend to overgraze crop biomass due to the lack of summer sources of feed for their animals (Fig. 7.2). Some ongoing scaling initiatives include the introduction of CA cropping with trees (e.g. rainfed olive orchards with large spaces between tree lines). Others include the enhancement of forage seed availability for smallholder farmers (especially for the most successful and in-demand seeds such as vetch). These scaling initiatives are enriching the diversity of farming systems where CA systems are being adopted.

7.5 Main Achievements

Early work on CA (1999–2003) in Tunisia showed that the introduction of NT practice increased grain yields components (e.g. tillering, ear density, grain number/ear) and straw production of cereal crops, in addition to improved soil moisture availability. However, for legume crops, yields were often better under CovA compared to CA, due to poor weed control under CA, which is based only on glyphosate at pre-sowing and selective herbicide at post-sowing. However, under CovA, weed control was based on selective herbicide at post-sowing and on mechanical weeding using light ploughing between the rows of legume crops (Raunet *et al.*, 2004). For the period from 2001 to 2009, Angar *et al.* (2011) recorded an average increase of 3000 kg ha^{-1} under CA compared to CovA in durum wheat grain yields (6500 kg ha^{-1} and 3500 kg ha^{-1}, respectively) in sub-humid (Mateur region) and semi-arid regions (Krib region). Following

Table 7.1. Relevant CA projects and initiatives in Tunisia. Authors' own table.

Project	Donor/Implementing	Period	Region	CA technologies considered	Level of intervention	Contribution to scaling*
PDRAI – Integrated Rural and Agricultural Development Project	IFAD/AFD-ESAK-CTC	1999–2014	Siliana-Kef-Mateur	NT	Farmer; regional	Low
PADAC-phase I : Projet d'Appui au Développement de l'Agriculture de Conservation	FFEM/AFD-CTC-ESAK	2001–2004	Zaghouan-Kef-Jendouba-Béja-Bizerte	NT; crop rotation	Farmer; regional	Moderate
PADAC-phase II : Projet d'Appui au Développement de l'Agriculture de Conservation	FFEM/AFD-CTC-INGC-ESAK-APAD	2007–2011	Zaghouan-Kef-Jendouba-Béja-Bizerte	NT; crop rotation; SCVP	Farmer; regional; national; policy maker	High
Conservation Agriculture for smallholders	AAAID/INGC-ESAK	2007–2009	Kef-Bizerte-Siliana	NT	Farmer; regional	Moderate
CANA-Rapid adoption of Conservation Agriculture in North Africa for smallholders	ACIAR/ICARDA-INRAT–INGC	2012–2015	Fernana	NT; crop rotation; alley cropping; residue management; forage crop mixtures	Farmer; regional; policy maker	Moderate
Conservation Agriculture project	FAO/ ICARDA-INRAT	2013–2014	Siliana	NT	Farmer; regional; policy maker	Low
CLCA-phase I-Integrated Crop-Livestock under Conservation Agriculture for Sustainable Intensification of Cereal-based Systems in North Africa and Central Asia	IFAD/ICARDA-INRAT	2013–2016	Siliana	NT; crop rotation; alley cropping; forage crop mixtures; crop–livestock integration	Farmer; regional; policy maker	Moderate
CRP-Dryland Systems: Agropastoral systems	CGIAR/ICARDA-INRAT-IRA	2013–2015	Béni-Kedache-Sidi-Bouzidi transect	NT; crop rotation; alley cropping; forage crop mixtures	Farmer; regional;	Low
AC-Maghreb-Conservation Agriculture in Maghreb	FERT/INGC-INRAT	2015–2017	El-Krib; Utique; Fernana; Tahent	NT; cover crop; forage crop mixtures; meslin; SCVP	Farmer	Low
Rainfed Conservation Agriculture project in the framework of PAPS – Eau (Programme d'Appui aux Politiques Publiques de Gestion des Ressources en Eau pour le Développement Rural et Agricole)	EU/IRESA-ESAK	2015–2018	Kef-Béja	NT; forage crop mixtures	Farmer; regional;	Low

CLCA-phase II-Use of Conservation Agriculture in Crop–Livestock Systems (CLCA) in the Drylands for Enhanced Water Use and Soil Fertility in NEN and LAC Countries	IFAD/ICARDA-IRESA-INRAT–INGC-OEP	2018–2022	Siliana-Kef-Béja-Zaghouan	NT; forage crop mixtures; meslin; crop–livestock integration	Farmer; regional; national; policy maker	High
ConServeTerra-Overcoming the physical and mental barriers for up-scaling Conservation Agriculture in the Mediterranean	PRIMA-EU/INRAT-OEP-INGC-APAD	2019–2023	Siliana-Kef-Ben Arouss-Mateur-Bou Salem	NT; minimum soil disturbance; crop–livestock integration; forage crop mixtures; meslin; residue management; crop rotation	Farmer	Starting project
4CE-MED - Camelina: a Cash Cover Crop Enhancing Water and Soil Conservation in MEDiterranean Dry-farming Systems	PRIMA-EU/INRAT	2019–2023	Kef-Ben Arouss-Bou Salem	NT; minimum soil disturbance; crop rotation	Farmer	Starting project
CAMA-Research-based participatory approaches for adopting Conservation Agriculture in the Mediterranean Area	PRIMA-EU/INRAT-APAD	2019–2023	Siliana-Kef-Ben Arouss	NT; minimum soil disturbance; crop rotation	Farmer	Starting project

*Contribution to scaling: The contribution to scaling was based on the appreciation of the direct farmers targeted by the project and also on the level of the intervention of the project (farmer, regional, national).

Low: fewer than ten farmers were targeted and/or only one region was considered

Moderate: between 10 and 50 farmers were targeted and/or between 2 to 4 regions were considered

High: More than 50 farmers were targeted and/or more than 4 regions were considered

NT, no tillage.

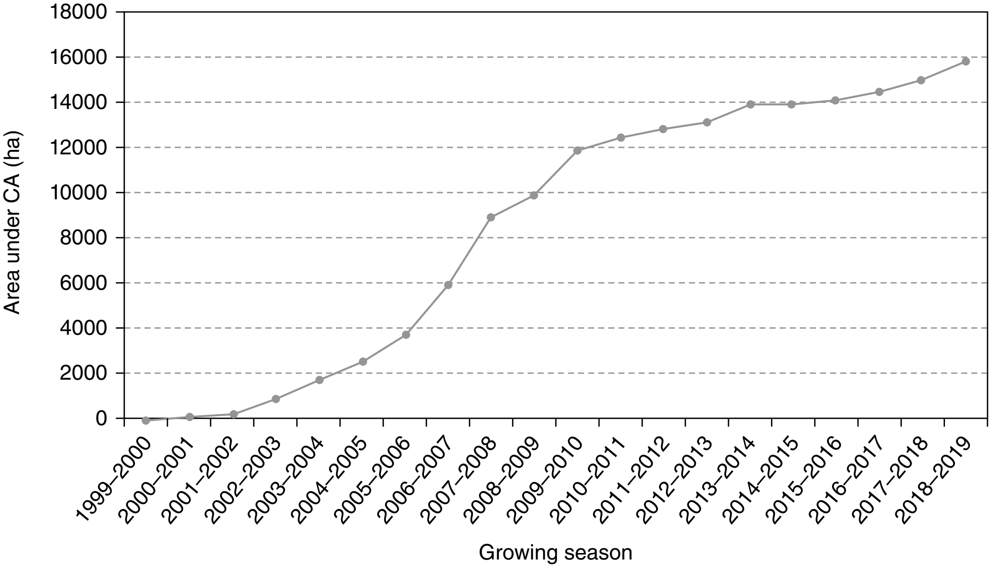

Fig. 7.1. Evolution of Conservation Agriculture (CA) areas (ha) in Tunisia, 1999–2019. Authors' own figure.

Fig. 7.2. (a) Stubble grazing during summer period; (b) Zero-tillage seedling in Beja Region, northwestern Tunisia. Photos courtesy of Zied Idoudi, 2019.

the same trend, Cheikh M'hamed *et al.* (2014) showed that the grain yield and above-ground biomass of durum wheat increased under CA, compared to CovA, after 3 years of experimentation (2007–2009) in the locality of Bourbiaa, a semi-arid region (Table 7.2). Higher wheat yields and improvements in soil water storage under CA indicated an increase in WUE (Table 7.2).

Results of experiments conducted in the framework of the CANA project during two growing seasons (2012/13 and 2013/14) in Fernana region (sub-humid) showed that CA improved the WUE of durum wheat compared to CovA for the 2013/14 and 2014/15 growing seasons by 7% and 15%, respectively (Cheikh M'hamed *et al.*, 2016). In addition, the results of 7 years of experiments (2000–2007) in Mateur

Table 7.2. Effect of Conservation Agriculture on grain yield (kg ha^{-1}), above-ground biomass (kg ha^{-1}) and water use efficiency (kg ha^{-1} mm^{-1}) of durum wheat in the locality of Bourbiaa (by permission of Cheikh M'hamed *et al*., 2014).

Growing season	Treatment	Grain yield (kg ha^{-1})	Above-ground biomass (kg ha^{-1})	WUE-g* (kg ha^{-1} mm^{-1})	WUE-b* (kg ha^{-1} mm^{-1})
2007–2008	CA	2800^{a}	6900^{a}	7.36^{a}	18.15^{a}
	CovA	2600^{b}	6300^{b}	6.19^{b}	15.00^{b}
	LSD $_{(0.05)}$	175	266	0.15	1.13
2008–2009	CA	3200^{a}	7600^{a}	8.08^{a}	19.00^{a}
	CovA	3000^{b}	7250^{b}	6.66^{b}	16.15^{b}
	LSD $_{(0.05)}$	192	320	0.36	1.32
2009–2010	CA	3050^{a}	7300^{a}	7.14^{a}	17.38^{a}
	CovA	2980^{a}	7280^{a}	6.52^{b}	15.82^{b}
	LSD $_{(0.05)}$	160	380	0.41	0.95

*WUE-g: Water use efficiency of grain yield.

*WUE-b: Water use efficiency of biological yield.

CA, Conservation Agriculture; CovA, conventional agriculture; LSD, least significant difference

^{a} and ^{b} indicate statistically significant differences between treatments means ($p < 0.05$) while values that have same letter indicate statistically no significant differences between treatment means ($p < 0.05$).

region (sub-humid) showed that water availability in the soil profile improved because of CA practices, compared to plots under CovA (Jemai *et al.*, 2013). In the same context, Nouiri (2010) showed that CA improved soil water balance compared to CovA and explained the results by the reduction in surface runoff and the improvement in water infiltration.

Furthermore, Errouissi *et al.* (2011) illustrated that CA improves the soil biological life compared to CovA. The results of their experiments in two sites (semi-arid) in northwestern Tunisia showed that several years of CA adoption leads to improved soil arthropod fauna (abundance and quality) and earthworms.

In the Tunisian context, the effect of CA on soil organic carbon (SOC) depends on the length of time since the conversion to CA was implemented, on the SOC inputs through shoot and root biomass and stubble biomass, and on the cropping systems/crop rotation (Bahri *et al.*, 2017). In fact, results from several on-farm experiments showed an improvement in SOC under CA compared to CovA on the surface soil layer (Angar *et al.*, 2011; Jemai *et al.*, 2012; Chibani *et al.*, 2018). However, Ben Moussa-Machraoui *et al.* (2010) and Bahri *et al.* (2017) did not observe an increase in SOC after CA adoption and found that the years since the conversion to CA were insufficient to increase SOC if only low quantities of biomass were left on the soil surface, due to the commercialization of cereal straws and also by overgrazing during the summer period.

Recently, a research study based on crop modelling (APSIM model) showed that adopting CA at a large scale in Tunisia contributes to making wheat production more resilient to CC through: (i) enhanced wheat yield (15%); (ii) improved WUE (13%–18%); (iii) increased organic carbon accumulation (0.13 t ha^{-1} year^{-1} to 0.18 t ha^{-1} year^{-1}); and (iv) reduced soil loss caused by soil water erosion by 1.7 t ha^{-1} year^{-1} to 4.6 t ha^{-1} year^{-1} of soil loss (Bahri *et al.*, 2019).

The same study created a map of potential areas where CA is technically suitable for adoption, and also the priority areas where CA can be adopted, specifically to reduce erosion and enhance soil fertility. For identifying CA priority areas, the approach was based on the map overlay process using a GIS tool. Three data layers were considered: soil organic matter content lower than 2%, land slope between 5% and 15%, and the cereal areas. Results showed that CA can be relevant for all field crop areas in Tunisia (2 M ha), which is considered as the potential area for CA adoption. However, results showed that the priority areas for CA adoption were spread across 260,000 ha (Fig. 7.3) in the north of the country (Bahri *et al.*, 2019).

Economic studies have confirmed that CA decreases the cost of land preparation by 20% to

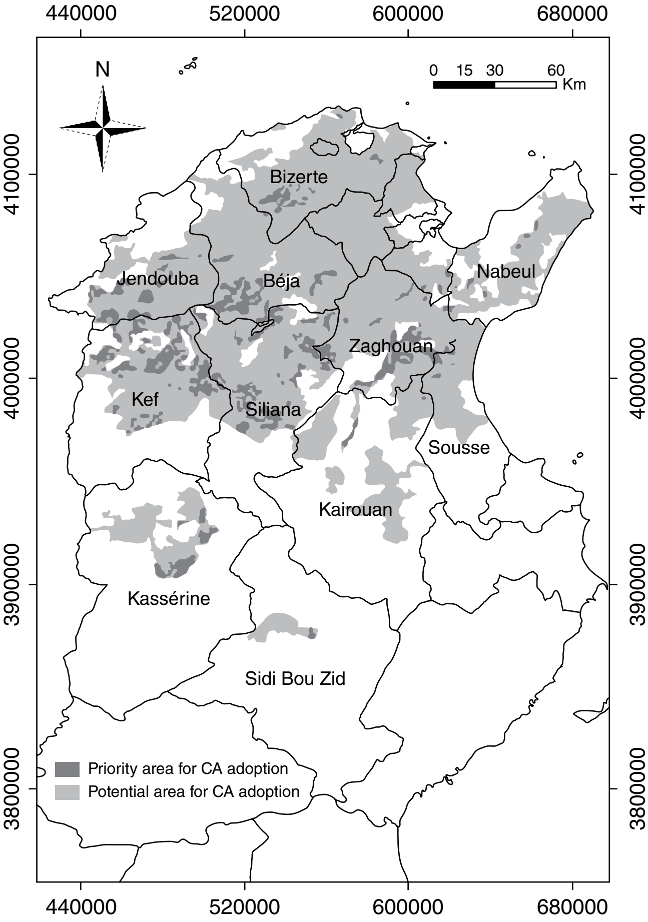

Fig. 7.3. Potential areas and priority areas for Conservation Agriculture (CA) adoption in Tunisia (Bahri *et al*., 2019).

40% (Angar, 2010), saving time and energy at farm level by up to 50% (Angar, 2010; Thabet, 2010). This is a good entry point to convince farmers to adopt CA. However, the full savings due to the reduction in land preparation costs at the beginning of the growing season is not always achieved during the first years of CA adoption, as it may take time to convert the whole farm; lack of experience and expertise about how to manage NT seeding and weeding may also have an impact.

Since 2013, research on CA in Tunisia focused on crop–livestock integration in CA systems, mainly on the conflict between mulch for covering the soil surface and biomass/stubble grazing, especially during the summer period, which is a common and traditional practice in Tunisia. Trade-offs between the use of stubbles for livestock feeding or for covering the soil have to be resolved, particularly in drylands where available crops for fodder production is low. The stubble and biomass retention principle of CA seemed to be a challenge with extensive livestock systems in Tunisia and, if it is adopted, competition with livestock feeding needs to be optimized and resolved.

In this context, a stubble grazing model (30:30 model) was developed in the framework of a CLCA project to give farmers adopting CA some options for reasonable stubble grazing during the summer period (Moujahed *et al*., 2015; Guesmi *et al*., 2019). The 30:30 model is based on the stocking rate of 30 animals ha^{-1} during 30 days of stubble grazing. This model allows the maintenance of adequate crop biomass (mulch) on the soil surface (more than 0.4 t ha^{-1} of residue on the soil surface or 40% of the initial biomass of residues on soil surface) and at the same time maintains animals in good condition (Moujahed *et al.*, 2015; Guesmi *et al.*, 2019).

For better crop–livestock integration in CA systems and for enhancing crop diversification/crop rotation, research has focused on the introduction of new promising forage species and forage crop mixtures (cereals and legumes). Increasing forage production allows reduction in the pressure of grazing crop biomass during the summer. Several alternative forage species (vetch, lucerne, sulla) and forage crops mixtures (triticale 40% + vetch 60%; oat 30% + vetch 70%; triticale 30% + vetch 70%) were introduced and disseminated among farmers adopting CA in northern Tunisia (Fig. 7.4). Results showed that the yields of forage crops and forage crop mixture introduced under CA ranged from 4 to 12 t ha^{-1} depending on the bioclimatic zone, with high nutritional quality of fodder, which would maintain an intensive production system for dairy products and small ruminants (Fig. 7.4). Indeed, for vetch crops, the crude protein content was an average of 14% (CANA project, 2015; Abidi *et al.*, 2019; CLCA project, 2019).

7.6 Major Constraints to Greater Adoption of Conservation Agriculture in Tunisia

Previous assessments and reviews conducted in the framework of the different CA projects (PADAC, CANA, CLCA) in Tunisia showed that the major constraints to CA adoption were related to: (i) competition between livestock (grazing) and maintaining biomass on the soil surface as mulch; (ii) high cost of NT seeders and lack of affordable, locally produced seeders for small- and medium-scale farmers with low investment capability; (iii) the unsolved problem of weed control management, especially in food legume crops and during the transition phase from CovA to CA; (iv) soil compaction problems after a few years of CA practice; (v) limited crop rotation (dominance of cereal monoculture) due to the lack of forage seed availability to interested farmers; (vi) limited range of species and choices for cover crop, especially in the summer period; and (vii) lack of a national strategy to promote good quality CA management and provide an enabling policy environment for wider adoption (Cheikh M'hamed *et al.*, 2019).

7.7 Future Perspectives and Approach for Rapid Adoption by Smallholder Farmers

The existing policy and institutional environments to promote the scaling of CA in Tunisia are still inadequate. It is recommended that a set of incentives be provided in the framework of a national strategy for promoting CA in Tunisia. Such a strategy should be based on: (i) encouraging the creation of farmers' organizations and subsidize their investments in sustainable land management; (ii) establishing a national committee on CA, bringing together different

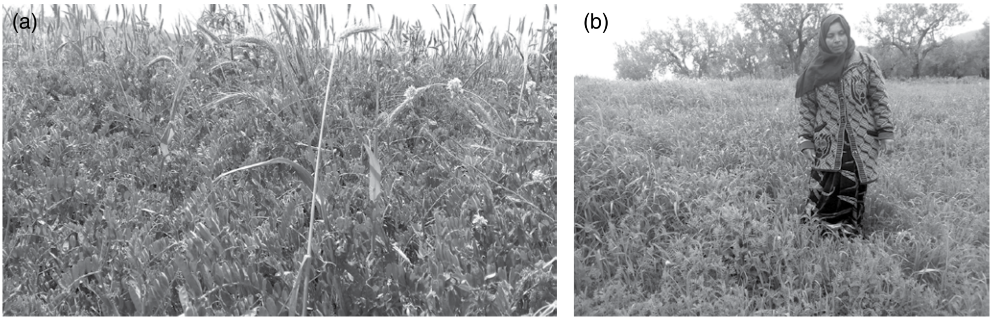

Fig. 7.4. (a) Forage crop mixture (vetch–triticale) in Fernan region, northwestern Tunisia. Authors' own photo. (b) Vetch crop in small integrated farm in northwestern Tunisia. Authors' own photo.

stakeholders working on CA promotion and development to further highlight the opportunities and impact of this practice; (iii) establishing a national R&D programme on CA to fill the existing knowledge gap; (iv) adopting an innovative and flexible technology transfer and adoption model well adapted to CA specificities and to different farmers' conditions and characteristics; (v) including CA in the training curriculum of agricultural technicians, agronomists and engineers; (vi) implementing the adoption of CA in the large publicly owned farms (e.g. OTD, OEP); (vii) considering specific subsidies for the purchase of zero-tillage seeders for enhanced land management practices; and (viii) raising public awareness through broadcasting CA topics by different media channels (e.g. radio, TV and newspapers).

Beyond a national strategy of CA, researchers, development agents and other stakeholders currently working on CA in Tunisia need to consider a more comprehensive and flexible approach for successful scaling agricultural practices under CA. Some pointers include:

- Promoting minimum soil disturbance practices which are relatively affordable to farmers, while continuing efforts to develop and commercialize locally produced zero-tillage seeders adapted to farmers' investment capacities and agroecologies.
- Promoting new, promising forage species and forage crop mixtures adapted in several agroecological zones developed in the framework of several R&D projects, for enhancing crop diversification (one of the three pillars of CA).
- Greater precision in defining which specific CA practices are feasible and adapted to different agroecosystems.
- Given the minimum resources currently available to promote CA in the country, it is most important to determine scaling opportunities that can generate the best return on investments.
- Monitoring progress made and documenting impacts of CA systems and practices in order to consider their further promotion in the future, since generating more evidence about the importance of CA practices helps to stimulate changes in the enabling policy environment (the demand for the technology in general).
- Using innovative tools for knowledge management and information sharing will be needed to further stimulate the demand for CA systems and practices from a wider range of clients (small- and large-scale farms, public and private, NGOs and other environmental activists, etc.). This will result in greater public engagement for CA systems and practices in different farming systems of the country.

7.8 Conclusions

Most farms in Tunisia are small (80% are less than 10 ha) and farming systems are mainly based on crop–livestock integration, one of the main pillars of the resilience of cropping systems in the Middle East and North Africa (MENA) region. Technologies introduced during the Green Revolution have induced an improvement in agricultural production. However, this agricultural intensification has accelerated the degradation of soil resources which has been accentuated in recent years by CC. Indeed, intensive/successive tillage operations have contributed extensively to soil degradation. The main objective of the introduction of CA in Tunisia was to mitigate the impact of CC and to restore and preserve natural resources. Despite promising research results on CA during the last 20 years of experience, current CA adoption of 16,000 ha is rather modest. An overview of the main research results and achievements in CA in Tunisia shows a lack of a specific national research programme, especially on NT seeders and agricultural practices adapted to different agroecologies. The development of CA-specific mechanization adapted for smallholders and the development of CA-specific farming practices, in particular crop sequences adapted to the local context and profitable for smallholders, are needed for wider adoption of CA in the coming years. Furthermore, the implementation of a national strategy to promote the scaling of CA in Tunisia is strongly recommended. Such a strategy should be based on the participatory management approaches that can involve all stakeholders (public, private and civil sectors).

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8 Assessing the Application and Practice of Conservation Agriculture in Malawi

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Abstract

The Conservation Agriculture (CA) system promoted by Total LandCare (TLC) and the International Maize and Wheat Improvement Center (CIMMYT) is based on 14 years of experience grounded on the principles of minimum soil disturbance, good soil cover and crop associations. The platform to promote CA in Malawi was to build a strong base of knowledge about best practices through an innovative non-linear research–extension approach. Long-term on-farm trials were conducted in multiple sites across Malawi to compare yields and labour inputs of CA with conventional ridge tillage on the same footing. Results showed the superiority of CA in terms of maize and legume yields with significant savings in labour and resilience to climate change. The results provided the basis to upscale CA although adoption was lower than expected. Key challenges included: (i) lack of exposure and training; (ii) conflicting extension messages; (iii) misconceptions about inputs and tools for CA; (iv) resistance to change unless CA is clearly seen to be a better practice; (v) fears about controlling weeds, pests and diseases under CA; and (vi) perceptions that increased termites and earthworms are harmful to soils and crops.

Keywords: On-farm trials, crop yields, labour savings, barriers to adoption, development of guidelines

8.1 Introduction

In 2019, the Human Development Index ranked Malawi 172 out of 189 countries. Of the population, 51.2% live below the poverty line, 28.5% face severe poverty and 70.9% earn less than US$1.90 per day (UNDP, 2019). The critical challenges facing smallholder farmers are well documented in the literature (UNICEF, 1993; Bunderson and Hayes, 1995; World Bank, 1995; Bunderson *et al.*, 2002; Ellis *et al.*, 2003; Government of Malawi, 2007a, b; 2017; UNDP, 2007; 2019; Denning *et al.*, 2009; Thierfelder and Wall, 2011; Thierfelder *et al.*, 2013a; Wall *et al.* 2013; Ministry of Agriculture, Irrigation and Water Development, 2016; 2018). The reality is that rural households face many inter-related challenges. These include: (i) declining soil health with rising needs for inputs and more sustainable practices; (ii) low farm productivity and diversification with overdependence on rainfed maize, a drought-sensitive, nutrient-demanding crop of low nutritional value; (iii) environmental degradation from poor land-use practices, which is eroding the productive capacity of the natural resource base; (iv) limited access to micro-finance and capital with weak linkages to markets; (v) decreasing abundance of wood for fuel and timber to meet basic domestic and

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farm needs; (vi) low opportunities to acquire new knowledge and skills; (vii) high incidence of water-borne diseases due to a lack of potable water and good sanitation; and (viii) inadequate support services, notably in agriculture, health and education.

The focus of this chapter is threefold: (i) to review the application and practice of Conservation Agriculture (CA) in Malawi in terms of its effects on crop yields and labour costs; (ii) to assess key barriers and drivers of adoption; and (iii) to present innovative participatory models of research and extension to scale up CA as a transformative technology for smallholder farmers in Malawi.

8.2 Background on Conventional Ridge Tillage (CRT)

The common method of land preparation among smallholders across most of Malawi involves manually clearing the land of crop residues and weeds, constructing ridges with hoes and planting crops on top of the ridges at a spacing appropriate to the crop. Ridging was introduced by the colonial government more than 70 years ago as a soil and water conservation practice. With ridges spaced at 75 cm, the manual work entails constructing 13 km of ridges per ha, which involves moving an average of 720 tons of soil ha^{-1} every year. At an average of 40-person days per ha, the labour cost of making ridges means that the first planting rains are often missed, along with the nitrogen flush that comes with them. The impact is significant because late planting typically reduces the yield potential of crops by 25%–30%. It is worth noting that farmers often plant late because they begin land preparation only a month or two before the onset of the rains.

Despite over 7 decades of promoting contour ridging in Malawi, no scientific basis has been advanced that it reduces runoff, erosion and general soil degradation (Aagaard, 2011). To the contrary, empirical evidence indicates that rainfall is channelled into the compacted furrows between the ridges, which results in water runoff that carries huge amounts of topsoil off the land (Mohamoud and Berger, 1998; NCATF, 2016; Bunderson *et al*., 2017). A report by FAO currently estimates the loss of topsoil in Malawi to average 29 tonnes ha^{-1} per annum (Omuto and Vargas, 2019), which is a significant increase from the 20 tonnes ha^{-1} per annum reported by the World Bank in 1992. The massive volume of soil loss is reflected by increasing levels of silt deposited in rivers, dams and lakes. This is clearly evident from bands of silt-laden waters extending from the mouths of rivers out into Lake Malawi. These bands of silt have steadily increased in size and width over time.

Fig. 8.1. Every year, old ridges are split to form new ridges in the position of the old furrow (Emanuel Banda (left) in Dedza, and Jaleke Roland (right) in Ukwe, Lilongwe). Authors' own photos.

Box 8.1 Land Clearing, Burning and Ridging

Imagine a bare piece of recently tilled land with ridges of dry, loose soil devoid of any live or dead plant material. Now imagine what happens when a heavy rainstorm hits the ground. The impact of the rain washes most of the dry, loose soil down the ridge into the compacted furrows and off the field, carrying away the topsoil into streams and rivers, ultimately reaching Lake Malawi.

After burning fields to remove crop residues and weeds, farmers expend a huge amount of energy to manually construct ridges. The result leads to water runoff and loss of valuable top soil which cannot be replaced, thus impacting long term farm productivity.

Ultimately, maintaining the status quo of conventional tillage and ridging is not an option for Malawi and its farmers, nor for those of us entrusted with making positive changes for the future sustainability of agriculture in this region.

8.3 Development and Application of Conservation Agriculture (CA) in Malawi

8.3.1 On-farm Trials

Long-term on-farm trials were established in ten sites across six districts in Malawi to compare maize and groundnut yields under CA with CRT (see map in Fig. 8.2). Table 8.1 provides details about the location and basic physical characteristics of each site in the six districts. Selection of sites took into account variability in rainfall, soil and elevation (see Table 8.1). All sites are deforested due to high population pressures for agricultural land, fuel wood and building material. Maize is the main food crop grown in all areas, often in a monoculture but sometimes intercropped with pigeon peas (*Cajanus cajan*) in the southern sites and cowpeas (*Vigna unguiculata*) in the more northern sites. Groundnuts (*Arachis hypogaea*) and cassava (*Manihot esculenta*) are also important crops. Key cash crops include tobacco (*Nicotiana tabacum*), cotton (*Gossypium hirsutum*) and various vegetable crops. Other factors affecting the selection of sites included the presence of Total LandCare (TLC) and government personnel with the resources, qualifications and interest to oversee the trials.

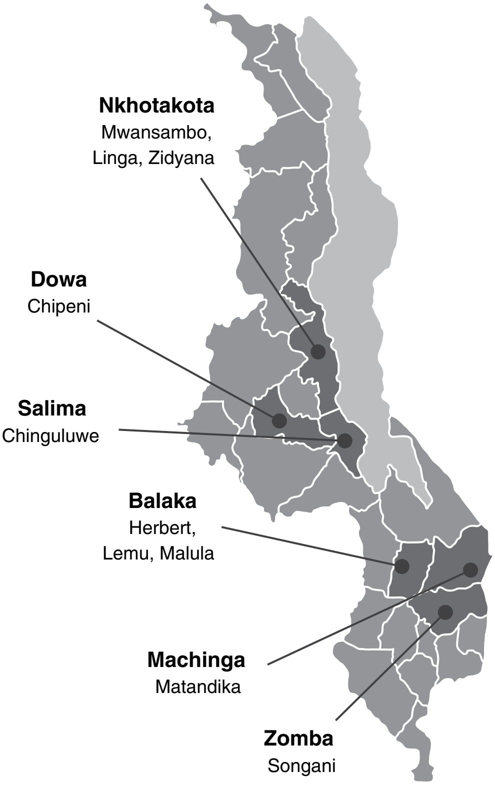


Fig. 8.2. Map showing the location of ten sites in six districts with clusters of six farmers per site. Authors' own figure.

Table 8.2 shows the number of farmers undertaking the on-farm trials by site and year. The trials were designed and implemented under a collaborative programme between TLC, the International Maize and Wheat Improvement Center (CIMMYT) and the Ministry of Agriculture, Irrigation and Water Development (MoAIWD). All trials were managed by farmers with technical support from TLC and MoAIWD staff. The numbers of sites and on-farm trials were increased over time, each with clusters of farmers. Year 1 involved only three farmers at one site (Malula). In years 2 and 3, the number of sites was increased to four and six, respectively, and the number of farmers was increased to five or six per site (see Table 8.2). Thereafter, new sites were added with clusters of six farmers per site. Attempts were made to maintain all trials, with few exceptions due to logistics or farmer illness (see Table 8.2).

Table 8.1. Location and physical characteristics of the on-farm sites. Authors' own table.

District	Sites	Latitude (degrees)	Longitude (degrees)	Metres a.s.l.	Texture 0–30 cm	Soil type	Mean rainfall (mm)
Balaka	Malula	–14.96	34.98	605	LS	Eutric Fluvisols	764
	Lemu	–14.79	35.00	720	SL	Chromic Luvisols	851
	Herbert	–14.88	35.04	635	SL	Chromic Luvisols	671
Dowa	Chipeni	–13.76	34.05	1166	SL	Chromic Luvisols	822
Machinga	Matandika	–15.17	35.28	688	SL	Cambic Arenosols	1099
Nkhotakota	Mwansambo	–13.29	34.13	632	SCL	Haplic Lixisols	1276
	Zidyana	–13.23	34.24	535	SCL	Haplic Luvisols	1266
	Linga	–12.80	34.20	491	SL	Alluvial soils	1078
Zomba	Songani	–15.32	35.39	803	SCL	Haplic Lixisols	1241
Salima	Chinguluwe	–13.69	34.24	657	SCL	Eutric Cambisols	848

LS, loamy sands; SL, sandy loams; SCL, sandy clay loams.

On-farm trials for each farmer included three treatments of 0.1 ha per treatment as follows:

1. Sole maize under conventional ridge tillage (CRT Maize): Ridges were formed manually each year 75 cm apart with a plant spacing of 25 cm for a plant population of 53,333 plants ha^{-1}. Planting was done with a hand hoe on ridges prepared in September and October. Generally, weeding was done twice with hand hoes, which included a second weeding when banking or rebuilding ridges.

2. Sole maize under Conservation Agriculture (CA Maize): Previous ridges were not maintained and maize was planted with a dibble stick on top of the (old) degraded ridges at the same spacing of 75 cm between rows and 25 cm between plants for the same population density as treatment 1. In the first year, crop residues in the form of maize stalks were imported and applied at a rate of 2.5 t ha^{-1} because the residues had been removed or burned. After the first season, maize stalks harvested from the experiments were retained *in situ* as crop residues. Weed control involved applying a mixture of 2.5 l ha^{-1} glyphosate (N-(phosphono-methyl) glycine). A pre-emergence herbicide was applied after planting at 6 l ha^{-1} (Bullet® (25.4% alachlor (2-chloro-N-(2,6-diethylphenyl)-N-(methoxymethyl) acetamide) and 14.5% atrazine (2-chloro-4-ethylamino-6-isopropylamino-1,3,5-triazine)). Spot hand weeding was done if weeds reappeared after applying the herbicides. The rate of Bullet in the central sites of Malawi was reduced to 2.5 l ha^{-1} based on observations that this level was adequate to control weeds. In 2010, Bullet was replaced in the central sites by the residual herbicide Harness® (acetochlor (2-ethyl-6-methylphenyl-d11)) at a rate of 1 l ha^{-1}. In South Malawi, Bullet was maintained at the rate of 6 l ha^{-1}.

3. Maize with a legume intercrop (CA Maize/Legume): Most operations were the same as for treatment 2 and used the same maize spacing. Legumes were interplanted with a dibble stick between maize rows at a plant spacing of 40 cm for cowpeas (for northern central sites) and 50 cm for pigeon peas (for southern sites). Weed control was achieved through the application of glyphosate at 2.5 l ha^{-1} at or just after planting followed by manual weeding with hoes. No Bullet or Harness was applied to these plots.

Starting in the 2011/12 season, all plots were split to assess the effect of maize rotations with groundnuts. The number of seasons of rotation depended on the starting date of each trial (see Table 8.2).

Management

All plots within a site were treated uniformly in terms of crop variety, time of planting, type and rate of fertilizer use, spacing and population density of maize. Experiments were managed by farmers with local support from extension officers from TLC and MoAIWD. Planting was done after the first effective rains in each area, which usually occurred between the last week of November and mid-December of each year. Maize varieties DKC8033 and DKC8053 were used in the south, whereas SC403, DKC8053 and DKC9089 were used in north–central sites. The variety of maize was uniform for all plots

Table 8.2. Numbers of farmers involved in on-farm trials by site and year. Authors' own table.

		Number of farmers by site and year of harvest[1]															
District	Sites	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Total
Balaka	Malula	3	5	5	6	5	5	6	6	6	6	6	6	6	6	6	**83**
	Lemu			5	5	6	6	6	6	6	6	6	6	6	6	6	**76**
	Herbert				6	6	6	6	6	6	6	6	6	6	6	6	**72**
Dowa	Chipeni		5	6	6	6	6	6	6	6	6	6	6	6	6	6	**83**
Machinga	Matandika			5	6	6	6	6	6	6	5	6	6	6	6	6	**76**
Nkhotakota	Mwansambo		5	6	6	6	6	6	6	6	6	6	6	6	6	6	**83**
	Zidyana		5	6	6	5	6	6	6	6	6	6	6	6	6	6	**82**
	Linga				5	6	6	6	6	6	6	6	6	6	6		**65**
Zomba	Songani				5		5			6	6	6	6	6	6	6	**52**
Salima	Chinguluwe					6	6	6	6	6	6	6	6	6	6	6	**66**
No. of farmers per annum		3	20	33	51	52	58	54	54	60	59	60	60	60	60	54	**738**

[1] Shaded cells indicate that trials had not started or that there were logistical problems at the site for that season.

within a particular site. All treatments received a uniform fertilizer application rate of 69 kg N ha^{-1} which was supplied as 100 kg N:P:K ha^{-1} (23:21:0 + 4S) at planting and 100 kg urea ha^{-1} (46% N) at approximately 3 weeks after planting. The correct fertilizer amount was initially weighed per plot and later applied with a calibrated fertilizer cup at each planting hill to achieve the desired application rate. The fertilizer application was based on the general recommendation currently used by MoAIWD. The row spacing of groundnuts under CA was cut by half to 37.5 cm with 20 cm between planting stations to achieve a more optimum plant population, which is not possible with ridges because they cannot be constructed so close together. As stated above, Treatment 3 used cowpeas for the northern districts and pigeon peas in the southern districts, according to tradition. All plots were kept weed free by hoe weeding in the CRT plots, while the CA plots included herbicides as detailed above.

Comparison of maize yields under CA versus CRT

Results from the on-farm trials clearly show the superiority of planting maize under CA (Fig. 8.3). From the second cropping season, significant differences in maize yields were recorded for all sites between the two CA treatments and CRT. Yield increases varied from 11% and 70% across years (Fig. 8.2), with greater differences in years of low rainfall (see Fig. 8.3). Legume intercrops had no negative effects on maize. Collection of yield data was limited on the intercrops of pigeon peas and cowpeas with maize under CA (see Fig. 8.4), but the data still showed increased returns to land and labour from growing two crops on the same land from the nutritional and market value of the legumes, which fetch a higher price per kg than maize. Other benefits from nitrogen fixation and increased soil cover and biomass (see Fig. 8.10) would be likely to accrue, but these parameters were not measured.

Comparison of groundnut yields under CA versus CRT

Farmers realized significant benefits from rotating groundnuts after maize under CA relative to CRT (see Fig. 8.6). This was achieved primarily because the row spacing was halved under CA to achieve optimum plant population, which is not possible with conventional ridging. The results also doubled the ground cover, which anecdotally was observed to reduce rosette disease. Although not measured, it is also likely that the increased ground cover increased

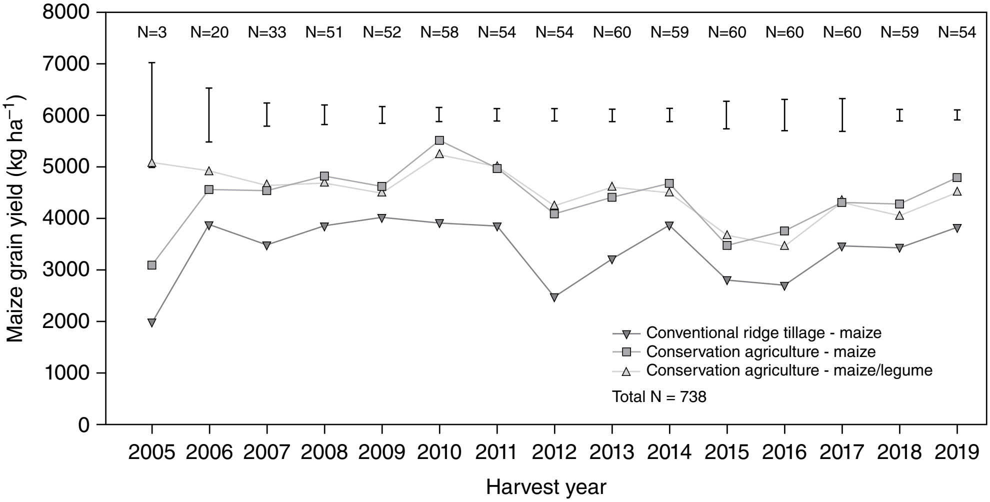


Fig. 8.3. Mean maize yields from on-farm trials, 2005 to 2019. p is significant between CA treatments and CRT for all years except 2005. Error bars represent the standard error of the difference (SED) of the means at $p < 0.05$. From: TLC, CIMMYT, Machinga ADD on-farm CA trials. Authors' own figure.

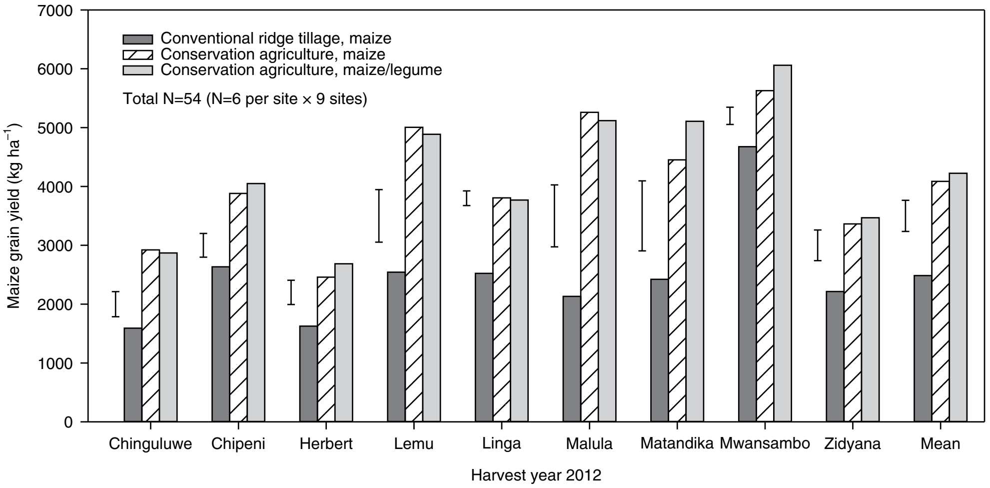


Fig. 8.4. Mean maize yields from on-farm trials in a year of low rainfall. p is significant between CA treatments and CRT for all plots. Error bars represent the standard error of the difference (SED) of the means at $p < 0.05$. From: TLC, CIMMYT, Machinga ADD CA on-farm trials. Authors' own figure.

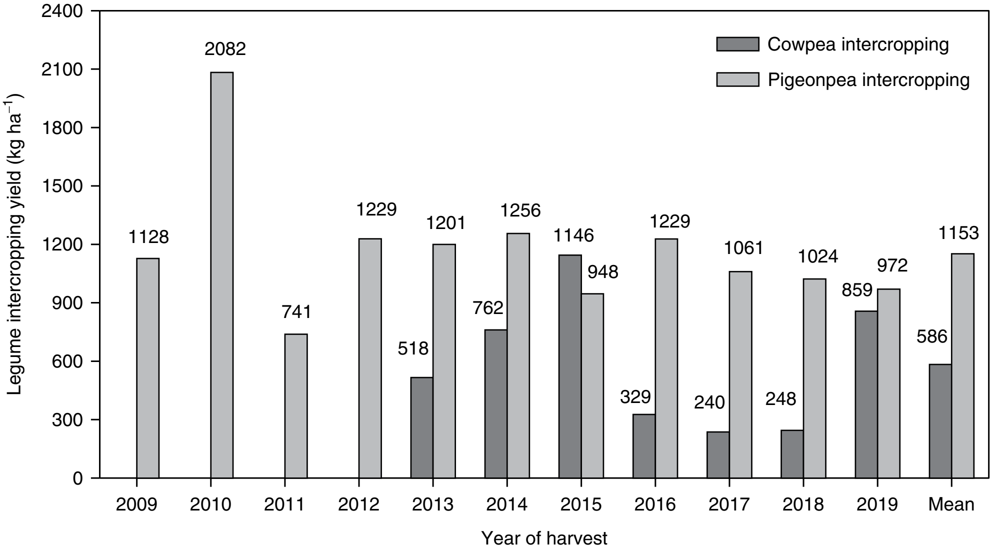


Fig. 8.5. Yields of intercropped cowpeas and pigeon peas from the CA maize/legume treatment in southern Malawi. Yield data for cowpeas were generated from one site (Herbert, Balaka) whereas data on pigeon peas were from four sites (Lemu and Malula in Balaka, Matandika in Machinga and Songani in Zomba). Authors' own figure.

biomass and N fixation while reducing runoff and loss of topsoil.

Labour costs

Labour data were collected from the on-farm trials (see Table 8.3 and Bunderson *et al.*, 2017).

The results reflect a labour savings of 47% and 33% for sole maize and intercropped maize, respectively, under CA versus CRT. The lower savings for intercropping were due to the extra labour for planting and harvesting the legume crop, but this was offset by the yield of the legume intercrop.

Table 8.3. Labour inputs of Conservation Agriculture (CA) versus conventional ridge tillage (CRT). From: TLC, CIMMYT, MoAIWD on-farm trials. Authors' own table.

Labour input (6-h days)	CRT maize	CA maize	CA maize/legume
Land prep/clearing	7.50	0.00	0.58
Ridging	36.00	0.00	0.00
Distributing crop residues on the ground	0.00	6.80	7.15
Planting maize	9.44	10.08	10.08
Planting legume intercrop	0.00	0.00	13.50
Basal dressing	12.28	12.60	13.56
1st weeding	24.63	3.85	3.25
Top dressing (CAN)	11.43	12.00	12.60
Drawing water for herbicide use	0.00	2.40	1.20
Roundup application	0.00	4.17	4.17
Harness application	0.00	4.17	0.00
2nd weeding & banking (rebuilding ridges)	23.29	4.25	2.20
Harvesting maize (stooking/collecting cobs)	12.69	12.69	12.69
Harvesting legume (uprooting plants/collecting pods)	0.00	0.00	11.42
Total labour inputs	**137.26**	**73.01**	**92.40**
Labour savings %	0%	47%	33%

CAN, calcium ammonium nitrate.

Overall, the on-farm trials conducted by TLC, CIMMYT and MoAIWD over the past 15 years provide clear evidence that CA produces higher and less variable yields under changing weather conditions than CRT across many agroecologies and with lower labour costs. These results provide compelling arguments for the positive impacts of CA on household food security, nutrition, income and resilience to climate change.

8.3.2 Development of Guidelines for Implementing Conservation Agriculture (CA)

The introduction of CA in Malawi was strongly influenced by research and on-farm trials on reduced tillage systems in the 1990s and early 2000s, notably by Materechera and Mloza-Banda (1997) and Bunderson *et al.* (2000) in Malawi, and by the conservation farming practices undertaken in Zimbabwe by Oldrieve (1989; 1993) and Munyati (1997), and in Zambia by Haggblade and Tembo (2003) and the Conservation Farming Unit (2007). Arguments in favour of CA over conventional farming are increased yields and soil fertility, reduced loss of rainfall and topsoil, lower production costs and mitigation of impacts from climate change (Munyati, 1997; Haggblade and Tembo, 2003; Ito, *et al.*, 2007; Wall, 2007; Giller *et al.*, 2009; Theodor and Kassam, 2009; Thierfelder and Wall, 2009; 2010a, b; 2011; 2012; 2013a, b, c; Lowe, 2011; Johansen *et al.*, 2012; Thierfelder *et al.*, 2012; Ligowe *et al.*, 2013; Ngwira *et al.*, 2013b).

Recent research and extension work in Malawi, Zambia and Zimbabwe have provided additional evidence that show significant impacts of CA on crop productivity, soils, resilience to climate change and general benefits to household food security, farm profitability and labour efficiency. Key publications include: Ngwira *et al.*, 2012; 2013a, b; 2014a, b, c; Bunderson *et al.*, 2014; 2016; 2017; Thierfelder *et al.*, 2014; 2015a, b; 2016a, b; 2017; TerAvest *et al.*, 2015; 2019; Chesseman *et al.*, 2016; Berre *et al.*, 2017; Kaluzi *et al.*, 2017; Ligowe *et al.*, 2017; Mupangwa *et al.*, 2017; Fisher *et al.*, 2018; Holden *et al.*, 2018; Setimela *et al.*, 2018; Steward *et al.*, 2018; 2019; Mutenje *et al.*, 2019; Eze *et al.*, 2020.

The CA system developed and promoted in Malawi today is described in an extensive set of guidelines produced by TLC with the National CA Task Force (NCATF, 2016). These guidelines drew heavily on the growing body of evidence-based results from the region, combined with TLC's extensive experience in promoting CA with smallholders across Malawi. This included experiences and lessons from the multi-locational on-farm trials described above, to understand and refine best practices, so that the impacts and benefits of CA can be maximized under different farm circumstances.

The basic system of CA in Malawi is similar to other parts of the world and focuses on the three core principles of minimum soil disturbance, good soil cover and crop rotations/associations. However, it includes flexibility to allow farmers to start with minimum soil disturbance because most farmers are unable to undertake all three principles at the onset. This is due mainly to over-reliance on cereal monocropping, which limits crop associations, and the deep-rooted culture of removing, burning or burying crop residues. Insistence on all three principles is a strong disincentive to even try CA on a small scale.

The principles and practices developed for CA in Malawi are illustrated in Fig. 8.7. It demonstrates the sustainable foundation laid by CA to incorporate many other good practices for multiple synergistic effects to increase the scale and range of benefits to farmers and their land. They include farmer-managed natural regeneration (FMNR), agroforestry, doubled-up legume rotations, contour vetiver hedgerows to reduce runoff and erosion, organic manures, drought-tolerant crops, etc. The guidelines for implementing CA in Malawi provide an overview of these complementary practices (NCATF, 2016).

The three core principles of CA are explained below in the context of Malawi:

1. Planting with minimum soil disturbance.
  - Do *not* till the soil or construct new ridges, basins or pits by mechanical or manual means, to avoid soil disturbance and high labour costs. After ridges subside, mark planting rows with pegs and string at the recommended spacing for the intended crop (see Table 8.4).
  - Make planting holes with a hoe on tops of old ridges to a depth of 10 cm, or use a dibble stick on fields with no ridges. Plant crops at the correct depth and spacing (see Table 8.4). This mimics the age-old method of planting in Malawi before the introduction of ridging during the colonial period.
  - For the crop in question, direct sow the recommended number of seeds into small planting holes after good planting rains.

2. Good soil cover.

The aim is to achieve good soil cover during the growing season as well as the dry season. For the

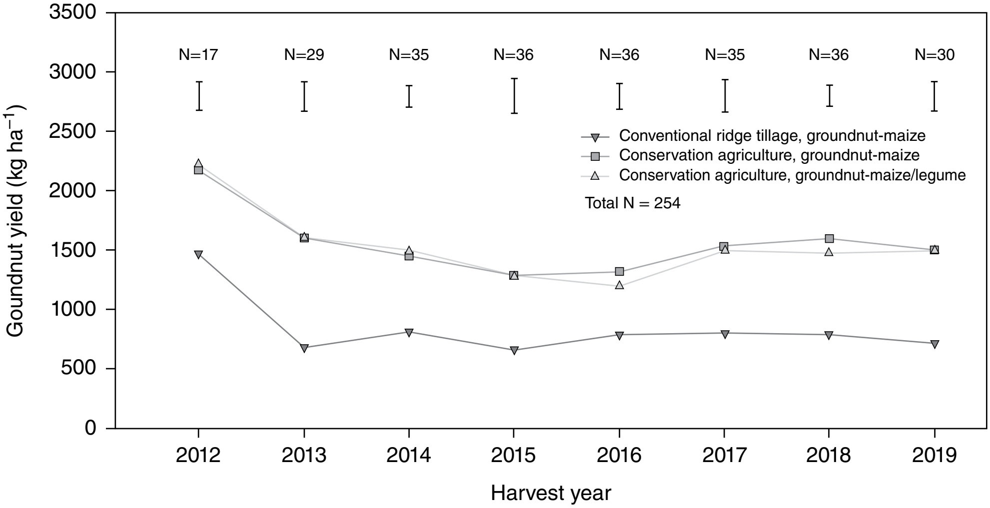


Fig. 8.6. Mean groundnut yields from on-farm trials after maize. Error bars represent the standard error of the difference (SED) of the means at $p < 0.05$. From: TLC, Machinga ADD, CIMMYT CA on-farm trials. Authors' own figure.

Table 8.4. Summary of plant spacing for major crops and legume/cereal intercrops. Authors' own table.

	Long-maturing varieties				Short-maturing varieties			
	Spacing (cm)				Spacing (cm)			
	Rows	Stations	Seeds/station	Plants/ha	Rows	Stations	Seeds/station	Plants/ha
Pure stand (sole crop)								
Maize	90	75	3	44,444	75	25	1	53,333
Sorghum	90	45	2	49,383	75	30	2	88,889
Groundnuts (with CA)[1]	45	15	1	148,148	37.5	10	1	266,667
Soybeans	45	10	1	222,222	37.5	10	1	266,667
Pigeon peas	90	60	2	37,037	75	20	2	133,333
Cowpeas	75	20	1	66,667	75	20	2	133,333
Beans	75	20	1	66,667	45	20	1	111,111
Tobacco burley	110	60	1	15,152	NA			
Tobacco flue/dark fired	100	50	1	20,000	NA			
Cotton	75	60	3	66,667	NA			
Cassava (for tubers)	100	100	1 stick	10,000	NA			
Cassava (for germplasm)	100	50	1 stick	20,000	NA			
Intercropping with legumes[2]								
Main crop								
Maize	90	90	3	37,037	90	75	3	44,444
Sorghum	90	75	2	29,630	90	75	2	29,630
Cassava	100	100	1 stick	10,000	NA			
Cotton	90	60	3	55,556	NA			
Intercrop spacing[3]								
Pigeon peas	90	30	1	37,037	75	25	1	53,333
Cowpeas	90	30	1	37,037	75	25	1	53,333
Beans	90	30	1	37,037	75	25	1	53,333

From: Ministry of Agriculture and Food Security (2012) and NCATF (2016).

[1] Recommendation on soy and groundnuts under Conservation Agriculture (CA) was modified by ability to cut the inter-row spacing in half which is not possible with ridges. This virtually doubles the ground cover and population density, which doubles the yields, while reducing runoff and erosion. It also increases N fixation and biomass production while reducing weed density and the incidence of rosette disease.

[2] The recommendation for intercropping under CA is to interplant between the rows of the cereals with variable spacing between stations depending on the crop and variety.

[3] Groundnuts, soy, common beans and cowpeas can be intercropped between rows of pigeon peas under a doubling-up legume system to provide two crops from the same land with little or no effect on the two crops. NA, not applicable.

latter, strong local by-laws are often needed to protect against burning and uncontrolled grazing. It is critical to make every effort to retain crop residues and weed biomass on the ground surface to reduce runoff, to conserve soil moisture, to increase soil organic matter and to prevent formation of shallow hard pans. Old ridges flatten out within two seasons, allowing use of a dibble stick in the softer ground created by good soil cover and increased soil organic matter. The benefits of good soil cover are:

- To protect the soil from the elements.
- To maximize capture of rainfall while minimizing evaporation, runoff and loss of topsoil.
- To improve soil structure, organic matter content and water-holding capacity; this also prevents clay soils from becoming compacted, which may occur without the retention of crop residues.
- To help suppress weeds and related competition for water and nutrients.
- To increase beneficial activities of termites, earthworms and other soil-based organisms.
- To increase fertilizer effectiveness by reducing nutrient losses from volatilization and leaching.

Box 8.2

Note: Biomass should *not* be imported from other fields because it leaves them exposed and limits expansion of CA across the farm. *If this is not possible on land targeted for CA, biomass may be used from other areas only if it was going to be burned or not used for other purposes*. The challenge for many farmers is to retain crop residues on their land. Since this is not always possible, farmers should make every attempt to retain crop residues by Year 2 at the latest. This may entail working through the community leadership to establish by-laws to protect residues and other biomass burned by people hunting mice for food or for sale, or removed by others who want to sabotage the practice out of spite or jealousy.

Retaining crop residues and other plant biomass on the ground is critical to maximize rainfall capture, to conserve soil and water for good crop survival and growth and to prevent soil compaction.

3. Crop associations: rotations, intercropping and relay cropping.

Crop associations improve soil health and help control weeds, pests and diseases, including *Striga*. The diversity of food available also increases to improve household nutrition and incomes. Crops used depend on farmers' interests, resources and markets. Legumes are encouraged to:

- reduce nutrient demands on the soil and the use of expensive fertilizers;
- increase diet diversity and nutrition, particularly among children and women; and
- increase income from higher legume yields under CA by reducing the row spacing to optimize the plant spacing and density (which is not possible with ridges or basins).

While balanced rotations are not presently feasible with farmers who have small land holdings, some level of rotation is possible to break the unhealthy cycle of monocultures. Although maize is the staple crop in most parts of Malawi, diversification is important for several reasons: (i) to reduce impacts on soil health from nutrient-demanding crops such as maize; (ii) to lower the incidence of pests and diseases associated with monocultures; (iii) to reduce vulnerability to climate change; and (iv) to provide more diverse options for increasing income based on volatile prices and markets. The point is to increase diversification to build resilience with healthier soils and crops, recognizing that more research is needed to adapt CA to different crops and eco-climatic conditions.

8.3.3 Monitoring the Application and Practice of Conservation Agriculture (CA) over Time

Positive early results from on-farm trials provided the basis for TLC to promote CA with smallholder farmers in Malawi starting in the

Box 8.3 Keep Conservation Agriculture (CA) Message Simple

Make small planting holes, retain crop residues and other biomass produced *in situ*, and diversify crops with rotations, intercrops and/or relay crops.

2005/06 season using its extensive network of field staff (see Fig. 8.11). The graph shows farmers supported by TLC who had undertaken one or more principles of CA as long as minimum soil disturbance was included as the core principle. It is important to note that participation by farmers depends to a large extent on the number and scale of projects funded to support CA. It is also important to point out that the figures are annual results: that is, they are not cumulative. To be able to track the area and numbers of farmers practising CA over time, TLC has developed a database to document by name and location the individual households practising CA, and the corresponding area. It also takes into account the CA principles undertaken, with minimum tillage as the qualifying principle. Unfortunately, the information to create a true picture of cumulative trends was not available from previous years to separate the addition of new CA farmers each year. Crucially, this would avoid double counting, which is a common although unintentional problem with most organizations. To help publicize this issue, TLC proposed a monitoring system in the national guidelines for CA to properly document the area and number of farmers implementing CA over time, which can also be adapted to other interventions (NCATF, 2016).

8.4 Drivers and Challenges of Adoption

Despite excellent progress in developing good practices for CA and demonstrating its multiple benefits, adoption levels were much lower than expected. This situation is common to all organizations that are promoting CA in Malawi. The

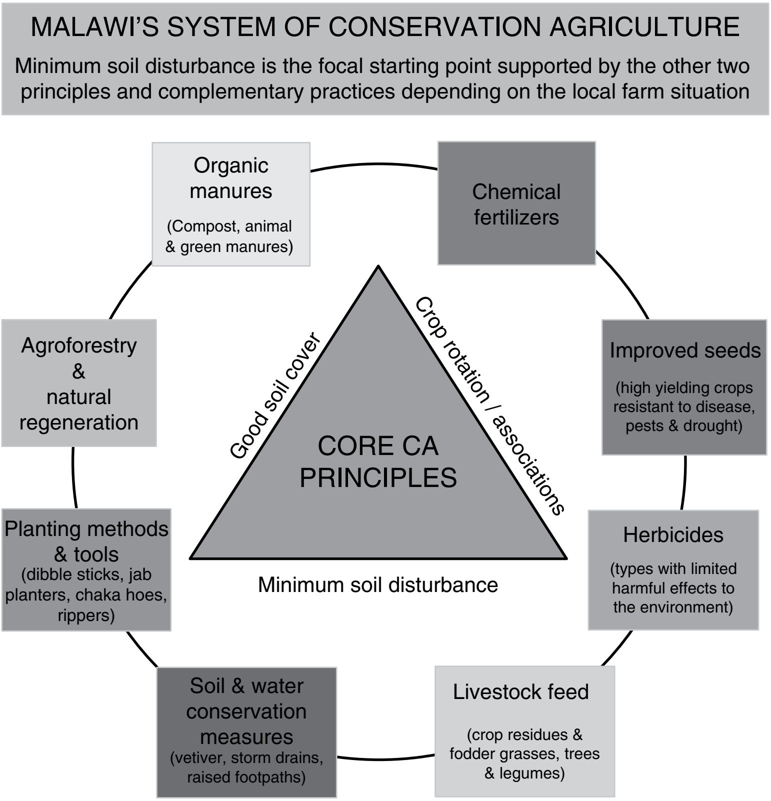


Fig. 8.7. Malawi's system of CA showing the integration of complementary practices as available. Authors' own figure.

question is: why isn't CA taking off in Malawi after 15 years to promote it, especially when there are clear advantages and benefits over conventional ridging?

To answer the question, TLC interviewed 1360 farmers across several TLC projects spanning all three regions of Malawi (north, centre and south) to identify major drivers and barriers to adoption (Mwale *et al.*, 2014a, b). Key findings on the main drivers and barriers to adoption are summarized in Table 8.5 with full details in Table 8.6. The gender breakdown of respondents was 51.3% male and 48.7% female. Note that certain questions elicited more than one response, which is reflected in the results.

8.4.1 Key Drivers of Adoption

In all districts where TLC promoted CA, key benefits consistently identified by farmers included increased food security and yields, savings in labour and time, improved soil moisture during dry spells, improved soil health and increased income or savings in input and labour costs (see Table 8.5).

About 90% of the respondents indicated that income increased by nearly 40% from crop sales under CA. The income was used for various needs with 75% on farm inputs and household effects. About 52% of the respondents indicated that labour savings enabled them to expand the area and diversity of crops to increase production and incomes. Women said it freed up time for more productive activities, and allowed children to attend school more regularly.

It was noteworthy that increases in legume yields were not specifically mentioned. This is surprising given that yields of legume crops like groundnuts were almost double under CA versus conventional ridging, which provided opportunities to increase incomes from the higher market value of legume crops. Follow-up interviews suggested that this was due to overemphasis on maize by extension staff and farmers based on the broad-based perception that CA is suitable only for maize. This issue is discussed below under challenges to adoption, with actions to increase knowledge about the application and benefits of CA with other crops, which could help tremendously in scaling up adoption.

Another important point was the failure to observe or mention the impact of CA on reducing the incidence of *Striga* and lodging with maize caused by damage from termites (Bunderson *et al.*, 2017). This has been commonly reported by researchers and extension staff, but rarely by farmers.

8.4.2 Challenges and Barriers to Adoption

Donors, policy makers, critics and others commonly complain about the slow uptake of CA, but there are many good reasons why this is the case. It simply requires patience and persistence to identify the factors impeding progress and to develop actions to systematically address the challenges.

The surveys conducted revealed five key factors that generated little or no interest in trying CA (see Tables 8.5 and 8.6). In order of importance, they included lack of knowledge or information on how to implement CA, lack of labour or tools to undertake CA, belief that CA offered no distinct benefit or advantage to attract interest, lack of biomass to cover the soil and a general resistance to change their traditional methods of farming. Among farmers who had tried CA, about 3% abandoned the practice for varying reasons. They included no access to inputs or residues/biomass, problems with

Table 8.5. Key reasons for and against adopting Conservation Agriculture (CA). Authors' own table.

Reasons for CA	%	Reasons against CA	%
Increases food security/crop yields	40.1	Lack knowledge/information to try CA	53.3
Saves labour/time	27.4	Lack of cash/labour/inputs/tools to try CA	18.9
Saves moisture to alleviate dry spells	14.8	Benefits of CA not convincing	13.7
Increases soil health/fertility	11.2	Lack of biomass to cover soil	10.5
Increases income/lowers costs of inputs	6.5	Resistance to change	3.6
Total	100	Total	100

Table 8.6. Key results of interviews with 1360 farmers on Conservation Agriculture (CA). Authors' own table.

Awareness about CA	%	Membership of CA clubs	%
Yes	98.0	Yes	95.9
No	2.0	No	4.1
Total	**100.0**	**Total**	**100.0**
Households practising CA		Land tenure under CA	
Practising CA	71.7	Customary land	97
Tried CA but stopped	2.8	Leased land	1
Never tried CA	25.5	Private land	2
Total	100.0	**Total**	**100**
Sources of information about CA		Sources of acquiring farm inputs for CA	
TLC	67.1	Own resources	62.3
Government	12.7	Government subsidy (FISP)	18.2
Radio	12.2	Credit	16.7
Demonstrations/field days	4.8	Project handouts	1.7
Community volunteers/lead farmers	1.9	Gifts/remittances from relatives	1.0
Members of CA clubs	1.4	**Total**	**100.0**
Total	**100.0**		
Sources of CA extension support		Change in income from CA	
TLC extension staff	60.6	Increase *	90.6
Community workers/lead farmers	37.4	No change	8.8
Staff from other NGOs and government	2.0	Decrease	0.6
Total	**100.0**	**Total**	**100.0**
		* The mean increase in income from CA was 39.8	
Reasons for practising CA		Reasons for never trying CA	
Increases food security/yields	39.3	Lack of knowledge/information	53.3
Saves labour	23.9	Lack of labour/tools for CA	16.2
Saves moisture during dry spells	14.8	CA considered unnecessary	13.7
Increases soil health/fertility	11.2	Lack of biomass to cover soil	10.5
Increases income/lowers costs	6.5	Resistance to change	3.6
Saves time	3.6	No cash for loan deposits	1.6
Improves crop growth	0.7	No trust in herbicides	1.1
Total	**100.0**	**Total**	**100.0**
Reason for increased yields		Reasons for abandoning CA (3 of farmers)	
Good moisture retention	33.3	No access to inputs/residues–biomass	42
Improved soil fertility	27.1	Problems with applying herbicides	27
Better weed control	22.0	No access to tools	19
Improved crop varieties	11.4	Lacks knowledge of CA	7
Timely planting	6.1	No longer interested/no benefit	5
Total	**100.0**	**Total**	**100.0**
Increased land area farmed		No. of years practising CA	
Significant increase	52.4	1 year	44.0
Slight increase	20.2	2 years	45.3
No change	27.4	More than 2 years	10.7
Total	**100.0**	**Total**	**100.0**
Uses of increased income		Challenges with herbicides	
Farm inputs	40.3	Ineffective	30.4
Household assets	34.7	No access, shortage or late delivery	27.0
Clothing	10.4	No protective gear	18.2
School fees	6.2	Limited access to or lack of sprayers	11.5

Continued

Table 8.6. Continued.

Uses of increased income	%	Challenges with herbicides	%
Food	3.8	High cost	6.8
Started new business	2.9	Limited knowledge on use	4.1
Repayment of loans	1.7	Limited to certain crops	2.0
Total	100.0	Total	100.0

TLC, Total LandCare; FISP, Farm Input Subsidy Programme; NGO, non-governmental organization.

applying herbicides, no access to tools for undertaking CA such as jab planters and sprayers for herbicides, lack of knowledge and a general decrease in interest from seeing little or no benefit.

Many farmers complained of several challenges in using herbicides. These included (i) ineffectiveness at controlling weeds; (ii) little or no access to herbicides or late delivery by non-governmental organizations (NGOs) and projects; (iii) no access to protective clothing; (iv) limited access to or lack of sprayers; (v) high costs; (vi) limited knowledge of applying herbicides; and (vii) limited applicability with certain crops (see Table 8.6).

To better understand the factors affecting adoption, the effectiveness of training and extension approaches were evaluated to identify the true causes of low adoption with the aim to overcome these obstacles. The results are discussed below under specific headings or topics.

- Early extension messages. Initial messages from research institutions emphasized (i) improved seed and fertilizer; (ii) maximum soil cover; and (iii) herbicides to provide more effective control of weeds with less labour and soil disturbance to complement CA. These messages were interpreted too literally by extension staff who conveyed the necessity to use improved seeds and fertilizers at recommended rates, to apply huge amounts of crop residues on fields and to use herbicides to control weeds. The message received was that CA was not possible without these inputs.
- Incorrect or conflicting extension messages.

(1) CA versus ridging: The Agricultural Technical Clearing Committee (ATCC) of MoAIWD has officially endorsed the CA practices of using dibble sticks, retention of crop residues *in situ* and crop associations (see DARS Extension Circular by Ligowe *et al*., 2013). However, MoAIWD has also maintained the antiquated policy of promoting planting ridges on the contour, which directly contradicts the basic premise of CA. (The introduction of ridging was discussed in Section 8.2.)

(2) Insistence on all three principles at the outset. Extension agents from many organizations often insist on undertaking all three principles of CA at the same time. In many cases, farmers are unable to undertake all three principles at the outset for many reasons; for example, residues from the previous season were burned by mice hunters. There needs to be some flexibility to avoid discouraging interest among farmers to try or experiment with CA.

(3) Maximum soil cover. Interviews with many farmers indicated little or no interest in adopting or expanding the area of CA owing to the lack of biomass and/or the labour costs involved.

(4) Herbicides. As stated above, the introduction of herbicides was intended to improve the control of weeds with less labour and soil disturbance, as a complement to CA. However, it has created more problems than it has solved. It reached a point where extension staff and farmers equated CA with herbicides. It affected adoption because few farmers had the resources to access herbicides and related spraying equipment.

There are many other challenges with herbicides, including access to clean and adequate sources of water at the farm level for diluting the chemicals to maximize efficacy. Except for glyphosate, many are not approved by most donor agencies because of their negative effects on the environment. This has limited the use of herbicides with most donor-funded projects. In the case of glyphosate, it can only be used as a post-emergent herbicide to control early-germinating weeds before planting the crop, but some weeds are resistant to glyphosate such as certain sedges (*Cyperus* spp.). It also means that there is no effect on later-germinating weeds, which must be removed by manual means. Most pre-emergent herbicides cannot be used with legumes grown in pure stands or as intercrops. Critical management decisions include when to apply the herbicide. For example, do farmers wait for weeds to grow before applying glyphosate, or do they plant without using glyphosate to avoid missing the early rains and associated nitrogen flush.

Other factors affecting use of herbicides included limited or non-availability in rural areas, training on its safe and proper use, and unscrupulous agro-dealers who sold herbicides diluted with water. Ultimately, the promotion of herbicides has not helped as expected to scale up adoption of CA in Malawi.

(5) Basins versus small holes and dibble sticks. The basin system of planting has added confusion among extension staff and farmers over the best practice to adopt, compounded by variable recommendations on basin size from shallow holes to deep pits. The greatest challenge has been the labour-intensive task of digging basins, levelling ridges and distributing the soil across the furrow. The basins recommended in Malawi and Zambia are 35 cm long by 15 cm wide and 20 cm deep. Farmers who tried basins in Malawi have generally not expanded the area owing to the labour costs involved, which have been reported to be five times higher than for ridging (Bunderson *et al.*, 2017). The fixed position of basins is also incompatible with the optimum plant population and spacing of different crops.

Overall, the basin system is generally not well accepted by farmers in Malawi. This is illustrated in Figs 8.12 and 8.13 from TLC's Regional Program on Conservation Agriculture funded by the Royal Norwegian Embassy from 2011 to 2015 (Ng'oma *et al*., 2016). The data show a preference for making small planting holes versus digging basins. The smaller area under basins is a reflection of the greater labour required relative to small planting holes. Research in Zimbabwe, Malawi and Zambia provide additional evidence of improved crop yields and water infiltration from direct seeding in small planting holes versus basins (Oldrieve, 1989; 1993; Lowe, 2011; Thierfelder and Wall, 2012; Nyagumbo *et al*., 2015).

(6) Misunderstanding the definition of CA. Some organizations promote adoption if any of the three principles is undertaken.

Fig. 8.8. At the start, many farmers have no crop residues for various reasons, but they can start CA without ridges by using a dibble stick (right) or hoe to make small planting holes (10 cm long × 10 cm deep × 15 cm wide) on old ridges. Use of crop residues can begin in Year 2. Authors' own figure.

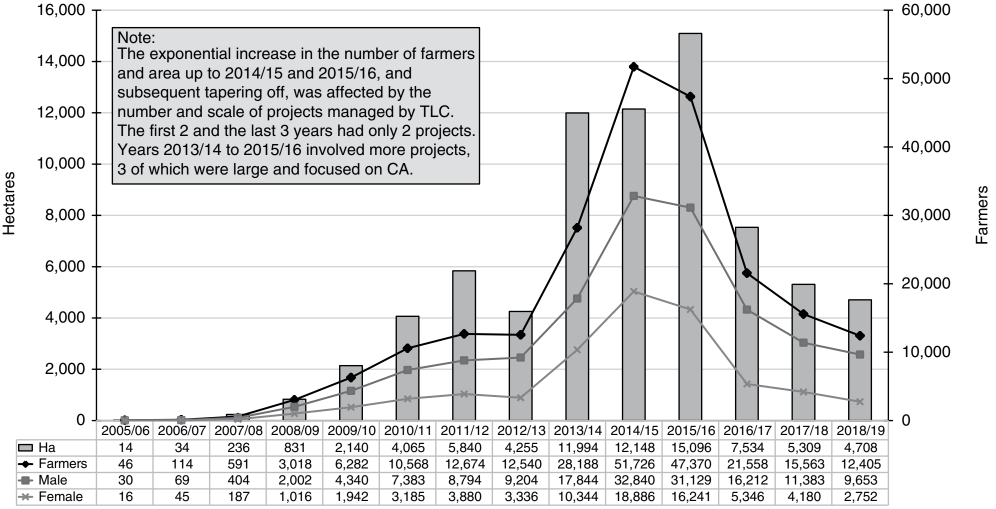
Fig. 8.9. Healthy weed-free maize at 3 weeks under CA (left) and with *Faidherbia* trees (right). Authors' own figure.

Fig. 8.10. Groundnuts under conventional ridges (left) versus CA (right). The row spacing can be cut in half under CA which effectively doubles the yield, soil cover and biomass (this not possible with ridges because they cannot be constructed that close). Authors' own figure.

Technically, there is a fundamental problem with this broad definition. For example, if farmers undertake rotations or intercropping, it is considered to qualify as CA. *If this were the situation, most farmers in Malawi would qualify as practising CA, which is clearly not the case.*

(7) Knowledge and training. The poor understanding of CA and contradictions over what it means reflect the absence of a standard training programme on CA that has been certified and endorsed by qualified practitioners for extension officers, students of agriculture and others who are involved with the extension of CA.

(8) Misconceptions about inputs and tools. Many farmers believe that CA cannot be undertaken without specific inputs or tools, which is a message often conveyed to them by extension staff (e.g. hybrid seed, fertilizers, herbicides, knapsack sprayers, jab planters and even *chaka* hoes, the tool used in Zambia for making planting basins). These beliefs have limited the uptake of CA in terms of number of farmers and area or scale on individual farms. While quality inputs and tools are important to maximize the benefits of CA, they are not a prerequisite and farmers have flexibility to undertake the practice without them as



Note:
The exponential increase in the number of farmers and area up to 2014/15 and 2015/16, and subsequent tapering off, was affected by the number and scale of projects managed by TLC. The first 2 and the last 3 years had only 2 projects. Years 2013/14 to 2015/16 involved more projects, 3 of which were large and focused on CA.

	2005/06	2006/07	2007/08	2008/09	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19
▭ Ha	14	34	236	831	2,140	4,065	5,840	4,255	11,994	12,148	15,096	7,534	5,309	4,708
◆ Farmers	46	114	591	3,018	6,282	10,568	12,674	12,540	28,188	51,726	47,370	21,558	15,563	12,405
■ Male	30	69	404	2,002	4,340	7,383	8,794	9,204	17,844	32,840	31,129	16,212	11,383	9,653
× Female	16	45	187	1,016	1,942	3,185	3,880	3,336	10,344	18,886	16,241	5,346	4,180	2,752

Fig. 8.11. Area of CA and number of farmers practising CA across TLC programmes in Malawi, 2006–2019 (not cumulative figures – see narrative above). Authors' own figure.

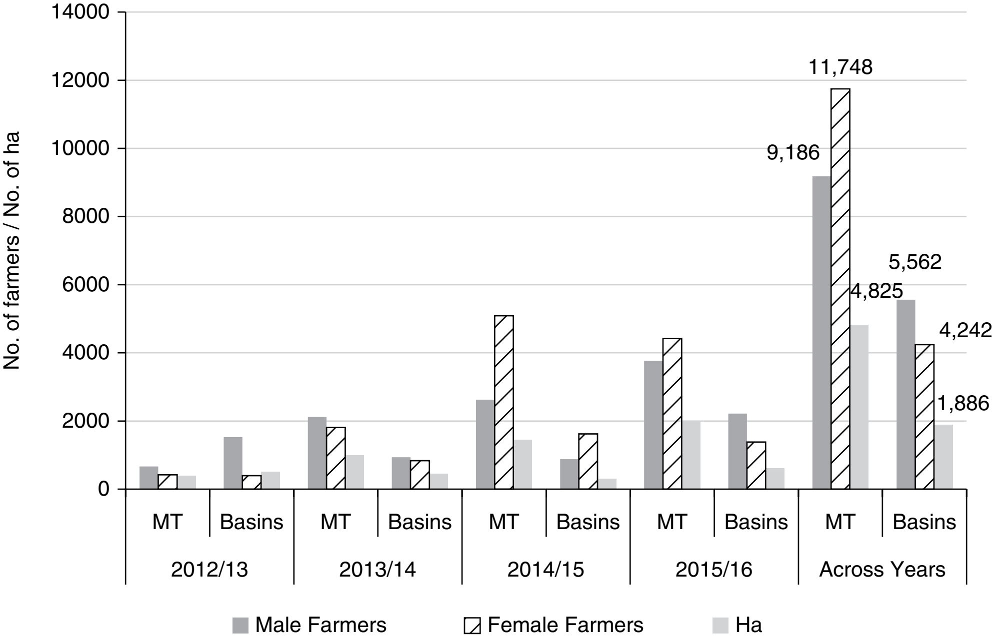


Fig. 8.12. Systems of CA selected by farmers across districts in northern, central and southern Malawi. MT indicates minimum tillage with small planting holes. Basins are 35 cm long by 15 cm wide by 20 cm deep. From Ng'oma *et al*. (2016).

they would with their traditional practices. The focus on inputs and tools creates the risk that CA becomes driven by inputs rather than by its merits. In the end, adoption of the practice will be short-lived.

(9) Resistance to change. In Malawi, it will take time and dedication to break the deep-rooted culture of ridging with clean fields in favour of CA, which requires making some significant changes. Generally,

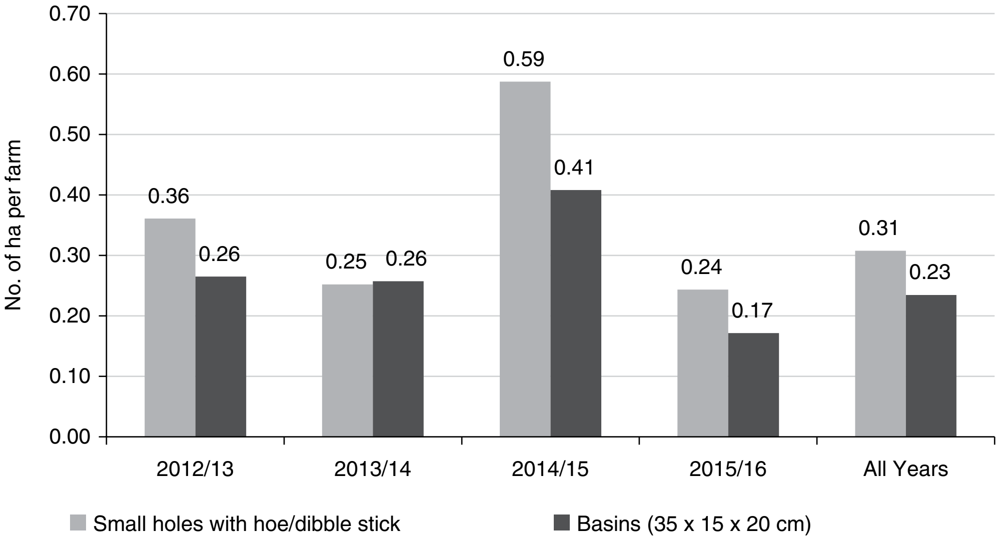


Fig. 8.13. Area of CA per farm under different **s**ystems of CA selected by farmers across districts in northern, central and southern Malawi. From Ng'oma *et al*. (2016).

farmers consider adopting new practices only when, *through experience and observation, they see tangible benefits within their capabilities*. The reluctance to try a new practice is compounded by the risk of ridicule from their peers for undertaking a different system of farming, which has sometimes led to acts of sabotage out of spite and jealousy.

(10) Pests and diseases. Many farmers are concerned about the difficulties of controlling pests and diseases under CA. A common fear is that the increased abundance of termites and earthworms is harmful when, in fact, they have beneficial effects on the soil and crops.

(11) Lead Farmer (LF) Extension Approach. One of the major constraints to adopting climate smart practices is poor access to agricultural extension services. Over the past 5 years the LF approach has been vigorously promoted and widely adopted in Malawi as a cost-effective approach to scale up adoption of new interventions. It basically involves LFs selected by fellow farmers in groups of 15–20 farmers to set up demonstration plots and to conduct training several times a year on various management practices related to specific interventions of interest. The LFs are supported and trained by extension staff to provide the same training to fellow farmers. However, studies by TLC (2017) and IFPRI (2017) revealed serious flaws in the system and/or the way it was being used by TLC, MoAIWD and NGOs in Malawi. The TLC study involved 11 districts in northern, central and southern Malawi with interviews of 28 extension staff, 53 LFs and 347 follower farmers. A summary of the findings is presented below:

- Percentage of group practising CA. While most LFs were observed to practice CA, the TLC study showed that only 63.1% of the follower farmers were practising CA. The study by IFPRI showed much lower figures, and the national average adopting minimum tillage was 6.4%.
- Poor understanding of the LF system. Extension officers often imposed the approach on the targeted beneficiaries with emphasis on setting up LF groups and mounting demonstrations rather than on explaining the purpose and function of the system (i.e. to provide quality training to fellow farmers with the aim of increasing adoption).
- Location of LFs. Lead and follower farmers should ideally hail from the

same village to facilitate frequent visits to all members and attendance at meetings and training; in many cases, follower farmers came from different villages. The IFPRI study indicated that 43% of the follower farmers came from different villages which compromised the training and learning of CA.

- Selection of LFs. Failure to follow the criteria for selecting LFs (e.g. adequate land for demonstrations, effective communication skills, trustworthiness, literacy levels, respect in terms of effective leadership in farming, balanced treatment of gender, participation of members in selecting LFs). With respect to gender, TLC found that 60.4% of the LFs were male, many of whom discouraged female farmers from joining the group. Although 77.3% of the respondents claimed involvement in choosing LFs, there were indications of interference by local leaders and extension officers during the selection process.
- Knowledge of CA. Although the TLC study showed that 93% of the LFs had received training in CA versus 53% in the IFPRI study, there were significant gaps in content, delivery and context starting with the extension officers down to the follower farmers. The problem also became more acute moving down the chain to the farmer.
- Inputs for LFs. Provision of inputs and other incentives to LFs created rifts with the follower farmers who felt that LFs could undertake CA because of the inputs received. This served as a disincentive for follower farmers to even try the practice. It raises a serious question about free or subsidized inputs to lead and follower farmers who may undertake the practice solely to secure the inputs with the risk that it would end when the inputs stop.
- Extension support. The TLC study revealed that the frequency of interaction or visits was low between extension staff, LFs and follower farmers. Only 39% and 26% of lead and follower farmers, respectively, were visited by extension staff more than three times over a period of 3 months. In the same vein, only 62% of the follower farmers were visited by LFs more than three times over 3 months. At the national level, the IFPRI study showed that only 56% of LFs reported indicators used by extension staff or projects to evaluate their performance. This implies that about half had no performance indicators and were not being monitored at all. These results clearly show that supervision at all levels of extension structures is weak.

8.5 Recommended Strategies to Address Challenges

The issues raised in Section 8.4 raise serious questions about the effectiveness of the LF approach. This suggests that farmer field schools may be more effective because they offer equal opportunities for participation and learning without providing an unbalanced distribution of inputs favouring any particular category of farmers (e.g. LFs versus follower farmers). There is now growing agreement that effective extension services need to focus on innovative participatory approaches with community leaders, farmers, researchers and extension staff to jointly identify, plan and evaluate the best interventions to address priority farmer needs and interests. This is similar to the extension approaches advocated by Ekboir (2002) and Thierfelder and Wall (2011). The concept is simple: adoption of a technology depends on the knowledge, interest and capabilities of farmers. Therefore, active farmer participation in evaluating and adapting a technology to their specific needs and circumstances is critical to attract the interest and ability to adopt a new practice. This participatory approach runs against traditional linear extension models where technologies developed on research stations are passed to extension services and then to farmers with the expectation of immediate adoption. Interactive participatory approaches with farmers in the forefront provide opportunities to understand and respond to the innovations, interests, needs and resources of farmers to create conditions favourable for adopting and upscaling a practice within the local context.

These issues clearly indicate a need for actions to address the challenges and weaknesses in promoting CA to increase the scale of adoption to benefit as many farmers as possible across the country. In this context, we offer specific recommendations:

- Strengthen knowledge and support for CA among all stakeholders with compelling evidence of its benefits and application with major crops across different farming systems and agroecologies. A key need is to quantify and publicize the wealth of knowledge about CA and its many benefits, including the synergies from integrating other good practices with CA. Important gaps also need to be filled, particularly efforts to conserve soil and water at the landscape level, because isolated trial plots are inadequate to quantify the broader impact of CA on the environment.
- Develop and deliver certified training courses on CA for LFs and extension staff from government, NGOs, projects and others who are promoting the practice in Malawi.
- Harmonize and simplify extension messages on best practices among implementers and how to maximize benefits to avoid confusing extension staff and farmers. A key need is to develop simple illustrated messages in the vernacular on how to implement CA in practice.
- Facilitate access to basic inputs and tools by farmers by improving linkages with agro-dealers and micro-finance to increase productivity with lower labour and input costs.
- Promote innovative participatory systems of extension. The greatest challenge facing adoption of any practice is the need for effective extension and training with the correct technical message and approach for delivering it. In response, TLC, CIMMYT, NCATF and others have made concerted efforts to investigate and publicize the true nature of the problem with the aim of galvanizing collective action to address the challenges in a collaborative and systematic manner. The results are influencing the mindset among major stakeholders and implementers in Malawi to change the focus and direction for promoting CA.
- Animal and mechanized ripping services. Building on the extensive experience of CIMMYT and the Conservation Farming Unit (CFU), and their handbooks, opportunities need to be explored to support the identification and emergence of entrepreneurs to offer ripping services to farmers. Land preparation using rippers powered by animals or machinery offer cost-effective, labour-saving methods to minimize soil disturbance and conserve soil and water for many farm operations. Based on past and ongoing projects under TLC, animal and mechanized ripping services are viewed by farmers as a modern method of CA that is attracting great interest from pilot trials conducted by TLC in different parts of Malawi. These opportunities are considered a real game changer to transform adoption of CA in Malawi and elsewhere in southern Africa. For this to happen, a well-thought-out plan is needed with active engagement from the donor community and government to kick-start programmes to support and train enthusiastic, young entrepreneurs with oversight for a number of years to ensure sustainability and profitability along the full supply chain. A programme to support animal and mechanized ripping services is now being implemented by TLC and its partners with funding from the Royal Norwegian Embassy.

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9 Research and Technology Development Needs for Scaling Up Conservation Agriculture Systems, Practices and Innovations in Africa

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Abstract

Although the net agricultural production across all regions of Africa has experienced a significant increase, African agriculture has performed below its potential over recent decades. Many aspects have been fronted to curb this situation, including sustainable intensification of farming systems and value-chain transformation through Conservation Agriculture (CA) across Africa. Based on the latest update, Africa has about 2.7 million ha under CA, an increase of 458% over the past 10 years with 2008/09 as baseline. However, this constitutes a mere 1.5% of the global area under CA, and less than 1.4% of the total cropland area in Africa. A combination of modern techniques and the optimization of agroecological processes in CA systems and practices requires that agricultural research plays a bigger role in its evolution and focus in the different regions of Africa. This targeted research should crucially contribute towards making agriculture in Africa more productive, competitive, sustainable and inclusive in terms of its functionality towards the farmer, society and nature. Scientific solutions for agricultural transformation need to be pursued without losing sight of the potentials and fragility of Africa's agricultural environments, the complexity of its agricultural production systems and the continent's rich biodiversity. The agricultural research and development agenda in Africa must build on the rich traditional farming culture, knowledge and practices, supported by coherent longer-vision for investments in science for agricultural development. Most of these investments are expected to come from national public and private sources, with governments also expected to invest in generation of 'public goods' such as the national or global environmental benefits typical of CA, and to also catalyse innovation and support market growth. The absolute imperative is that farmers must shift from outdated conventional tillage-based methods to modern, well-tested and knowledge-based methods of land use. Making this transition will be difficult without the creation of an enabling environment. This chapter discusses the various roles and advances required in CA-based research that will support the adoption of CA systems by millions of smallholder farmers in Africa with a view to enhancing sustainable and effective agricultural development and economic growth.

Keywords: Smallholder agriculture, opportunities for food production, CA research needs in Africa

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9.1 Overview of the State of African Agriculture

Although the net agricultural production across all regions of Africa has experienced significant increase, African agriculture has performed below its potential over recent decades, especially when compared with the production increases observed in Asia and Latin America. The increases in production are not commensurate with increases in population, meaning that per capita availability of domestically grown food has remained largely unchanged over the last 50 years and has even fallen substantially in some areas (Pretty *et al.*, 2011). At the current rate of population growth, African agriculture will have to provide adequate food and nutrition security for at least 2 billion people by 2050. Sub-Saharan Africa's (SSA's) spiralling food import bill stood at US$43 billion in 2019 (Fox and Jayne, 2020). This scenario presents a significant opportunity for the agriculture and food sector, including farmers and institutions that support agricultural development, to promote sustainable intensification of agriculture that can meet domestic needs and generate surpluses for regional and international markets. It also has the potential to spur agricultural growth to support agricultural industries (including agro-food industries and manufacturing of agricultural inputs), generate employment and improve livelihoods.

SSA has large agroecological diversity and farming systems and is endowed with abundant natural resources, including about 60% of the world's arable land, some of it still virgin. These resources, if effectively and efficiently harnessed, could reduce the threat of food insecurity. Increased agricultural productivity, combined with viable agribusiness that adds value to farmers' production and improved access to markets, can drive broader economic growth across the continent and vastly improve food security (FARA, 2014).

Initially, the increase in agricultural production in SSA, alongside population growth, has largely resulted from a rise in the amount of land cultivated rather than an improvement in yields or the intensification of agricultural practices. This puts greater pressure on natural forests and pastures, with medium-term negative impacts on ecosystems and maintenance of soil fertility as well as on biodiversity and the climate. The negative impacts of climate change – particularly shifts in weather patterns, rising frequency of droughts and floods, and incidences of pests and diseases – will predictably continue to threaten Africa's future food and nutrition security. Moreover, climate change is a global phenomenon which needs all nations and continents to ensure that sustainable agricultural intensification is based on the best adaptability and mitigation practices that science and innovation can offer.

To many African farmers and professionals, it is clear that 'business as usual' based on conventional tillage agriculture and recycled Green Revolution models is not providing a credible and sustainable way forward. A different approach is needed, based on Conservation Agriculture (CA), supported by all stakeholders benefiting from both global knowledge about CA and new knowledge generated through research and innovation in Africa. This is premised on the understanding that CA already covers more than 180 million ha globally, of which 2.7 million ha are in Africa. Some 1.5 million ha in Africa are managed by about 3 million smallholder farmers. While the area under CA has increased by 458% over the past 10 years, with 2008/09 as baseline (see Chapter 4, this volume), this constitutes a mere 1.5% of the global area under CA and less than 1.4% of the total cropland area in Africa.

Experiences from countries worldwide where CA has been spreading extensively (e.g. South Africa, Zambia, Brazil, Argentina, Paraguay, Spain, Italy, Kazakhstan and China) show that it takes a long gestation period of some 15 years to reach a point in the early fragmented adoption process at which several necessary conditions become established and allow the scaling process to take off. Local knowledge has to be generated regarding CA practices, and farmers have to be supported to acquire sufficient new knowledge to begin to drive the change process. Assuming the presence of effective demand, private and public-sector institutions must become part of the process of change in terms of research and education, new technologies, service provisioning, production inputs and governance to promote policy and institutional changes. To sustain the aggregate change process with increasing momentum, five conditions appear to be necessary (see Chapter 4). These are: (i) individual and institutional pioneers, champions and leaders; (ii) farmers' organizations; (iii) alignment of education and training systems as well as research and innovation systems; (iv) presence of governance that creates policies and institutional support in favour of CA; and (v) effective institutional capacity to partner with the private sector in ways that will benefit the farmer and society at large.

This chapter focuses on the research and innovation systems to generate technologies and new knowledge about the nature of constraints and challenges to change to CA systems and how to overcome them. Sustainable intensification through CA relies on a combination of modern techniques and the optimization of agroecological processes. Agricultural research for development has a large role to play in this process. It must adopt a more inclusive and participatory approach by developing close collaboration with farmers regarding both planning and implementation. It must also contribute to public policies by answering pertinent questions about which agricultural development models to promote, helping to increase land tenure security and setting up mechanisms for concerted management of natural resources, and supporting institution building at the local, national and regional scales.

Through the African Union, the African heads of state recognized the need to transform agricultural production systems to make them more climate resilient as far back as 2014. The Malabo Declaration of 2014 set a target of 25 million farmers adopting climate-resilient production systems by 2025 to protect their food and nutrition security and livelihoods. Agenda 2063 (African Union Commission, 2015) has the aspiration that, by 2063, African countries will be among the best performers in the global quality of life measures. This will be attained through strategies of inclusive growth, job creation and increasing agricultural production; investments in science, technology, research and innovation; gender equality; youth empowerment; and the provision of basic services including health, nutrition, education, shelter, water and sanitation. The adoption of climate smart agriculture is a pathway to strengthen the climate resilience of smallholder farmer production systems (FAO, 2013). One climate smart agriculture approach, which offers an opportunity for many smallholder farmers in Africa to transform their production systems, is CA. Research and development systems need to facilitate the evolution of farmer ingenuity and the private sector with regard to CA approaches and practices that can be customized to suit various farming systems, farmer categories and/or production and motivation systems. The wide range of farmer typologies across Africa comprises small-scale subsistence producers using dibble sticks, to medium-scale producers using animal and tractor drawn equipment, to large-scale commercial farms using complex, satellite-guided precision machinery.

9.2 Role of Research in Agriculture and Technology Development

In agriculture, science actively seeks to improve biophysical production processes that will improve the performance and resilience of farming systems. This translates into increased crop and livestock productivity, improved farm output, reduced losses due to weeds, diseases and insects, development of more efficient equipment, conservation of natural resources and increased overall food quality across commodity chains. In addition, the science of sustainable intensification seeks to improve the delivery of a wide range of ecosystem services to society. These include soil biodiversity, clean and regulated water supplies, minimum soil erosion and environmental pollution, carbon sequestration, pollination services and maintenance of food webs and chains in and above the ground.

Globally, research crucially contributes towards making agriculture more productive, competitive, sustainable and inclusive. Agricultural research is regarded as one the main necessary factors (Kassam *et al.*, 2014) contributing to shifts in agricultural production systems and changes in the rural sector. In particular, it is helping to improve productivity, increase agricultural incomes and change agricultural practices. Various impact assessments have shown that it is one of the most effective investments for increasing agricultural production. Although for many years the primary objective of agricultural research has been increases in agricultural production, it has recently evolved to contributing also to increasing resilience, improving nutrition and women's empowerment and the delivery of ecosystem services. Today, there is a consensus for increasing agricultural production in Africa by increasing yields per hectare, and that this increase must suit local conditions and be based on new practices that use fewer inputs and are less harmful to the environment than the Green Revolution approach.

Scientific solutions for African agricultural transformation need to be pursued without losing sight of the potentials and fragility of the agricultural environments and natural resource base, the continent's rich biodiversity and the complexity of its agricultural farming and production systems. Transforming Africa's agriculture requires a science system that produces 'technical', 'institutional' and 'sociopolitical' innovations. It is, therefore, essential that science becomes mainstreamed as an essential part of agriculture-led economic and social transformation in Africa (FARA, 2014). Any programme or intervention needs to support cutting-edge research to help farmers produce greater quantities of safer and better-quality food, fibre and fuel to meet the needs of a growing population. This will require the continuous generation of new knowledge and enhanced translation of knowledge into use, entailing considerable effort in terms of research and innovation. Research will need to integrate diverse disciplines and perspectives to address multiple objectives at the field, landscape and value-chain levels. A systemic approach oriented towards user needs must be a part of agricultural innovation systems and include farmers, enterprises and bridging institutions. It will require sustained and predictable public funding as well as higher levels of private investment for generation and transfer of technologies, building upon successful experiences.

9.3 Support of R&D in Sub-Saharan Africa (SSA)

The agricultural research and development (R&D) world over is changing, and in ways that will definitely affect future global patterns of poverty, hunger and other outcomes. The overall impetus is one in which the middle-income countries are growing in relative importance as producers of agricultural innovations through public investments in R&D. Consequently, these countries have better prospects as producers of agricultural products, although the important role of privately performed R&D gives a substantial innovative edge in a few of those countries. A vibrant agricultural R&D agenda in Africa will only translate into stronger nations and better lives for the people if it is supported by coherent investment in science for agriculture for development. This will also inspire institutional reforms. Most of these investments are expected to come from national public and private sources through well-crafted public–private linkages. Furthermore, governments are expected to invest in attainment of the beyond-the-farm public goods such as national or global environmental benefits, or to catalyse innovation and support robust and inclusive market growth.

According to Beintema and Stads (2017), both public and private-sector funding for agricultural R&D has decreased over the years. The data available on agricultural research spending levels indicate that spending by African countries is relatively low (0.6% of agricultural GDP). Stads and Beintema (2015) further report that agricultural R&D spending in SSA has been more volatile than in other developing regions, because of low levels of government funding, coupled with high dependence on short-term and ad hoc donor and development bank funding. Given the recognition of the need for food and the cost of R&D, most people now view this reduction in funding as largely counterproductive. However, several public agencies, non-governmental organizations (NGOs) and private-sector firms are now reversing this trend. Although private funding is increasingly playing an important role in taking the new developments to the farmer, many of the breakthroughs in research happen in the public sector, which is perhaps best placed to help the world meet the food demands of the future. Rather than relying too much on external funding, African governments need to clearly identify long-term priorities, design focused and coherent agricultural R&D programmes, commit sufficient funding for the implementation of the programmes and align donor funding to address national priorities.

In 2003 African leaders launched the Comprehensive Africa Agriculture Development Programme (CAADP) as an important framework for revitalizing agriculture on the continent (AU, 2003). To date, CAADP has helped countries to refocus attention on agriculture and has also encouraged and facilitated a refreshed and complete overhaul of national agricultural sector strategies, investment plans and programmes (NEPAD Agency, 2013). The Framework for African Agricultural Productivity (FAAP), which is a reference document for implementing the CAADP tenet on agricultural science and technology (otherwise known as CAADP Pillar IV), challenges African governments to invest prudently in agricultural research and farm technology to increase productivity of staples and enable farmers to also engage in the production of more remunerative, high-value products (FARA, 2006).

9.4 Conservation Agriculture (CA) Needs Systems Development Research

9.4.1 A Multidisciplinary Systems Approach is Needed

Since the start of farming systems research as a discipline, its application and methods have diversified from addressing adoption constraints and farmer participation to examining farming processes, functionality and infrastructure (Collinson, 2000; Whitfield *et al.*, 2015). However, agricultural research continues to be largely carried out through discipline-specific approaches (e.g. social science, agronomy, economics and climate impacts) that focus on component parts of the system. Hermans *et al.* (2020) argue that, despite efforts by various disciplines to increase our knowledge of what, where and for whom CA is suitable, the discussed CA paradox of low adoption despite positive biophysical results persists. A major knowledge gap is the understanding of why CA has worked in certain farming systems and not others. It is, therefore, critical that CA research is conducted in a multidisciplinary and multi-institutional way to ensure all aspects that can contribute to increased adaptation are addressed. The diversity of farming and land use systems in smallholder farming areas make it ideal for promotion of CA to provide solutions based on its three interlinked principles of minimum soil disturbance, permanent soil cover and crop rotation. In Africa, research–extension–farmer linkages must continue to strengthen to effectively allow the formulation and integration of new systems and practices. Africa must, therefore, continue to invest in participatory systems research and training for technology development and transfer of CA practices and innovations for various farming systems. This is likely to accelerate CA adoption and spread in a manner similar to that reported for some countries in Africa such as Zambia, Mozambique, South Africa and Ghana, and in other countries in the developing regions such as Brazil, Paraguay, Iran and China.

CA is known to improve soil health, increase crop yields and reduce production costs. In addition, CA reduces drudgery, increases residue soil moisture and therefore improves farm productivity. Despite all these benefits, the current CA adoption rates are low and are unlikely to be increased by continued research into the technical aspects of CA. Some of the ‘missed’ research opportunities considered vital to improve adoption rates include (i) integration of livestock with CA; (ii) diversification of enterprises to harness forward and backward linkages; and (iii) validation of the economic benefits/viability of CA to private-sector investors (including medium-scale farmers). CA allows integration with livestock keeping because of improved biomass production on the crop production enterprises and also by incorporating fodder crops as cover crops or rotational crops. Enterprise diversification based on CA and guided by research should be emphasized to promote the growth of smallholder economies, food security and alleviate poverty.

9.4.2 Technology Push, Market Pull or Combined Approaches?

A move away from ‘technology push’ or ‘market pull’ approaches to joined-up ‘market pull–technology-push’ approaches across whole value chains is necessary for effective farmer engagement in improving production performance. Research should thus go beyond biophysical boundaries to also address value-chain-based business models such as contract farming and outgrower schemes. In addition, holistic value-chain approaches should be promoted to embrace various actors, from farmers, policy makers, extension workers and input suppliers to mechanization service providers and aggregators/buyers of agricultural commodities.

A priority hurdle to overcome is the typical poor coordination of smallholder producers, and the need to build their capability to acquire production inputs and services affordably and in a timely manner, as well as pool produce and capability to negotiate for equitable and above break-even point product prices. Poor coordination in managing such an enabling environment resulted in the downfall of the powerful cooperatives of the 1970s across Africa, such as those for coffee and cotton. Government and other stakeholders should empower farmers to demand CA services to enable them to realize profitable farming. African governments, through continental institutions like the African Union and its partners, should also create the demand for CA and support access to production inputs through enabling policies. Farmers are at one extreme end of the CA services supply chain. If research and demonstrations can generate demand among farmers for CA services then the rest of the supply chain upstream, made up of the private sector in most countries, is likely to respond (perhaps with the aid of incentives) and invest in the necessary CA-based services and products. Examples would vary greatly but would include incentives that promote ecologically sustainable and profitable production and local manufacture of CA equipment.

Thus, there is a need for participatory research to increase investment in strategic interventions that will create demand for CA services, equipment, inputs, knowledge and information. Local and central governments need to drive the research for a development agenda to locate and make available more funds for upscaling CA to a critical level of adoption, beyond which the private sector will be attracted to offer its services to continue supporting CA-based production intensification more sustainably.

9.4.3 Smallholder Commercial Farming Needs Different Drivers

CA is the pathway to empowering smallholder farmers to produce a surplus (due to improved productivity and climate change resilience) that is competitively priced owing to its reduced production costs and efficient use of resources. Smallholders producing a surplus and with access to reliable and profitable markets – classified as commercial – have distinct attributes compared to subsistence farmers. These latter farmers, who constitute an estimated 80% of smallholders, produce for subsistence consumption and to a larger extent are involved in farming as a way of life. Subsistence farmers are risk averse and minimize investments in farming to reduce risks and prevent costly failures.

The different attributes between commercial and subsistence farmers draw distinct boundaries on capabilities of technology uptake and adoption. However, most interventions have taken smallholder farmers as a homogeneous group, save for superficial sex/gender differentiation, thus missing the opportunity to identify and harness unique opportunities for upscaling or the dedicated pathways targeting either commercial, subsistence or both. It is our view that smallholder food production should be viewed either as a livelihood for some rural dwellers (thus deserving welfare/social/political/policy support) or be treated as a business, where it has been or must prove itself to be profitable. Much of the promotional push for CA has been based on the assumption of producing for food security for the rural poor. The time has come to promote CA farming as a reduced risk and highly profitable investment option, which in addition contributes to the Sustainable Development Goals (SDGs). Promoting CA farming involves capturing and packaging its productivity, competitiveness, environmental sustainability and climate change resilience. CA farming should be seen as the obvious choice for private investments (including by youthful farmers) because of its productivity and low risk (resilience). It is, therefore, important that all of the medium- and most of the large-scale farmers are included in the target group and benefit from the support dynamics within the groups.

Socio-economic research should be conducted for all farmer typologies, farm sizes and value chains, to establish the business risk and economic indicators (e.g. net present value, internal rate of return and investment payback periods) and package them to highlight that farming the CA way is a preferred investment option. Government support is needed to document and promote CA economic feasibility to farmer organizations, the private sector and civil society organizations.

Subsistence farmers without access to reliable market incentives to support surplus production require separate and dedicated livelihood interventions. Food security as a government welfare obligation should be emphasized initially, up to and until the natural resource base has been adequately regenerated to enable farmers to produce a surplus, and equitable market linkages developed, for them to transit to becoming partly commercial and then universally commercial.

9.5 The Need for Conservation Agriculture (CA) Research Tailored Beyond Biophysical and Socio-economic Situations

The introduction of CA in Africa is a profound change in farm management. Benefits on technical performance obtained at the field level, albeit being one of the essential determinants, are not a sufficient condition for the needed community/society adoption. As with other approaches to increasing agricultural productivity, the production constraints, farmers' objectives and the expected benefits and costs of implementing CA are important aspects that influence adoption of CA. At a regional level, factors such as the market conditions, interactions among stakeholders and other institutional and political dimensions are critical. At each of the farm, village and regional levels, opportunities or difficulties emerge that either enhance or impede development, adaptation and adoption of CA, demanding research from a multi-stakeholder and interdisciplinary perspective. Therefore, research on CA must take cognizance of various facts about Africa. First, the smallholder farm sector – the bedrock of agricultural production and livelihood for the majority of inhabitants in rural Africa – is under threat from exploitive slash and burn or tillage-based nutrient mining subsistence agriculture. Many years of extractive farming and inadequate measures to ensure sustainability have degraded core resources of production at landscape level, resulting in destitution and vulnerability of whole communities (Kassam *et al.*, 2017). New and presumably better-yielding crop varieties have neither cured the problem of degraded soils nor reduced vulnerability to climate-related extreme events. Production of staple food crops has brought only a marginal and unstable increase in the last 20 years to date, despite acreage expansion and the release and commercialization of higher-yielding crop varieties. Soil and land degradation have consistently contributed to low crop yields through poor crop growth and low production of above-ground biomass, the latter implying less crop biomass to cover the soils and protect them from the effects of erosive rain and wind. Furthermore, the farmers' ability to invest in mitigation of degradation under the unsustainable conventional tillage of agricultural land use is greatly diminished, thus fuelling a downward spiral of low productivity and further degradation and poverty (Scherr, 2000). A similar situation exists in the pastoral sector where large areas of land across Africa remain in a degraded condition due to overexploitation, calling for effective crop–livestock integration and rehabilitation of ecosystems combined with development of viable alternative opportunities in other forms of non-traditional livelihoods. This state of affairs poses a real threat to African food and nutritional security and genuine sovereignty. Professionals and citizens of the African continent must fully appreciate the enormity of the challenges ahead and feel the compelling urgency to utilize every opportunity to mitigate further degradation of core resources of production and ecosystem services, and to embark on a path of restoration and environmentally sustainable land use. As indicated earlier, extractive land use practices with tillage agriculture and extractive livestock systems without adequate measures to replenish fertility and biodiversity are the root cause of declining soil fertility and degradation of core resources of production. Intensification under conventional intensive agriculture leads to higher frequency of tillage and excessive use of agrochemical and fossil energy, whose adverse consequences for soil quality and crop yield – as well as climate change – become more apparent over the longer term. Existing knowledge (Ngwira *et al.*, 2013; Thierfelder *et al.*, 2013; Kassam *et al.*, 2017; Lalani *et al.*, 2017a) confirms without doubt that CA can overcome land degradation and restore degraded farmland over relatively short periods of sustained use, opening up greater opportunities for effective livestock integration (FAO, 2009; Owenya *et al.*, 2011). CA is also climate smart, and thus would enable farmers to mobilize greater crop and land potentials in terms of productivity as well as ecosystem services such as a clean and regulated water supply; runoff and erosion control; improved cycling of water, carbon and nutrients; and biodiversity and pollination services.

Research in CA should address many of the dynamic challenges Africa is facing, including the sustainable intensification of agriculture at all scales in order to keep food prices competitive in growing cities. This also makes it possible for productivity increases to reduce encroachment of crop and livestock farming onto fragile environments. Research-based solutions will be needed to promote value addition to agriculture products, the demand for which is rising through urbanization and expanding export markets both within and outside Africa. Many of the incremental costs associated with adopting CA accrue at the farm level, while most of the benefits are captured by society (Knowler and Bradshaw, 2007; Kassam *et al.*, 2013). Society needs to encourage the adoption of CA for its own good and this should be supported using the appropriate penalty and incentive schemes available at its disposal.

It is critical to note that the many challenges faced in promotion and adoption of CA requires a systemic and participatory research approach with the aim of finding solutions to the specific problems associated with different categories of farmers and their farming systems in the various and diverse agroecological and sociocultural settings. Indeed, it is not enough to merely adopt an ecosystem approach in isolation, but one must also organize a true dialogue with those who use the research-derived evidence, in this case the farmers, to identify appropriate solutions that suit their constraints and implementation capacities. It is also important to consider a matter of effectively combining farmers' local and traditional knowledge with scientific methods by developing new research protocols, research in partnership and even research initiated by farmers themselves according to the 'farmer-to-farmer' model.

9.6 Specific Areas of Research and Innovation for Scaling Up Conservation Agriculture (CA) Systems

As stated previously, existing knowledge and experience lead to a general consensus that adopting CA systems at landscape level is perhaps the best way to mitigate degradation caused by conventional tillage systems and restore degraded soils, as well as achieve climate change adaptability and mitigation. CA is applicable over a wide range of farming systems and agroecological conditions. However, despite the exponential increase in CA adoption rate in Africa (see Chapter 4, this volume), its wide-scale uptake across Africa will continue to face many challenges until the continent is adequately organized in terms of policy and institutional and strategic support to sustain its Africa-wide adoption.

The age-old justification for regular tillage is primarily to manage weeds and to create a seedbed of fine tilth for seed germination and crop establishment. By tilling their fields, farmers are able to shift the advantage from the weed to the crop and allow the crop to grow with minimum competition with resulting higher yields. It is now also well understood that regular soil disturbance is not an absolute necessity for good crop yields and maintenance of healthy soils, as it causes serious soil degradation in the long run. However, in order to change mindsets and promote buy-in of CA interventions by farmers and policy makers, the scientific community must address key niche and site-specific challenges associated with CA, as has been done in the rest of the world outside Africa. As resources for R&D are limited in many African countries, there is urgent need to link the private and public sector for better leveraging of resources and dedicated research and technical support; this will enhance understanding of CA niches and factors that would enhance adoption. How that is to be done remains a R&D challenge and a worthy intervention by African R&D professionals and policy makers. The following aspects of CA will need further research to enable CA to be a truly farmer-led, knowledge-driven innovation.

9.6.1 Conservation Agriculture (CA) Facilitates Integrated Pest and Nutrient Management

While herbicides can help in the integrated pest (weed, insects and pathogens) management strategies, most of the 2 million farmers practising CA do so with little reliance on synthetic pesticides or fertilizers (e.g. Owenya *et al.*, 2011; Khan *et al.*, 2017; Lalani *et al.*, 2017b). Better research with biological strategies is needed to help farmers control weeds and meet crop nutrition needs with minimum use of pesticides and fertilizers. Approaches and techniques that allow this include minimum soil disturbance; good-quality soil cover; intercropping and rotations; cover cropping involving annual and perennial legumes, including nitrogen-fixing trees, green and animal manures; and push–pull integrated pest management for weeds, insects and pathogens. African scientists also need to fill knowledge gaps on herbicide formulations and combinations to manage weeds, insects and pathogens that are unique to African environments. They also need to design integrated weed management regimes capable of pre-empting emergence of herbicide-resistant biotypes and preventing dominance of invasive weeds. Where possible, biological forms of integrated weed and nutrient management should be a research priority (Bunch, 2017; Garrity, 2017; Khan *et al.*, 2017).

9.6.2 Conservation Agriculture (CA) is Pillared on Maintenance of Permanent Soil Cover

Maintenance of a permanent or a semi-permanent soil biomass cover may be done through growing live crops (cover crops and intercrops) or leaving dead biomass mulch (crop biomass including stubble) to serve as protection of the soil from sun, rain and wind. However, crop biomass by its nature creates challenges with management and, especially when loose and unshredded, can create problems for some types of seeders, making it generally harder to achieve good stand establishment. This highlights the critical importance of suitable equipment for success with CA. Surface biomass can also harbour pests and pathogens, and more research is needed to develop appropriate interventions. Research is also needed to demonstrate whether this problem is common in diverse cropping systems which are a key feature of CA. Success of CA interventions is much higher where suitable no-till (NT) seeding equipment is available to drill seed through surface biomass mulch at the proper depth for good germination. It is, therefore, urgent that appropriate CA equipment is perfected and made available for CA farming systems and used by trained operators. The private sector has a big role to play in making CA machinery and equipment available to farmers in the region at affordable prices, with training support for equipment operators.

The quantities and types of ground cover (dead or living biomass) required to maintain a favourable and sustainable ecological balance is largely undetermined for farming systems in Africa. Small-scale farmers would prefer a cover crop that fits into their normal cropping system and has multiple purposes which may include edible seeds and vegetables, soil fertility improvement, animal fodder and weed suppression. System compatibility research is critical particularly on live soil plant covers to forestall proliferation of invasive weeds such as *Striga*. Exploratory research on plant species with the possibility of multiple uses as ground cover and animal feed is critical for mixed farming systems. Permanent soil cover depending on type and quantities may create unique microclimates and shifts in biota and chemical ecology. These are areas that are yet to be explored and illuminated.

9.6.3 The Conservation Agriculture (CA) Pillar of Minimum Soil Disturbance Introduces New Research Needs

The CA pillar of minimum soil disturbance, while having significant benefits including reduced machinery time, savings on fuel and maintenance, and drastic reductions on drudgery, also opens up a new research arena calling for new research questions and agenda. In the short term, all the advantages of CA may not become apparent, as crops may not benefit from mineralization of increased soil organic matter. CA is associated with higher microbial biomass and activity in upper soil layers and this concentration may also lead to the build-up of pathogen inoculums. The depth of knowledge on these dynamics is lacking in typical smallholder settings where farmers hardly attempt to control weeds, pathogens, diseases and insect pests.

9.6.4 Research is Needed to Address Context-specific Enhancers or Barriers to Conservation Agriculture (CA) Adoption

Some of the enhancers or barriers to CA adoption are articulated by Smith *et al.* (2017) and include, land (tenure), human resources, equipment, infrastructure, finances, institutional, cultural, policy regulatory environments information, knowledge, skills, technologies innovations and governance. Since innovation is a complex and inherently a non-linear process, appropriate policies and/or incentives are necessary to attract investment in CA research (e.g. credit guarantees or tax breaks) to spur investments in appropriate technologies including locally made low-cost seeders and a service industry. If well addressed these enhancers will contribute significantly to enhancing adoption of CA practices towards directional and successful adaptation of best-bet practices to Africa's farming systems.

9.6.5 Investments in Long-term Research Experimental Sites are Necessary for Learning

Investments in long-term farmer field schools and research experimental sites are necessary to enhance the farmer discovery and learning process and encourage the participation of private-sector businesses and input suppliers. These will demonstrate the benefits of CA and illustrate to policy makers and development partners the evidence of CA advantages. The design of CA research projects will, therefore, need to be based on more realistic and relevant expectations about the impact of the CA systems and practices. The bottom line is that transition to CA must make economic sense to the farmers, private sector and society. Hence, economic evaluation research into the primary and secondary benefits of CA on the farm and beyond the farm gate is necessary to inform policy on mechanisms for mainstreaming CA.

9.6.6 Need for Research for Conservation Agriculture (CA) Systems that Generate Ecosystem Services

The private sector has traditionally partnered with governments to support research funding. However, CA is unique in that the CA production systems generate not only biological products for sale (to which the private sector can attach a profit to drive their investments in research), but also ecosystem services to communities and society in general. These include: control of run-off, soil erosion, and flooding; control of water pollution and improved quality and quantity of water resources; carbon sequestration to mitigate climate change; and improved biodiversity including pollination services, for which there are no established markets. Research will thus have to innovate solutions that would involve payments to farmers for such environmental and ecosystem services. Research would also need to focus on solutions involving broker systems for international conventions and national governments that would involve compensating farmers for delivering such national or global public services. A research option worth pursuing would propose blending CA for ecosystem services with provision of a commercial commodity or service. Such examples could include rewarding specific mechanization services that are based on CA operations, such as direct seeding, amelioration of compacted soils, precision operations (e.g. the 4R fertilizer/nutrients management operations) and weed management operations.

9.7 Looking Ahead

Transforming conventional and traditional agriculture into CA has high potential to be part of the solution to African poverty alleviation, food security and climate change goals. As is already happening in other parts of the world, this transformation will come from the development (and subsequent adoption) of productive and profitable new and context-specific CA systems and technologies with low investment costs. Technology adoption requires the appropriate adaptation and empowerment of all categories of farmers across the continent to make better and informed decisions. While a great deal can be achieved in terms of adoption and uptake of CA in different areas initially, widespread scaling across Africa will require the development of effective policy and institutional support, including sustained support of the research and knowledge system at both national and regional levels (Kassam *et al.*, 2014).

The public sector needs to reverse the negative trend in funding agricultural research and technology development by increasing the spending on R&D, making investments in strategic and basic scientific research in agriculture and supporting technologies a reality. Governments need to foster an attractive environment for venture capital funds and corporate ventures focusing on agricultural innovation and help ensure that the investments being made by the private sector can make the desired impact (Barry *et al.*, 2017). This could be achieved by:

- Supporting agricultural extension efforts to disseminate knowledge about new technologies and techniques and to demonstrate their business case. Publicly funded agricultural extension has been a key historical link between agricultural R&D and farmers and ranchers in high-income countries. Governments and other organizations should prioritize implementing such programmes in Africa.
- Streamlining regulation to reduce lag times, providing targeted tax relief to enhance farmers' incomes and financial security, and offering preferential access to land and market support for promising agricultural techniques and technologies.
- Creating public–private partnerships, which governments can use to leverage public-sector investment, enhance private-sector involvement in agriculture infrastructure and fill gaps in the delivery and adoption of innovation by public- and private-sector entities acting independently.
- Maintaining and expanding regional and international trade in agriculture outputs. Many of the gains in productivity in recent decades have been enabled by globalization and the rise of extended agricultural value chains.
- Bringing about changes in local land and natural resource management modes. This implies real research action systems involving the local authorities, consumers, customary authorities and the government. The aim is to develop joint management capacities to allow optimal and sustainable use of natural resources.
- Supporting the emergence of farmers' organizations able to meet local challenges, market needs and opportunities, and mobilizing them towards technical changes and self-training.

The rise of remodelled agricultural R&D is under way today and the resulting innovations in improving yields, asset productivity and sustainability provide the means for meeting the food needs of the world's growing population by 2050. But to reach that goal, both the public and private sectors will need to keep the R&D pipeline flowing and make investments and commitments to ensure that innovative technologies and techniques are widely and rapidly adopted by countries across the income spectrum.

9.8 Conclusions

Clearly, there is a compelling need for change and appropriate interventions to mitigate agricultural degradation that erodes away agricultural potentials and needed services. The absolute imperative is that farmers must shift from outdated traditional methods to modern well-tested and knowledge-based methods of sustainable and profitable land use based on CA. Making this transition will be difficult without the creation of an enabling environment. Viability of CA as a best-bet option must be demonstrated on a continuing basis across Africa by producing and replicating a convincing frequency of successful CA outcomes in situations that closely mimic the diversity of farm biophysical and socio-economic environments. This is possible only through building and institutionalizing a knowledge-based technical backstopping capacity, and participatory research, at every level of the crop and livestock value chains. Countries of the continent of Africa must, therefore, invest more in research needed for the fine-tuning of CA technologies to customize them for local conditions and generate a package of good practices. Of particular relevance is the need to understand, quantify and demonstrate the role of critical productivity-enhancing factors and practices, the cost reduction impacts of CA interventions to drive adoption and deploying the knowledge as an important starting element for convincing risk-averse smallholder farmers to participate in the ongoing CA revolution in Africa and globally. Research – also covering technical, economic and social factors – is one of the several essential ingredients for mass adoption and mainstreaming of CA across Africa. However, to play its rightful role, CA R&D, in one way or another, must be funded as a matter of priority.

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10 Moving Paradigms – Conservation Agriculture with Alternative Agronomics to Minimize Inputs

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Abstract

The African Union Malabo Declaration outlines goals to achieve sustainable production practices for economic growth in the agriculture sector by 2025. Conservation Agriculture (CA) practices represent a climate smart and resource friendly sustainable production system, and these need to be adopted and refined. This will be a paradigm shift for academics, experts and farmers who are embedded in the intensive external-input monoculture tillage systems. From our review of literature, recent history has shown that CA systems are successful and profitable while using less external inputs and expending less energy. Energy use can be reduced by 40% and labour needs by 50%–90%. Research has shown that CA farming is superior in terms of enhancing soil functions, biodiversity, beneficial insects, energy consumption, greenhouse gas (GHG) emissions and resilience to extreme climate events. Nitrogen and other essential elemental crop needs can be reduced by 10%–70% through CA systems. African research and farm testing have shown integrated CA cropping systems can control insect and weed pests while providing more diverse economic crops. For the paradigm shift to occur quickly, efficiently and economically, institutions need to lead change. Policy makers need to start strategic changes to research and institutions by initiating support programmes identified by innovative researchers and agricultural leaders that can move the Malabo dial towards the 2025 goals.

Keywords: agronomy, soil health, fertility, pest management, push–pull, energy, paradigms, planting green

10.1 Introduction

The Malabo Declaration of the African Union (2014) recognized that the future path of development cannot be the same path and strategies of the past. It expressed concern about the limited progress in agribusiness development and the current dependencies on external factors, and stressed the need to conserve all natural resources in finding sustainable use practices. The Declaration recognized that agriculture needs to lead pan-African development with specific commitments for sustainable and reliable production, access to affordable inputs and be resilient to potential impacts of climate change.

The Inaugural Biennial Review (African Union, 2017) found that only 43% of the Malabo participating states were on track for 2025 targets using their agreed-upon metrics. Recommendations were given for renewed efforts in developing data and sharing of knowledge to renew the efforts of the Agriculture Transformation agenda embedded

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in the Malabo Declaration. The New Partnership for Africa's Development (NEPAD) co-sponsored a review of barriers to climate smart agriculture in Africa which identified Conservation Agriculture (CA) as a desirable form of climate smart agriculture that also met environmental conservation and farm income needs (Barnard *et al.*, 2015). It identified two groups of impediments to farm practice adoption and scaling of CA: 'hardware' barriers (equipment, land, inputs, finance, etc.) and 'software' barriers (extension services, policies, governance, institutions). Milder *et al.* (2011) visited a number of CA locations in Africa and reviewed additional efforts to assess the suitability of CA for climate change mitigation and adaptation. They concluded that, for a number of reasons, CA was 'a particularly timely strategy for rural development and conservation in Africa'. Even though CA had generated substantial benefits for farms where it had been deployed, the Africa continent constituted only 1% of the global adoption level.

CA has increasingly been adopted in many countries around the world in a wide range of agroclimatic environments and cropping–agronomy systems. Kassam *et al.* (2019) tracked adoption around the world to an estimated 180 million ha in 2015/16, a doubling on the previous decade. In Africa, the CA cropland area in 2015/16 was more than 1.5 M ha, having nearly trebled since 2008/09. If the CA cropland area with trees is taken into consideration, CA cropland systems are currently being used on several million hectares in Africa across 30 or more countries, with the majority of farmers being smallholders (FAO, 2011; FAO, 2016; Garrity *et al.*, 2017). The transition to no-till (NT), permanent soil cover and diverse rotations and associations was a paradigm shift for most farmers, but the rapid and widespread adoption of CA is a testimony to their innovation in finding pragmatic solutions to the barriers they were faced with, whether technical or conventional (Garrity *et al.*, 2017).

Farm implementation was introduced in different circumstances than those experienced by researchers who, in this case, for the most part followed along behind the CA movement. Researchers were bound by conventions of small plots, short-period research grants and single factor experimentation rather than by the more systems-orientated research needed for CA. Research plot arrangements were designed to minimize experimental soil variance, and intensively cultivated, so that variety or fertilizer treatment effects could be highlighted. Early researchers did not have plot-scale equipment for NT planting into the soil with vegetative biomass cover, so experimental results were mixed and variable. Derpsch *et al.* (2014) reviewed the variable CA research results globally in the published literature and identified many of the factors that would produce discrepancies in research results (erroneous results) and suggested a protocol for a better systems view of tillage research. Baudron *et al.* (2015) recognized that successes in CA research at the plot scale could not be scaled out successfully to smallholder farmers in Africa, suggesting that dissemination of knowledge did not accompany the practice nor a systems approach that farmers operate with. To understand the frustrations of conventional research tackling CA and to help to highlight future opportunities, we need to remember fundamental soil science and examine emergent alternative agronomic practices in the context of CA as a system at temporal and spatial scales beyond that which often exists on research stations.

Farms have more diverse soils, landscapes, adjacent land uses, equipment (in many cases) and longer periods of change management than researchers. Farmers have to assemble the range of research results available to them into a coherent systems approach applicable to their farm circumstances. Often weak extension services are unable to fill in the many gaps, and farmers are left to themselves to innovate and rely on each other's experience. They often have less access to inputs than researchers, or inputs are cost prohibitive, so they often need to substitute and have alternative options available to them.

Farmer success in achieving sustainable benefits from CA requires complementary good management of agronomy, labour and other farm resources, sometimes in new frameworks and combinations. This extends beyond the experience and knowledge that plot-based research can provide. CA systems rely on undisturbed soils that are covered with vegetative biomass and have diverse crops. The soil system evolves into a different biophysical state and cycling capacity than that found under conventional tillage research plots or initial stages of CA succession. These factors result in a thin library of published literature on the topics discussed in this chapter.

Nevertheless, farmers are looking for answers in order to reduce risks in adopting efficient CA systems.

CA systems rely on integrated pest management strategies to manage weeds, diseases and insect pests. All three core principles of CA systems, when implemented effectively, contribute to reducing weed infestation and to enhancing the abundance of natural enemies of insect pests. Thus, when farmers embark on transforming their conventional systems into CA systems, the weed and insect pest pressure begins to reduce as the systems establish themselves. This occurs in smallholder CA systems as well as in larger-scale CA systems. This allows for biological control of weeds and insect pests in the smallholder systems, and to reduced application of herbicides and insecticides in the case of larger-scale systems (assuming complete CA implementation).

Further, CA systems can enhance soil through the ability to regenerate soil health and function by increasing soil organic matter, and soil life and biology. Integration of legumes and cover crops in the CA systems and return of crop biomass enhances and conserves biological nutrient pools, thus reducing the need for mineral fertilizers by a significant amount. This occurs in smallholder CA systems as well as in larger-scale CA systems.

Furthermore, CA systems do not rely on tillage for crop establishment or weeding. Consequently, there are significant reductions in energy use, regardless of the nature of farm power being used, whether manual, animal traction or motorized. Associated with the reduced energy requirement, there are savings in the use of time as fewer operations are needed. Given the absence of tillage in CA systems, capital costs are lower as the power requirement is lower and tractor life is extended significantly.

This chapter introduces new thinking about some key agronomy components to reduce the need for (or better optimization of) external agrochemical inputs. Three sections will review insect, weed and fertility management while a fourth will discuss energy requirements. We refer to some of the global and Africa published literature on the topics and how CA may be able to unlock benefits that are repressed with monoculture tillage systems. These areas of exploration are nascent, but show promise, and may provide options for CA farmers to reduce dependencies on inputs.

10.2 Material and Methods

We recognize that CA works as a system and the sum is greater than the parts; however, to examine the expected or unexpected performance of components of a system it can be helpful to consider components independently. We separately consider insect pests, weeds and soil fertility from CA or complementary practices such as ‘sustainable intensification’ or ‘organic production’. We have tried to limit our review to more recent peer-reviewed literature, realizing the deficiencies or limitations of early research and the disconnect with the continued status quo of applied researchers attempting to quantify new farm practices. We did not look for comparative literature comparing CA or practices such as NT to conventional practices for selected components (e.g. yields) or CA for climate adaptation or farm types. Some research reviews focus on yield differences of plot research. Farmers are more sensitive to profit margins and returns over variable costs. CA farmers often find they can reduce input costs without a loss in yields and significantly increase profits. Higher yields are not necessarily required to make farming more profitable or sustainable.

We looked for alternate agronomic practices in CA systems that could mitigate external-input needs. We did not conduct a meta-analysis, as (i) there is a paucity of data on the topics; and (ii) the papers do not lend themselves well to systematic filtering on keywords and assigning coding variables to data. We recognized that gems of agronomic knowledge and outliers would be hidden in the nascent literature, and applied a more classical approach an exploratory review of the literature.

10.3 Results and Discussions

There is a wide range of inputs required for cropped agriculture and CA enlarges the options in time and space as it recognizes the complexity, interdependencies and long-term impacts of management practices. Items like labour and time management, seed choices and mechanization options are important inputs, in addition to the major issues of fertility, insects, weeds and pathogens. We recognize that small landholders have different economic, mechanization and rotation options than large farms and found less peer-reviewed material on CA systems relevant to them. There is still limited material on the main issues but we felt a brief glimpse of relevant literature from larger farms may shed light on opportunities for small landholders and arguments for CA in general.

10.3.1 Weed Management

Weeds and their control are another changing paradigm under CA and have been reviewed by a number of scientists, most recently by Sims *et al.* (2018) and Basch *et al.* (2020). CA systems have built-in capacity for integrated weed control because of the three core principles and the corresponding practices plus additional practices that combine preventative with cultural methods. While CA systems do use herbicides, the amounts are low because of the integrated approach that is followed to manage weeds. Monoculture tillage systems have limited options for weed control either by tillage or chemicals. The system also favours certain types of weeds while CA systems often experience a shift in weed species. Farmers need to anticipate different weed pressures in the transition years and be diligent. If seed set is avoided the 'conventional cropping' weed seed bank will become exhausted. The lack of tillage and residue cover will keep new seeds at the surface where chances of germinating seed progression is reduced. Better, the use of cover crops will provide prolonged weed competition.

Nichols *et al.* (2015) comprehensively reviewed the research literature around weed dynamics in CA systems. They noted that crop rotations and surface biomass retention are in themselves methods of weed control but that the combined effect of all three CA principles has disproportionate advantages. Again, this supports the argument against applying only one or two CA principles and expecting agronomic success. All three legs of a stool have to be present, fully formed and strong, to provide successful support. Increased biomass at the soil surface can reduce the light, and provide physical barriers and an allelopathic effect to prevent weed growth and, if a weed does grow, the consequential poor growth reduces seed set. NT and surface biomass increased predatory seed loss by two to three times. With more weed seeds at the surface rather than buried in the topsoil of tillage systems, the weeds are exposed to predation as well as to micro-climate extremes and allelopathic exposure. Crop rotation introduces altered management and changed patterns of resource competition along with further allelopathic pressures. CA systems are found to enable earlier plantings, which also can ensure a time advantage over weed growth. Nichols *et al.* (2015) highlighted the issues of conventional research methods not being able to isolate the effects of weeds and weed control methods, and farmer field trials (citizen science) became key information sources that showed reduced use of herbicides in regions of the world under CA systems.

In Africa, cover crops such as *Lablab*, *Mucuna*, *Canavalia* or *Crotalaria* can be used as a mulch crop, further smothering weeds (Kassam *et al.*, 2009; Owenya *et al.*, 2011; Ddamulira *et al.*, 2015). Diverse crop rotations and associations are also a method to change weed competition and, if herbicides are used, to ensure different herbicide groups are used to prevent the development of herbicide-resistant weeds. Different crops provide management options for biomass management, growing season length and use of cover crops as well as allelopathic suppression of weeds. The complexity of CA systems allows for diverse options for weed management that introduce cultural options to minimize weed populations where judicial mechanical or chemical controls can be used more economically.

The push–pull cropping system designed in Africa is a broad-based CA solution that covers a number of aspects – weed control; insect control; fertility and moisture; and temperature enhancements (Khan *et al.*, 2017). The system focuses on two main pests: the stem borer insect that devastates maize yields and the *Striga* parasitic plant (weed) that chokes maize. Interplantings of the low-growing *Desmodium* legume among the maize or target economic crop emit chemicals that both repel ('push') stem borers and suppress *Striga* growth (Khan *et al.*, 2020). Similarly, *Mucuna* has been shown to control *Striga* in a CA system (Kassam *et al.*, 2009). The co-benefits of moisture, temperature and biodiversity of natural pests all add up to an integrated system with economic benefits without the annual (and variable) costs of pesticides. The popularity of the push–pull system has driven knowledge development so extension services and smallholders can understand the interrelated details and customize the system to their conditions. The International Centre of Insect Physiology and Ecology (ICIPE) hosts a website dedicated to the continued development of the technology (http://www.push-pull.net/, accessed 30 July 2021).

A significant future exists for further development of integrated cropping innovation in managing weeds, living vegetative biomass or cover crops with the use of planting green techniques for crop establishment (Duiker, 2017). Planting green minimizes or avoids the use of herbicides by using a roller crimper to subdue the vegetation and sowing directly through the rolled green biomass. By retaining living vegetation or crop biomass on the surface (accompanied by no disturbance planting), one can manage weeds with little or no herbicide use.

Unfortunately, emergent technologies for farms can be very promising but hard to implement as the technology or material is hard to source. Such is the case with *Desmodium*, napier and diverse cover crop blends. In remote rural areas even the conventional tools of fertilizers and pesticides (and application equipment) can be difficult to access. Policies need to anticipate research developments, or at least be aligned with them, and enable resources to be accessible and affordable by farmers.

10.3.2 Insect Pest Management

Altering the insect pest–predator dynamics to suppress crop damage is at the core of insect pest management in CA. This allows the possibility of encouraging as much biological control of insect pests as possible in CA systems, leading to reduced or minimum application of insecticides.

However, insects are the least predictable and the most difficult to study as they are impacted by short-term changes in climate (e.g. a strong wind, a short rainstorm) and spatial scales of field variability and surrounding lands. Insects do not conform to research plot boundaries nicely, and researchers are often compelled to do field- or farm-scale studies – a sensible benefit for CA farmers. Regardless, early reviews of NT practices found both increases, decreases and no effects on insect pests, indicating there are both opportunities and risks to understand (Baig and Gamache, 2011). Fusser *et al.* (2017) studied slugs and predatory carabid species in wheat fields in Germany and found that species richness of carabids increased with semi-natural vegetation adjacent to the wheat fields, while slugs preferred simple landscapes. A comprehensive review of 15 studies across five countries found natural pest control was reduced as the landscape simplified (defined as the amount of tillage within 1 km of test sites) with an average reduction of 46% compared to more complex landscapes (Rusch *et al.*, 2016). Chabert and Sarthou (2017) sampled CA farm fields in France which were found to have the highest populations of hoverflies (predators of aphids) over reduced till and where there was diversity in adjacent landscapes. They found that many field conditions fell under various definitions, making differentiation difficult, an issue inherent in the variable results of researchers. A larger cross-sectional study of farms in France found low pesticide use rarely decreased productivity (in 77% of farms) and the authors (Lechenet *et al.*, 2017) estimated that total pesticide use could be reduced by 42% on 59% of the farms. In the northern prairie region of the USA, LaCanne and Lundgren (2018) studied maize fields on farms with established CA or conventional practices and found ten times more insect pests (sum of six types) on insecticide-treated conventional fields than on untreated CA farms. A larger study on the role of pollinators was completed across 33 crop systems in small and large holdings in Latin America, Asia and Africa (Garibaldi *et al.*, 2016). They found that for small landholders, the yield gap between high- and low-yielding farms (with a range of conservation-cropping practices) could be alleviated by 24% with enhanced pollination strategies, and the remaining gap of 76% could be closed by deploying other technologies, including CA.

For smallholders in Africa and elsewhere, biological control of insect pests in CA systems would be ideal. One particularly effective biological control approach is the push–pull system (FAO, 2016; Khan *et al.*, 2017; Khan *et al.*, 2020). Push–pull production and protection system was developed as a control measure for cereal stemborers, the *Striga* weed and low soil fertility. The practice harnesses resource-conserving integrated pest management and integrated fertility management approaches using natural processes and locally available bio-resources to increase farm productivity by addressing biotic and abiotic constraints in smallholder agriculture (Cook *et al.*, 2007; Hassanali *et al.*, 2008; Khan *et al.*, 2020). Originally designed for the tillage-based cereal–legume intercropping system, push–pull was further developed for CA systems, providing continuous soil cover with a perennial cover crop of *Desmodium* (live mulch) and vegetative biomass, and a diversified cereal–legume–fodder intercropping practice involving napier grass planted as a border crop around the cereal–*Desmodium* intercrop. The *Desmodium* repels stemborer moths (push) while the surrounding napier grass attracts them (pull). The push–pull practice is based on companion cropping which effectively controls stemborers and fall army worm (FAW) insect pests as well as parasitic *Striga* weeds, while improving soil fertility by fixing nitrogen; reducing soil erosion; capturing more rainfall; conserving soil moisture; sequestering C; and providing a source of forages for improved livestock production (Khan *et al.*, 2017; Khan *et al.*, 2020). Farmers practising push–pull in CA systems have realized substantial grain yield increases with minimal use of external synthetic inputs. The perennial legume intercrop improves above-ground and below-ground arthropod abundance, agrobiodiversity and the food web of natural enemies of stemborers (Midega *et al.*, 2015; Khan *et al.*, 2020). The practice effectively controls the major insect pests of cereals in Sub-Saharan Africa, mainly the lepidopteran stemborers, and more recently the invasive FAW, as well as parasitic *Striga* weeds. Push–pull practice has been disseminated in several countries in Sub-Saharan Africa (Khan *et al.*, 2020).

With CA systems it is possible to promote integrated insect pest management strategies in combination with the three core principles of CA and supplemented with other complementary insect pest management tactics such as the push–pull strategy (Fanadzo *et al.*, 2018; Khan *et al.*, 2020). Soil mulch cover and diversified cropping have been reported to reduce or avoid insect pest damage by encouraging the base populations of predators. Crop rotations and sequences in diversified cropping systems help to break insect pest cycles, thus reducing the populations of insect pests. Similarly, mixed cropping or intercropping have a significant effect on reducing pest attack and damage (Khan *et al.*, 2017; Fanadzo *et al.*, 2018; Khan *et al.*, 2020).

10.3.3 Disease Management

Crops sown in CA systems are susceptible to the same diseases as under conventional tillage systems. However, the presence of crop biomass on the soil surface requires special attention, as vegetative crop material can sometimes provide an important medium for the survival of pathogens. In this context, crop rotation is the main tool to reduce the inoculum of the disease, as is the need to alternate crops with different rooting depths to avoid soil compaction, which favours root diseases due to waterlogging and poor water drainage.

For a disease to occur, three conditions are needed: (i) the presence of pathogen (bacteria, fungi, viruses or nematodes); (ii) a host, which could also be a crop; and (iii) favourable environmental conditions (temperature, humidity, soil type, fertility, etc). Some diseases occur in only one crop – that is, they are host specific – while others occur in several different crops and plant families. In all cases, the host provides the pathogen with food. The host can occur as seed, as vegetative parts or weeds. The dependence of the pathogen on the host is quite strong: when the host is no longer present, the pathogen will disappear as well (Dávila Fernandes, 2000).

The disease intensity depends on the density of inoculum for infection. Therefore, the answer in solving the disease problem lies in the presence or absence of crop biomass, as this is the only available nutrient (food) source for some pathogens after harvest. The conventional practices for solving the problem through immediate destruction of the vegetative residues after harvest by burning crop biomass and/or incorporating it into the soil through ploughing and harrowing, are not rational options in CA systems. Crop rotation from the disease management point of view means refraining from planting the same crop until there is complete decomposition of crop residues, and consequently the elimination of pathogens from the area has occurred.

The presence of more crop biomass on the ground surface can provide a habitat for disease organisms that may develop and spread in cooler and moister environments. However, on the other hand, ground cover can form a physical barrier in the completion of the development cycle of certain pathogens such as *Sclerotinia* spp., or prevent pathogens from spreading through soil movement by wind, water or agricultural equipment (Costamilan, 2000). In CA, crop biomass and stubbles are retained on the soil surface and the soil is no longer disturbed by tillage activities. Therefore, disease control strategies focus on alternative effective measures of control, which include crop diversification involving rotations and associations (intercropping); use of resistant cultivars; avoidance of soil compaction and maintenance of good drainage; and treatment of seeds with fungicides.

Infected seed may also be a vector for disease introduction. Nevertheless, in areas with infected crop biomass, infected seeds contribute a relatively small part of the inoculum. The seeds can be infected during seed development, which justifies crop protection measures, even at the last stage of the crop growth cycle. Chemical and non-chemical seed treatment is an important tool to reduce the incidence of these diseases, especially in areas where rotation is practised to break the disease cycles. Clean sources of seed or seed treatments can prevent introduction of additional disease loading (Huang *et al.*, 1995).

For smallholders in Africa, intercropping and other forms of crop diversification in CA systems including push–pull cropping systems have been shown to be able to biologically control crop diseases (Khan *et al.*, 2020). Further, improved soil structure and internal drainage and aeration in CA systems result in a drier and healthy soil environment that is less prone to spreading diseases.

10.3.4 Soil Health and Fertility Management

Soil health is the capacity of soil to function as a vital living system, with ecosystem and land use boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and promote plant and animal health (Doran and Zeiss, 2000). The state and dynamics of soil health and fertility are the result of both the diversity of live and dead vegetation and microorganisms in CA systems and the resulting changes in the health profile of the soil (changes in chemical, physical, hydrological and biological properties and their derivative functional characteristics such as moisture and nutrient retention and supply, porosity and aggregate stability, load-bearing capacity, aeration, drainage, temperature regulation, soil formation, etc.) (Kassam *et al.*, 2013). Soil fertility is the capacity of the soil to supply nutrients and water to crop plants in adequate proportions for plant growth, thus affecting plant habitat, crop performance, biomass and yield (Cooke, 1975).

The CA system can have a variety of crop biomass at the surface, then a partially decomposing mulch integrated into the topsoil and decomposing root biomass further below. There is also decomposing biomass from decaying microorganisms such as protozoa, bacteria and fungi, and mesofauna such as earthworms, nematodes, ants and termites. The relatively undisturbed topsoil has a changed structure with not only a greater pore size distribution but more connectivity (contiguous macroporosity) and a variety of roots and mesofauna providing more channels and biomass. The changed soil climate and biophysical properties move the soil health and functions to a far different state than in conventional agriculture. Monoculture tillage systems chop, mix and aerate soils several times a year. We should not be surprised that the massive volumes of research based on those systems may be a rough approximation of CA soil state and functions.

Both the high cost of research and the push for short-term research projects do not bode well for answering the needs of CA production and upscaling. Perhaps the emergent interest in field scale and farm trialling may better answer the questions than small plot, research station results. Perhaps new, sophisticated process-based models and their operators will more efficiently provide insights and answers to CA issues. In the meantime, some researchers have provided intriguing results from studying CA type states and functions.

CA starts with a crop biomass management plan – which crops to rotate or mix, cover crops, animal or other fibre needs, and so forth. Then the degree to which soil disturbance occurs from animal hooves to the design of the planters determines how much and how often crop biomass is retained on the soil surface. Jat *et al.* (2019) found after 4 years of climate smart agriculture

(CSA) plots in India that soil organic C (SOC) had increased by 70% over conventional treatment. This did not simply represent a changed stock of C; the authors also found maximum counts of bacteria, fungi and actinomycetes along with higher dehydrogenase and alkaline phosphatase activity and higher microbial N and C. In the UK a change in soil C from 2.1% to 6.3%, with a consequent 80% reduction in phosphorus and potash applications and 50% decrease in nitrogen applications during that period, has been reported (Kassam and Brammer, 2016). Adding C-rich fertilizer (compost, manure, etc.) or crop biomass will increase macro- and meso-fauna such as earthworms, ants and termites (Ferris *et al.*, 2004; 2012; Liu *et al.*, 2016; Ranaivoson *et al.*, 2017). Liu *et al.* (2016) found that species richness and omnivore–predator nematode abundance increased with organically fertilized regimes and was reduced in inorganic N fertilized systems. They also found manure-based fertilizers reduced plant feeding nematode populations. Ferris *et al.* (2012) reviewed nematode literature and found nematodes can make up to 25% of the N mineralized in soils. Zhang *et al.* (2017), working with long-term studies in California, found NT systems (especially those with cover crops) increased SOC and the amount and diversity of nematodes, which in turn increased N mineralization. The effect was amplified with the use of cover crops in the cropping system. Lu et al. (2018) found NT systems in China resulted in more arbuscular mycorrhizal fungal diversity, numbers and key species along with more soil carbon and aggregation. We acknowledge that soil biology is complex but we need to remember that measures of quantity of C, fungi, nematodes, bacteria and the like imply different soil functions and thus soil health and fertility parameters. Undisturbed soils with C inputs and stratified levels of decomposition immobilize and mineralize nutrients differently than conventionally cultivated soils. The different types of organic material have different decomposition rates and favour different complexes of microorganisms responsible for cycles of decay. Undisturbed soils retain a richer and more diverse biological species that are responsible for ‘slow release’ of nutrients for plant uptake.

In a pan-European study of experts examining the impacts of different cropping systems on five soil functions (productivity, water regulation, C regulation, habitat, nutrient cycling) they found conventional practices had negative effects on soil functions while CA had overall positive effects (Ghaley *et al.*, 2018). Turmel *et al.* (2015) conducted a global review of literature on residue management and found that, besides the biophysical benefits to CA soils, surface crop residue increased mycorrhizal fungi and phosphorus availability, especially important for tropical soils. A short-term comparative study in north-western India on poor soils found CA cultural practices increased soil organic matter (and thus fertility) with available N being 33%–68% higher under CA, as well as some extractable micronutrients (Jat *et al.*, 2018). After 4 years of CA, savings in wheat agronomy were 30% for N and 50% for K. A greater reduction in N requirement (some 75%) has been reported after 10 years of CA in Portugal (Carvalho *et al.*, 2012). Assainar *et al.* (2018) in Western Australia found that a multiple species microbial inoculant on wheat had similar yields to conventionally fertilized treatments. New biologically-based fertilizers may become commercialized in the near future in various continents and countries as demand dictates.

In general, soils under CA systems have been shown to have higher infiltration rates, increased water retention capacity and better drainage properties. Thus, CA soils are able to capture greater quantities of rainfall water and benefit from higher effective rainfall. This is because of the improved soil surface conditions, structure, porosity, aggregate stability and network of biopores due to improved soil biology and reduced runoff, soil erosion and degradation (Basch *et al.*, 2012; Kassam *et al.*, 2013; Kassam and Kassam, 2020). In the semi-arid and sub-humid areas of the world, improved soil water balance during the growing season is particularly valuable to farmers as it leads to better resilience against the impact of rainfall variability and greater stability in yields; increased length of growing season and improved cropping intensity; and overall improvement in biomass availability and management (Derpsch, 2003; Shaxson *et al.*, 2008; Thierfelder *et al.*, 2013; 2015a, b; Kassam *et al.*, 2017; Lalani *et al.*, 2018; Wall *et al.*, 2020). These improved hydrological conditions have a positive effect on water productivity as well as on nutrient productivity, thus minimizing water and nutrient requirements per unit of output and improving water and nutrient use efficiencies.

A recent pan-African study shows that African soils have a high potential for sequestering C under CA systems in different agroclimatic zones (Gonzalez-Sanchez *et al.*, 2020). For smallholder farmers in Africa, CA can help to regenerate soil health and fertility and sustain higher yields, with a much lower need for mineral fertilizers in systems with deep-rooted legumes such as pigeon pea, cowpea, *Lablab, Mucuna*, *Canavalia* and *Crotalaria* as well as *Brachiaria* (Kassam *et al.*, 2009; Owenya *et al.*, 2011; Ddamulira *et al.*, 2015; Kassam and Brammer, 2016; Lalani *et al.*, 2017). Similarly, CA cropping systems with perennial legume and non-legume trees are important in improving land stability, crop yields and farm economics in dry and moist semi-arid and sub-humid areas of Sub-Saharan Africa (Garrity *et al.*, 2010; Garrity, 2017; Kassam *et al.*, 2020).

10.3.5 Energy Use Management

Energy costs are a significant annual cash cost for farmers (using power units) next to the costs of external chemical inputs. Fossil fuel combustion also has implications for the public costs of climate change both in the context of direct field emissions and in the manufacturing of fertilizers and pesticides. Savings in fossil fuel use can, therefore, produce a win–win scenario for both farmers and society at large. In addition, energy expenditures can also be thought of in electrical units or caloric effort of animal or human effort, the latter important for smallholders.

Baig and Gamache (2011) reviewed total non-renewable energy costs of conventional and NT production systems that were relevant to the Canadian prairie region. Gulden and Entz (2005) analysed commercial farm-scale production systems with different tillage and crop rotation practices. Incorporation of legumes into rotations saved nitrogen fertilizer and thus the energy footprint of the crop rotation. NT saved about 40% of machinery fuel usage and about 10% of the energy costs of fertilizer inputs, while pesticide energy costs were higher. The net result of all sources was 14% less energy use with the NT system. Camargo *et al.* (2013) applied a farm energy assessment tool to common cropping systems across the USA and concluded that ‘sustainable practices such as NT and a legume cover crop reduced energy use and GHG emissions from corn production by 37% and 42%, respectively’. In the UK, a decrease in fuel consumption from 96 to 42 l ha^{-1} has been reported, corresponding to a decrease in crop establishment cost from GBP266 ha^{-1} under conventionally tilled crops to GBP30 ha^{-1} under CA production (Kassam and Brammer, 2016). Tullberg (2008) found a 40% diesel fuel saving with NT production in Australia with a further 50% reduction in fuel by moving to controlled traffic farming. The total energy emission of NT was higher, however, due to increased herbicide use. The extra embedded energy in fertilizers and pesticides (and manufactured equipment) is very important when calculating energy footprints, but farmers are interested in cash costs which are sensitive to fuel usage.

Farmers can win if they reduce fuel purchases and use the funds for other farm production needs. If pesticides and fertilizer can be reduced, as they can be in CA systems, cash savings can also be gained. The management challenge is to maintain yields at the lower costs for higher profit margins.

Lynch *et al.* (2011) reviewed the literature on organic versus conventional cropping systems in terms of energy use and global warming potentials (GWP). A compendium of European and North American literature revealed an organic production advantage in most cases (less energy use, less GHGs) and in most cases that advantage was beyond their threshold of +20%, with more variability in vegetable crops than field crops. Lynch *et al.* (2011) did not look at NT systems but suggested the savings in fuel combustion may be more than offset by higher pesticide rates. Neither did they look at soil C storage differences. Pimmental (2009) compared the energy intensity (energy input:output ratio per unit of production) of crop production for 12 crops around the world. The author found in the case of maize that the USA used 25% more fuel for labour-saving machinery and obtained higher yields than in India and Indonesia (at a lower production cost of US$100 per tonne). The input:output ratio was 1:1.4 versus 1:1 in Indonesia. The USA maize yield was 5.5 times that of Indonesia, however, which implied that a small yield increase in Indonesia could equalize the ratios. Seufert and Ramankutty (2017) found tillage energy emissions in organic systems were more than offset by reduced emissions from fertilizer and pesticide use; however, they noted that in the USA organic farmers and conventional farmers were both equally moving to reduced tillage systems. Organic farms were rated poorly for energy use and N and P losses but higher for reduced pesticide exposure (for both the farmer and the environment).

In the case of smallholder farmers in Sub-Saharan Africa, minimizing soil disturbance in manual systems can reduce human energy requirement by 50%, and this is particularly appreciated by women and senior farmers. An associated saving in time has been shown to improve time available to look after children and household matters, and may also lead to expanding the area under production. In Zambia, Aagaard (2011) reported that direct seeding with an animal-drawn ripper-seeder with a knife or chisel soil opener for line sowing and fertilizer placement took 4 h per hectare compared with 14 h for conventional ploughing; and farmers using small tractors could direct seed 1 ha in 1 h and reduce fuel consumption from 15 l/ha to 6 l/ha. The latter is an important economy measure in parts of Asia where tractor cultivation is increasingly being practised. Minimum soil disturbance practices for seeding using hand implements can reduce labour input by up to 90%. This reduced drudgery is particularly important in areas where farming is mainly practised by women or elderly farmers, or by those who suffer from HIV/AIDS. These time economies enable farmers to plant crops more nearly on time, which can greatly increase yields and security of production (Kassam and Brammer, 2016).

By increasing soil organic matter contents and moisture-holding capacity, CA can double subsistence crop yields in areas where use of fertilizers is uneconomic, and it can sustain production in years with low rainfall (Aagaard, 2011; Marongwe *et al.*, 2011; Silici *et al.*, 2011). In Karatu District, Tanzania, where CA was introduced in 2005, average yields of maize increased from 1 t/ha to 6 t/ha using only organic manure as a source of plant nutrients (FAO, 2011; Owenya *et al.*, 2011). In the semi-arid Laikipia District, Kenya, maize grain yields from CA were increased by 50% to 60% in years of reduced rainfall, while net benefits increased by 130% to 153% (Mkomwa *et al.*, 2017). The CA equipment used was hand jab planters and oxen rippers (to open planting furrows but also to break hard/plough pans), and animal-drawn NT seeders. The benefits of lower costs for fuel and/or draft animals and hired labour for smallholder farmers in the drylands systems of Iraq, Syria, Morocco and Tunisia were also highlighted by the International Center for Agricultural Research in the Dry Areas (ICARDA, 2012). Farmers who use tractors to plough are able to reduce their fuel use by two-thirds when they switch to CA. Enhanced soil structure makes it easier for farm machinery to cross the soil for the remaining operations, further reducing fuel costs, as well as equipment wear and tear.

Labour savings mean more time for members of the farming family to pursue other livelihood options, interests and investments such as education, and a smaller portion of farm household income paid out to hired labour. Time savings allow farmers to plant earlier, perhaps by weeks, which can improve the odds that the crop will mature and be ready to harvest before the onset of late-season drought. It may allow farmers to squeeze in a third cropping per year in what had been a system producing only two crops per year, adding perhaps a crop of high-value vegetables or another cash crop.

10.3.6 Issues and Policy

CA agronomic research can get complex quickly as we need to be aware of the whole system and interrelations. Researchers have had difficulty in the past with CA equipment for plot-scale applications. Research funding is biased towards short-term research which is counter to the CA characteristic of diverse crop rotations and planning on the effects of historic crops (previous year). Ranaivoson *et al.* (2017) did a meta-analysis of literature for the effects of residue on soil properties. To look at nutrient status, they reviewed literature that had up to 3 years of data, which would be the transition period and provide interesting nutrient boundary curves, but may not be the reality of field conditions after CA had been established. Researchers are under pressure to publish quickly and we may only receive ‘transition state’ results – informative but not the end product farmers are interested in.

The historic international research institutions of CGIAR that were key in ushering in the Green Revolution have recently experienced a daisy-chain of reviews and reforms to effectively continue research and development services to country clientele around the world. Leeuwis *et al.* (2018) reviewed the state and future imperatives for CGIAR, encouraging it to refocus on research and building capacity with partnerships. Large institutions are like large ships, which have difficulty turning rapidly or navigating up tributaries of opportunities. Research funding has become progressively shorter in duration and large institutions are stuck in conventional, reductionist scientific research. CA is counter intuitive to them as it requires systems approaches and long-term research as the soil–plant system moves to a new equilibrium with different factors and drivers. The need for long-term systems or integrative research was pointed out by Nichols *et al.* (2015) as a shortcoming to extrapolate historic research into a CA framework. Baig and Gamache (2011) found they had to look to farm trialling and long-term contrasts to elucidate the changes presented by CA systems. CA can be thought of as a disruptive technology to the future of agricultural research in that it prompts paradigm shifts from conventional research methodology utilizing current technology advancements and enabling applications of 'citizen science' (Goddard *et al.*, 2020). The drivers of economic and efficient research that determine place-based climate smart agricultural systems create a compelling argument for changes.

Increased comprehensive research and extension efforts are needed in Africa on CA generally, and especially for smallholder farmers. This is easy to say, but difficult for governments to increase funding or reallocate funding from other agronomic endeavours. The research field has grown, and the inertia of conventional agricultural research demands has encountered entries from organic production and the new derivative, regenerative agriculture as well as from the overlay of precision agriculture and the technologies of a reincarnated Green Revolution. Soil health is a renewed area of interest that begs for more expensive systems approaches in research. CA has made admirable research inroads thanks to innovative and courageous scientists willing to take on new challenges. CA can be compatible and integrative with the above taxonomy of research topics, which increases the complexity – or opportunities – to be researched. Regardless, systematic extension efforts are needed at the institutional and policy level in every country, in partnership with private sector, to accelerate the uptake. The education sector must move away from conventional tillage agriculture to CA-based education, covering all aspects of this new agricultural paradigm with its multifunctional contributions to economic, environmental and social development.

Ogunkunle and Chude (2018) considered the need and pathways to maintain and improve soil health in Africa. They favoured CA as the most logical and best-fit system, with organic agriculture and integrated soil fertility management showing promise as well. They found that fertilizer access (and approaches incorporating intensive agronomic inputs) collapsed once external funding and support ceased, and they illustrated the success of CA in four countries where external inputs were not readily available. They called upon African leaders and policy makers to ensure soil health is on development agendas. Although Ogunkunle and Chude (2018) referred to an exhaustive list of soil health parameters that might be more suitable for research scientists, Seufert *et al.* (2012) suggested a simpler set of principles and metrics more suited for smallholder agriculture. It was intended to evaluate organic agriculture but would be equally appropriate for smallholder CA systems. Simple farm-level or landscape assessments and metrics are needed for policy makers as well as for programme managers, auditors and other actors.

10.3.7 Perceptions and Constraints to Adoption of Biological Systems

Agriculture that does not use a lot of external industrial inputs and technology does not often attract support or funding from the private sector. CA, organic and low-input systems tend to fall into that category and need to rely on support from governments, independent agencies or farm organizations. The results are often meritorious as they generate a win–win–win scenario, specifically farm profitability, sustainability, environmentally good (ecosystem services) and being climate smart. The public benefits generated are substantial and deserve support. They further support the Malabo goals of sustainable and reliable production, agricultural growth and resilience to climate change.

Current market pricing gives no preference to products that are healthier or reduce climate impacts. On the contrary, policies often support tillage-based agriculture; for example, through subsidies or by disadvantaging efforts to innovate to CSA technologies. Providing incentives for farms to reduce greenhouse gas (GHG) emissions, rebuilding soil C, reducing input uses and being able to identify their products as low climate-impacting in the marketplace could generate a pull effect to sustainable technologies. Consumers could become sensitized to the appeal of 'climate-friendly products' that align with consumers' values, and underscoring the connection between the health of their families and the well-being of the planet. Development finance institutions could set and promote best practices, or provide favourable lending rates that encourage climate smart farming.

Who is the custodian of the biological knowledge systems? Capacity to implement CSA systems is inadequate at all levels – including farmers, production inputs and output businesses, extension agents, researchers, academia and policy makers – yet knowledge and skills are essential for successful implementation and to generate data providing the evidence of the benefits of change. Earlier sections have explained that CA is predominantly led by farmers (smallholders and large scale) with academics following behind. Academics and farmers (particularly smallholders in developing countries) have different understandings and perceptions as they are informed by different sets of evidence data. The absence of practically applied research conducted at farm-scale stems from plot-size research in highly controlled conditions that cannot be replicated on farmers' fields. However, it is the academics who are given the priority to influence decision making for agricultural policy. Without the relevant CA research evidence nor the field experience, their recommendations are constructed on shaky foundations. On the other hand, the successful smallholders require platforms and networks to consolidate their experiences and support championing the course for their peers.

10.4 Conclusions

The Malabo Declaration has declared commitments to developing sustainable and reliable agricultural production that exhibits climate change resilience and contributes to growth of the agricultural economy. CA can provide solutions, even in difficult circumstances where external production inputs are expensive or have limited availability. CA has a number of radical differences from monoculture tillage systems such as permanent residue cover, NT and diverse crop rotations. All of these interact to make it a unique package that presents a paradigm shift to manage as well as to research and extend (both with enhanced capacities).

CA is a system and needs to be considered as such, not as a few new factors that have no lag, residual or interconnected characteristics. It is no longer an issue of selecting a new crop type that yields a few percentage more, but rather of understanding the interconnected physical and biological cycles as the soil changes and improves (a moving target). CA systems can magnify the influence of microsites (topographic or soil types), introduce many more organisms above and below ground, and underline the importance of time scales. CA helps to look at both conventional and CA agronomic paradigms from the context of the whole soil system (including above- and below-ground biomass) which has changed and, in doing so, has shifted to new agronomic needs and opportunities.

Increasingly, it is being realized that there are biological and ecological opportunities to reduce the application of agrochemicals in CA systems for effective crop protection and crop nutrition. Increased benefits and, indeed, threshold effectiveness is achieved when all principles of CA are deployed.

Fertility needs are mitigated through the introduction of diverse crops including legumes. The biomass cover and NT yield more mycorrhizal fungi and nematodes, and enhanced nitrogen and phosphorus availability. External nitrogen requirements have been shown to be reduced by up to 75%. Ground cover can be a barrier to physical transmission of diseases. Pest control needs are reduced with the combined diversity introduced by CA landscapes. The innovative push–pull integrated pest management system designed for Africa controls insects, diseases and weeds within the one system. Reviews of published literature find that non-chemical weed control is most effective when all three principles of CA are operational. Fuel use in CA systems can be reduced by 40% and human energy (time) reduced by 50%–90%. The benefits are sometimes greater on small landholdings. The time savings can also mean that timelines of operations are optimum, and earlier plantings can provide better weed control as well as better crop yields.

In situations where agrochemicals are not available, it has been shown that CA systems can be established by smallholder farmers, based on the practical applications of the integrated CA principles along with other complementary biological and ecological practices. The ability of CA farmers to minimize agrochemical use will depend on many factors including the nature of the biotic and abiotic stress conditions, availability of locally adapted biological and ecological solutions, economic environment, farmer innovativeness, research support, and agricultural development priorities and strategies.

Answers to CA farmer issues have proven difficult to derive within conventional research and academic institutions. Historic experience of CA pioneers found academia and government research institutions unwilling, unable or fearful of stepping beyond conventional agriculture and classical research methodologies. Perhaps research and extension institutes dedicated to CA could generate the needed knowledge. The needs of CA information combined with the global movements towards systems, integrated complex problems, and environmental and social consciousness have put expectations on governments and research institutions to pivot policies and institutions to adapt. CA is knowledge intensive, requiring concerted efforts to develop and support extension capacity. Combined with digitization and technologies, the new needs and expectations have yielded creative disruptions across economic sectors, including agriculture.

We are beginning to explore the range of CA applications on diverse agroclimatic and socio-economic circumstances. The potential to produce more – with less reliance on external inputs – is intriguing, and new science can pull us down new pathways faster. A more diverse R&D community approach, institutional disruptions and government leadership can combine to shift paradigms, find new efficiencies and enable upscaled solutions to a broader audience in support of national and regional policy goals.

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11 Economic and Yield Comparisons of Different Crop and Crop–Pasture Production Systems

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Abstract

Over the past 15 years the adoption rate of Conservation Agriculture (CA) in southern South Africa has increased at a fast rate, although the adoption of the three pillars of CA was to varying degrees. The adoption of CA happened in the absence of any policy support framework directed to CA. The market drove the adaptation rate with a handful of local producers being the first to adopt no-till (NT) strategies. Long-term field experiments demonstrate that the effects of crop rotation include increased yields from the main wheat crop so that two-thirds of the present total wheat production may be achieved with only half the cropped area under the main crop, and gross margins are better – and dramatically better – with integration of cropping and livestock. This chapter presents an overview of the benefits to yield and economic sustainability of including alternative cash and pasture crops into CA farming systems in the winter rainfall region of southern South Africa.

Keywords: Mediterranean, animal factor, Conservation Agriculture, gross margin, medics, wheat

11.1 Introduction

Rain-fed agricultural production systems in the Mediterranean (winter rainfall) southern South Africa (Western Cape Province) have been based on winter cereals since the 1700s. The Dutch and English colonial powers initially encouraged monoculture production of wheat due to their economic and expansionist policies (Anon., 2000). Due to the region's inherent production potential for wheat, the availability of commercial fertilizers, the 'Green Revolution', improved chemical pest control measures and government subsidies, wheat production was, until recently, based on monocropping, even though some alternatives were available. These factors also encouraged expansion of grain production into marginal areas (Arkcoll, 1998). Increased input costs; competitive world market prices since the introduction of a free market economy in 1994; uncertain production due to decreased soil potential; and variable, unpredictable rainfall have greatly reduced the biological and economic sustainability of wheat production in southern South Africa.

Research on newly introduced plant species during the first half of the 1900s had identified a number of annual legume species (as well as perennial lucerne) that showed the potential for inclusion as pastures under rain-fed conditions,

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in the region then currently under monoculture wheat systems (Van Heerden, 1998). Initially root diseases, insect pressure and the persistence (the ability to re-establish over time) of these legume pastures over time limited wide adoption of these legumes as suitable pastures for the local farming systems. New research efforts during the 1970s and 1980s resulted in the identification of species and cultivars better suited to the local Mediterranean environment. Long-term research results on grazing systems showed the value of including these legume pastures in local rain-fed crop–livestock farming systems. An incentive scheme introduced by government in the early 1980s encouraged farmers to include these pastures in their production systems, with limited success.

Conventional production practices, including tillage and the removal or burning of residues, have played a significant role in the degradation of soils across the world and specifically in South Africa (Laker, 2004; Montgomery, 2007; Farooq *et al.*, 2011). This contributed to a decrease in the world's capacity to produce food, according to the World Resources Institute (2000). In 2011 Farooq *et al.* (2011) stressed the fact that a point of no return will be reached where food security cannot be maintained if agricultural production continues on the conventional production trajectory. According to Swanepoel *et al.* (2017) this is also true for South Africa as well as the rest of Sub-Saharan Africa.

Over the past 15 years the adoption rate of the individual principles of Conservation Agriculture (CA) in southern South Africa has increased at a fast rate, although the adoption of the three pillars of CA was to varying degrees. The adoption of CA happened in the absence of any policy support framework directed to CA (Knot *et al.*, 2017). The market drove the adaptation rate, with a handful of local producers being the first to adopt no-till (NT) strategies.

A CA systems research trial, based on minimal disturbance of the soil, crop rotation and retention of residues on top of the soil as described by Hobbs *et al.* (2008) and Kassam *et al.* (2012) started in 2002 (Langgewens Research Farm, Moorreesburg, Western Cape), although the trial was initiated in 1996. Since 2002 five more such trials have been initiated in the Western Cape. Other global research findings indicated the multiple benefits of crop rotations through the differences in ecology and economy of the different crops (Davis *et al.*, 2012; Thierfelder *et al.*, 2015; Flower *et al.*, 2017). The variation in the different management approaches associated with the different crops also drives these benefits (Gaba *et al.*, 2013; McLaren *et al.*, 2018).

This chapter presents an overview of the benefits to yield and economic sustainability of including alternative cash and pasture crops into CA farming systems in the winter rainfall region of southern South Africa. The results from the study featured in the overview tie into the Malabo Declaration and Agenda 2063 and the commitment to enhance the resilience of livelihoods and production systems to climate variability and other related risks (African Union, 2014). This research was also taken up as a priority case study in the Western Cape Climate Change Response Framework and Implementation Plan for the local Agricultural Sector (Midgely *et al.*, 2016).

11.2 Location, Climate and Soil

The research area is located on the Langgewens Farm in South Africa's Western Cape Province (33°17′078″ S, 18°42′2809″ E). This forms part of the Swartland region, an important winter cereal production area on the western coast of South Africa. Small grains are grown under dryland conditions. This is a semi-arid Mediterranean climate with cold wet winters and hot dry summers. The site receives an average annual rainfall of 450 mm, with approximately 80% received during the winter months of April to September. This constrains regional production to one crop per year, sown in April and harvested in November, with a fallow period during summer.

The soils in this region are sandy loam mainly derived from Malmesbury shale and tend to be shallow and stony. The dominant soil forms are Swartland, Oakleaf and Glenrosa as classified by the South African soil classification system (Soil Classification Working Group, 1991). The maximum working depth of the soils range from 30 to 60 cm and are composed of 40%–60% coarse fragments and have a clay content of 10%–15%. The carbon (C) content range is 0.5%–2.0% (Cooper, 2016).

11.3 Resources

In this chapter wheat yields and subsequent gross margins are presented, which were obtained in a large-scale, long-term experiment comparing several crop and crop/annual legume pasture rotation systems to determine the potential implications of CA practices in systems with and without an animal factor. The trial was implemented in 1996 and is currently in its 24th year of production. From 1996 to 2001 minimum soil disturbance (scarifier and adapted seed drill, residue retention and crop rotation) was used in all systems. From 2002 onwards, full CA production practices (NT, residue retention and crop rotation), as per the FAO definition (FAO, 2008), were implemented for all crops in the experiment. NT planters that were used had a knifepoint opener. All crops in each of the eight rotation systems were present on the field every year to be able to compare systems. All actions on the trial were done using normal size farm implements.

Monoculture wheat (NT) served as the control. Wheat yield and system gross margin data from the 2002 to 2015 seasons are included in the discussion. Eight 4-year rotation systems were compared (Table 11.1). A randomized block design was used. Gross margins (including all direct allocable costs) and yields of all crops were determined. Crop species included in the trial were wheat (*Triticum aestivum*), canola (*Brassica napus*), lupines (*Lupinus angustifolius*) and an annual self-regenerating legume forage using medic species (*Medicago truncatula* and *M. polymorpha*) and white clover (*Trifolium repens*).

Wheat and canola function as cash crops, lupines as ungrazed cover crops (with seeds harvested for income) and annual self-regenerating medics and clovers as legume forage crops (once established, the plants re-seed themselves), grazed by sheep at a stocking rate of four sheep per ha (Basson, 2017). Sheep are moved onto the forage crops when the medic and clover pastures begin to establish in April or May (these regenerate each year but are sprayed off when cash crops are planted). In rotation system H, sheep are kept aside in additional pastures to forage on saltbush (*Atriplex nummularia*) for approximately 6 weeks until the annual medic/clover mix has reached at least 90% groundcover. Sheep also graze winter crop residues during the dry summers in systems E–H, and are occasionally used for short periods (4–5 days) toward the end of the summer fallow period in the ungrazed systems, as their trampling can break up high residue loads to ease planting. All rotation systems are managed according to local best practices and industry recommendations.

11.4 Yield Response of Wheat

One of the aims of CA is to increase yields, but more importantly to sustain yields over time. Yields depend largely on a systems approach to alternating crops in well-managed sequences, and management of the residue on the field, as well as a proper crop nutrition approach (Farooq and Siddique, 2015). The CA practice is site-specific and adaptations need to be implemented to suit the area (Kirkegaard *et al.*, 2014). The yield results discussed in this chapter are a good case in point. The specific rotations and crops grown might not be applicable everywhere, but the findings underline the positive effects of CA implementation.

As indicated earlier in the chapter wheat is the dominant field crop produced under rain-fed conditions in southern South Africa. The discussions around yield performance under CA production will therefore focus on wheat yields. All of the wheat produced in the different rotational systems is discussed in relation to wheat monoculture production which served as the control system.

The yield data discussed in this section were obtained over a period of 14 years following full CA implementation in 2002. The average wheat yield for each of the systems tested is presented in Fig. 11.1. The systems that included a legume pasture and an animal factor outperformed the monoculture wheat system by 1137 kg ha^{-1} on average. These crop–pasture systems also yielded 409 kg ha^{-1} more on average than the three pure cash crop rotations that included wheat, canola and lupines. The three cash crop rotations yielded an average of 728 kg ha^{-1} more than the wheat monoculture.

In 2003, 1 year after CA implementation, the average wheat yield in all the treatments was only 524 kg ha^{-1}. This result was obtained on 210 mm of rainfall during the production season from April to September (well below the long-term average). The first 4 months of the season

Table 11.1. Composition of the crop rotations in the eight different rotation systems included in the Langgewens long-term crop rotation trial. Author's own table.

System code	Rotation system	Letter sequence of each system
A	Wheat–Wheat–Wheat–Wheat	WWWW
B	Wheat–Wheat–Wheat–Canola	WWWC
C	Wheat–Canola–Wheat–Lupine	WCWL
D	Wheat–Wheat–Lupine–Canola	WWLC
E	Wheat–Medic–Wheat–Medic	WM[g]WM[g]
F	Wheat–Medic/Clover mix–Wheat–Medic/Clover mix	WMc[g]WMc[g]
G	Wheat–Medic–Canola–Medic	WM[g]CM[g]
H	Wheat–Medic/Clover mix–Wheat–Medic/Clover mix	WMc[sg]WMcs[g]

[g] Crop phases grazed by sheep; [s] with saltbush pastures to rest medic/clover pastures. W, wheat; M, medic; L, lupine; C, canola; Mc, medic/clover mix; s, saltbush.

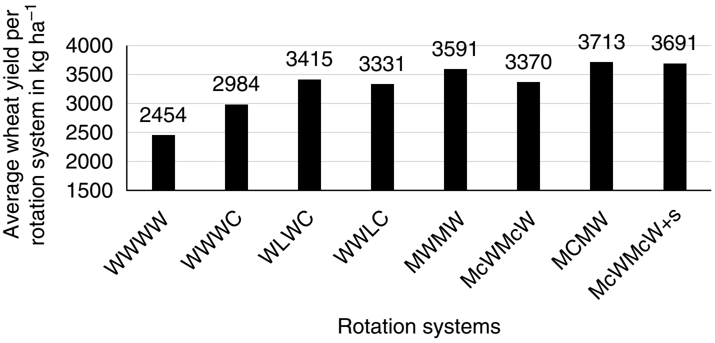

Fig. 11.1. Average wheat yield for each of the eight rotation systems tested from 2002 to 2015. W, wheat; C, canola; L, lupine; M, medic; Mc, medic/clover mix; s, saltbush. Author's own figure.

received very little rainfall and it was only the rotation systems that included medic and medic–clover pastures that managed to sustain the wheat until August. Most of the 210 mm for the production season fell in August and September. The 2015 season recorded even lower rainfall of 169 mm (the second driest year in the area since 1900). The benefits of the CA system in soil structure improvement with higher water-holding capacity, improved infiltration rates and higher residue volumes on top of the soil contributed to an average yield of 2000 kg ha^{-1}. The average yield over all seasons and rotations (except the two drought years) was 3500 kg ha^{-1} on 351 mm of in-season precipitation. The CA effects in sustainable production were even more evident in the 2017 and 2019 production seasons (data not included in this chapter; annual reports of the trial available from author). In 2017 wheat yielded an average of 2488 kg ha^{-1} on 175 mm of in-season rainfall, while in 2019 the average was 3658 kg ha^{-1} on 210 mm, with only 28 mm falling during the grain-filling stage.

Looking at the improvement of wheat production per ha for each of the different crop rotation systems a very interesting picture emerged. To compare the possible improvement per system the percentage increase was calculated on the assumption that the average yield of monoculture wheat was 100% (Fig. 11.2).

By substituting a single wheat crop in a 4-year rotation cycle with a broadleaf cash crop, the average wheat yield increased by 22% compared to the monoculture system, while the inclusion of two broadleaf cash crops resulted in an increase of 37.5%. The inclusion of the

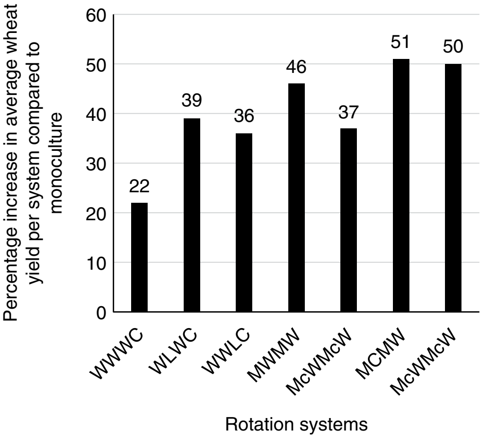

Fig. 11.2. Wheat yield improvement in different cropping systems compared to wheat monoculture. W, wheat; C, canola; L, lupine; M, medic and Mc, medic/clover. Author's own figure.

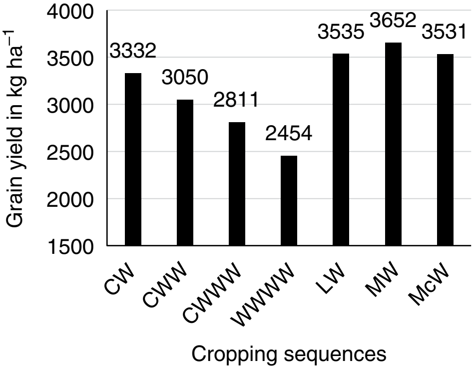

Fig. 11.3. Average wheat yield following different preceding crops. W, wheat; C, canola; L, lupine; M, medic and Mc, medic/clover. Author's own figure.

annual legume pasture increased the average wheat yield by another 9%. Systems that included a single legume crop, over a 4-year period, increased average wheat yield by 37.5% and 46% in the systems where a legume pasture made up 50% of the cropping rotation.

The rotational effect on the improvements in wheat yield is shown very clearly in Fig. 11.3, which illustrates the negative effect of planting wheat on wheat. The decline in the average wheat yield from two consecutive wheat crops was 282 kg ha^{-1} and this dropped by another 239 kg ha^{-1} for a third consecutive wheat crop. The average dropped by another 357 kg ha^{-1} in the fourth consecutive wheat crop.

The decline in wheat production can be attributed to increased weed and disease pressure year on year. Lamprecht *et al.* (2006; 2011) showed the importance of crop rotation in the control of soil-borne diseases on canola, lupine and wheat within these rotational systems. A study of seedbank data from the long-term CA trial has shown that the most effective control of weeds in a CA system lies in animal integration with cropping systems and management diversity (McLaren *et al.*, 2018). Herbicides and grazing apply contrasting selection pressures on weeds, and this combination was more effective in reducing weed pressure than increasing herbicide quantities or mode-of-action diversity. This shows the value of an integrated approach to management of CA cropping systems to ensure sustainability over time.

11.5 Economic Comparisons for Whole Systems

There are still producers who question the inclusion of crop rotation as part of a conservation strategy, because if they include other crops into their system, less wheat will be produced. This may be true to a certain extent. Table 11.2 explains this statement where the average wheat yields per system, as discussed earlier, is converted to total wheat production on a farm with 800 ha arable land.

The monoculture, or system A, produces the most wheat compared to the other systems, since 100% of the arable land is planted to wheat. Wheat in system B is planted on 75% of the available production area, while the wheat area in systems C, D, E, F and H is only 50% of the arable land. In system G wheat is planted to 25% of the cropping area. It must be remembered that systems E, F, G and H also have an animal component that contributes to the final gross margins of all the systems. The percentage area allocated to wheat thus plays a significant role in the ranking of the total production in these systems. With the exception of systems B and G, all systems that produce wheat on only 50% of the production area only lose about one-third of the total wheat production compared to the monoculture system. In system H it is only a 25% reduction. Based on this ranking alone system G would probably be shot down but, stepping back and looking at the big picture, it shows that the priority that profitability plays in sustainability changes dramatically.

The average gross margin (GM) per system is determined from all the different components of the system. In system B the GM is determined from the wheat and canola, while in systems C and D it is wheat, canola and lupines that contribute. Most of the pasture–crop systems have a wheat and animal component (wool and meat), while system G adds canola to the mix as well. GMs were determined by subtracting direct allocable production costs from the gross income for each system. All cash crop systems were left ungrazed at the end of the season, while the legume pastures were grazed during the production season, after which the residues of both the wheat and pastures in these systems were grazed during the summer months. Grazing was managed so that at least 50% of the material was left on the field before the next planting season to meet the minimum soil cover guidelines of 30%.

The average GM of the monoculture wheat system (A) was the lowest, while system H was the highest (Table 11.3). The cash crop rotation systems (B, C and D) show a 17% increase compared to the monoculture system, while the pasture–crop systems (E to H) have a 42.5% increase. The average GMs of systems C and D could have been higher than current data show. The reasons for this statement can be attributed to the poor performance of the legume cash crop (lupines). The long-term average yield for the

Table 11.2. Example summary of total wheat production on an average wheat farm in different system scenarios. Systems are ranked for total wheat production and an indication of total production differences compared to monoculture is shown. Author's own table.

System code	Systems	Average wheat yield (kg ha^{-1})	Total wheat production (kg)	Production ranking	Decline in total production compared to monoculture (%)
A	WWWW	2454	1,963,384	1	
B	WWWC	2984	1,790,482	2	9
C	WCWL	3415	1,365,960	5	30
D	WWLC	3331	1,332,247	7	32
E	WMWM	3591	1,436,510	4	27
F	WMcWMc	3370	1,348,090	6	31
G	WMCM	3713	742,646	8	62
H	WMcWMc+s	3691	1,476,544	3	25

W, wheat; C, canola; L, lupine; M, medic; Mc, medic/clover; s, saltbush.

Table 11.3. Example summary of gross income on an average wheat farm in different system scenarios. Systems are ranked for gross income and an indication of total gross income differences compared to monoculture is shown. Author's own table.

System code	Systems	Average gross margin (ZAR/ha)	Increase in gross income compared to monoculture (%)	Total gross income (ZAR)	Gross income ranking
A	WWWW	2281		1,824,554	8
B	WWWC	2765	21	2,211,825	5
C	WCWL	2712	19	2,169,306	6
D	WWLC	2557	12	2,045,751	7
E	WMWM	3359	47	2,687,105	2
F	WMcWMc	3052	34	2,441,596	3
G	WMCM	2909	28	2,327,127	4
H	WMcWMc+s	3670	61	2,936,208	1

W, wheat; C, canola; L, lupine; M, medic; Mc, medic/clover; s, saltbush.

crop was only 1000 kg ha^{-1} and, adding to that a low commodity price over several seasons, it recorded a negative GM, which resulted in a lower GM for the system. The configuration of system D also contributed to the slightly lower GMs of the system. Two cereal years followed by two broadleaf years with crops that share similar diseases contributed to lower average wheat and canola yields, thus impacting the GM compared to that of system C and B. The excellent performance of system H compared to all the other systems can again be attributed to the setup of the system. With the added saltbush pasture planted on marginal soil the animals of the system could be withheld from the legume pasture at the start of the growing season until a 90% cover is reached before the introduction of the animals. This leads to a slightly higher stocking rate compared to the other pasture–crop systems.

When we look at the rankings of the different systems (Table 11.3) in terms of their total GMs, a drastic difference can be seen compared to their total wheat production in Table 11.2. Monoculture went from position 1 to position 8. System B, the second highest in total wheat production, fell from 2nd to 5th. System H outperformed all the other systems. Input costs such as diesel, pest and disease control and fertilizers are lower in the pasture–crop systems than in the cash crop systems, which has a significant effect on the economic performance of these systems. After adding to that the impact of the lower carbon footprint and the ecological benefit of the more diverse management strategies in systems E to H (McLaren *et al.*, 2018), the sustainability of these systems is clear.

11.6 Conclusions

Sustainability under rain-fed wheat production, as well as other crops, in properly designed crop rotation systems including the integration of livestock under a holistic CA approach is only achievable if these systems are profitable as well. Implementation of the system takes time and requires a mind-shift from any producer, irrespective of farm size to pick the fruits of the CA system. The time is now to move away from the old unsustainable and ecologically unfriendly farming practices, with the ‘Green Revolution’ currently under pressure due the environmental impacts and the tendency of such systems to select for a small number of highly injurious pests, weeds and diseases. The call for a stronger agroecological-based systems approach to sustainable intensification in a bid to feed the growing world population through a rediversification of cropping systems is growing rapidly (Pretty and Bharucha, 2014).

The inclusion of alternative crops in rotation with wheat improves wheat yield on a per ha base. Although the inclusion of these crops means that a lower percentage of a farm is planted to wheat, it does not mean that the farm income is reduced. Combining the timeliness, reduced labour cost, reduced input cost and the advantages of higher yields associated with well-planned rotations, significant increases in profit levels (Hardy *et al.*, 2011; Strauss *et al.*, 2011; Crookes *et al.*, 2017) are achievable. The inclusion of animals into CA systems also benefits the overall sustainability of the CA system (Basson, 2017).

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12 Livestock Integration in Conservation Agriculture

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Abstract

Grazing livestock have been presented as an unsurmountable obstacle for Conservation Agriculture (CA) in Africa, because they consume organic cover. But grazing livestock can also make positive contributions to CA, while, if properly managed, sufficient organic cover can be left for soil erosion control and soil health improvement. Urine and manure improve soil fertility and soil health, and increase the agronomic efficiency of fertilizer nutrients. Grazing livestock increase options for crop diversity, such as crop rotations with perennial forages, increased use of cover crops and tree–crop associations. Further, as crop yields improve through application of sustainable intensification methods, greater amounts of above-ground residue become available for livestock nutrition, while greater quantities of below- and above-ground plant residues can be left to improve soil health than are currently returned to the soil. At the same time, in areas where extensive systems are still common, greater amounts of crop residue can be left for soil function because alternative feed sources are available. More research and education on proper integration of livestock in CA in the African context, and successful models of pastoralist–crop farmer collaboration are needed, so both livestock and soil needs can be met.

Keywords: grazing, management-intensive grazing, crop diversity, cover crops, pastures, coralling

12.1 The Challenge of Livestock for Conservation Agriculture (CA) in Africa

Conservation Agriculture (CA) is seen as an important component of sustainable intensification and climate smart agriculture. It can help to achieve the goals set by heads of state and governments of the African Union in the 2014 Malabo Declaration to: (i) double agricultural production by 2025; (ii) sustain annual agriculture GDP growth rates of at least 6%; and (iii) ensure that, by the year 2025, at least 30% of farm, pastoral and fisher households are resilient to climate- and weather-related risks. The three components of CA are: (i) permanent organic matter cover of the soil; (ii) minimal soil disturbance; and (iii) diverse crop rotations, sequences and associations (Kassam *et al.*, 2009). Although CA is now practised on 180 million ha of cropland around the world, it is used on less than 6% of cropland in Africa (Kassam *et al.*, 2019). While there are different reasons for low adoption of CA in Africa, we will focus on the challenge of livestock and CA (Giller *et al.*, 2009). Worldwide, CA has been most widely adopted in cropping systems that exclude livestock. For example, CA cropping systems in the midwestern

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USA and Argentina consist predominantly of grain crops without integration of animals. However, livestock play a very important role in people's lives in Africa, and are usually an integral part of cropping systems. In 2018 there were an estimated 356 million cattle, 438 million goats and 384 million sheep in Africa, particularly in East, West and northern Africa (FAOSTAT, 2020). Most of these ruminants are grazed on permanent and seasonal communal pastures and on post-harvest crop residues left on croplands. Often, grazing animals consume the crop residue in situ plus any volunteer vegetation that is present after harvest. Alternatively, farmers may collect the crop residues to feed them to livestock in zero-grazing production systems. The latter leave the soil nearly bare, thus violating one of the three principal components of CA (Giller *et al.*, 2009; Jaleta *et al.*, 2013; Duncan *et al.*, 2016). Another challenge in connection with livestock is the practice of burning tall, over-mature grasses in the dry season to favour new grass growth in the following rainy season and to help in reducing parasite load (worms and ticks in particular). Bush fires can also consume crop residue and dry cover crop residues left in the field, again leaving the soil devoid of organic cover.

Organic cover is one of the three pillars of CA because almost all environmental and soil health benefits of CA are due to the organic 'armour' on the soil. Without it, runoff from no-till (NT) soil can be higher than from tilled soil (Gómez *et al.*, 2009); soil erosion increases (ibid); water conservation is not realized; surface soil organic matter content will not improve; nutrient losses exacerbate; earthworm populations will be reduced; and soil microbial biomass is negatively affected, just to mention a few impacts (Duiker, 2011; Jat *et al.*, 2014).

However, the important role of livestock in Africa's farming systems needs to be acknowledged. Animals such as cattle provide (i) draft power for field work, processing and transport; (ii) meat, milk and hides; (iii) capital reserves and buffers against food shortages in years with low crop yields; and (iv) social and religious functions (Powell *et al.*, 2004). The number of livestock is indeed a reflection of wealth in many African communities. In many parts of Africa, pastoralists have special arrangements with crop farmers, allowing them to graze their stocks on post-harvest crop residues. There is also a general trend, particularly in Eastern Africa, showing many previously pastoralist communities rapidly transitioning to agro-pastoralism. In Tanzania, for example, around the Lake Victoria zone, the central and eastern zones, and on the semi-arid lowlands of the northern zone, agro-pastoralism has almost entirely replaced pure pastoralism (Niboye, 2010).

As grasslands are being converted into cropland with increasing population pressure, crop residues are becoming more important to feed livestock (Duncan *et al.*, 2016). Fencing of cropland is often the recommended solution to exclude grazing livestock from croplands, but this approach has been shown to be untenable in many parts of Africa (Adebo and Olotu, 2018). Alternatively, farmers may be asked to raise livestock in zero-grazing systems and feed the animals fodder produced elsewhere. This may be a difficult proposition because the crop fields are often close to the barn and it will be more laborious to gather forage from distant fields. Zero-grazing does involve extra labour and care compared with grazing to produce, harvest, store and feed forage; supply water to the animals; and spread manure, and it takes investment in structures to keep the animals. Further, it may be extremely challenging to keep livestock alive in a highly variable climate where years of high and low rainfall interchange. Historically, pastoralists are less susceptible than crop farmers to highly variable precipitation because they can move their livestock from areas with scant to high rainfall zones as the seasons progress. It has also been argued that zero-grazing would work only where stock productivity is high enough to offset the additional cost of management (Chagunda *et al.*, 2016). This means the local Zebu cattle kept for beef production would not suit a zero-grazing system.

Superficial observation may suggest that CA is incompatible with ruminant livestock. However, when examined holistically, it becomes clear that ruminant livestock – and indeed the entire spectrum of livestock production – can be beneficial to CA. Ruminants convert low-value crop residues into high-value end products (meat, milk, hide/skin) while returning to the soil organic enrichments (urine and manure). The challenge is how to foster community engagement in a more visible symbiotic coexistence between crop farming and livestock keeping. There is now increasing recognition that grazing livestock can be successfully integrated with CA (Ayarza *et al.*, 1998; Liebig *et al.*, 2012). Increasing attention is being given to facilitate adoption of innovative crop/pasture livestock systems globally such as in Brazil, Canada and Australia (Russelle *et al.*, 2007; Gil *et al.*, 2015; Nie Zhongnan *et al.*, 2016). In this review we will discuss research from Africa showing the valuable contribution livestock can make to improve soil health, increase crop diversity and increase use of cover crops in CA, and offer suggestions how organic cover can be maintained at the same time.

12.2 Manure and Urine Improve Soil Fertility and Soil Health

12.2.1 Manure and Urine Deposited by Grazing Animals

Soil fertility is among the most important constraints to increase crop productivity in Africa. Folberth *et al.* (2013), for example, estimated that with application of only 50 kg N ha^{-1} and 18 kg P ha^{-1} maize yields could be doubled in most areas of Sub-Saharan Africa (SSA). Livestock manure and urine provide valuable organic matter and nutrients to improve soil fertility and organic matter content. Manure and urine are deposited directly by grazing animals, saving farmers precious time and effort. Stobbs (1969) reported an average 19% crop yield improvement over 3 years following night grazing of Rhodes grass/*Hyparrhenia*/*Stylosanthes* pasture and 10% following day grazing (both compared with cropping following pastures without grazing). Night grazing was at 3× higher animal density than day grazing and therefore included greater manure and urine deposition. This suggests that high stock density, management-intensive grazing can be highly beneficial to improve soil fertility. The estimated average manure production over a period of 8 months of Sahelian livestock is 301, 60 and 41 kg of manure from grazing cattle, sheep and goats, respectively (Fernandez-Rivera *et al.*, 1995). The estimated amount of manure that can be produced by those livestock when fed ad libitum is 2.4 kg dry matter (DM) day^{-1} for cattle of 300 kg, 345 g DM day^{-1} for sheep of 37 kg and 197 g DM day^{-1} for goats of 22 kg, meaning that the amount of faeces excreted can be much higher when feed resources are freely available.

Given the nutrient content of these manures (Table 12.1), grazing animals can, therefore, contribute to soil fertility improvement where they are corralled on croplands after harvest. Corralling leads to lower ammonia volatilization and is therefore more efficient than storing then spreading manure and urine in zero-grazing systems.

Table 12.1. Average nutrient content of different types of manure in the Sahel. From Powell *et al.*, 1995.

		Nutrient contents (% of DM)		
Sites	Types of manures	N	P	K
Burkina Faso	Cattle manure	1.28	0.11	0.46
	Sheep and goat manure	2.20	0.12	0.73
Niger	Cattle manure	1.2–1.7	0.15–0.21	Na
	Sheep manure	1.0–2.2	0.13–0.27	Na
Nigeria	Cattle manure	1.88	0.95	0.54
	Sheep/goat manure	1.85	0.93	0.25
Senegal	Fresh cattle manure	1.44	0.35	0.58
	Dry cattle manure	0.89	0.13	0.25

DM, dry matter.

Fig. 12.1. Cattle herd grazing crop residues on crop field in Burkina Faso. Courtesy of Nouhoun Zampaligre.

12.2.2 Collecting and Spreading Manure in Zero-grazing Systems

Manure can also be collected in zero-grazing systems (Fig. 12.2) and returned to the crop fields from which crop residues were collected as fodder, thus closing the nutrient cycle. In practice, however, manure from zero-grazing systems is usually concentrated at high rates on small plots devoted to high-value crops such as vegetables (Duncan *et al*., 2016). This favours nutrient depletion in crop fields at the expense of nutrient enrichment in small plots devoted to high-value crops. Additionally, there are greater potential losses of some nutrients such as nitrogen if manure is collected and distributed versus deposited by grazing animals. Powell *et al*. (2004) reported 20%, 122% and 127% pearl millet yield increase in the 1st, 2nd and 3rd seasons after application of cattle manure from the barn (which contained no urine). At the same manure application rate, 83%, 167% and 136% greater yield was achieved in these respective seasons after corralling (which included urine deposition besides manure), showing the potentially greater nutrient use efficiency of managed grazing than zero-grazing. The manure and urine effects lasted many years in these trials, suggesting that manure does not necessarily need to be applied annually. Mixing crop residues with manure helps improve manure quality by immobilizing nitrogen released from manure and urine in the cattle kraal or barn (Rusanimadhodzi *et al*., 2016). It is common for a portion of feed crop residues to be wasted in zero-grazing systems, and if these residues get mixed with manure and subsequently returned to the crop field, nutrient use efficiency of collected manure can be improved.

12.2.3 Combining Manure and Chemical Fertilizer Improves Fertilizer Use Efficiency

Unfortunately, there is not enough manure to fertilize all cropland in Africa (Stoorvogel *et al*., 1993). In western Niger, for example, only 3%–8% of cropland received manure (Hiernaux *et al*., 1997). This may be partly the result of high labour requirements to spread manure, but it is also due to inadequate amounts of manure to maintain the proper nutrient status of farmlands in Africa. Therefore, use of chemical fertilizer in addition to use of organic sources is a must to raise crop yields. Considering that large fertilizer applications are not realistic at this time because most smallholders cannot afford them,

Fig. 12.2. Zero-grazing system in central Kenya where weeds and grasses from field edges are fed to dairy cattle. Courtesy of Sjoerd Duiker.

combining small rates of manure and fertilizer has been considered. Interestingly, this combination has been found to increase the agronomic efficiency of fertilizer significantly. In a meta-analysis Vanlauwe *et al.* (2011) found that the maize grain yield per unit of fertilizer N applied increased from 26 to 36 kg grain per kg fertilizer N if fertilizer and manure were combined instead of the use of fertilizer alone. The principle of combining organic with inorganic fertilizer has been incorporated in the concept of integrated soil fertility management (ISFM). It is likely that the effect of manure on soil biological and physical properties (sometimes called 'the magic of manure') – such as improvement of organic matter content, labile organic carbon, aggregate stability, bacterial and fungal populations, moisture retention and greater earthworm and arthropod (especially termite) activity – helps reduce losses of highly water soluble nutrients in chemical fertilizers. In addition, fixation of certain nutrients such as phosphorus, which is common in tropical soils, can be lessened if organic matter content is improved. Further, pH can be increased and buffered by bicarbonates and the carboxyl and phenolic hydroxyl groups on organic acids by addition of manure that helps improve organic matter content (Whalen *et al.*, 2000). Manure can, therefore, help improve soil health (Boonman, 1993), one of the primary purposes of CA.

12.3 Increasing Crop Rotation Diversity and Increasing Cover Crop Adoption With Grazing

12.3.1 Crop Rotations With Perennial Forages

Livestock can help increase cropping diversity in CA. Perennial forages become attractive components of crop rotations, and these perennial grasses, legumes and forbs typically have a highly beneficial, long-lasting effect on soil health, nutrient use efficiency and following crop yields. Foster (1971) showed that maize yields after unfertilized, grazed, Napier grass increased 142% and 50% in the first and third year, and bean yields increased 59% and 64% in the second and third year, respectively (Table 12.2). Higher yields were achieved after grazed grass than when grass was cut and removed. Boonman (1993) emphasized the benefits of grass ley in crop rotations for soil conservation, nitrogen and potassium provisioning, and soil structure improvement resulting in increased water infiltration. Greater integration of regularly grazed or harvested perennial grasses and forbs for livestock grazing in crop production can also help reduce the use of burning of overmature grasses.

Table 12.2. Crop yield (kg ha^{-1}) after unfertilized Napier grass or continuous cropping in Kawanda, Uganda. From Foster, 1971.

	Maize		Beans	
Previous cropping	I(2)	III(1)	II(2)	III(2)
Continuous cropping	1580	1550	920	560
Undisturbed grass	3140	2290	1130	770
Grass cut and removed	3450	2060	1030	860
Grass grazed	3830	2330	1460	920
LSD	670	490	ND	250

1st and 2nd season within year I, II or III.

12.3.2 Revolutionizing Cover Crop Adoption With Livestock

While no-till (NT) adoption in Africa is low, it is probably fair to say that cover crop adoption is even lower. It is extremely challenging for the African smallholder to buy or harvest cover crop seed for planting, prepare the land for cover crop establishment, make sure weeds are not overtaking the cover crop and finally terminate the cover crop, all of which take either labour or financial resources, not to mention skill (Tarawali *et al.*, 1999). Cover crop adoption could be improved if its value as livestock feed is emphasized besides its value in improving soil health (Zyl and Dannhauser, 2005; Kamanga *et al.*, 2014). It will be necessary to make some compromises and allocate some of the cover crop residue for livestock feed while leaving enough to improve soil health and provide residue cover. Nonetheless, the stubble left after grazing or harvesting narrowly spaced cover crops with a high C:N ratio can provide long-lasting residue that provides the essential functions for CA. Rusanimadhozi *et al.* (2016) reported that farmers in Mozambique burn crop residue before planting because of the presence of the itchy weed *Mucuna* spp. The hairs lining *Mucuna* seed pods cause severe itching due to their serotonin and mucunain content and the calix below the flowers also contains itchy spikules. However, *Mucuna* is also known as an N-fixing cover crop that can suppress weeds, supply large amounts of N and mobilize P for subsequent crops (Sogbeji *et al.*, 2006), and it equals *Gliricidia* leaves as a protein source to improve milk production in lactating cows raised on a grass diet (Table 12.3; Muinga *et al.*, 2003; Juma *et al.*, 2006). Instead of burning it, therefore, *Mucuna* could be used to graze livestock before it generates flowers and pods. *Mucuna* beans treated by boiling have been incorporated in Sasso chicken diets to replace the more expensive soybean by up to 50% (Luena *et al.*, 2020).

12.3.3 Stimulating Tree–Crop Associations

Trees can provide high-quality browse (Mokoboki *et al.*, 2011) and be integrated in CA, such as in alley grazing/cropping rotations with *Leucaena leucocephala* (Atta-Krah, 1990), tree–crop mixtures involving *Faidherbia albida* and other trees in the Sahel (adopted on at least 5 million ha; Reij and Garrity, 2016), or forage grass–legume associations (Juma *et al.*, 2006). There is indigenous knowledge among local populations that could be tapped to develop CA systems with trees that can be used either to supplement other forages, or to sustain livestock through dry periods. Livestock in Niger rely for 6 months per year on trees for their feed, so pastoralists are aware of their value and have extensive knowledge about different tree species and their uses (Reij and Garrity, 2016). At the same time, the trees provide services such as conservation of organic matter, crop protection from wind erosion and sand blasting, and reductions in evaporation by acting as windbreaks, resulting in crop yield improvements (Felix *et al.*, 2018). *Faidherbia* trees have unusual reversed phenology, dropping leaves in the rainy season, thus enabling excellent solar radiation to reach crops beneath them, while their leaves can provide fodder in the dry season. A project by the Conservation Farming Unit of the farmers' Union of Zambia successfully coupled *Faidherbia* seedling establishment in CA-based systems. Trees also provide firewood,

Table 12.3. Mean daily intakes (kg), and milk yield (kg) for dairy cows fed Napier grass ad libitum with or without a legume supplement. From Juma *et al*., 2006.

		Supplements		
Fodder type	None	*Clitoria*	*Gliricidia*	*Mucuna*
Dry matter intake (kg day^{-1})				
Legume	0	1.8	2.1	1.6
Napier grass	5.5	4.0	4.4	4.0
Maize bran	2.6	2.6	2.6	2.6
Total	8.1	8.4	9.1	8.2
Crude protein intake (kg day^{-1})				
Legume	0	0.40	0.49	0.29
Napier grass	0.42	0.30	0.33	0.30
Maize bran	0.35	0.35	0.35	0.35
Total	0.77	1.05	1.18	0.94
Dry Matter Digestibility (g kg^{-1})	579	589	603	608
Milk yield (kg day^{-1})	4.0	5.1	4.8	5.3
Milk yield increase (%)	–	27.5	20	32.5

nuts and fruits. The value of legume cover crops or trees was shown in a trial in Kenya where Napier grass (*Pennisetum purpureum*) was supplemented with forage from three different legumes, the vine *Clitoria ternatea*, the tree *Gliricidia sepium* and the cover crop *Mucuna pruriens* (Table 12.3). Supplementing Napier grass with these high-protein forages resulted in milk yield improvements for dairy cows of 20%–33%.

12.3.4 Favouring Diversity by Increasing Mixed Cropping Options With Livestock

If the vegetative parts of plants become valuable livestock feed, the options for mixed cropping dramatically increase, and hence the potential to expand crop diversity in CA if livestock is integrated with crop production. The possibilities are endless: perennial forage legumes and cereals (Hassen *et al*., 2017), mixes of annuals (Armstrong *et al*., 2008), relay-cropping of forage species in grain crops (Mthembu *et al*., 2018) and agroforestry systems that combine grain and forage species (Sileshi *et al*., 2012) can be envisioned. Consequently, Rusanimahodzi *et al*. (2016) and de Moraes *et al*. (2013) report higher crop diversity and ecosystem services on farms with livestock than those without livestock. A substantive review on broad ecological implications has been published by Martin *et al*. (2016).

12.4 The Challenge and Opportunities of Using Livestock to Maintain Organic Cover in Conservation Agriculture (CA)

12.4.1 Extensive Versus Intensive Systems

Despite these positive aspects of livestock for CA, there remains the issue of maintenance of organic cover in the presence of ruminant livestock. Research from Kenya and Ethiopia shows that African farmers rely heavily on crop residue to feed their animals. In this area as much as 45% of crop residue was used as animal feed either by grazing or stall-feeding, while the remainder was used for a variety of purposes such as fuel and construction material, and only 15% was left on the soil (Duncan *et al*., 2016). Reliance on crop residues as livestock feed is increasing due to the expansion of cropland into what used to be communal grazing areas. However, the study also discovered that as farms intensified and improved production, more crop residue was returned to the soil, which was attributed to higher yields with greater use of new technologies such as modern maize hybrids and fertilizers, as well as manure, while farmers also had more off-farm income. In the least intensified area, almost no crop residue was left on the soil, but in the most intensified area, 25% of crop residue was left on the soil. It is commonly accepted that crop yields need to increase to feed the future population on the African continent, hence the need for sustainable intensification, which might increase the residue returned to the soil. To illustrate how CA and livestock could be integrated successfully if maize yields would double with sustainable intensification we contrasted two scenarios (Table 12.4). Currently, maize yields in SSA are very low – an average of 1.9 Mg ha^{-1} in ten countries in West and East Africa for example, or 15%–27% of water-limited yield potential (Van Ittersum *et al.*, 2016). Assuming a harvest index of 0.5, this means that 1.9 Mg ha^{-1} of crop residue is left after crop harvest. If we assume a root:shoot ratio of 0.18 (value for maize from Prince *et al.*, 2001, where shoot is the sum of both grain, stalk and leaves) root DM would be 0.68 Mg ha^{-1}, and total plant matter returned to the soil would be 2.58 Mg ha^{-1}. Assuming yields would double with use of better agronomic practices, then above-ground crop residue production would increase to 3.8 Mg ha^{-1}, and root mass to 1.37 Mg ha^{-1}. In addition, twice as much root mass would be added to the soil in the intensified system, so a total of 5.17 Mg ha^{-1} crop residue would be returned to the soil without crop residue removal. It is now recognized that a much higher proportion of root matter is converted into soil organic matter than from above-ground crop residues, so the increased root mass would have a proportionally greater effect on soil organic matter content (Austin *et al.*, 2017; Xu *et al.*, 2018). In reality, of course, very little crop residue is left in many African cropping systems because much is consumed by animals. If 80% of crop residue (1.52 Mg ha^{-1}) at current production levels is consumed, and assuming one tropical livestock unit (TLU) of 250 kg needs 5 kg DM/day or 2% of its body weight in DM/day (Rasby, 2013), 1 ha would sustain 0.83 TLU, and only 0.38 Mg ha^{-1} would be left for the soil, plus 0.68 Mg ha^{-1} in root mass, totalling 1.06 Mg ha^{-1} returned to the soil. In the scenario where crop yields are doubled, we assume crop residue consumption by livestock

Table 12.4. Hypothetical contrast of crop residue production with current average maize yields versus doubled yields achieved with sustainable intensification, and crop residue available for livestock production and soil improvement at consumption of 80% of current versus 50% of sustainable intensification crop residue produced. Authors' own table.

	Current average maize yield	Maize yield with sustainable intensification[a]
Maize grain yield (Mg ha^{-1})	1.90	3.80
Harvest index	0.5	0.5
Above-ground crop residue (Mg ha^{-1})	1.90	3.80
Root:shoot ratio	0.18	0.18
Below-ground root residue (Mg ha^{-1})	0.68	1.37
Total above- & below-ground plant residue returned to soil without livestock consumption (Mg ha^{-1})	2.58	5.17
Crop residue fed to animals if 80% of current or 50% of intensified consumption of above-ground plant residue by livestock (Mg ha^{-1})	1.52	1.90
TLU supported per ha per year if 80% of current above-ground residue consumed or if 50% of intensified above-ground residue is consumed[b]	0.83	1.04
Above-ground crop residue returned to soil if 80% of current or 50% of intensified consumption of above-ground plant residue by livestock (Mg ha^{-1})	0.38	1.90
Total crop residue returned to soil if 80% of current or 50% of intensified consumption of above-ground plant residue by livestock (Mg ha^{-1})	1.06	2.27

[a] Assuming a doubling of current yields.

[b] One TLU (Tropical Livestock Unit) weighs 250 kg and is assumed to consume 2% of its bodyweight in dry matter per day.

would be limited to 50% to also leave residue for soil health maintenance. At this level of consumption (1.9 Mg ha^{-1}), 1.04 TLU could be supported, and still 1.9 Mg ha^{-1} of crop residue would be left to feed the soil, plus 1.37 Mg ha^{-1} in root mass, totalling 2.27 Mg ha^{-1} left for the soil. Thus livestock production would be improved 25% while the addition of above- and below-ground DM to the soil would increase 114%. These simple calculations show that with sustainable intensification the integration of livestock in CA becomes possible while soil health can be improved at the same time. On the other hand, we would give the wrong impression by suggesting that, in extensive systems, more crop residue cover is always used to feed livestock and less left for the soil. Jaleta *et al.* (2013) found that the reverse was true when comparing more intensive farms in central with more extensive farms in western Kenya. In central Kenya livestock relied more on crop residue because less communal pastureland was available for grazing than in western Kenya. Similarly, Jaleta *et al.* (2013) found that, as farmers in western Kenya had more land under maize production, more was left on the soil because not all of it was needed to sustain livestock. We believe, therefore, that successful integration of livestock in CA is possible in intensified cropping systems, as well as in extensive systems, depending on the local context. Attention must also be drawn here to the type of extensive systems. There is a wide variation in the conduct of communal grazing among pastoralists. In many parts of Africa extensive grazing takes the form of large-scale rotations whereby grazing stocks would return for grazing on the same area only after 2–3 years. It is for this very reason that conflicts are born, as crop farmers are often caught unaware of the livestock rotations.

12.4.2 Livestock Intensification and Feed Quality

One matter that is overlooked in many studies is the relatively low feed quality of crop residues after harvest. When crop production intensifies, livestock production typically also intensifies, which means better-quality feedstock is required to improve animal productivity. For example, milk production was very low in the least intensified farming area in Ethiopia, while it was three to four times greater in the most intensified farming region in western Kenya (Jaleta *et al.*, 2013), which could only be achieved if higher-quality feedstock were used. To sustain high livestock productivity (either milk production or faster growth) one can no longer solely rely on crop residues left after grain harvest because they are too high in undigestible fibre and too low in protein. The feed value of crop residues can be improved by providing livestock also with highly digestible, high-protein feed such as cover crops, leguminous fodders, grass in a vegetative stage or leaves from leguminous trees and shrubs such as *Cajanus cajan*, *Gliricidia*, *Acacia* and *Leucaena* (Juma *et al.*, 2006; Mokoboki *et al.*, 2011; Nakamanee *et al.*, 2019). Relay intercropping of maize with fodder legumes or grasses before harvest can enrich nutritional value and improve utilization of corn stover (Mupangwa and Thierfelder, 2013). Further, when livestock productivity increases, fewer animals are needed to produce the same amount of livestock product, and this can reduce the area of land needed, liberating more crop residues to be left on the soil. In the semi-intensive crop–livestock integrated system, in which crop residues are a valuable feed resource for improving livestock productivity, trade-offs in crop residue uses are evident between short-term benefits (livestock feed) and longer-term benefits such as soil fertility, soil health and water-holding capacity (Blümmel *et al.*, 2013). In addition to manure return to the fields through collection and spreading by farmers, innovative grazing approaches at farm and landscape levels – including controlled or rotational grazing and moveable-corralling in farmers' fields by transhumant pastoralist herders – are important contributions to CA.

12.4.3 Controlled Grazing

Successful integration of grazing in CA is not possible if grazing is uncontrolled. Guidelines such as 'leave half, take half', or at least leaving a minimum amount of residue to protect soil function, have been suggested (Green and Brazee, 2012). The importance of residue quality is also important. Grazing vegetation that is relatively tall (higher C:N ratio) means the residue left behind remains longer to protect and feed the soil. Further, grazing animals tend to graze the leaves and leave the stems behind; these have a higher C:N ratio and thus provide soil protection for longer periods of the year. Therefore, livestock could consume the high-quality portion of cover crops, while trampling the lower-quality residues on the soil; thus smaller amounts of residual crop residue might suffice to provide its essential functions in CA. This contrasts with cover crops only grown for soil improvement. These are often terminated when they are relatively small, and their C:N ratio is low, resulting in quick disappearance of the cover by biological activity. Methods of grazing such as 'management-intensive grazing' or 'holistic grazing management' therefore need to be part and parcel of successful integration of grazing in CA. Management-intensive grazing methods (Gerrish, 2004) allow sufficient rest periods so that even less grazing-tolerant plant species have sufficient time to regrow for the next grazing cycle. High stocking density for a short time (days, not weeks) is followed by sufficient rest to allow the vegetation to regrow for the next grazing cycle. Stocking density and duration of grazing exposure also needs to match the forage stand so that the forages can regrow quickly. More is demanded of the manager because he/she needs to determine when animals need to move to new pasture, and when pastures are ready to be regrazed. Some of the effects of management-intensive grazing are improved forage yields, larger and deeper root systems, and better manure distribution (Gerrish, 2004). Management of intensive grazing methods need to be developed for the local climates, soils, forage species, cropping systems and socio-economic conditions in Africa. Education about its principles and demonstration of new grazing methods are needed, and agreements negotiated between crop farmers and pastoralists in areas where these co-habitate (Reij and Garrity, 2016).

12.4.4 Burning for Pasture Renovation

Burning of vegetation is common in Africa as a method to renovate natural pastures. However, regular burning has negative effects on the environment and the soil, and eliminates organic cover in CA. Burning of vegetation is a major contributor to global greenhouse gas (GHG) emissions, averaging more than 2.0 Pg C yr^{-1}, while fossil fuel combustion contributed 10.2 Pg C yr^{-1} in 2018 (NOAA, 2020). More than half of the global burned area has been found to be in Africa, emitting more than half of global pyrogenic GHGs (Zubkova *et al.*, 2019). More than 80% of the burned area in Africa was in savannahs with the balance in forests and croplands, suggesting that the purpose of burning is often renovation of natural grasslands (Zubkova *et al.*, 2019). Annual burning of a tree–grass savannah for 5 years in Krueger National Park in South Africa caused a small decrease in soil organic carbon (SOC) and nitrogen in the top 7 cm of soil (Coetsee *et al.*, 2010). However, the indirect effect of reduction in tree cover due to fire caused a very large loss of C and N (50% reduction in N, for example). Savadogo *et al.* (2007) observed 30% reduction in infiltration rate due to early prescribed burning in a 12-year grazing experiment in Burkina Faso. Doamba *et al.* (2014) measured reduced total numbers of surface-dwelling macroinvertebrates after burning a savannah–woodland, which was attributed to destruction and migration of insects by fire, creation of a less favourable microclimate after fire and diminished resources. Soil-dwelling fauna were not affected, however. Fire reduces the total biomass of standing vegetation in savannah environments, but improves forage grass quality. However, high-quality grass can also be produced without fire. Increases in grass crude protein content can be achieved without fire if N fertilizer is added (Mbatha and Ward, 2010). Keeping grass in the vegetative stage by regular grazing or mowing is another method to maintain forage quality (Skidmore *et al.*, 2010). Considering its negative environmental effects and available options to renovate natural pastures without it, it is desirable to reduce the use of burning, especially in the African savannahs. This would also help preserve organic cover essential for CA.

12.4.5 Corralling and Stubble Grazing Contracts Between Pastoralist Herders With Crop Farmers

In Sahelian countries such Mali, Niger and Burkina Faso, sedentary and transhumant pastoralist herders have practised corralling contracts or so-called manure contracts during the late dry season with crop farmers (Williams *et al.*, 1995; Hoffman and Mohamed, 2004). Under manure contracts, crop farmers hire pastoralists to corral their animals during the night on crop farmers' fields, leaving manure in the fields surrounding the villages. Considering the important number of transhumant pastoralist livestock in the Sahel (about 70% for cattle and 40% for small livestock) these herds can contribute important amounts of organic matter and nutrients to CA. The corralling contract is also a socio-economic tool that can be used to mitigate crop farmer–livestock herder conflicts (Hoi Yee Fu, 2020**)**. Other agreements between pastoralists and crop farmers that can contribute to managed utilization of crop residues in CA is the stubble grazing contract, in which herders graze crop residues left over on crop farmers' fields and in return leave animal faeces and urine; these compensate for the removal of organic matter and provide supplemental nutrients from common rangelands (Hoffman, 2002). At present this often results in excessive removal of residue cover, which leaves the soils completely devoid of vegetation at the start of the rainy season which, for success with CA, should be avoided through managed grazing practices.

12.5 Conclusions

This review presents evidence that livestock integration can be successful in CA systems. Manure and urine can help improve soil health and soil fertility, and fertilizer use efficiency, through their effects on soil biological and physical properties. Further, ruminant livestock can stimulate crop diversity, for example by increasing the use of grass leys in crop rotations that can help improve soil health and following crop yields. Managed grazing can improve soil fertility in leys compared with application of collected manure in zero-grazing systems. Fencing, including living fence and solar-powered electric fencing, may be increasingly relevant in managing grazing in Africa. Communal control of dry season grazing works well in some rural communities, but this rarely works to protect crop residues needed for CA-based systems. Livestock can also help increase the very low rate of adoption of cover crops in Africa. While cover crops for weed suppression or soil improvement alone have not been adopted to any significant degree, adoption is likely to increase if they have a utility to feed livestock, while still providing soil health and mulching benefits. Relay-cropping of cover crops could enhance biomass production. Further, if crop yields increase by use of improved agronomic practices ('sustainable intensification'), it becomes possible to use a portion of crop residue to feed livestock, while leaving more crop residue to feed the soil than is currently produced by low-yielding crops. The increased addition of root biomass in higher-yielding systems contributes more to soil organic matter build-up than above-ground biomass, further justifying partial removal of above-ground residues as livestock feed. Nonetheless, research is needed to determine the level of residue cover needed to sustain soil health, which will depend on factors such as climate, soil, and topography; quality of residue such as its C:N ratio; and the time until the new vegetation has achieved full soil cover. Where land is plentiful, crop residues can be left on the soil as long as sufficient pasture is available. Therefore, CA and livestock integration is not necessarily limited to regions of crop intensification. When livestock intensification becomes profitable, however, farmers cannot rely purely on crop residues to feed their animals, because of their low feed value. It then becomes beneficial to offer low-fibre, high-protein forages to the animals; these help improve the feed conversion of low-quality crop residues, and hence the interest in growing perennial forages or annual cover crops that are grazed or harvested in their vegetative state, or leguminous cover crops or trees that can be used to supplement crop residue fed to animals. Ethiopian farmers who successfully integrated cover crops such as *Desmodium* in their CA systems testified that 'with CA I am fattening the soil & oxen' (Milkamu, 2020). Integrating livestock in CA is a way to strengthen climate change resilience further – failed crops can still be used as livestock feed, cover crops become an important safety guarantee to feed livestock, while livestock present an important source of capital and food in times of drought. The increased potential for cropping and farming system diversification with integration of CA and livestock is another important mechanism to improve climate change resilience into African farming systems. In summary, a conflict between livestock and CA-based intensification is a myth that should no longer be used as an argument against the potential of CA for agricultural development in Africa. Production systems research is urgently needed, as are investments in enabling farmers to adopt proven SI practices.

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13 Enhancing Climate Resilience Using Stress-tolerant Maize in Conservation Agriculture in Southern Africa

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Abstract

Recurrent and widespread droughts in southern Africa (SA) reduce agricultural productivity and increase food insecurity among smallholder farmers. The average growing-season temperatures are expected to increase by 2.5°C. In SA maize is a staple food, accounting for more than 30% of total calories. The crop is mostly grown by smallholder farmers with limited inputs of fertilizers and improved seed. Most of the maize cultivars grown by farmers are susceptible to heat and drought. Multi-stress-tolerant maize germplasm is one of the climate smart agriculture (CSA) components and, when used in combination with others, can sustainably increase production and resilience of agricultural systems. In this paper we review the performance and economic benefits of drought-tolerant maize cultivars under conventional monocropping practice, under conventional intercropping and in Conservation Agriculture (CA) as part of sustainable intensification to ensure food security for smallholder farmers.

Keywords: Climate change, drought-tolerant maize, intercropping, maize

13.1 Introduction

Droughts are frequent phenomena in southern Africa (SA), causing yield variability and food insecurity among smallholder farmers (Cairns *et al.*, 2013). These droughts are intense and widespread with long-term impacts on agricultural productivity and food security (Masih *et al.*, 2014). Even where total rainfall is enough for crop production, the distribution within a season is often erratic, resulting in poor water use efficiencies (Liebig *et al.*, 2002). Climate change models predict a future scenario in which the region will experience increased seasonal and extreme temperature events such as droughts and floods (IPCC, 2007). The average growing-season temperatures are expected to increase by 2.5°C, with maximum temperatures increasing much more than minimum temperatures, and with consequences of increased evapotranspiration rates (Rowhani *et al.*, 2011; Cairns *et al.*, 2013). The largest increase in temperature is expected to be in November, when maximum temperatures will increase by over 3.5°C and

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minimum temperatures by 2.5°C (Waha *et al.*, 2013). It is expected that maize yields in Africa will decline by 6%–24% by 2050 under future climate scenarios, depending on the country (Waha *et al.*, 2013; Tesfaye *et al.*, 2015). Furthermore, vulnerability assessment climate modelling shows that a gradual increase in temperatures is already occurring and is likely to continue. The modelling also shows that the highest temperature increases are likely to occur during planting and crop germination months (Tetra Tech ARD, 2013).

Therefore, farmers need to adapt their tactical and strategic planning to these evolving climate risks, given the existing magnitude of food insecurity. Usually, when farmers are faced with a severe climate shock, they employ a range of strategies to cope with the resulting crisis by reducing nutrient inputs and over-exploiting natural resources to reduce the risks (Cooper *et al.*, 2008). Most of the strategies are short term and they do not help households to build a better life in the future as they erode productive assets. Risk aversion leads to under-investment and under-adoption of improved agricultural technologies (Carter *et al.*, 2008).

Maize is the staple food, accounting for more than 30% of the total calories and protein intake in SA (FAO, 2010). Most of the maize cultivars grown by farmers are susceptible to heat and drought stresses, as the majority were developed for optimal environments with good rainfall distribution and high soil fertility (Cairns, 2013; Setimela *et al.*, 2017). Given this scenario, Lobell *et al.* (2011) highlighted the need to incorporate heat and drought tolerance into the maize-breeding pipelines to mitigate against climate change. Most of the parental lines used in hybrid formation for maize were found to be susceptible to both heat and drought stress under high-temperature conditions (Cairns *et al.*, 2013b).

The development of heat- and drought-tolerant (DT) maize cultivars is an important step towards improving maize productivity. The focus has been to promote a single technology such as fertilizer or improved seed, which has not been a sustainable practice to increase productivity (Garrity *et al.*, 2010). In recent years the use of DT maize cultivars, rotations or intercropping with legumes, coupled with sustainable land management practices, provides considerable promise in boosting productivity and reversing the decline in soil fertility that is the fundamental cause of poor yields under smallholder conditions (Thierfelder *et al.*, 2015). Several studies conducted in SA have highlighted that the use of DT cultivars in CA systems increased maize yield by 20%–30% under drought (Setimela *et al.*, 2018). CA is a cropping system based on the three principles of minimum soil disturbance, crop residue retention and crop rotations, and is considered a climate smart agricultural technology (Thierfelder *et al.*, 2017). CA systems improve soil water infiltration and maintain greater soil moisture throughout the season (Thierfelder and Wall, 2010), while reducing evaporation, and lowering heat stress and surface runoff (Thierfelder and Wall, 2009). We believe that development of DT cultivars, along with other climate smart technologies, addresses the Malabo Declaration on Accelerated Agricultural Growth and Transformation for Shared Prosperity and Improved Livelihoods which was adopted by African Union Heads of State and Government in June 2014 at the 23rd Ordinary Session of the African Union (AU) Assembly. The Declaration commits leaders to a set of actions that will accelerate agricultural growth and transformation across Africa. The Declaration was a re-commitment to the principles and values of the Comprehensive Africa Agriculture Development Programme (CAADP), as well as containing additional commitments and targets for results and impact.

The objective of this study was to review the performance of DT maize hybrids under conventional and CA systems as part of sustainable intensification, and to assess their economic benefits.

13.2 Performance of Drought-tolerant (DT) Maize Varieties Under Smallholder Conditions

The annual yield loss in maize due to drought is estimated at between 15% and 90% depending on the crop development stage when drought occurs (Bänziger and Araus, 2007; Tesfaye *et al.*, 2015). The development and deployment of DT maize cultivars is a highly relevant intervention to reduce vulnerability to climatic change and improve food security among smallholder farmers. Conventional breeding has been used to improve maize for DT and has resulted in yield gains of up to 144 kg ha^{-1} $year^{-1}$ in tropical maize when stress was imposed at flowering (Edmeades *et al*., 1999). To validate the performance of the new DT germplasm against commercially available germplasm and farmer-preferred cultivars, 80 trials were conducted in farmers' fields by CIMMYT in the 2011/12 growing season in eastern and SA. Before the DT maize cultivars were selected for regional on-farm testing, they were first evaluated under CIMMYT on-station trials in four types of environments: (i) recommended agronomic management and high rainfall conditions (> 750 mm per annum and a temperature range of 24–33°C) (optimum); (ii) low nitrogen stress (about or less than 30 kg N ha^{-1}); (iii) managed drought; and (iv) random stress conditions (Bänziger *et al*., 2006). Detailed information on environments is described by Bänziger *et al*. (2000). Selected DT maize cultivars from on-station trials were composed of commercial and DT maize which were taken to be evaluated under farmer management practices. A randomized complete block design was used and each farmer served a block. Each plot consisted of six rows 8 m long with crop spacing decided by the farmers based on their normal farming practice. All trials were grown under rain-fed conditions, with farmers using their management system for fertilizer application, weeding, and pest and disease control.

The trials were subsequently divided into two categories based on yield levels: high-yielding trials (≥ 3 t ha^{-1}) and low-yielding trials (< 3 t ha^{-1}). Low-yielding trials were taken to be representative of smallholder farmers who apply little or no nitrogen fertilizer. The genotype means from each category were used to calculate the yield advantage of each genotype compared to the common best check, SC513. The yield advantage was calculated as the mean of a given genotype minus the mean of the check, SC513 and were expressed as a percentage.

The average grain yields across environments ranged from 6 t ha^{-1} in the high-yielding environment trials to as low as 0.2 t ha^{-1} in the low-yielding environment trials. The new stress-tolerant hybrid CZH0616 was the best yielder under low- and high-yielding environments (Table 13.1). The new DT hybrid yielded better than the older DT hybrid PAN53, which shows genetic improvement under drought in the development of a new generation of DT hybrids. The hybrid CZH0616 yielded about 20% higher grain than one of the most popular hybrids (SC513) under high-yielding environments and more than 29% under the low-yielding environments. The yield gap was wider under low-yielding conditions compared to high-yielding ones (Table 13.1).

13.3 Performance of Improved Drought-tolerant (DT) Maize Cultivars in Conservation Agriculture (CA) and Conventional Systems

The DT maize cultivars were also evaluated under ridge and furrow, and in mouldboard

Table 13.1. Means of maize cultivars grown in eastern and southern Africa for two seasons, 2011 and 2012. From Setimela *et al*. (2011), with permission.

Hybrid		High-yielding sites (t ha^{-1})	Low-yielding sites (t ha^{-1})	% difference high-yielding conditions to SC513	% yield low-yielding conditions to SC513
CZH 0616	DT hybrid	5.5	2.1	20	29
CZH 0928	DT hybrid	5.3	1.8	17	17
CZH 0837	DT hybrid	5.2	2.0	15	25
Pris601	DT hybrid	5.1	1.6	14	7
PAN53	DT hybrid	4.9	1.8	10	0
09SADVE-F2	DT OPV	4.8	1.7	8	5
CHECK	Non-DT	4.5	1.5	2	0
CZH1033	DT hybrid	4.4	1.8	0	17
SC513	Non-DT	4.4	1.5	0	0
Means		4.5	1.75		
LSD (0.05)		1.4	0.75		
H		0.7	0.6		

DT, drought-tolerant.

conventional tillage systems, complemented by good agronomic practices. These practices complement the use of DT maize with timely planting, use of recommended crop density, balanced fertilization for specific locations and growing appropriately in the most relevant target agroecology. Under these conditions, some of the newly developed DT maize cultivars yielded about 15%–29% more grain than commercial hybrids (Setimela *et al.*, 2018). Table 13.2 also shows the performance of DT maize cultivars during the 2016 and 2017 seasons under CA and conventional practice (CP) in Zambia. The performance of DT cultivars was higher under CA compared to CP. The integration of DT maize cultivars and sustainable intensification practices such as CA thus helps buffer smallholder cropping systems against highly variable seasonal rainfall and climate change.

CA practices have been tested and adapted for SA conditions including planting basins, dibble stick, jab planter, animal traction rip line and direct seeding (Ngwira *et al.*, 2012; Mupangwa *et al.*, 2017; Nyagumbo *et al.*, 2017). Yields of DT maize cultivars grown under basin and direct seeding CA-based practices have consistently yielded higher than the local or commercial cultivars in SA (Thierfelder *et al.*, 2016). Late-maturing DT maize cultivars such as ZM625 were more productive when grown under CA systems compared with early-maturing ones. Improved soil quality and increased soil moisture conservation under CA allow late maturity varieties to maximize biomass accumulation, and hence give higher final yield than early maturity ones. In rip line and dibble stick CA systems, DT hybrid PAN 53 had 6%–28% higher grain yield than in the conventional ridge and furrow system (Mupangwa *et al.*, 2017).

Table 13.2. Performance of drought-tolerant cultivars under Conservation Agriculture (CA) and conventional practice (CP), Zambia, 2016 and 2017. Authors' own table.

	2016		2017	
Cultivar	CA	CP	CA	CP
SC 627	5837	5586	4618	4291
ADV 637	5914	5693	4243	3834
KAM 601	5817	5468	4681	4392
KAM 602	5795	5521	4595	4492
KKS 501	5788	5480	4434	4217
KKS 603	5768	5447	4483	4326
p-value	ns	ns	ns	0.081
SE (n)	167(174)	157 (174)	164(174)	158 (174)

Ns, non-significant; SE, standard error.

A study conducted in Malawi demonstrated that DT maize varieties outperformed commercial cultivars and quality protein maize cultivars across CA and conventional systems in both drought and wet growing seasons (Setimela *et al.*, 2018). DT maize cultivars had 4%–26% higher grain yield compared with the commercial variety DKC 8053 across sites and years. CA and DT cultivars are part of sustainable food production and are key factors in reducing poverty, providing nourishment to ensure healthy and productive lives and preserving resources for future generations, and so address the Malabo Declaration.

13.4 Yield Stability of Stress-tolerant Maize Under Different Environments and Management

Figures 13.1 and 13.2 show the evaluation of three DT hybrids (Peacock 10, CAP 9001 and MH 26), two DT open-pollinated cultivars (ZM 523 and Chitedze 6) and a control hybrid (DKC 8053) in the drought-prone areas of Malawi. The cultivars were tested across 318 farms under CA and CP. The mean performance versus stability genotype × genotype environment (G+GE) biplot shows the hybrids' relative mean performance and stability. The average-environment coordination (AEC) (x-axis) abscissa is a line that passes through the origin of the biplot and the 'average environment' (the small circle defined by the average PC1 and PC2 scores across the environments. Based on their mean performance across all environments, the entries are ranked along the AEC, with the arrow pointing to a greater value (Yan, 2001; Yan and Kang, 2003). The line that passes along the y-axis in the middle of the biplot measures the genotype x environment interaction; and the further away a genotype is from the centre, the more it is affected by the environment.

In Malawi, DT maize hybrid Peacock 10 and CAP 9001 were more stable and high yielding across the two seasons under CA and CP. The non-DT DKC 8053 and Chitedze 6 were

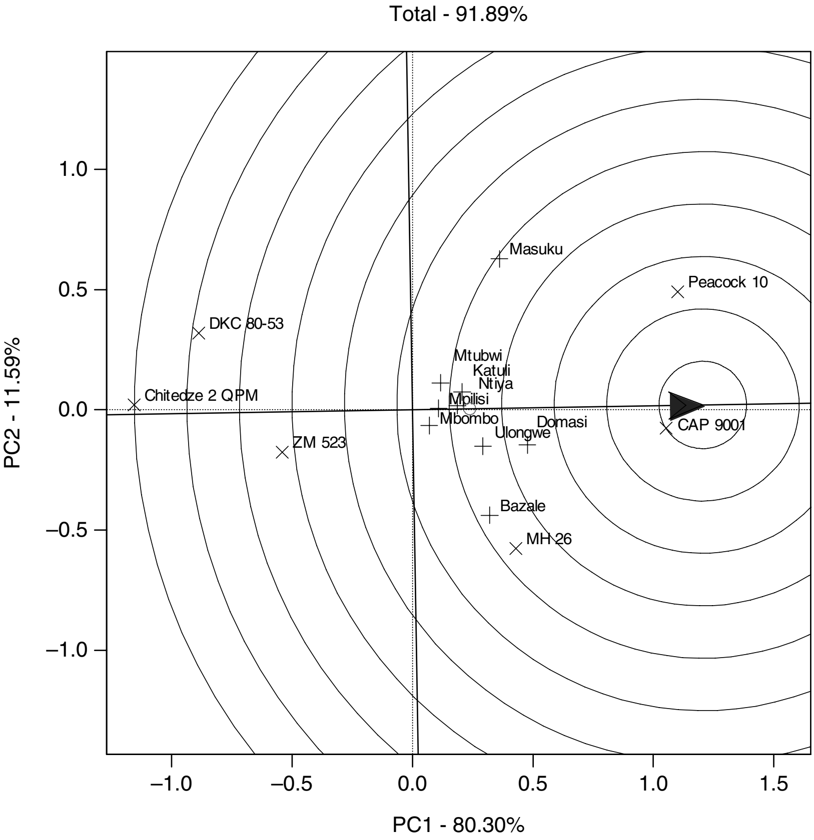

Fig. 13.1. An average tester coordinate view showing the performance of six cultivars based on mean performance and stability across nine extension planning areas in Malawi for 2 years under conventional practice. The biplot was produced based on genotype focused singular value partitioning (SVP); the data were environment centred, and therefore appropriate for visualizing the similarities among genotypes. They explained 91.89% of the total genotype + genotype by environment (G+GE) for the subset. From Setimela *et al*. (2018).

very low yielding and unstable across locations. The hybrid CAP 9001 was very stable under CA and CP while Peacock 10 was more stable under CA but less stable under CP. This shows that CA adds stability to yield performance compared to just practising CP alone. Peacock 10 and CAP9001 were the highest yielding and DT hybrids developed by CIMMYT, confirming genetic gain in yield under stress. The biplots show which hybrids are more responsive to either practice, and therefore it is important to select hybrids that will perform well under either system. The significant interactions observed between cultivar, cropping system and locations suggests that cultivar performance can vary across locations and management systems. The combination of stress-tolerant maize cultivars and CA thus improves resilience of the overall production system. Both CA and DT cultivars add resilience to the cropping system rather than just using one technology. Therefore, sustained productivity increases should not only depend on chemical fertilizer, but on a combination of on- and off-farm strategies. Climate smart agricultural practices such as agroforestry, fertilizer tree systems, farmer-managed natural regeneration of trees, CA, DT crops and crop diversification are among such strategies aimed at increasing productivity of smallholder farming systems. Policy makers should promote climate smart technologies to support sustainable intensification practices.

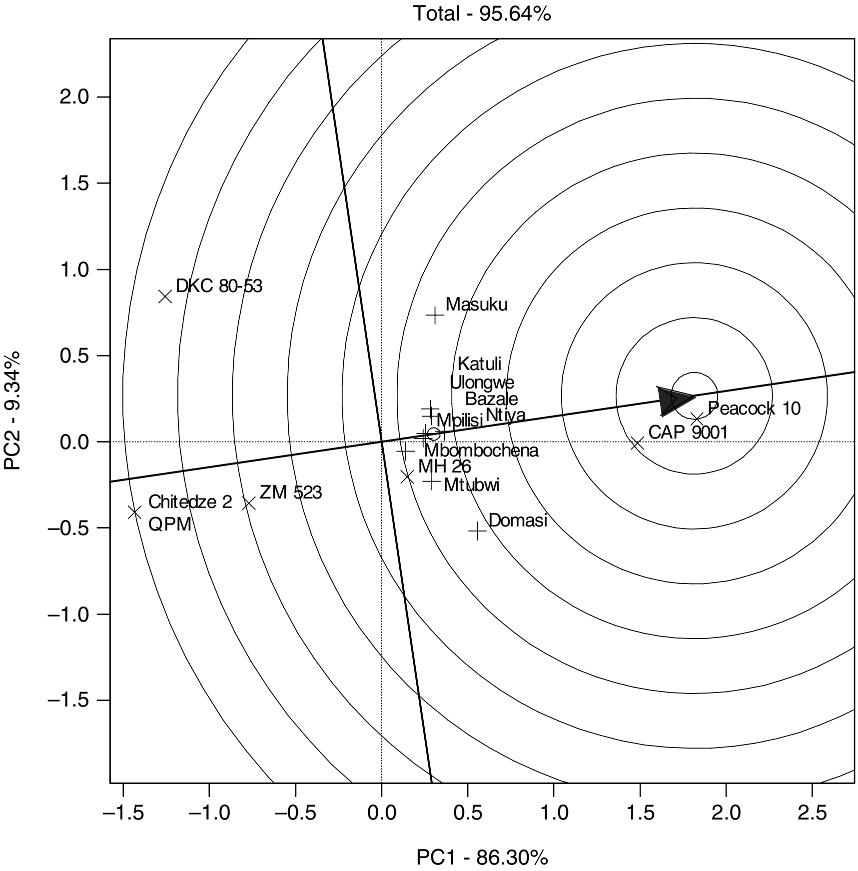

Fig. 13.2. An average tester coordinate view showing the performance of six cultivars based on mean performance and stability across nine extension planning areas in Malawi for 2 years under Conservation Agriculture. The biplot was produced based on genotype focused singular value partitioning (SVP); the data were environment centred, and therefore appropriate for visualizing the similarities among genotypes. They explained 95.64% of the total genotype + genotype by environment (G+GE) for the subset. Authors' own figure.

13.5 Intercropping Experiences and Lessons Learnt

Intercropping, defined as the growing of two or more crops at the same time, is one such strategy that is recommended for intensifying productivity. These crops usually include a mix of cereals (e.g. maize, sorghum or finger millets) with legumes (e.g. cowpea, common beans, soybeans and groundnuts). The concept of the land equivalent ratio, first proposed by Andrews and Kassam (1976), is often used as a measure of how advantageous it is to intercrop as compared to sole cropping; and, when greater than 1, indicates that intercropping is advantageous compared to sole crops (Mead and Willey, 1980).

Traditionally, intercropping or mixed cropping systems have been used by smallholders in Sub-Saharan Africa as strategies to minimize the risk of crop failure. These have been largely replaced in many places by monocropping systems based on tillage. In Zimbabwe, such mixed cropping practices were described by Alvord, one of the early Christian missionaries in the 1920s, as primitive, unorganized and 'a miss and hit' approach to agriculture (Page and Page, 1991). Thus, from the 1920s, Africans in Zimbabwe and elsewhere were taught to use modern, 'civilized', intensive ways of growing crops. These practices were based on cash crops grown as sole crops using ploughs, inorganic fertilizers and hybrid maize seeds that introduced food and cash crop farming systems and also replaced the traditional shifting cultivation practices as land pressure increased. Yet modern day thinking now considers intercropping as an effective strategy towards sustainable agricultural intensification as it brings about greater crop diversification and improved food security (Pretty *et al*., 2011; Rusinamhodzi *et al*., 2012; Musumba *et al*., 2017). Intercropping with legumes, particularly in low-input systems, can contribute significant amounts of nitrogen through biological nitrogen fixation and thus alleviate nitrogen deficiencies in these nitrogen-scarce environments, thereby providing multiple benefits to the farmer. Depending on yield, some legumes can fix up to 30 kg N ha^{-1} $year^{-1}$ or more depending on the type of legume (Giller, 2001).

Intercrops are often better adapted in non-mechanized systems where planting and weeding are done manually. Farmers using mechanized animal traction or motorized planters and cultivators often find intercrops a nuisance for the main crop. Furthermore, harvesting is also a lot easier for monocrops than intercrops, particularly when using mechanized harvesting techniques. Crop rotations of cereals with legumes are generally more suited to farmers with larger pieces of land, who can afford to spare some land for growing legume crops, without compromising on their capacity to produce enough of the staple food cereal crop to meet their annual requirements. On the other hand, intercrops are preferred by farmers with smaller pieces of arable land who must intensify and diversify crop production. It is thus important for farmers to adopt intercropping practices as a strategy towards sustainable intensification. Various studies have shown that farmers can derive several advantages from the use of cereal legume rotations or intercrops (Mutenje *et al*., 2019). Table 13.3 lists the advantages and the disadvantages of intercropping.

Studies suggest the use of leguminous crops provides yield advantages to the farmers in that they get more crops from the same piece of land when they intercrop. The use of intercrops, and in particular under CA, can help farmers to become more resilient to climate change-induced dry spells and their crops can withstand severe moisture stress. Furthermore, the use of inter-

Table 13.3. Advantages and disadvantages of intercropping. Authors' own table.

Advantages of intercropping	Disadvantages of intercropping
• Diversification of soil flora and fauna • Increased water infiltration through channels created by diverse roots structures • Growing different crops diversifies sources of food. This also provides insurance against failure of crops in very dry or very wet years and contributes to increased food and feed outputs for human and livestock. If one crop fails, the other may survive • Intercropping gives additional yield income/unit area than sole cropping and often higher biomass and usually gives a land equivalent ratio that is greater than 1 • Improved soil cover and thereby reduced susceptibility to runoff and erosion • Weeds are more likely to be smothered by the high biomass levels in intercrops • Intercropping can also help to suppress pests. For example, farmers using intercrops often find that the infestation of maize by Fall Army Worm is reduced in intercropped maize • Suppression of parasitic weeds such as *Striga asiatica*	• Initial yield decreases of the individual component crops compared to sole crops as the increased cropping density causes more competition for water, light and nutrients • Mechanization can be difficult in intercropped systems and so planting and weeding may need to be done by manual methods • May require more basal fertilizer since the crop density is higher • Harvesting can be difficult as the crops may interfere with each other • Time consuming: it requires more attention and thus increased intensive, expert management • Lack of leguminous crop seeds for farmers to use in intercrops

crops brings about increased diversification of crops and thus helps to reduce the risk of crop failure in times of drought. This means the use of intercrops in rain-fed cropping systems could enable farmers to be more productive, leading to better food and nutrition security and incomes. In studies carried out across Eastern and Southern Africa (ESA) between 2010 and 2017, testing different cropping systems including intercrops, maize yields were more compromised when intercrops were implemented in environments with less than 700 mm of seasonal rainfall (Fig. 13.3). In this rainfall regime (< 700 mm), CA intercrops tended to depress maize yields compared to other CA systems, but still increased yields by 12% above the conventional till systems. This effect was attributed to increased moisture competition arising from the two crops under these soil moisture-constrained conditions. The plant density in intercrops combining maize and the associated legumes were often 1.5–2 times the density of plants in sole crops. This, therefore, suggests that CA intercrops under low rainfall conditions deliver smaller maize yield advantages; and, in seasons with excessive moisture stress, can present a high risk of depressed maize yields, particularly if non-DT cultivars are used. In contrast, when rainfall conditions improved to the 700−1300 mm regime, CA systems including intercrops increased maize yields by 15% over CP. However, when the rainfall regime exceeded 1300 mm, the yield advantage of CA intercrops over conventional depressed to 9%. This suggests that the use of intercrops in this study was found to be most beneficial to the cereal crop in the rainfall regime 700–1300 mm (Nyagumbo *et al*., 2020).

Other findings from different studies carried out on intercrops in the region suggest that intercropping cereals and legumes can have many beneficial effects. For example, in South Africa, intercropping maize and *Lablab purpureus* had beneficial effects in the third year and beyond with relative yields above 100% (Table 13.4).

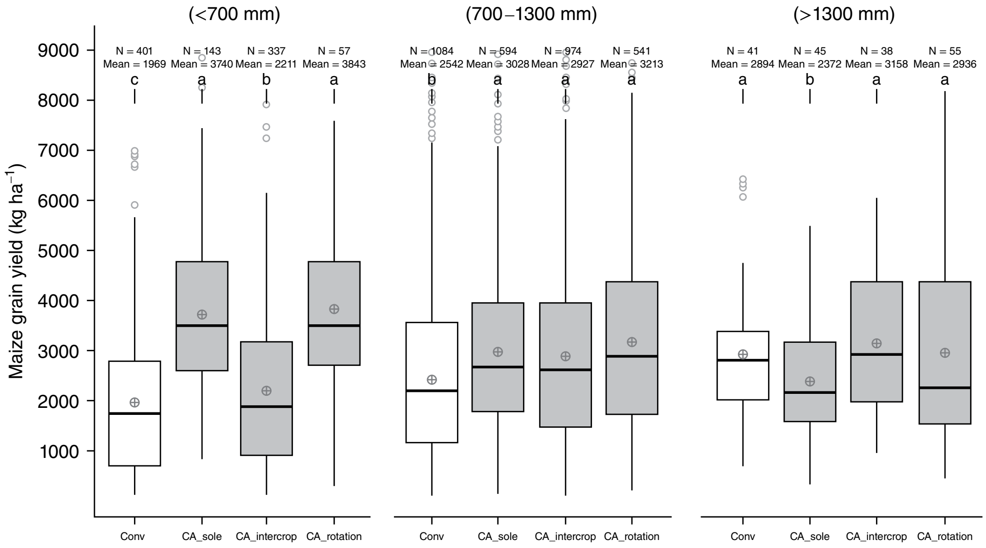

Fig. 13.3. Maize grain yield responses to Conservation Agriculture in three different rainfall regimes (< 700, 700–1300, >1300 mm) from five eastern and southern African (ESA) countries (2010–2017). Circles inside boxes represent means; black horizontal bar in the middle of each box represents the median; upper and lower ends of each box represent 75% of the upper and lower quartiles. For each rainfall regime the different letters above bars indicate significant differences between respective cropping systems at $p < 0.05$. LSD (0.05) (< 700 mm), 493 kg ha^{-1}; LSD (0.05) (700–1300 mm), 241 kg ha^{-1}; LSD (0.05) (> 1300 mm), 460 kg ha^{-1}. Cropping systems: Conv, conventional tillage practice; CA sole, Conservation Agriculture with continuous maize on its own; CA intercrop, Conservation Agriculture maize intercropped with a legume; CA rotation, Conservation Agriculture maize in rotation with a legume. From Nyagumbo *et al*. (2020).

Table 13.4. Effect of intercropping strategy on maize grain dry matter yield (kg ha^{-1}) and relative yield (RY) of maize across year. Courtesy of Mthembu (2018).

	Treatments		
Year	Monocrop maize (means ± SE)	Maize–*Lablab* intercrop (means ± SE)	Relative yield % (maize)
2004	1288 ± 240^{a}	1112 ± 200^{a}	86
2006	1240 ± 720^{a}	1260 ± 990^{a}	102
2007	1490 ± 300^{a}	4460 ± 820^{b}	299

Means in the row followed by different superscripts are significantly different ($p < 0.05$); SE, standard error of the mean.

The maize yield increase would contribute to increased household food security while the *Lablab* fodder would be used as winter livestock supplementary feed. In Zimbabwe, considerable efforts on intercropping with legumes were carried out through the Soil Fertility Network in the 1990s (Waddington *et al*., 2008).

Legume intercropping has also been shown to reduce parasitic witchweed (*Striga asiatica)* infestations in Malawi and Zimbabwe (Silberg *et al*., 2020). In Mozambique, maize–cowpea and maize–pigeon pea intercrop studies suggested planting configurations were important factors influencing the productivity of such systems (Rusinamhodzi *et al*., 2012). Further work in Zimbabwe focused on integrating crop–livestock systems showed that maize–cowpea and maize–*Mucuna* CA systems had beneficial forage effects compared to conventional sole cropped maize (Mutsamba *et al*., 2019) but did not improve maize grain yield (Table 13.5). Gross margin analysis of these systems suggested maize–*Mucuna* systems were the most beneficial (Fig. 13.4). In Zambia, CA intercropping systems also gave the highest returns. Thus CA maize–cowpea intercropping using dibble stick produced the greatest net returns (US$312–767 ha^{-1}) compared with dibble stick maize–cowpea rotation (US$204–657 ha^{-1}), dibble stick maize monoculture (US$108–584 ha^{-1}) and the CP with maize and cowpea (US$64–516 ha^{-1}) (Mupangwa *et al*., 2017). Thus, when intercropping practices are used together with DT maize cultivars, farmers can become more resilient and thus climate smart.

The use of intercropping technologies varies widely with farmers across the region. Cash crop-oriented farmers rarely use intercrop systems. In Mozambique, around 70% of the households intercropped maize with legume crops, while in eastern Zambia some 30%–40% of the farmers use intercropping practices (Mutenje, personal communication, 2020).

13.6 Enhancing Climate Resilience Using Stress-tolerant Maize Cultivars and Conservation Agriculture (CA) in Southern Africa: Socio-economic Perspective

Many practices and technologies assumed to enhance climate resilience have been introduced and promoted for smallholders through field demonstrations and on-farm trials in SA (Mutenje *et al*., 2019). These on-farm trials have provided promising results in terms of generating higher and more stable crop yields. However, successful on-farm trials results have often failed to translate over time into widespread and sustainable adoptions for these climate smart agriculture (CSA) technologies and practices (Ngwira *et al*., 2014; Thierfelder *et al*., 2017). One main reason cited is that the application of CSA technologies under SA's diverse agroecologies and heterogeneous sociocultural and socio-economic smallholder farming systems is a challenge (Thierfelder *et al*., 2016; Mupangwa *et al*., 2017). CSA technologies adoption and adaptation can engender trade-offs that can impact farmers differently according to local agroecological and institutional environments, household typology, socio-economic status and other factors (Thierfelder *et al*., 2017). Working to ensure that CSA technologies and practices are adaptable to specific agroecological and socio-economic/sociocultural contexts is increasingly becoming very important (Neufeldt *et al*., 2013; Mutenje *et al*.,

Table 13.5. Forage and maize grain yields (kg ha^{-1}) from intercropping and sole cropping systems from 2012/13–2014/15 seasons in Murehwa district, Zimbabwe.

	Forage yield		Maize grain yield	
Treatments	2012/13–2014/15 no manure	2014–15 with manure	2012/13–2014/15 no manure	2014–15 with manure
CT + sole maize continuous	3076^{a}	3565^{a}	2670	2878^{b}
CT + sole maize continuous	3646^{b}	4115^{a}	2729	2847^{b}
CA + maize + cowpea intercropping	4134^{c}	4820^{b}	2565	2280^{a}
CA + maize + *Mucuna* intercropping	3999^{bc}	4481^{b}	2623	2394^{a}
p value	0.014	0.018	0.961	0.012
LSD$_{0,05}$	460	796	NS	433
(n)	8	8	8	8

CT, conventional tillage using the mouldboard plough; CA, Conservation Agriculture means with different letters within the same column are significantly different ($p < 0.05$); NS, not significant at $p < 0.05$; LSD, least significant difference at 5%; n, number of replicates. Table courtesy of Eleanor Mutsamba, 2019 (Mapfeka *et al*., 2019).

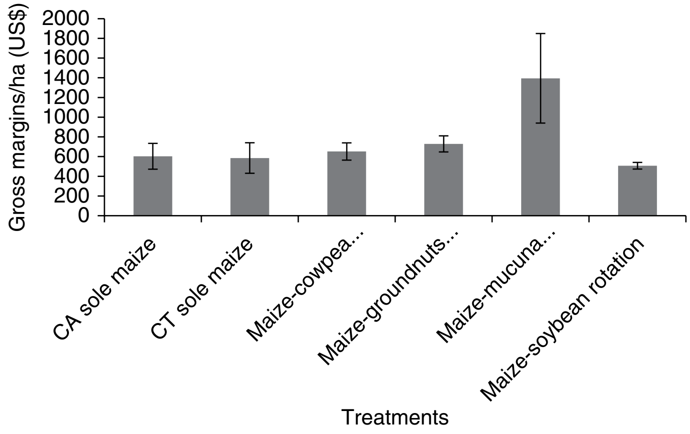

Fig. 13.4. Gross margins of cropping systems tested from 2012/13–2014/15 seasons across eight farms in Murehwa district, Zimbabwe. Vertical bars represent standard error (n, 8). From Mutsamba *et al*. (2019).

2019). CSA technologies and practices need to be feasible in situ, with realistic capacity and resource requirements, and should contain the ability to provide optimal net benefits at minimal risk. To understand the choices and trade-offs that smallholder farmers are making this study uses cost-benefit analysis (CBA) and participatory rapid appraisals (PRAs) to evaluate the economic cost, benefits and social relevance of CSA technologies and practices promoted in SA. It draws upon farm-level data from Malawi, Mozambique and Zambia.

In this study we used a range of participatory appraisal assessment tools including: (i) hazard and vulnerability mapping; (ii) vulnerability matrices; (iii) transect walk to understand evolution forest degradation; (iv) field profiles; (v) seasonal calendars to understand how vulnerability is expressed at different times of the year; (vi) vulnerability matrices that link climate stressors or hazards with the sensitivity of the forest ecosystem and farming system; (vii) adaptation and livelihoods assets; (viii) wealth ranking; (ix) climate impact; (x) key informant interviews (KIIs) with community traditional leaders, community organization representative and government official working in the agriculture, forestry and social welfare departments, livelihood portfolio evolution and household portfolio management; and (xi) village history.

The CSA results support the biophysical results that integration of CSA approaches, especially CA and DT maize cultivars, enhances climate resilience in the diverse production systems of SA. The benefits from the agronomic and economic complementarities of the CA technology, crop diversity and DT maize cultivar combinations provided a wide range of profitability values as measured by a positive net present value (NPV), an internal rate of return (IRR) greater than the discount rate and the payback period (Table 13.6). These results highlight the importance of integrated CSA adaptation strategies comprising CA cropping systems for diversity, sustainable soil management methods for improved soils and water conservation, and improved crop cultivars for thermal shocks (Thierfelder *et al*., 2017). For example, in lower-potential areas of Malawi, which are prone to droughts, a combination of basin CA, and DT maize cultivars integrated with pigeon pea intercropping, had the highest positive NPV. In addition, CBA results highlighted the importance of diversity to achieve explicit adaptation of smallholder agriculture systems to climate change and variability. Optimal CSA packages such as the rip line CA and DT maize cultivars rotated with soybean generated the highest economic benefits in low-potential Mozambique and Zambia (Table 13.6). CA-based cropping systems with DT maize cultivars, in general, tend to be more agronomically stable and are known to improve the long-term resiliency of smallholder farming systems. These results support the promotion of

Table 13.6. Cost-benefit analysis of selected climate smart agriculture (CSA) technologies and practices[a]. Authors' own table.

Country	Agroecological zone	CSA	Net present value (ha^{-1}) (30%), USD $	Net incremental benefits for CSA option (%)	Internal rate of return	Payback period (years)	Change in labour (person-days ha^{-1})
Malawi	Low potential	CP, VMz	468.74	▨	53	1	▨
		bsCA,DTMz, Ppint, F	1665.73	69	84	2	21
		dsCA, DTMz, Ppint, F	1449.16	112	363	2	–26
	High potential	CP, VMz	888.55	▨	57	1	▨
		dsCA, DTMz, G/nuts R, F	1702.66	122	132	4	–37
Mozambique	Low potential	CP, VMz	–10.41	▨	25	1	▨
		dsCA,DTMz, Cpint, rSm	466.16	153	179	2	29
		rpCA, DTMz, SbR	681.02	126	114	3	–18
	High potential	CP,VMz	813.58	▨	52	1	▨
		dsCA, VMz, SbR, rCb	2442.69	172	489	2	–23
		dsCA, VMz, Ppint	1251.87	84	369	4	–31
Zambia	High potential	CP, VMz	758.84	▨	48	1	▨
		bsCA, DTMz,Cpint	1093.41	81	242	3	27
		rpCA, DTMz, SbR	1866.01	132	529	4	–39

[a] Grey areas indicate missing numbers.

bs, planting basins; CA, conservation agriculture; CP, conventional practice; Cp, cowpea; ds, dibble stick direct seeding; DT, drought-tolerant; F, fertilizer; G/nuts, groundnuts; int, intercropping; Mz, maize; Pp, pigeon pea; rCb, rotation common beans; R, rotation; rp, ripping; rSm, rotation soybean maize; Sb, soybean; V, improved variety/cultivar.

a diverse menu of adaptation practices that farmers can select from and modify based on their contexts, needs and experiences.

In low-potential areas in Malawi, very prone to droughts, farmers use a composite set of adaptation strategies including planting DT early-maturing maize cultivars, diversifying tillage systems and fertilizer micro-dosing. During discussions with farmers they emphasized that it is a common practice to allocate equal maize areas under different CA and CP systems depending on how they perceived the season to be. If they perceived the season to have low, poorly distributed rainfall, they would allocate more maize under CA basins tillage. They also pointed that there is a shift in crop choices and agricultural practice towards more DT options such as cassava, sweet potatoes, pigeon pea, cowpeas, CA and agroforestry (Fig. 13.5). Although intercropping has been their tradition, climate-induced shocks such as droughts have steered farmers to intensify and to adapt it to their land and precipitation limitations. The common intercrops include maize–pigeon pea–cowpea, maize–cassava, groundnuts–pigeon pea and maize–cowpea. The participants perceived that about 40% of the community members were practising CA. Farmers in this community highlighted that DT crops such as cassava and sweet potatoes have become important adaptation strategies for erratic onset of rains, dry spells, moderate and severe droughts. A chicken manure programme was also highly rated as an adaptation strategy to climate change in this community.

In lower-potential areas of Mozambique, the increased frequency of climate-induced shocks has prompted farmers to use a combination of strategies, such as crop species, tillage and spatial diversification. Intercropping of maize–sorghum with cowpea, groundnuts and soybean is a commonly used drought mitigation strategy. The community also noted that it is allocating more land to DT crops such as sorghum and groundnuts. A variety of practices ranging from basins, manual ripping and direct seeding using dibble sticks are also some of the strategies adopted by the farmers to cope with climatic changes (Fig. 13.6). In the high-potential areas in Mozambique, agroforestry and forest regeneration ranked high compared to other technologies. In the high-potential areas, drought is not severe compared to the low-potential areas. Savings clubs in the high-potential areas were ranked high by farmers. Savings clubs allow farmers to acquire

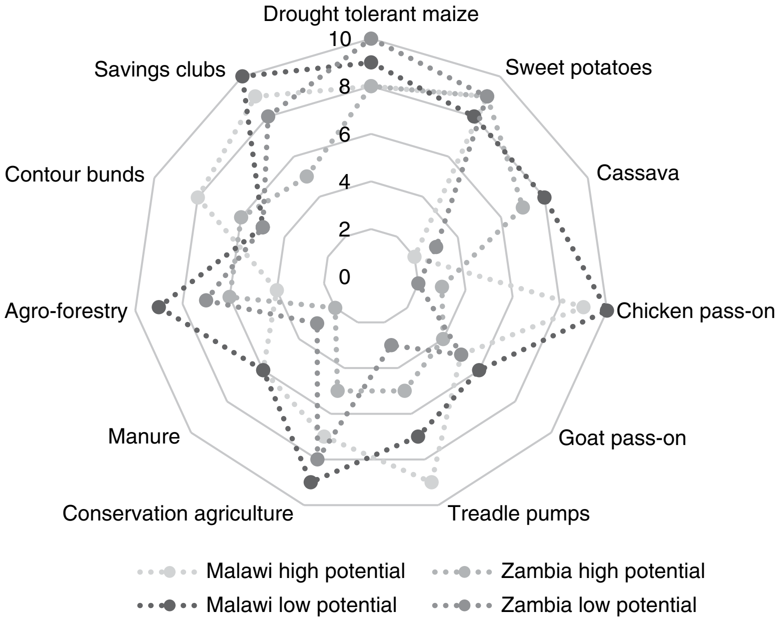

Fig. 13.5. Integrated adaptation strategies for improving smallholder farming system resilience to climate change in Malawi and Zambia. Chicken and goat 'pass-on' schemes enable farmers to pass on live young to other farmers in the community in rotation. Authors' own figure.

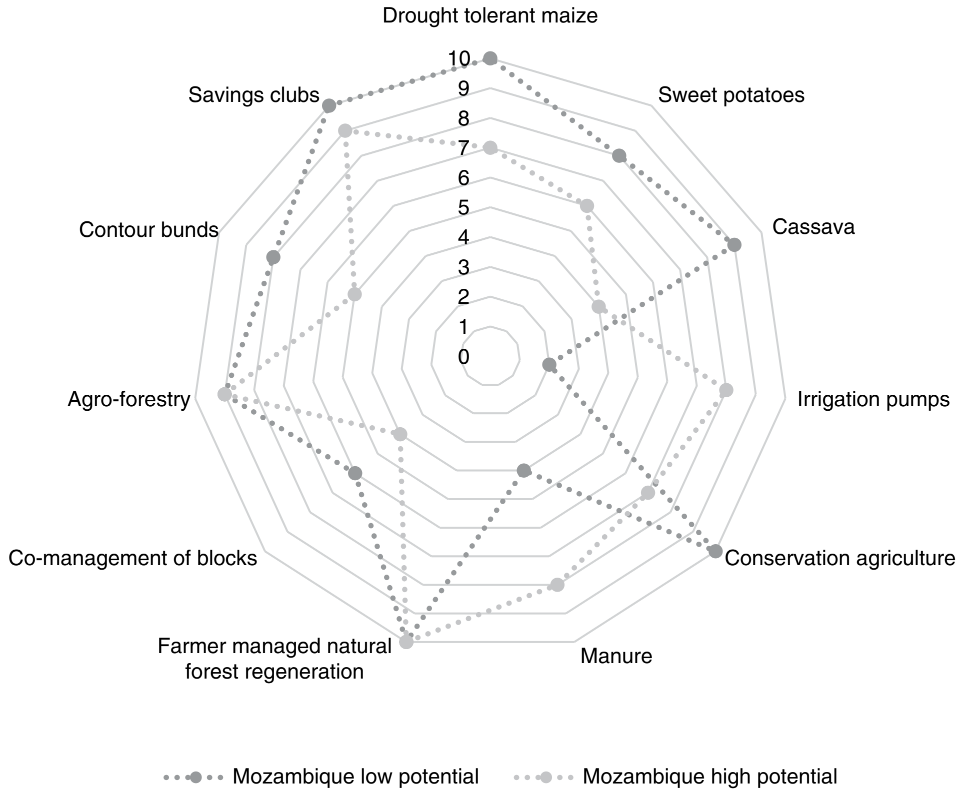

Fig. 13.6. Integrated adaptation strategies for improving smallholder farming system resilience to climate change in Mozambique. Authors' own figure.

assets and resources to buy seed for replanting, with increased erratic onset of seasons, that can be used for better livelihoods. Integration of adaptation strategies with short- and long-term benefits were most preferred in all the communities (Fig. 13.6).

13.7 Conclusions

Maize yields and stability can be improved if farmers can use DT maize cultivars in CA systems to mitigate against climate change. Intercropping systems have also shown to reduce labour required by farmers, by suppressing pests and diseases, and at the same time improving profitability. Environments with rainfall between 700 mm and 1300 mm were the most ideal for intercropping, enabling intercropped legumes to perform well. Diversification of cropping systems to include various cereals and legumes as well as tubers feature as one of the most widely used coping strategy for improved resilience. Therefore, deployment of stress-tolerant maize cultivars in CA systems would increase the overall resilience of food systems under future climate change scenarios, thereby improving food security for smallholders. Farmers preferred integrated systems and technologies as a mitigation strategy against climate change. The results from this study, therefore, suggest that the tested CSA practices effectively address two of the CSA pillars (productivity and resilience/adaptation) to mitigation. Supportive policy and institutional support environments are required to incentivize and help smallholder farmers to take up and apply these CSA practices on a relatively larger scale for improved climate smartness. The results show that CA, in combination with other technologies, can enhance the food security of smallholders in a highly variable climate induced by climate change.

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14 Tillage Effect on Agronomic Efficiency of Nitrogen Under Rainfed Conditions of Tanzania

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Abstract

Nitrogen (N) deficiency is a common feature in soils managed by smallholder farmers in Africa. Crop residue retention, in combination with no-till (NT), may be a pathway to improve agronomic use efficiency of applied N for small-scale farmers under the predominant rainfed conditions. This chapter reports on the results of a study carried out over two cropping seasons in the long rains of 2014 and 2015 on two sites: (i) on-farm (Mandela); and (ii) a research station (SARI) in eastern Tanzania. The experiment consisted of two tillage systems, conventional tillage (CT) and Conservation Agriculture (CA), with a minimum of 2.5 t ha^{-1} crop residue cover maintained in the plots during the experiment. CT consisted of soil inversion through tillage and removal of crop residues. In the on-farm experiment, maize was grown in plots with four rates of N application: 0, 27, 54 and 108 kg N ha^{-1}. In the on-station trial, five rates were used: 0, 20, 40, 60 and 100 kg N ha^{-1}. Maize yield and agronomic efficiency (AE) of N were used to assess and compare the productivity of the tested treatments. The results showed that tillage, soil type and rate of N application influenced crop productivity. In the clay soils, the differences between tillage practices were small. Under CT, AE ranged between 21.6 and 53.9 kg/kg N, and it was 20.4–60.6 kg/kg N under CA. The lowest fertilizer application rate of 27 kg ha^{-1} often had the largest AE across the soil types and tillage practices. In the on-station trials at SARI, the largest AE of 24.6 kg/kg N was recorded under CA with 40 kg N ha^{-1}. As in the on-farm trials, the highest N application rate on-station did not lead to the largest AE. In the CT, AE ranged between 11.5 and 16.8 kg/kg N compared with a range of 15.1 to 24.6 kg/kg N for the CA treatment. Overall, crop residue retention, in combination with NT, is important to improve soil moisture and use efficiency of applied nutrients. Additionally, the initial soil fertility status is also important in determining the magnitude of short-term crop response to applied nutrients. Innovative pathways are needed to achieve the multiple objectives played by maize crop residues for results reported here to be sustainable. However, efficiency of nutrient use needs to be assessed, together with returns on investments, as small yields may mean high nutrient use efficiency but not necessarily significant increased returns at the farm level.

Keywords: sustainable intensification, Conservation Agriculture, climate smart agriculture, N application rate, maize yield, soil fertility

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14.1 Introduction

Nitrogen (N) deficiency is a major limitation to achieve sustainable intensification on smallholder farms in Sub-Saharan Africa (SSA) (Stewart *et al.*, 2020). This is mainly because soils have been cultivated for decades with inadequate nutrient inputs, coupled with the high nutrient demands of crops such as maize resulting in nutrient mining (Smaling *et al.*, 1997). Chemical fertilizers are a key component of improved crop production technologies, along with legume crops in the cropping system. Yet, in this region, the use of synthetic fertilizers is often below optimum due to differences in both micro- and macroeconomic conditions (Chianu *et al.*, 2011). The risk of crop failure resulting from low rainfall is a strong disincentive to the purchase and use of fertilizers on the subsistence crops often grown by farmers (Chianu *et al.*, 2011). Thus, strategies are needed to increase the use efficiency of the limited fertilizers that smallholder farmers regularly apply, by overcoming the biophysical limitations exerted by erratic rainfall and degraded soil fertility.

In the recent past, considerable effort and resources have been invested in research and out-scaling of Conservation Agriculture (CA) as the most suitable sustainable intensification (SI) option farmers could readily utilize. CA is defined by FAO (http://www.fao.org/conservation-agriculture/en/, accessed 31 July 2021) as an ecosystem approach to regenerative sustainable agriculture and land management based on the practical application of the context-specific and locally adapted three interlinked principles of: (i) continuous no or minimum mechanical soil disturbance (NT seeding/planting and weeding); (ii) permanent maintenance of soil mulch cover (crop biomass, stubble and cover crops); and (iii) diversification of cropping system (through rotations and/or sequences and/or associations involving annuals and/or perennials, including legumes). Among the recent initiatives is the project funded by the Australian Centre for International Agricultural Research (ACIAR) on Sustainable Intensification of Maize–Legume Systems for Food Security in Eastern and Southern Africa (SIMLESA). One of the major objectives of the project is to test and develop productive, resilient and sustainable smallholder maize–legume cropping systems and innovation systems for local scaling out.

Some of the main benefits of CA with a main focus on southern Africa have been summarized (Thierfelder *et al.*, 2014). The immediate major effect of CA at farm level is the reduction in labour and energy demand as a direct result of the reduced tillage operations (Pannell *et al.*, 2014). At plot level, presence of mulch on the soil surface will reduce run-off, check soil erosion and increase infiltration of rainwater, and reduce evaporation (Rusinamhodzi *et al.*, 2011; Micheni *et al.*, 2015). In the long term, mulch in combination with no-till (NT) will contribute to increased biodiversity (Kihara *et al.*, 2012), increased soil organic carbon (SOC) and reduced bulk density and soil compaction (Govaerts *et al.*, 2009). In manual systems, labour and draft-power demand are expected to be eased, while in mechanized systems machinery and fuel costs are reduced. Most studies show that the CA till option has yield advantage over the conventional in most agroecological zones (Rusinamhodzi *et al.*, 2011; Pittelkow *et al.*, 2014; 2015). Improved moisture conditions in the soil are likely to improve nutrient uptake and use efficiency, resulting in increased farm yield benefits (Rusinamhodzi *et al.*, 2020).

CA is also considered an important component of climate smart agriculture (CSA) due to the ability to ensure production stability (Knapp and van der Heijden, 2018), resilience (Steward *et al.*, 2018) and carbon sequestration (Chivenge *et al.*, 2007; Fuentes *et al.*, 2012), which reduce emissions (Palm *et al.*, 2014). CSA is defined as an approach for transforming and reorienting agricultural systems to support food security by integrating climate change into the planning and implementation of sustainable agricultural strategies (Lipper *et al.*, 2014). Therefore, CA has a potential bigger role to support food production and ensure sustainability of the majority smallholder farmers depending on small farms under fragile biophysical and socio-economic conditions. In this chapter we assess the short-term effects of CA and soil type on the N agronomic use efficiency over two seasons (2014 and 2015) and in two locations in Tanzania. The underlying hypothesis is that cropping systems based on a combination of NT and *in situ* organic mulch cover will increase agronomic N use efficiency and may be a pathway to achieve SI for resource-constrained smallholder farmers cultivating maize under rainfed conditions.

14.2 Materials and Methods

14.2.1 Site Description

The on-station experiment was carried out at Selian Agricultural Research Institute (SARI) Arusha (03° 22′ S, 36° 37′ E and an altitude of 1387 m above sea level) and the on-farm study was established in Mandela village, Kilosa district (06° 22′ S, 38° 42′) (Fig. 14.1). Both sites have a mean annual temperature of 25°C and a mean annual rainfall of between 1000 and 1500 mm. The dominant soils for both sites are classified as Eutropic Fluvisols, formed from alluvial deposits brought down from the mountains by floodwater. The sites are characterized by mixed crop and livestock farming where livestock consume crop harvest residues in the dry season.

14.2.2 Experimental Design

The experiment was carried out over two cropping seasons in the long rains of 2014 and 2015. The experiment consisted of two tillage systems: conventional tillage (CT) and CA, with a minimum of 2.5 t ha^{-1} maize crop residue cover maintained in the plots during the experiment. The experimental design was a randomized complete block design with three replications and laid out in split-plot arrangement. The main plots were assigned to tillage systems (CA versus CT), the sub-plots were assigned to the different N rates of application. CT consisted of soil inversion through tillage and removal of crop residues. In the CA treatment, planting holes were opened using hoes while maintaining the surface mulch. In the on-farm experiment, maize was grown in plots with four rates of N application: 0, 27, 54 and 108 kg N/ha. In the on-station trial, five rates were used: 0, 20, 40, 60 and 100 kg N ha^{-1}. The plot sizes measured 7 m wide × 6 m long. Maize was planted at a spacing of 75 cm between rows and 30 cm within rows to give a plant population of 44,444 plants ha^{-1}. All plots received a basal fertilizer application of 40 kg P and 20 kg K ha^{-1}. The plots were kept weed free by using the hand hoe for weeding in the CT plots, and the use of 2.5 l/ha glyphosate (N-phosphono-methyl glycine) at planting in the CA plots. Post-planting weed control was achieved through shallow scratching the soil surface with a hand hoe.

14.2.3 Soil Moisture Measurement

Soil moisture was estimated by the gravimetric method (Anderson and Ingram, 1993). Soil was sampled in experimental fields from 0–20 cm depth. A fresh soil core was weighed then oven dried at 105°C until there was no further change in mass. The dry sample was reweighed and mass recorded. The moisture content was expressed as mass of water per mass of dry soil and expressed as percentage. The formula used (Eqn 14.1) was:

$$\text{Soil moisture}\,(\%) = ((\text{fresh weight} - \text{dry weight}) / \text{dry weight}) * 100 \tag{14.1}$$

Owing to logistical considerations, soil moisture content was only measured in on-station trials at SARI. The reported results are for measurements recorded at the V10 stage where soil moisture is critical for the subsequent grain-filling stage.

14.2.4 Yield Measurement and Data Analysis

Grain and above-ground biomass yield measurements were estimated from five rows × 2 m yield plots in the centre of each plot after physiological maturity. Maize cobs were removed from the stalk and shelled. Maize grain yield was calculated at 12% moisture content and stover on dry weight basis. Sub-samples for stover and cores were taken and dried at 70°C for moisture correction.

Maize grain yields were subjected to the Shapiro–Wilk normality test (Shapiro and Wilk, 1965). The data did not satisfy the assumption of normality and were thus log-transformed before analysis. The log-transformed data exhibited homogenous variance ($p < 0.05$) as confirmed by Bartlett's test (Snedecor and Cochran, 1989). The generalized linear model (GLM) was fitted by REML option using the R-package ade4 in R-Studio Version 0.99.892 (RStudio, 2016) to assess the effect of N rate, tillage and soil on maize grain yield. AE-N, a parameter

Fig. 14.1. The location of the sites in Tanzania where the Conservation Agriculture field experiments were established in 2014 and 2015. Drawn using QGIS open source software.

representing the ability of the plant to increase yield in response to N applied (Montemurro and Diacono, 2016), was calculated using the formula (Eqn 14.2):

$$\mathrm{AE-N} = (\mathrm{GYf} - \mathrm{GYu}) / \mathrm{Na} \qquad (14.2)$$

where GYf is grain yield of fertilized maize, GYu is grain yield of unfertilized maize and Na is the amount of N applied.

14.3 Results

14.3.1 Crop Productivity

Maize yield increased significantly ($p < 0.001$) with increasing rate of N application, and also depended greatly on the tillage method used across the sites. Similarly, site as defined by soil fertility status was also highly significant ($p < 0.001$) on maize grain yield. At the on-station trial CA without application of N recorded 1.6 t ha^{-1} maize grain yield and the same treatment under CT recorded 1.3 t ha^{-1} (Fig. 14.2). The CA treatment increased to 2.1 t ha^{-1} with addition of 20 kg N ha^{-1} and topped at 3.3 t ha^{-1} with addition of 100 kg N ha^{-1}. In CT, addition of 20 kg N ha^{-1} increased yield to 1.9 t ha^{-1} and the maximum yield of 2.7 t ha^{-1} was achieved at 100 kg N ha^{-1}.

On the on-farm station, maize yields without fertilizer application (0 N) were low, averaging 1.3 t ha^{-1} across tillage and soils (Table 14.1). On sandy soils, the effect of CA on the response to added N was significantly larger than the

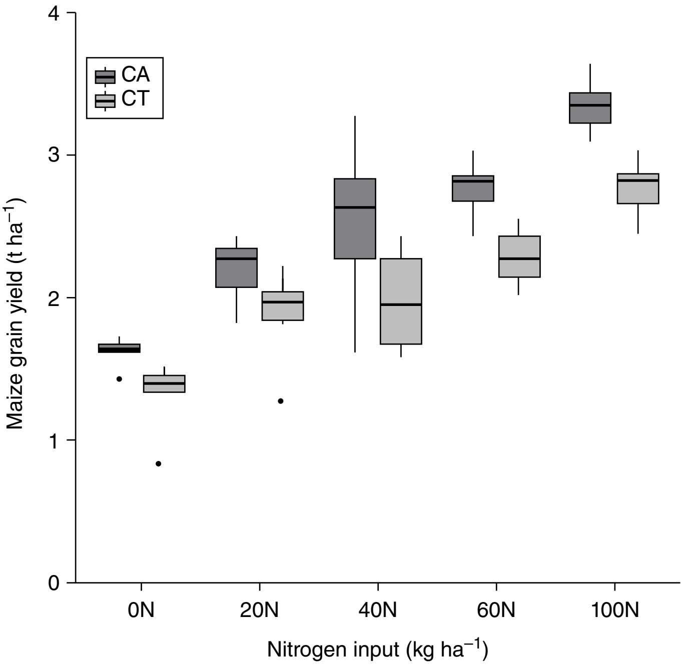

Fig. 14.2. Productivity maize as affected by tillage methods and increasing rates of nitrogen (N) at Selian Agricultural Research Institute (SARI), Arusha, Tanzania, in 2014 and 2015. The middle line that divides the box into two parts the is the median and the whiskers show the data ranges (minimum and maximum) for each treatment. The black dots show outliers. Authors' own figure.

Table 14.1. Average maize yield as affected by increasing N application rates, soil type and tillage method in an on-farm experiment at Mandela village, Kilosa, Tanzania**.** Authors' own table.

	Maize grain yield (t ha^{-1})			
	Sandy soil – low fertility		Clay soil – high fertility	
N applied kg/ha	CT	CA	CT	CA
0	1.4	1.3	1.5	1.4
27	1.8	3.4	3.0	3.0
54	2.7	6.0	4.9	4.9
108	4.7	5.7	5.8	5.2
SE	0.5	0.7	0.7	0.6

CT, conventional tillage; CA, Conservation Agriculture; SE, standard error

effect on clay soils. In sandy soils, the highest yield of 6 t ha^{-1} was obtained with the addition of 54 kg N ha^{-1}, and larger (108 kg N ha^{-1}) applications of N depressed yields to 5.7 t ha^{-1}. The effect of CA in general was larger in sandy soil than in clay soil.

14.3.2 Soil Moisture

The moisture content reported here was measured at the on-station trial at SARI. CA plots consistently recorded higher soil moisture content than CT plots at all the three soil depths considered (Fig. 14.3). At 0–15cm, CA recorded 29% and CT recorded 27%, and a difference of at least 1% was maintained at all depths with CA recording more moisture.

14.3.3 Agronomic Efficiency (AE) of Nitrogen (N)

In the on-farm trials, AE for CT in sandy soil was low: it ranged from 3.7 kg/kg N to 13.2 kg/kg N but was high in the CA treatment at 20.2–77 kg/kg N (Table 14.2). In the clay soils, the differences between tillage practices were small. Under CT, AE ranged between 21.6 and 53.9 kg/kg N, and it was 20.4–60.6 kg/kg N under CA.

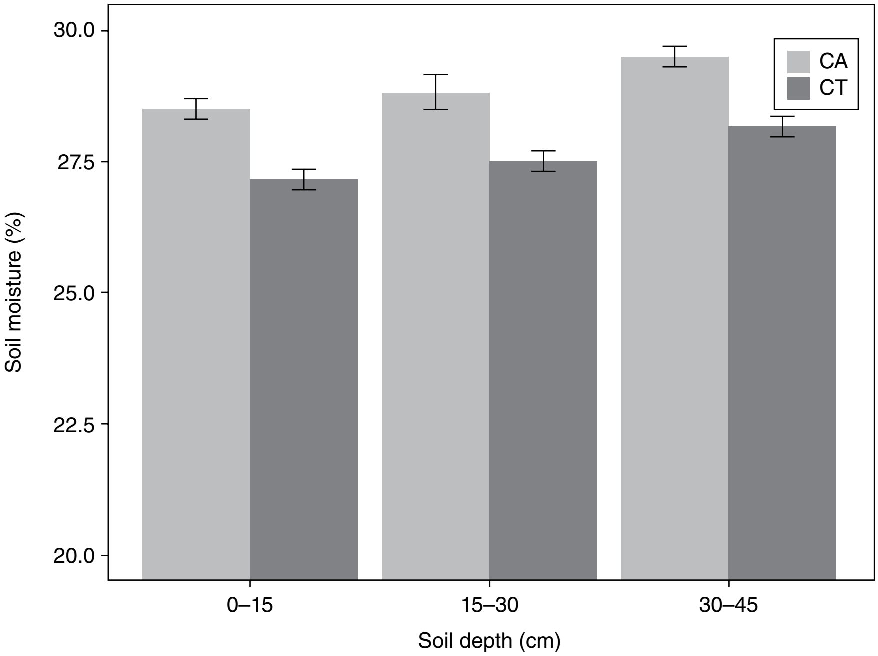

Fig. 14.3. Soil moisture content (%) measured at Selian Agricultural Research Institute, Arusha, Tanzania. Authors' own figure.

Table 14.2. Average nitrogen (N) agronomic use efficiency as affected by increasing N application rates, soil type and tillage method in an on-farm experiment at Mandela village, Kilosa, Tanzania. Authors' own table.

N applied kg/ha	Agronomic efficiency (kg grain/ kg N)			
	Sandy soil – low fertility		Clay soil – high fertility	
	CT	CA	CT	CA
27	13.2	77.0	53.9	60.6
54	3.7	47.5	37.7	37.7
108	10.1	20.2	21.6	20.4
SE	2.3	13.4	7.6	9.5

CT, conventional tillage; CA, Conservation Agriculture; SE, standard error.

The lowest fertilizer application rate of 27 kg ha^{-1} often had the largest AE across the soil types and tillage practices. In the on-station trials at SARI, the largest AE of 24.6 kg/kg N was recorded under CA with 40 kg N ha^{-1} (Fig. 14.4). As in the on-farm trials, the highest N application rate on-station did not lead to the largest AE. In CT, AE ranged between 11.5 and 16.8 kg/kg N compared with a range of 15.1–24.6 kg/kg N for the CA treatment.

14.4 Discussion

14.4.1 Crop Productivity

The short-term effect of CA on crop yield was positive in the conditions of our study sites. At the SARI research station CA consistently outyielded CT across all fertilizer levels. Similarly, CA was superior under the poor soil fertility conditions in the on-farm trials. Under the rainfed conditions (water-limited) of our trials, the positive responses in CA were mainly attributed to short-term moisture conservation (Fig. 14.3). The positive performance of CA under limited rainfall conditions has been reported previously (Rusinamhodzi, 2015a). CA has been reported to quadruple yields under low-yielding conditions with the right management regimes, although care in interpretation is needed, taking into account baseline yields and whole-farm conditions. Reduced tillage and surface cover increase

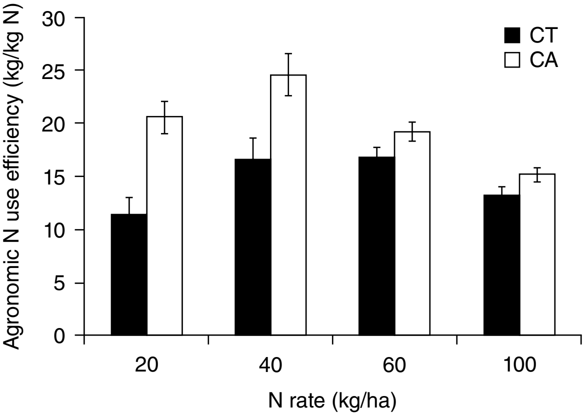

Fig. 14.4. Average agronomic nitrogen (N) use efficiency with increasing rates of N application at Selian Agricultural Research Institute, Arusha, Tanzania. Authors' own figure.

soil water available for crop growth by increasing infiltration and by limiting run-off and evaporation losses, making CA practices climate smart. However, mulching is not positive in all circumstances; under continuous rainfall, mulching can cause waterlogging because of reduced evaporation (Araya and Stroosnijder, 2010), leading to reduced soil aeration (Cannell *et al.*, 1985).

Results suggested that a combination of crop residue retention and NT can improve the agronomic efficiency of applied N, and that the initial soil fertility status is important in determining the magnitude of crop response to applied nutrients. It is likely that the crop residues in the CA treatment increased rainfall infiltration and also reduced water loss from the soil through evaporation (Hussain *et al.*, 1999), thereby improving nutrient uptake by the crops. In the long term, the consistent retention of crop residues may also increase SOC, providing another opportunity for improved nutrient use efficiency. However, crop residues may also immobilize N, resulting in deficiency especially in the short term. The N response results reported here are in agreement with similar research, which has shown a larger response to added nutrients in poor soils than in fertile soils, and that a combination of chemical and organic inputs was the best strategy to increase productivity (Chivenge *et al.*, 2011). However, some soils may be naturally fragile, extremely sandy and P-fixing, leading to challenges for increased nutrient use efficiency (Chikowo *et al.*, 2010). As a result, crop responses to added nutrients vary widely due to the wide diversity in biophysical and management practices. Results from more fertile soils suggest that nutrient management in these soils should be aimed more at replenishing nutrients taken up by the plant to increase sustainability. Crop residue retention is a promising strategy to increase nutrient use efficiency. The challenge for small-scale farmers is how to produce and retain sufficient maize residues in light of persistently low productivity and the competition for feed with livestock (Rusinamhodzi, 2015b). Thus, innovative pathways are needed to meet the multi-objectives of crop residue use for sustainable crop production.

A recent example (Rusinamhodzi *et al.*, 2020) showed that the moisture conservation benefits of CA can be reinforced by tactical decisions; these may include choice of cultivars with stress-tolerant traits. This is also in line with the suggestion by Spiertz (2013), who reported that agronomists and plant breeders can jointly improve crop performance by introducing new technologies and farming practices, and by exploiting new knowledge on genetic traits and physiological relationships in advanced breeding programmes for genotypes tolerant to multiple stresses such as drought, heat and salinity. Such partnerships will enable targeting and local adaptation of tillage, cropping systems and management options: a key tenet of the application of CA as outlined in the FAO definition.

14.4.2 The Socio-ecological Environment and Conservation Agriculture (CA)

The plot-level benefits reported here are important to provide evidence on the performance of CA. However, enabling conditions need to be created for these potential benefits to accrue to the generality of farmers. In the system studied, and in much of SSA, poor crop productivity limits the availability of crop harvest residues (especially in the dry season) against multiple objectives creating trade-offs for their uses. The importance attached to livestock means that the little crop residue available on the farm is allocated for livestock feed, restricting the potential for adoption of CA (Erenstein, 2002).

It is apparent that improving maize yields under CA depends on the duration and promotion of good agronomic practices such as targeted fertilizer application, timely weeding and crop rotations (Thierfelder *et al.*, 2018). It has long been known that crop rotation is part of good agronomy and it is important for CA. Legume production as currently practised does not cover more than 10% of the cultivated area (e.g. Mapfumo and Giller, 2001) under most smallholder farms in many countries, meaning that only 10% of the cultivated area may be rotated with legumes per year. For many years, most farmers in Africa have not been able to achieve sufficient fertilization and crop rotations, and more work is needed to integrate legumes in the predominantly cereal cropping systems to support the widespread practice of CA.

In the study sites, as in many smallholder systems in Africa, the formal seed systems are poorly developed. Only limited varieties of maize seed are supplied, and these are often open-pollinated varieties. The majority of farmers use retained seed, informal seed exchanges with other farmers and seed bought from local markets, owing to lack of capital. An Africa-wide study has revealed that up to 90% of farmers purchase their seed from the informal seed system, of which local seed markets dominate (McGuire and Sperling, 2016). They see their local seed as better adapted to their conditions, but lack of quality uniformity means they are less preferred at the market (Rohrbach and Kiala, 2007). Seeds accessed from local markets may lack the modern traits needed to withstand multiple stresses, and this may limit potential benefits provided by CA.

Results presented here clearly show the importance of chemical fertilizer for improved productivity. Chemical fertilizers are a key component of improved crop production technologies, yet their widespread use in Africa is heavily dependent on precarious politics (Gilbert, 2012). As a result, adoption and application rates among smallholder farmers in eastern and southern Africa remains below optimum, despite concerted efforts to address this problem (Nkonya *et al.*, 1997; Sanchez, 2002; Fufa and Hassan, 2006). Fertilizer use varies greatly between and within countries as a result of differences in both micro- and macroeconomic conditions. Locally, household and farm characteristics, social and human capital, and farmer-perceived effects of fertilizers on soil fertility are important determinants of fertilizer use (Mapila *et al.*, 2012). Green and Ng'ong'ola (1993) identified crop, farming system, credit access, off-farm income and regular labour – in that order – as important determinants of fertilizer use. Additionally, biophysical conditions such as amount of rainfall, crop (rotational scheme) and soil type determine amount and or type of fertilizer to be applied in a situation (Nkonya *et al.*, 1997). The risk of crop failure resulting from low rainfall is a strong disincentive to the purchase and use of fertilizers on subsistence crops (Probert *et al.*, 1995). Although many factors influence fertilizer use, socio-economic conditions seem to have an overruling effect. There is a need to create enabling policy environments that can guide new initiatives on fertilizer use and improved crop productivity to fully achieve the potential benefits of CA.

14.5 Conclusion

This study assessed the effect of CA on the agronomic use efficiency of N. Our hypothesis that crop residue retention, in combination with NT (CA), may be a pathway to improve agronomic use efficiency of N for small-scale farmers under the rainfed conditions of Tanzania was supported. The improved moisture conditions of CA plots improved nutrient uptake and use as compared with CT plots. The initial soil fertility status is also important in determining the magnitude of short-term crop response to applied nutrients. Innovative pathways are needed to achieve the multiple objectives played by maize crop residues for results reported here to be sustainable. The efficiency of nutrient use needs to be assessed, however, together with returns on investments, as small yields may mean high nutrient use efficiency but not necessarily significant increased returns at the farm level. The increase in crop yield under CA due to improved soil moisture conditions supports the climate smart nature of CA. These benefits can be maximized by combining moisture conservation strategies with stress-tolerant crop varieties. More work is needed to promote the widespread integration of legumes in the predominantly cereal cropping systems in support of the practice of CA.

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15 Effect of Conservation Agriculture on Soil Properties and Maize Grain Yield in the Semi-arid Laikipia County, Kenya

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Abstract

Low and unreliable rainfall, along with poor soil health, is a main constraint to maize production in the semi-arid parts of Kenya that account for over 79% of the country's land area. In the vast county of Laikipia, farmers continue to plant maize despite the predominantly low quantities of precipitation. Participatory farmer experimentation with Conservation Agriculture (CA) was undertaken for six consecutive growing seasons between July 2013 and December 2016 to determine the effectiveness of CA as a method of improving soil properties and enhancing maize yields with the limited rainfall quantities received in these parts of Kenya. The main CA practices tested include chisel tine furrow opening (ripping) and live legume (*Lablab purpureus*) cover crop, as well as maize stover mulches, all implemented under varying inorganic fertilizer rates. The research was done across 12 administrative locations of Laikipia County where soils are mainly Phaeozems and Vertisols with a clay–loam texture. The research design used was researcher-designed and farmer-managed. In each of the 12 trial sites, participatory farmers' assessments and field days were carried out as a way of outreach to the bigger farming communities around the trial sites. The research findings obtained demonstrated that the use of CA impacts positively on soil properties and is a viable practice for enhancing maize yields in these moisture deficit-prone parts of the country. Soil chemical analysis assessment results showed that CA impacted positively on a number of soil mineral components including organic carbon, total nitrogen, phosphorus, potassium, calcium and pH. Mid-season chlorophyll content assessment of the maize crop showed that there was good response to fertilizer application, as well as to mulching with crop residues for soil cover. Maize grain yield data also showed that the use of a CA package comprising chisel tine ripping combined with mulching by plant residues and use of mineral fertilizer resulted in a two- to threefold increase in grain yields above the farmer practice control. Mean maize grain yield in farmer practice plots was 1067 kg ha^{-1} compared with the CA-treated plot with mineral fertilization that yielded 2192 kg ha^{-1}.

Keywords: ripping, *Lablab purpureus*, cover crops, soil mulch cover, semi-arid

15.1 Introduction

Inadequate and erratic rainfall coupled with infertile soils are key factors limiting agricultural production (Liu *et al.*, 2010). Arid and semi-arid lands (ASALs) form 79% of the entire land area in Kenya with varying degrees of aridity, ranging from semi-arid and arid to very arid agroecological

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zones (Jaetzold *et al.*, 2007). Poverty levels are highest in the ASALs, and are above 80% in the remote, arid, sparsely populated northeastern parts of the country (World Bank, 2016). Tillage has effects on soil physical, chemical and biological properties at different levels. This is determined by a number of factors such as soil type and prevailing environmental conditions. Knowing that agricultural production will have to rise by 70% between now and 2050, if the numbers of hungry people on the planet are not to increase from the current 1 billion, the vagaries of climate change makes it essential to examine again how production in the semi-arid areas, the home of the poor, can be improved. CA is considered to be an essential, climate smart basis for production systems that enhance crop and livestock production, livelihoods and quality of life as stated in the African Union's Malabo Declaration and Agenda 2063 alongside the Vision 25×25 of having 25 million households practising climate smart agriculture in Africa by 2025.

15.1.1 Conservation Agriculture

Conservation Agriculture (CA) is a method of managing agroecosystems for improved and sustained productivity, increased profits and food security, while preserving and enhancing the resource base and the environment (FAO, 2014). CA provides environmental services such as contributing to atmospheric carbon sequestration, preserving biodiversity, managing watersheds and preventing soil erosion. It has the potential to support crop production under tropical conditions while mitigating natural resource degradation (Sainju and Ventrella, 2009; Corsi *et al.*, 2012; Kassam *et al.*, 2017).

Conversion from conventional to CA results in an improvement in soil structure, an increase in soil organic carbon, minimizing of soil erosion, conservation of soil water and the moderation of soil temperature and its environmental regulatory capacity (Vercauteren, 2013). Thierfelder *et al.* (2013) found that there was an increase in carbon in on-station long-term trial plots. This showed that, over time, CA plots outperformed conventional practice, leading to an overall increase of 12% carbon in the first 30 cm compared with decreases of 15% in the conventional control. The high carbon sequestration potential with CA in Africa has been shown by Gonzalez-Sanchez *et al.* (2018). CA has also been shown to stimulate soil fauna that play an important role in soil aggregation, soil C sequestration, soil nutrient and water use efficiencies, and influence crop yields (Paul *et al.*, 2015).

In a study conducted in the semi-arid county of Laikipia, Kenya, Mkomwa *et al.* (2017) concluded that CA resulted in a significant increase in maize grain yields, by 1.4%, 67% and 50% during the 1st, 2nd and 3rd year, respectively. Furthermore, the net benefit from the CA treatments that included a cover crop (*Lablab* or pigeon pea) was 255% higher compared to conventional tillage practices in years of average rainfall. When rainfall was below average (which is often the case in the ASALs), a 'cocktail' of pigeon pea and *Lablab* cover crops yielded the best results with KES 9734 ha^{-1} $year^{-1}$ profit while farmers' practices yielded KES 4215 ha^{-1} $year^{-1}$.

The three CA principles, when implemented together, result in increased soil carbon and fertility, improved infiltration of rainwater, soil water conservation and higher crop productivity compared with conventional agriculture (Hobbs *et al.*, 2008; Kassam *et al.*, 2009; Mupangwa *et al.*, 2013; Kassam *et al.*, 2017). According to Ali *et al.* (2006), the lowest values of soil organic matter (OM), N, P, K, Ca and Mg were recorded in conventional till plots and this could be due to the inversion of topsoil during ploughing, which shifts less fertile subsoil to the surface, in addition to possible leaching. The negative effect of tillage on crop yield in soils that have been destructured and compacted as a result is directly related to its impact on root growth, which affects water and nutrient uptake.

15.1.2 Use of *Lablab purpureus* as a Cover Crop

Using living or dead mulches produced from cover crops helps in the reduction of soil temperature at the surface, lowers the maximum soil temperature and slightly increases soil minimum temperature. Mulches also reduce soil erosion and build soil fertility. The cover crop selected depends on the objective of the farmer.

For example, in the management of nitrogen, deep-rooted leguminous crops could be used to fix atmospheric nitrogen and for recovery of nutrients deep in the soil (Price and Newsworthy, 2013). Cover crops could also be used to increase the resilience of cropping systems to climate change challenges (Mwangi, 2016). As a cover crop, *Lablab* produces more dry matter than cowpea, especially during drought, and this translates into more soil nitrogen and improved soil physical conditions. *Lablab* is a long-lived annual or short-lived perennial crop which is drought tolerant. It is a bushy herb from the family Fabaceae and is spread globally from arid, low-altitude areas to humid highlands. It is a good cover crop since it yields 5–10 t ha^{-1} of green matter. It can be used as food, fodder or green manure and it also improves soil quality (Gowda, 2012).

15.1.3 Soil Furrow Opening

Opening narrow furrows with a chisel tine implement (often referred to as a ripper) is an operation where the soil is left undisturbed save for narrow rip-lines (15–20 cm wide and 10–20 cm deep) opened during the dry season either by animal or tractor-drawn chisel tine rippers. Riplines are used mainly to address soil compaction or to break plough or hoe pans, capture greater amount of rainwater for *in situ* soil moisture conservation and open the space for seeding (Mkomwa *et al*., 2015). When possible, ripping should be done on the same line furrows as the previous season. At the start of the rains these lines can be ripped again to a total depth of about 20 cm. At this time fertilizer (both organic and inorganic) and lime (if needed) are applied by hand into the open line furrow and covered with soil from the rip line sides.

The benefits of tine ripping include enhanced water infiltration, reduced soil erosion and lower costs when compared to conventional tillage. It facilitates early seeding, resulting in higher yields. In a survey carried out by Ngoma *et al*. (2015) on the effect of tillage systems in agroecological zone 2a of Zambia, it was found that maize yields on NT (with tine ripper) plots were 332 kg ha^{-1} and 330 kg ha^{-1}, higher than those in land ploughed by oxen or tractors and hand-hoed, respectively. The study also revealed that the timing of ripping had an impact on maize yields. Ripping resulted in significantly higher yields, especially when done before the onset of the rains.

15.1.4 Conserving Soil Moisture with Plant Residue Mulch

Minimum soil disturbance alone – without mulching – is less effective for water conservation, particularly in areas where rainfall amounts are low, or higher but variable. This is because of the ability of the mulch to conserve soil moisture by increasing infiltration and decreasing the evaporation from the soil surface (Jalota and Prihar, 1990). Retention of crop residues to act as mulch protects the soil from the impact of raindrops while minimizing soil disturbance and erosion. It enhances soil biological activities and structure as well as soil air and water movement. The effects of CA on crop yield largely depends on the specific CA practices, regional climate characteristics and cropping systems (Stolte *et al*., 2009).

The aim of our study was to determine the effect of the NT, cover crop and residue management aspects of CA and their impact on soil properties and maize yield. Participatory farmer experimentation with CA was undertaken for six consecutive growing seasons between July 2013 and December 2016. It was carried out to determine the effectiveness of CA as a method of improving soil properties and enhancing maize yields with the limited rainfall quantities received in the County of Laikipia in Kenya.

15.2 Materials and Methods

15.2.1 Study Site

Laikipia County (Fig. 15.1) consists mainly of a rangeland plateau dominated by the Ewaso Nyiro North basin tributaries that flow from the southern to the northern parts. The county borders seven other counties and has a land area of 9462 km^2 and is ranked as the 15th largest county in the country by land size. The estimated population in 2012 was

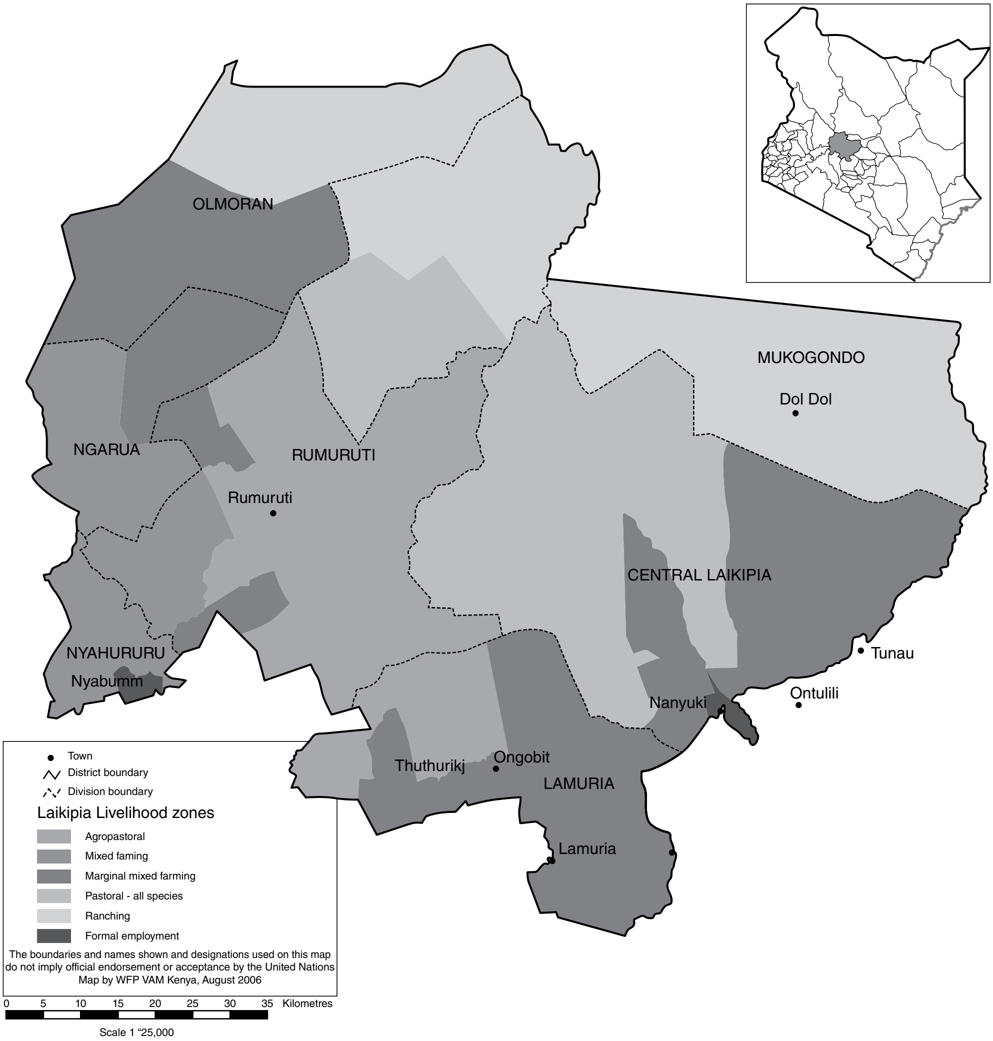

Fig. 15.1. Map of Kenya showing the position of Laikipia County (from Survey of Kenya, 2013).

427,173 persons. Laikipia lies between latitudes 0°18" and 0°51" N and between longitudes 36°11" and 37°24' E. The altitude of the county varies between 1500 m above sea level at Ewaso Nyiro basin in the north and 2611 m in the south. The marked altitude gradient from south to north of Laikipia has an associated impact on climate, with annual rainfall varying from 750 mm in the south to 300 mm in the north. Rainfall typically falls in two seasons: the long rains between April and June, and the short rains between October and December (Gichuki *et al.*, 1998). The variation in altitude and rainfall across the county is associated with marked changes in vegetation cover. Broadly this includes protected upland forest and a belt of mixed cultivation in the south, giving way to a mosaic of bushland, savannah, open grassland and woodland in the north. A single perennial river, the Ewaso Nyiro and its tributary, the Ewaso Narok (both with smaller tributaries originating in Mt Kenya and the Aberdares, respectively) drain Laikipia County and provide the only natural permanent source of water for people and wildlife to the north.

15.2.2 Crops and Land Holdings

Agriculture is the dominant economic activity. The majority of residents keep livestock and grow different food crops such as maize, wheat and potatoes, as well as horticultural crops. The three main crops produced in the county under rainfed cropping are maize, beans and potatoes, while in irrigated agriculture the crops grown are tomatoes, kale, beans and cabbages. Other important crops grown in the county are snow peas and watermelons. Laikipia County is known for its big open ranches, such as Solio, Borana and Oljogi, which provide a significant source of beef for local consumption and export. Today land in Laikipia is held under private, communal and government ownership. There are 48 large-scale ranches that are greater than 800 ha in size, under private ownership (mean = 7770 ha). These large-scale ranches cover a total area of 3824 km^2 (39% of Laikipia). Twenty-one of these large-scale ranches are greater than 800 ha in size. Subdivided ranches intended for smallholder settlement, under varying degrees of occupancy, cover 3347 km^2 (34%) of Laikipia County (Fig. 15.1).

15.2.3 Experimental Procedure

To enhance technology adoption, the project used the 'mother–baby' trial design (Snapp *et al.*, 2002). Table 15.1 shows the villages and locations in Laikipia County where 'mother' demos were situated. The 12 mother trials tested the full set of all six CA treatments (Table 15.2). These served as sites for the farmers to learn about CA concepts and practices, as well as the integrated soil fertility management (ISFM) technologies and other agronomic managements systems for maize and legume cover crops used in the project. The mother trials demonstrated CA and ISFM practices aimed at improving the productivity of maize. We held 100 'baby' demos, and these hosted only half of the treatments.

Table 15.1. Villages and locations in Laikipia County where mother demos were situated. Authors' own table.

Sub County	Division	Location	Village
Laikipia East	Ethi	Ngenia	Kairigire
Laikipia East	Daiga	Mugumo	Mugumo
Laikipia East	Daiga	Umande	Kalalu
Laikipia East	Daiga	Nturukuma	Nturukuma
Laikipia East	Daiga	Umande	Nyariginu
Laikipia Central	Lamuria	Muhonia	Sirima
Laikipia Central	Lamuria	Tigithi	Male
Laikipia Central	Lamuria	Matanya	Weruini
Laikipia Central	Lamuria	Muhonia	Mwakinya
Laikipia Central	Munyaka	Withare	Withare
Laikipia Central	Munyaka	Wiyumiririe	Wiyumiririe
Laikipia Central	Munyaka	Wiyumiririe	Sugroi dam
Laikipia Central	Munyaka	Ngobit	Marina

Table 15.2. List of treatments applied in the trial plots in trial sites of Laikipia, Kenya. Authors' own table.

Treatment coding	Treatments applied in the experimental plots
T_1	Farmer practice: conventional ploughing (ox/tractor), no fertilizer and no residue retained
T_2	Conventional plough practice with fertilizer, no residue retention
T_3	No-till, with no fertilizer and no residue retention
T_4	No-till, with fertilizer and no residue retention
T_5	No-till, with no fertilizer, with residue retention
T_6	No-till, with fertilizer and with residue retention

Full field experimentation commenced during the March/April long rains (LR) 2014 cropping season. In this initial or preliminary LR 2014 cropping season, all the six treatments were laid out, except that no residues were applied in treatments T_5 and T_6, since these were expected to be generated *in situ* in the plots.

The test crop in this experimentation was maize while *Lablab* was intercropped with maize to act as the cover crop. The main crop was planted at the onset of the rains and the cover crop 2 weeks later. Each plot measured 10 m long × 10 m wide. The inter-row maize spacing was site specific but ranged between 0.75 m and 0.9 m, while the intra-row spacing varied from 0.3 m to 0.5 m depending on location, resulting in plant populations of between 37,000 and 44,000 plants per hectare. Maize cultivar Duma 43 was used, while the DL 1002 KARI variety of *Lablab* was grown in all 12 trial sites to serve as the cover crop and source of protein for consumption. This variety has a determinate growth habit, matures within 80–90 days and has a yield potential of 3000–4000 kg ha^{-1}. Ripping was done either by oxen-drawn chisel tine ripper (Fig. 15.2a) or hand tools before the onset of first rains. Rip-lines were opened between the past season maize rows at the recommended spacing.

Where applicable, maize was fertilized with 60 kg N ha^{-1} + 20 kg P2O5 ha^{-1}. *Lablab* was planted in rows between the maize rows as follows: one row and hill to hill spacing of 50 cm (two seeds) for *Lablab*.

Weed management was carried out using the manual shallow weeder, ideally chopping and mulching of weeds with no soil disturbance, maintaining soil surface cover with crop residues to smother weeds and prevent them from growing. Mechanical weed control was done not later than the two-leaf stage (Fig. 15.3). Herbicides, a critical ingredient of large-scale CA farming, are also used in smallholder CA. Glyphosate was the recommended option with emphasized training on selection and on accurate and safe application.

The maize data collected included stand count and plant height as well as grain and stover yields. Legume weight assessments proved more difficult owing to the indeterminate nature of the variety used. Rain gauges were installed in each of the mother demo sites for recording rainfall amounts. For the purposes of statistical data computation, each farmer was treated as a replicate. Initial soil characterization was done prior to the initial planting in all treatment sites. Soil chemical properties were determined after the final season of experimentation to assess the effect of various treatments on the soil chemical characteristics.

15.2.4 Leaf Chlorophyll Content

To determine the depth of green colouration and hence quantity of chlorophyll content in the leaf (which is an indicator of plant vigour due to nitrogen), physiological assessments using the soil plant analysis development (SPAD) chlorophyll meter (Fig. 15.4) were used. The SPAD readings for each plot were taken on the leaves of six plants within each plot. On each plant, measurements were taken in the middle of the leaf between leaf tip and leaf base, and in between the leaf midrib

Fig. 15.2. Ripping mother demo plots ready for planting (a) and planting in progress by the farmer group hosting the trial (b). Authors' own photos.

Fig. 15.3. Maize growing in a mulched plot of plot T6 in Margaret Wangui's demo in Wiyumiririe, Laikipia. Authors' own photo.

Fig. 15.4. SPAD apparatus taking leaf readings. Authors' own photo.

and the edge of the blade. The leaves measured were those above the ear, ideally the same leaf on each plant within the replicate (e.g. 4th–6th leaf above the uppermost ear). An average value for each plot was automatically calculated by the machine and recorded. Measurements were done weekly after anthesis.

15.3 Results and Discussion

15.3.1 Rainfall

Rainfall data (Fig. 15.5a–d) from the rain gauges installed showed that, as expected, rainfall differed from season to season, but there were more rain deficit seasons than surplus/adequate ones. Rainfall was also different across the 12 administrative locations where these trials were carried out. Other than the short rains in the 2015 cropping season (termed the 'El Niño' rain-type season), all the other seasons recorded suboptimal quantities of rain that mainly tapered off at the critical grain-filling stage of the maize crop growth and development. Further, many demo sites could not produce any grain yield in a number of seasons, and hence the values reported were for those that had some grain harvest. Waweru (2013) has noted that, in Laikipia County, the lengths of the long and

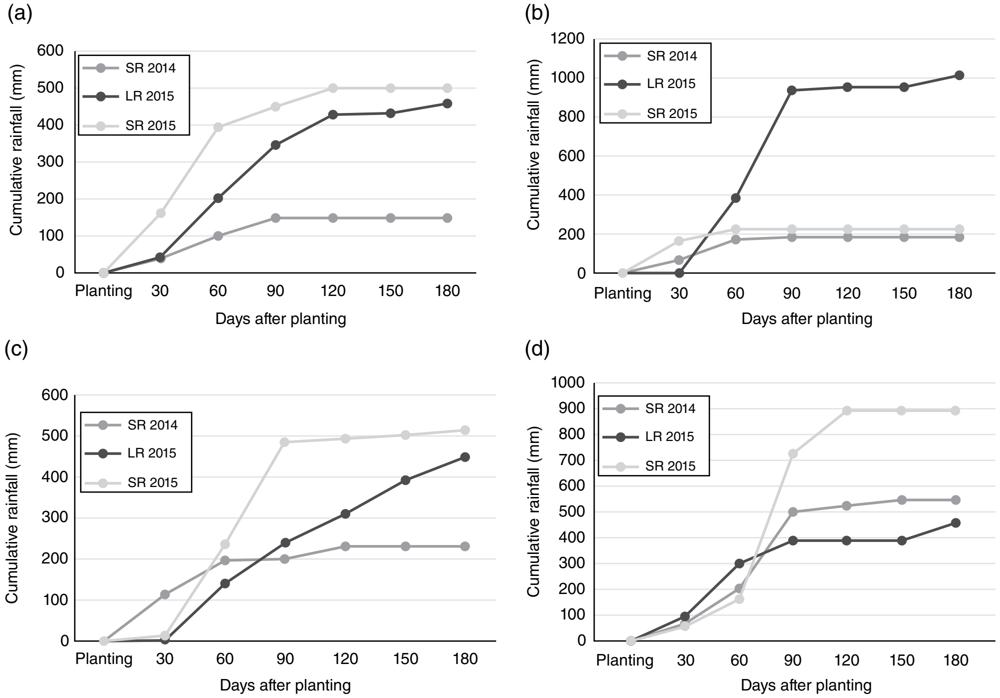

Fig. 15.5. Seasonal rainfall received at (a) Nturukuma; (b) Kairigire; (c) Wiyumiririe; and (d) Male villages, Laikipia County. SR, short rains; LR, long rains. Authors' own figures.

short rainfall seasons are shorter than the growing periods for most crops grown. Experimental locations found in the central sections of the county, such as Matanya, Tigithi and Muhonia, tend to receive their main rains during the October season; these are designated short rains (SR). Those in the eastern area, such as Ethi, Nyariginu, Mugumo and Muramati, receive their rains in the March/April season. These are known as long rains (LR). The October season is almost completely dry and hence farmers do not even bother planting any crop. The situation is rather more complicated in the extreme south-western locations of Withare, Wiyumiririe and Marina, all found in Munyaka Division. Here, rainfall is not determined purely by the presence of Mt Kenya but also by the Aberdares ranges, since these locations are even closer to the Aberdares than to Mt Kenya itself. Jaetzold *et al.* (2007) have observed that rainfall in Laikipia County are locally and geographically influenced by Mt Kenya and the Aberdare Ranges.

15.3.2 Soil Properties

Results of soil analysis revealed that, after six consecutive seasons in 3 years of experimentation, CA practices impacted differently on targeted soil properties (Table 15.3). An evaluation of soils at the start in 2013 and at the end of the trials in 2016 showed that CA practices had a positive influence on a number of soil mineral components including organic carbon, total nitrogen, phosphorus, potassium, calcium and pH. Furthermore, manganese and copper showed increases but not uniformly across the county. Overall, the application of CA led to an increase in organic carbon of between 14% and 19% (treatments T_5 and T_6). No noticeable change occurred in the no-CA treatments (T_1 and T_2). The differences were, however, only statistically significant ($p < 0.05$) in total nitrogen, while the variability between farms was high. The increased amount of total nitrogen could most probably be attributed to the presence of decomposing residues applied in these respective plots. All of the treatments led to a decrease, with time, of zinc and sodium in the soil (Table 15.3).

Table 15.3. Change in soil chemical characteristics from the initial (2013) to final (2016) period of sampling in Laikipia, Kenya. Authors' own table.

Treatment	pH	N (%)	C (%)	P (ppm)	K (me%)	Ca (me%)	Mg (me%)	Mn (me%)	Cu (ppm)	Fe (ppm)	Zn (ppm)	Na (me%)
T1	–0.06	0.0275^{ab}	0.04	2.80	0.15	0.01	2.17	0.52	4.27	35.80	–8.35	–0.20
T2	–0.11	0.0005^{a}	–0.04	6.80	0.07	0.87	2.30	0.44	4.11	31.20	–8.91	–0.30
T3	0.06	0.0095^{a}	0.06	11.80	0.17	0.99	2.10	0.34	4.21	43.60	–8.91	–0.17
T4	0.06	0.0605^{b}	0.06	8.60	0.16	0.93	2.07	0.37	4.01	32.40	–8.45	–0.24
T5	0.20	0.0630^{b}	0.15	8.20	0.27	1.29	2.51	0.33	3.91	34.80	–8.69	–0.17
T6	0.34	0.0680^{b}	0.18	8.20	0.38	1.67	2.69	0.41	3.63	39.40	–8.47	–0.10
CV (%)	41.20	55.60	51.20	37.8	27.80	48.9	39.00	52.10	10.0	54.50	10.20	56.10
LSD$_{0.05}$	0.37	0.05	0.19	7.12	0.34	1.22	0.62	0.32	0.53	12.51	1.16	0.14
p value	0.17	0.02	0.22	0.24	0.49	0.16	0.28	0.81	0.19	0.35	0.86	0.13

Values with the same letter down the columns were not significantly different at $p < 0.05$.

CV, Coefficient of variation; LSD, least significant difference; (me)%, milliequivalent percentage which is the unit used to measure the respective elements in the soil.

15.3.3 Chlorophyll Content in Leaves: Soil Plant Analysis Development (SPAD) Readings

Mid-season assessment of crops using SPAD showed that there was a good response to fertilizer application as well as to the CA options implemented at the sites. The lowest mean readings of 28.95 were recorded in plots of treatment T_1, while T_6 gave the highest mean readings of 42.11 (Table 15.4). These readings indicate that treatment T_6 had dark-green leaves because of a higher chlorophyll content (and hence more photosynthetic capacity) while T_1 had light-green or yellowish leaves that had less chlorophyll, implying less photosynthetic capacity leading to less plant vigour.

15.3.4 Maize Grain Yields

Maize performance during the initial LR 2014 season was low owing to the small quantity of rains received during this particular season (Table 15.5). In some sites very small quantities of maize grain were realized in all six treatment plots of the experiment, while others had no grain at all. The sites of Mwakinya, Mwituria and Endana recorded no grain in any of the six plots, while the maize stover quantity was very small due to the stunting of the crop as a result of lack of adequate moisture in the soil. Barron *et al.* (2003) have cautioned that maize growing in Laikipia County is faced with the greatest risk owing to its lengthy growing period and its sensitivity to unevenly distributed

Table 15.4. Mean soil plant analysis development (SPAD) readings at Laikipia sites during LR 2015 season. Authors' own table.

Treatment	Description	Mean SPAD Reading
T_1	Farmer practice (FP), no fertilizer, no residue retention	28.95^{a}
T_2	Farmer practice (FP), full rate fertilizer, no residue retention	37.98^{b}
T_3	No-till seeding, no fertilizer, no residue retention	34.02^{b}
T_4	No-till seeding, no fertilizer, total residue retention	39.50^{b}
T_5	No-till seeding, full rate fertilizer, no residue retention	34.00^{b}
T_6	No-till seeding, full rate fertilizer, total residue retention	42.11^{c}
CV (%)		2.71
$SD_{0.05}$		15

Values with the same letter down the column were not significantly different at $p < 0.05$.
CV, Coefficient of variation; SD, Standard deviation.

Table 15.5. Effect of Conservation Agriculture and integrated soil fertility management treatments on maize grain yield in Laikipia, Kenya. Authors' own table.

		Maize grain yield (Mg ha^{-1})	
Treatment coding	Treatment description	Means for six sites, baseline (LR 2014) season	Means for 10 sites in four seasons (SR 2014 to LR 2016)
T_1	Farmer practice (FP), no fertilizer, no residue retention	0.083	1.067^{a}
T_2	Farmer practice (FP), full rate fertilizer, no residue retention	0.517	1.471^{a}
T_3	No-till, no fertilizer, no residue retention	0.158	1.143^{a}
T_4	No-till, no fertilizer, total residue retention	0.191	1.579^{ab}
T_5	No-till, full rate fertilizer, no residue retention	0.034	1.685^{ab}
T_6	No-till, full rate fertilizer, total residue retention	0.570	2.192^{b}
CV (%)		56.0	48
$SED_{0.05}$		0.229	0.340

Values with the same letter down the column were not significantly different at $p < 0.05$.
CV, Coefficient of variation; SD, Standard deviation.

rainfall. Observations similar to those of LR 2014 were repeated during the October or SR 2014 season, where only two of 12 trial sites registered some maize grain, while the rest failed. Overall, the grain yields realized were less than 10% of the potential, signifying that the SR 2014 cropping season could be considered as a crop failure in the entire Laikipia County. Waweru (2013) has noted that, in central Laikipia, the SR are greater and more reliable than the LR. The lengths of the long and short rainfall seasons are 55–90 days and 62–85 days, respectively, which means that the lengths of the rainy seasons are shorter than growing periods for most crops grown in the study area, including maize, which requires 125 days to mature.

In this study, there were clear moisture-conserving effects by residue mulch coupled with fertilization effects in the full CA treatment. In the LR 2015, SR 2015 and LR 2016, more reasonable yields were realized in these demo sites. The best performance was recorded during the SR 2015 when rainfall was inadequate in the eastern locations but adequate in the western locations, where grain yields averaging 3.41 to 4.48 t ha^{-1} were realized. The yield range was 0.8 to 5.7 t ha^{-1} and 2.6 to 3.7 t ha^{-1} for eastern and western Laikipia sites, respectively.

In the final cropping season (LR 2016), the average yield for the 12 sites in the county was 2.19 t ha^{-1}, which signified a fair cropping season. As in the previous seasons, the highest yields were observed in the central areas, in the villages of Male and Weruini.

Maize yields in conventional tillage and CA treatments fluctuated widely from year to year (Table 15.6). Mean maize yield for CA was, overall, 89.5% greater than that for conventional tillage in four seasons in two years, and yield differences were significant in all three years ($p < 0.05$)

Table 15.6. Maize yields (kg ha^{-1}) from conventional tillage and Conservation Agriculture (CA) treatments from 2014 to 2016. Authors' own table.

Treatment/Season	LR2014	SR2014	LR2015	SR2015	Mean
Annual rainfall (mm)	398.1	546.4	458.4	894.5	
Conventional tillage	480	502	1,033	1,258	818
CA	416	929	2,124	2,732	1,550

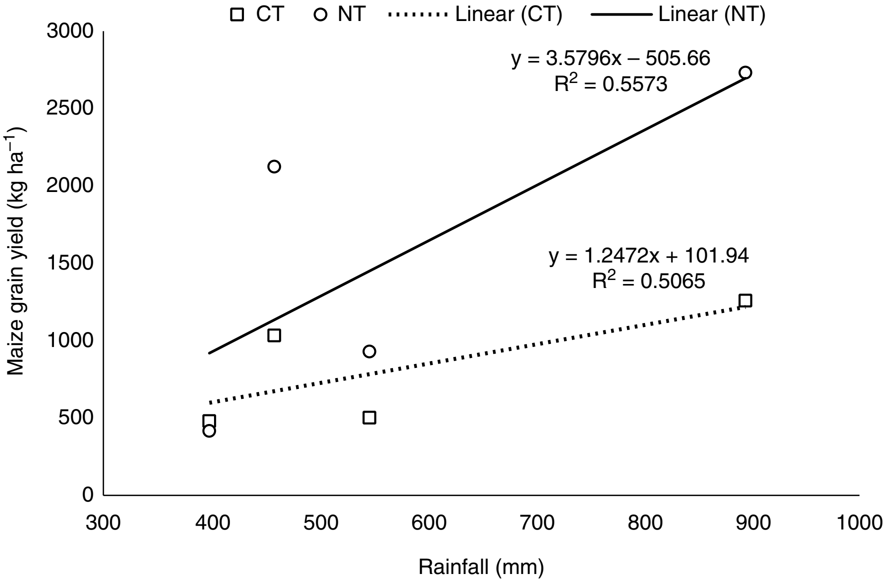

Fig. 15.6. Enhanced water use efficiency under Conservation Agriculture (CA) no-till, illustrated by the relationship between rainfall and maize yields. CT = conventional tillage, NT= no-till (CA). Authors' own figure.

after the first year. There was a strong positive correlation (Fig. 15.6) between the rainfall and maize yields in CA plots ($R^2 = 0.557$) compared to the plots with conventional tillage treatment ($R^2 = 0.507$).

In semi-arid Laikipia County, with its frequent droughts and degraded soils, the improvement in soil water combined with increased fertility under CA management is of particular importance for stabilizing and improving crop yields.

Overall, research conducted in this work has revealed that the use of CA is a necessary water conservation practice in the ASAL Laikipia County. Some of the benefits associated with CA may be realized almost immediately while others build up over time as soil health and quality improves. In dryland agriculture, one of the immediate benefits of CA is improved rainwater capture and use efficiency by the crops, which is achieved through increased water infiltration and decreased evaporation from the soil surface (Gonzalez-Sanchez *et al*., 2018). The findings of this study have also demonstrated that, to reap greater benefits, farmers need to also use inorganic and organic fertilizers for soil amelioration, given the fact that a number of smallholder farms in the county do not possess adequate nutrient stocks. The data we collected over four consecutive cropping seasons indicated that the use of a CA package of tine ripping coupled with mulching of plant residues plus use of mineral fertilizer resulted in a two- to threefold increase in maize grain yields above the farmer practice where neither fertilizer nor CA were used (Table 15.5). These results also support conclusions by other authors such as Usman *et al*. (2015) who have stated that the use of a combination of organic such as crop residues and inorganic fertilizers is a suitable soil fertility management practice in countries such as Tanzania, India and the Central African Republic.

15.4 Conclusions

Research conducted in this study has demonstrated that the use of CA is a necessary water conservation practice in the vast ASAL county of Laikipia, Kenya, and in areas of similar agroecologies. The use of soil surface cover using crop residues as mulch had a greater and more significant effect on maize grain yield than use of inorganic fertilizers, or of either NT alone or conventional tillage alone. In addition to the limited amount of rainfall, variability in its distribution is another challenge. We found that only one of the four cropping seasons recorded adequate rainfall. All the other seasons recorded suboptimal quantities of rain that mainly tapered off at the critical grain-filling stage of maize crop growth and development.

CA increased soil mineral components including organic carbon, total nitrogen, phosphorus, potassium, calcium and pH. The differences were, however, only statistically significant ($p < 0.05$) in total nitrogen. Overall, the application of CA led to an increase in organic carbon of between 14%–19% (treatments T_5 and T_6). All treatments led to an unexplainable decrease with time of zinc and sodium.

These findings have also demonstrated that, to reap maximum benefits, farmers need to complement CA with mineral nutrient inputs for soil fertility recuperation. This is because the smallholder farms in this county have depleted soil nutrient stocks due to years of nutrient mining and tillage. Data collected over three seasons of consecutive cropping indicate that the use of a CA package of minimum soil disturbance and mulching with plant residues, complemented by use of mineral fertilizer, resulted in a 105% increase in maize grain yields above the farmer practice of conventional tillage without fertilizers, and an increase of 49% when inorganic fertilizers were used under conventional tillage.

The farmers' uptake of CA was observed to be dependent on individual farmer situations such as gained knowledge levels, innovativeness and traditional beliefs. Most farmers were fast in adopting the reduced tillage principle of CA and adopted the soil cover. With better harvests and diversification through incorporation of cover crops the farmers were able to gradually leave substantial residues for soil cover over time. To enhance further uptake and scaling up of CA, regular capacity building and backstopping of farmers is essential to address new challenges likely to arise with time.

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16 Increasing Adaptation to Climate Stress by Applying Conservation Agriculture in Southern Africa

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Abstract

Climate change and soil fertility decline are threatening food security in southern Africa and efforts have been made to adapt current cropping systems to the needs of smallholder farmers. Conservation Agriculture (CA) based on minimum soil disturbance, crop residue retention and crop diversification has been proposed as a strategy to address the challenges smallholder farmers face. Here we analyse the potential contributions of CA towards adaptation to the effects of climate change by summarizing data on infiltration, soil moisture dynamics and crop productivity under heat and drought stress. The data were taken in the main from CIMMYT's on-farm and on-station trial network. Data show that CA systems maintain 0.7–7.9 times higher water infiltration than the conventional tilled system depending on soil type, which increases soil moisture during the cropping season by 11%–31% between CA treatments and the conventional control treatment. This leads to greater adaptive capacity of CA systems during in-season dry spells and under heat stress. A supporting regional maize productivity assessment, analysing the results of numerous on-farm and on-station experiments, showed that CA systems will outperform conventional tillage practices (CP), especially on light-textured soils, under heat and drought stress. With higher rainfall and low heat stress, this relation was more positive towards CP and on clay soil there was no benefit of practising CA when rainfall was high. The long dry season and limited biomass production of CA systems in southern Africa require complementary good agricultural practices to increase other soil quality parameters (e.g. increased soil carbon) to maintain higher productivity and sustainability over time. This can be addressed by combinations of improved stress-tolerant seed, targeted fertilization, inclusion of tree-based components or green manure cover crops in the farming system, scale-appropriate mechanization and improved weed control strategies.

Keywords: sustainable intensification, climate smart agriculture, adaptation, no-tillage, resilience, southern Africa

16.1 Introduction

Smallholder farmers in southern Africa, as in many regions, are faced with future impacts of climate variability and change (Wheeler and von Braun, 2013; Ramírez Villegas and Thornton, 2015; Tesfaye *et al.*, 2015; Nhamo *et al.*, 2019). Already, farmers have to cope with erratic rainfalls, delayed onsets of rainy seasons, floods, droughts, heat stress and early tailing-off of the cropping seasons (Burke and Lobell, 2010). By 2065, projected mean annual temperature for southern Africa will increase by 1.5–2.1°C (Christensen *et al.*, 2013) with

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maximums of 4°C or higher towards the end of the century under low mitigation scenarios (Landman *et al.*, 2018). The most affected crops will be maize, beans and wheat (Lobell *et al.*, 2008; Ramírez Villegas and Thornton, 2015), three of the main staple food crops in southern Africa. Heat stress is projected to be the most devastating factor (Burke *et al.*, 2009) as current cultivars will not be able to cope with increased heat stress (Cairns *et al.*, 2013). By the year 2080, there is a potential yield penalty of −15% to −50% expected if no adaptation measures are taken (Ahlenius, 2009).

Smallholder farmers in southern Africa cultivate land holdings of 0.5–5 ha using traditional manual or animal traction seeding systems. They often plant their cereal crops as monocrops in mixed crop–livestock systems and graze, burn or remove their crop residues (Wall *et al.*, 2014). Maize yield gaps in the region are high due to limited use of organic or mineral fertilizers and machinery, combined with poor or lacking diversification and weed control strategies. Current maize yields range between 0.5–2.5 t ha^{-1} against a potential yield of 10–15 t ha^{-1} (Thierfelder *et al.*, 2018; FAOSTAT, 2019).

Increasing population, overuse of soils and a low carrying capacity of rural farm- and rangeland has added to the problem. Periodic droughts and unsustainable land-use practices contribute to increasing soil depletion, food and nutrition insecurity, and poverty (Godfray *et al.*, 2010; Wheeler and von Braun, 2013). Farmers have to increase productivity while maintaining soil fertility in their farming systems – a challenging task. In response to these threats, in 2004, the International Maize and Wheat Improvement Center (CIMMYT) began to roll out a large research for development programme on Conservation Agriculture (CA) with the vision to adapt smallholder farming systems to increasing temperatures, risk of low rainfall and/or dry spells, and declining soil fertility (Thierfelder *et al.*, 2015a, b; 2017). The program focused on adaptation of CA systems, based on the principles of no-tillage (NT), crop residue retention and crop diversification, to the needs and agroecological conditions of smallholder farmers. It covered all aspects of CA cropping systems including research on productivity; profitability; environmental sustainability; chemical, biological and physical soil fertility; biotic and abiotic stresses; weed control; residue retention; and detailed process research.

Increasingly, CIMMYT's CA research programme was operating under the concept of 'climate smart agriculture' which is a new framework that classifies systems that adapt to the changes in climate, improve their productivity and profitability while mitigating climate change effects by sequestering more atmospheric carbon in soils and reducing greenhouse gas (GHG) emissions (Lipper *et al.*, 2014).

The programme found significant evidence that CA systems can facilitate adaptation to hotter, drier climates (Steward *et al.*, 2018; 2019), improve crop productivity (Thierfelder *et al.*, 2015b; 2016), gradually sequestering soil carbon (Thierfelder and Wall, 2012; Thierfelder *et al.*, 2013a; Ligowe *et al.*, 2017) while complying with the principles of sustainable agriculture intensification. However, challenges remain, with research from southern Africa finding that the current implementation of CA systems is often insufficient to reap all the potential CSA benefits (Thierfelder *et al.*, 2017).

For example, CA systems are difficult to apply in mixed crop–livestock systems with unimodal rainfall seasons and 7–8 months of dry season conditions. Cattle need feed during this period, which leads to grazing and often overgrazing of the available biomass resources (Valbuena *et al.*, 2012), despite the critical need for biomass as surface mulch to improve soil fertility, reduce evaporation and generally conserve soil moisture. Another issue is that commonly used annual legumes in rotation do not carry over enough mulch or soil nutritional benefits, especially if they decompose rapidly, leading to low or zero sequestration of soil carbon (Powlson *et al.*, 2016; Corbeels *et al.*, 2019).

This chapter aims to summarize the key benefits related to adaptation of CA cropping systems to climate change and challenges learnt from CIMMYT's experiences and published research papers on long-term CA research. It highlights avenues and adjustments needed for future CA systems in Africa, with the prospects of increased temperature and more erratic rainfall.

In the following sections we describe the experimental locations and mixed methods used to assess the adaptive capacity of CA systems under climate stress. We discuss them in view of future climate challenges (especially heat and drought stress) and end with a conclusion of the main findings.

16.2 Site Descriptions and Methods

16.2.1 Site Description

Research trials to gather the necessary experimental data were carried out on six on-station long-term trials coupled with data from more than 30 on-farm communities with replicated trials, spread across four countries, each with multiple participating farmers (Table 16.1). The experimental design was in the form of clustered validation trials in target communities which were incrementally established, all in a paired-plot design, from 2004 onwards. More sites and research angles were included over time as we obtained more and different sources of funding. Detailed information on the site descriptions and their previous management is provided in Thierfelder *et al.*, 2013b, c; 2015b.

The experimental sites stretched from southern Zimbabwe and Zambia to central Mozambique, southern and central Malawi and eastern Zambia, covering climates with mean annual unimodal in-season rainfalls of 450 mm to more than 1800 mm and a range of soil textures including very sandy to loamy clay soils (Table 16.1). The experimental preconditions at each on-farm trial location had to meet the following conditions:

1. On-station trials were set in strategic research locations, representative for the wider agroecology in the particular regions (Table 16.1).
2. On-farm trials consisted of clusters of 4–9 on-farm replicates in each community, each replicate being a different farmer.
3. At least two CA systems were tested on-farm against a conventionally tilled practice in a paired-plot design.
4. The main CA systems tested were either: (i) a manually planted maize-based system, seeded with a dibble stick, jab planter or in planting basins; or (ii) established with animal traction using an animal traction ripper or direct seeder. No tractors were used for land preparation and seeding at any site.
5. All comparisons and replicates at each community used the same fertilizer level and crop varieties in a particular year. However, these could differ between on-farm trial communities and seasons, given site specific recommendations and farmer choice.
6. All research trials across all on-farm communities had maize as test crop and were incrementally diversified using different rotation and intercrops as well as drought-tolerant maize varieties.
7. All CA systems had crop residues retained aiming at a residue retention rate of at least 2.5–3 t ha^{-1}.
8. Conventional systems had their residues removed (sometimes grazed or burned), mimicking current conventional practices.
9. All on-farm sites were managed by farmers with the support of extension officers and scientific oversight by a researcher.

As indicated before, we used two data sets which came from CIMMYT's trial network of on-farm and on-station trials. For infiltration and soil moisture assessment we used data from two on-station long-term trials. For the maize yield analysis we used data sets previously described in Steward *et al.* (2018). The earlier study published by Steward *et al.* (2018) was based on modelling results only, whereas this book chapter provides additional data on water infiltration and soil moisture to support the results of the previous studies.

16.2.2 Trial Management and Data Collection

On-farm and on-station trials were seeded after the first effective rains, which are, as a rule of thumb, rainfalls between 30–50 mm falling in 1–3 days between 15 November and 31 December in each year. Conventional tillage was practised with an animal traction mouldboard plough at shallow depth (10–15 cm) or in manually prepared annual ridges as is common in eastern Zambia, Malawi and northern Mozambique. Crop residues were maintained on the soil surface at approximately 2.5–3 t ha^{-1}. If residue

Table 16.1. Site locations of the trial sites mostly used for assessing the performance of Conservation Agriculture systems against conventional control practices. Authors' own table.

Country	District	Site name	Description	Latitude	Longitude	Altitude	Duration	Soil type	Seasonal rainfall (mm)
Malawi	Lilongwe	Chitedze	On-station	–13.973	33.654	1147	2007–	Luvisol	747
Zambia	Monze	Monze	On-station	–16.240	27.441	1111	2005 –	Lixisols	681
Zimbabwe	Mazowe	Henderson	On-station	–17.573	30.987	1271	2004 –	Arensols	884
Zimbabwe	Goromonzi	Domboshawa	On-station	–17.608	31.140	1545	2009 –	Luvisol	823
Mozambique	Sussundenga	Sussundenga	On-station	–19.317	33.242	621	2006–2015	Lixisols	1178
Zambia	Chipata	Msekera	On-station	–13.646	32.559	1018	2010 –	Luvisol	1053
Malawi	Nkhotakota	Zidyana	On-farm	–13.228	34.263	515	2005 –	Luvisol	1324
Malawi	Nkhotakota	Mwansambo	On-farm	–13.290	34.132	630	2005 –	Lixisols	1194
Malawi	Nkhotakota	Linga	On-farm	–12.80	34.200	494	2007 –	Alluvial	1256
Malawi	Salima	Chinguluwe	On-farm	–13.693	34.236	658	2008 –	Cambisols	799
Malawi	Dowa	Chipeni	On-farm	–13.763	34.053	1167	2005 –	Luvisols	831
Malawi	Balaka	Lemu	On-farm	–14.780	35.027	689	2006 –	Luvisols	823
Malawi	Balaka	Malula	On-farm	–14.959	34.986	610	2004 –	Fluvisols	763
Malawi	Balaka	Herbert	On-farm	–14.884	35.046	635	2006 –	Luvisols	769
Malawi	Machinga	Matandika	On-farm	–15.180	35.276	680	2006 –	Arenosols	1170
Malawi	Songani	Zomba	On-farm	–15.298	35.396	790	2007 –	Ferralitic	1124
Zimbabwe	Shamva	Madziwa	On-farm	–16.991	31.415	1174	2005 –	Arenosols	679
Zimbabwe	Shamva	Chavakadzi	On-farm	–17.190	31.493	1164	2004 –	Lixiols	809
Zimbabwe	Bindura	Hereford	On-farm	–17.423	31.445	1099	2005 –	Lixisols	762
Zimbabwe	Zaka	Zaka	On-farm	–20.110	31.200	1110	2010 –	Arenosols	805
Zimbabwe	Kariba	Kariba	On-farm	–16.315	29.464	964	2010 –	Arenosols	763
Zambia	Monze	Malende	On-farm	–16.254	27.419	1087	2005 –	Lixisols	748
Zambia	Katete	Kawalala	On-farm	–14.095	31.489	927	2011 –	Acrisols	706
Zambia	Chipata	Chanje	On-farm	–13.233	32.479	878	2011 –	Luvisols	801
Zambia	Chipata	Kapara	On-farm	–13.301	32.293	709	2011 –	Luvisols	657
Zambia	Chipata	Mtaya	On-farm	–13.344	32.312	790	2011 –	Luvisols	824
Zambia	Chipata	Kayowozi	On-farm	–13.696	32.626	1081	2007–2012	Luvisols	950
Zambia	Lundazi	Vuu	On-farm	–12.160	33.023	1074	2011–	Acrisols	903
Zambia	Lundazi	Hoya	On-farm	–12.072	33.080	1101	2011 –	Acrisols	753
Mozambique	Manica	Gondola	On-farm	–19.017	33.720	682	2009–2014	Lixisols	1040

Continued

Table 16.1. Continued

Country	District	Site name	Description	Latitude	Longitude	Altitude	Duration	Soil type	Seasonal rainfall (mm)
Mozambique	Manica	Malomwe	On-farm	–18.109	33.185	586	2007–2015	Lixisols	1206
Mozambique	Manica	Nhamatiquite	On-farm	–19.347	33.245	620	2009–2015	Lixisols	1165
Mozambique	Manica	Nhamizhinga	On-farm	–18.363	33.209	592	2008–2015	Lixisols	1197
Mozambique	Manica	Mussianharo	On-farm	–18.346	33.280	591	2013–2015	Lixisols	1077
Mozambique	Sofala	Lam Segredo	On-farm	–19.350	34.345	23	2009–2015	Fluvisols	549
Mozambique	Sofala	Lam. Ndeja	On-farm	–19.332	34.353	21	2012–2015	Fluvisols	594
Mozambique	Tete	Gimo	On-farm	–14.902	34.526	1436	2009–2015	Lixisols	1158
Mozambique	Tete	Maguai	On-farm	–14.774	34.428	1303	2009–2015	Lixisols	1119
Mozambique	Tete	Nzewe	On-farm	–14.518	34.302	1371	2009–2015	Lixisols	919
Mozambique	Tete	Ulongue	On-farm	–14.721	34.306	1215	2009–2015	Lixisols	897

On-farm trials that have an end date are terminated whereas sites with a dash are still ongoing; seasonal rainfalls are means of the rainfalls captured during the trial period.

amounts were not sufficient, they were increased by locally available thatching grass (*Hyparrhenia* ssp.). After seeding, the crops were managed by farmers and on-site extension officers and harvested at maturity stage ('black layer') of the crop. Grain and biomass yield data were collected from 10% of the cropped area. Maize cobs were harvested and weighed *in situ*, then a representative subsample was collected, weighed fresh, dried for 4 weeks, weighed again, shelled and the grain weight recorded. The field weight of cobs was then corrected for moisture and yield expressed as grain yield in kg ha^{-1} at 12.5% moisture content. Biomass was measured in the field, subsampled, dried and weighed again. The biomass yield was expressed as biomass yield in kg ha^{-1}. All treatments were sampled separately. For detailed harvest procedures consult Thierfelder *et al.* (2013c).

Rain gauges were installed in each community and daily rainfall captured by the hosting farmers or extension officers. Additional climate data were captured from adjacent weather stations, including records of daily minimum and maximum temperature, average wind speed, precipitation and air pressure. We used this to determine the precipitation balance (rainfall–evapotranspiration), number of consecutive days without rainfall within a cropping season and heat stress around anthesis within a cropping season. In cases where weather station data were not available, we substituted data from the AgMERRA Climate Forcing Dataset for Agricultural Modelling (Ruane *et al.*, 2015), Prediction Of Worldwide Energy Resource (POWER; NASA, 2016), Tropical Rainfall Measuring Mission (TRMM) Version 7 3B42 (GES DISC, 2016) or the integrated HOAPS/GPCC global precipitation data set (Andersson *et al.*, 2016) according to the quality and availability of each data set (see Steward *et al.*, 2018, for methodological details).

16.2.3 Water Infiltration and Soil Moisture

Infiltration and soil moisture data were captured at two on-station long-term trials, Monze Farmer Training Centre, Zambia, and Henderson Research Station, Zimbabwe. These sites are the oldest CA long-term trials in southern Africa which have full instrumentation to measure soil moisture dynamics. Infiltration was measured with a mini-rainfall simulator and soil moisture with capacitance probes using methods and procedures described by Thierfelder and Wall (2009).

Rainfall simulations for infiltration measurements were carried out in January of each year. To obtain an accurate assessment of final water infiltration rates after 60 min we simulated 12 times and 15 times per treatment at Monze and Henderson, respectively. Soil moisture was recorded for the period 2014–2017 which includes a strong El Niño season (2015–16) with much lower than usual rainfall.

In all treatments, soil moisture at multiple depths was measured twice per week during the cropping season (one time per week during the dry season) using a capacitance probe (model PR2 from Delta-T devices, https://www.delta-t.co.uk/, accessed 4 August 2021) and access tubes installed to a 1 m depth. Soil moisture was analysed as soil moisture (in mm) for 0–60 cm soil depth.

16.2.4 Data Analysis of Maize Yield Data

To test the performance of CA versus conventional tillage agriculture (CP) yield performance we used paired comparisons at the farm or site (for long-term trials) to calculate the natural log of the response ratio ($\log_e(RR) = \log_e(CA_{yield}/CP_{yield})$) as our dependent variable. Only maize performance was analysed; the rotational legumes or legume intercrop yields were not included owing to different legume varieties between sites complicating the validity of comparisons.

Observations were excluded from the data set if: (i) yields for either CA or CP were zero (which were then handled as missing data) or more than five standard deviations from the weighted mean response ratio (RR); (ii) climate data were unavailable; or (iii) the date of planting was unknown or its uncertainty was greater than 2 days.

Meta-regression was performed using generalized linear mixed effects models in R. Random-effects were included to account for spatial and temporal autocorrelation in the data and to reduce heterogeneity between sites or years when estimating fixed-effect parameters. Models included the random intercepts: (i) study nested within location nested with country; and (ii) harvest year.

To explore the influence of context and management, models included fixed effects for interactions between climate variables and soil texture and climate variables and the rate of elemental nitrogen (N) applied as fertilizer (Rusinamhodzi *et al.*, 2011; Pittelkow *et al.*, 2015). Starting model fixed effects included interactions between precipitation balance (the difference between rainfall and Penmann–Monteith evapotranspiration for the growing season), growing season or anthesis heat stress (base temperature = 30°C, optimum temperature = ∞; GDD30+) or seasonal optimal growing degree days (base temperature = 8°C, optimum temperature = 30°C; GDD8,30), soil texture (% clay content at 0–30 cm depth), rate of elemental fertilizer application rate and study duration (these variables and their interactions were chosen based on the findings of studies such as Rusinamhodzi *et al.*, 2011; Brouder and Gomez-Macpherson, 2014; Corbeels *et al.*, 2014; Pittelkow *et al.*, 2015).

Growing season precipitation balance (PB), heat stress (GDD30+) and heat (GDD8,30) around anthesis were the best predictors of relative yield performance (loge(*RR*)) in the global models. After simplification the final model (Eqn 16.1) used was:

$$\log_e(\mathrm{RR}) = (\mathrm{GDD}_{30}+ \times \mathrm{GDD}_{8,30} \times \mathrm{SD}) + (\mathrm{PB} \times \mathrm{GDD}_{30}+ \times \mathrm{CD}) + (\mathrm{PB} \times \mathrm{GDD}_{30}+ \times \mathrm{CL}) + (\mathrm{GDD}_{30}+ \times \mathrm{GDD}_{8,30}+ \times \mathrm{PB}) + (\mathrm{GDD}_{30}+ \times \mathrm{NF}) + (1 \mid \mathrm{Country{:}Site{:}Study}) + (1 \mid \mathrm{Year}) \qquad (16.1)$$

where SD = the duration of reduced tillage in the CA treatment; CD = crop diversification (nominal variable with three classes: no crop diversification in either treatment, crop diversification in both treatments, or crop diversification in CA only); CL = percentage of clay (depth 0–30 cm); and NF = elemental nitrogen applied in fertilizer (kg ha^{-1}). Model Akaike Information Criterion (AIC) was −75.0 with residual degrees of freedom n = 1010. More details about data collection, model specification and analysis can be found in Steward *et al.* (2018).

16.3 Results and Discussion

16.3.1 Effect of CA on Water Infiltration

Soils at Monze were predominantly Lixisols with a sandy clay loam texture. At Henderson, Arenosols and Luvisols were dominant with a sandy to sandy loam texture and an underlying clay rich sub-surface, which affected the infiltration rate and soil moisture.

Mini-rainfall simulations showed that NT treatments with residue retention and crop diversification maintained higher levels of final

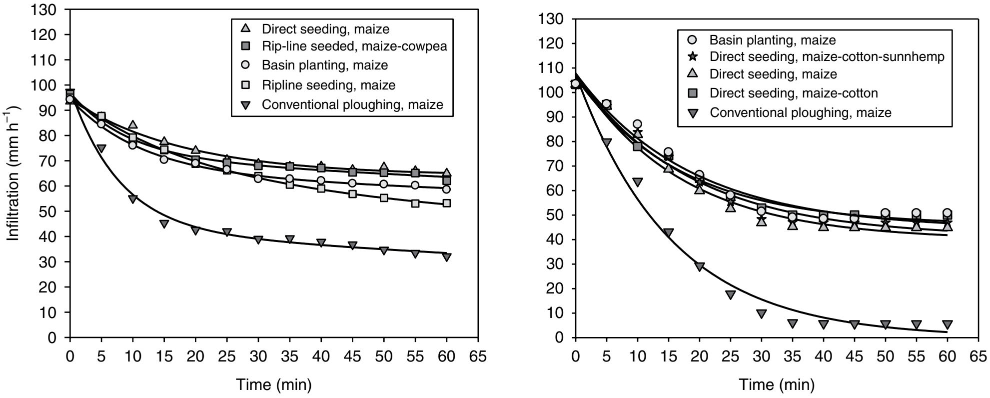

Fig. 16.1. Infiltration rates in two Conservation Agriculture long-term trials at Henderson Research Station, Zimbabwe (left) and at Monze Farmer Training Centre, Zambia (right) in cropping season 2013/14. Authors' own figure.

infiltration compared with conventionally ploughed control treatments (Fig. 16.1). There was a strong and highly significant improvement in infiltration at both research sites when practising CA. The highest infiltration rates at Henderson were recorded in the least disturbed direct seeding treatments and at Monze in a basin-planted system. The CA systems at Henderson had between 21 and 33 mm h^{-1} greater final infiltration rate (+ 65%–102%) than the conventional tillage practice (CP). At Monze, CA systems had between 39–45 mm h^{-1} greater final infiltration rate which translated into a 684%–788% difference than the CP, which had a very low final infiltration rate.

Our findings add to a growing body of evidence that show greater resistance against droughts and/or dry spells through higher water infiltration rates and reduced run-off when CA is practised (Thierfelder and Wall, 2009; Rusinamhodzi *et al.*, 2012; Ngwira *et al.*, 2013; Mupangwa *et al.*, 2016). Together, these studies provide evidence that CA could meet the CSA adaptation criteria in contexts where climate change is likely to result in an increased risk of drought (Thierfelder and Wall, 2010b). We discuss how this generally translates into crop yield performance in Section 16.3.3. Conversely, in contexts where there is an increased risk of very high rainfall, CA may not be well adapted. Too much rainfall may lead to waterlogging, especially in the predominantly sandy soils of Zimbabwe (Thierfelder and Wall, 2009), often characterized by an impermeable sub-surface bedrock or an underlying dense clay layer as it was the case at Henderson.

Therefore, we explored whether increased infiltration under CA leads to higher soil moisture in Section 16.3.2 and what effect this could have in respect to the adaptive capacity of the system.

16.3.2 Effect of Conservation Agriculture (CA) on Soil Moisture Content

At Henderson the conventional ploughed treatment had consistently lower soil moisture levels throughout the wet and dry seasons as compared with the different CA systems (Fig. 16.2). In all seasons under CA, soil moisture remained above or near field capacity. However, this was

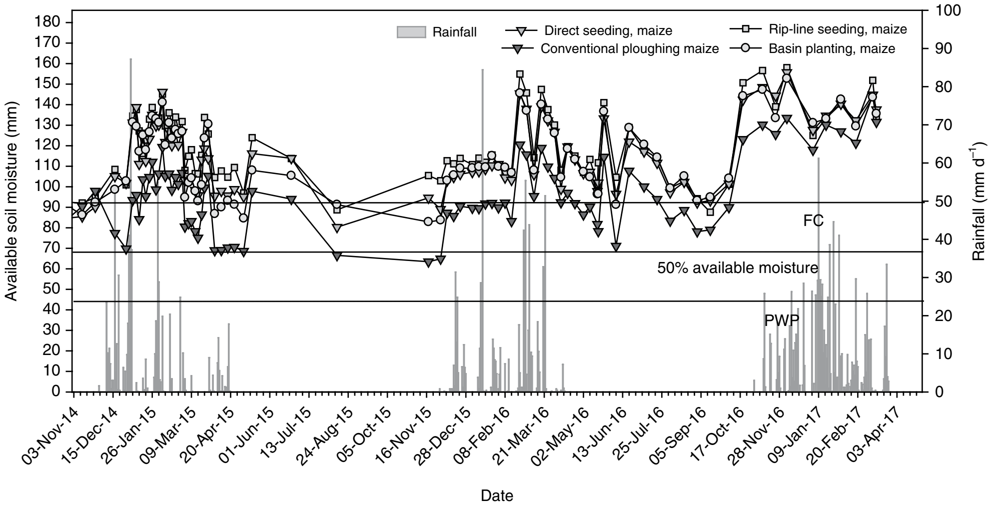

Fig. 16.2. Effect of cropping systems on available soil moisture content (mm per 60 cm soil depth) at Henderson Research Station, Zimbabwe, 2014–2017. FC, field capacity; PWP, permanent wilting percentage. Field capacity is the amount of soil moisture or water content held in soil after excess water has drained away and the rate of downward movement has materially decreased. The permanent wilting percentage is the minimum amount of water in the soil that the plant requires not to wilt. If the soil water content decreases to this or any lower point a plant wilts and can no longer recover its turgidity when placed in a saturated atmosphere for 12 h. Author's own figure.

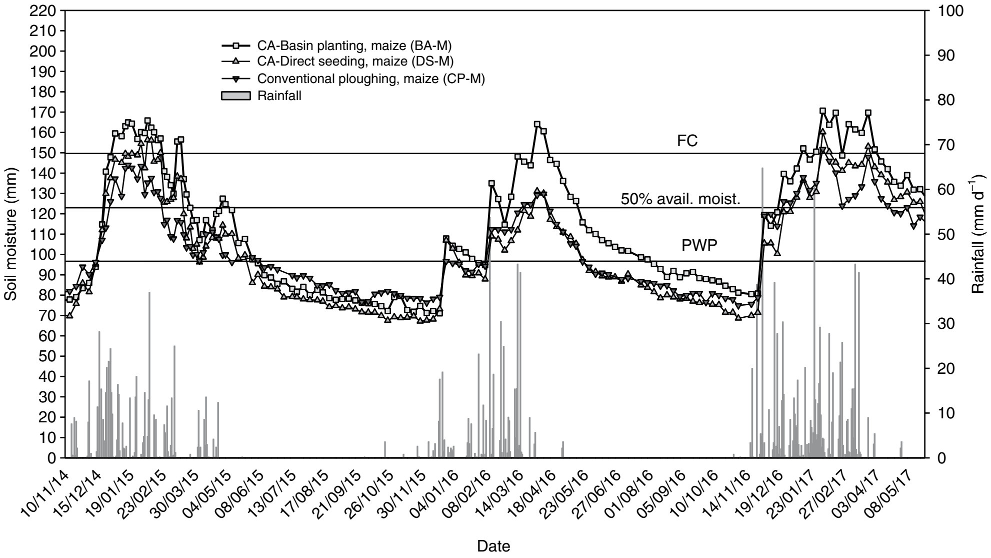

Fig. 16.3. Effect of cropping systems on available soil moisture content (mm per 60 cm soil depth) at Monze Farmer Training Centre, 2014–2017. See Fig. 16.2 for explanation of abbreviations used. Authors' own figure.

not the case for the conventional treatment. In 2014/15 available soil moisture fell below 50% available moisture, indicating an in-season drought (especially at the soil surface) affecting the crop at a critical time of development. In 2015/16, a dry El Niño year (NOAA/NWS, 2019), the conventional system was below field capacity and water-stressed for all but 1 month of the cropping season. In the wet 2016/17 season, well distributed and abundant rainfall raised soil moisture levels in all cropping systems well beyond the field capacity, primarily due to water accumulation in the lower soil horizons. On average, soil moisture was 21%–31% higher in a rip-line-seeded CA treatment as compared with the CP in 0–60 cm soil depth in the three cropping seasons.

At Monze, soil moisture closely followed daily rainfall patterns and, once the rainy season ended, all treatments fell below the permanent wilting percentage (PWP) (Fig. 16.3). During the cropping season the highest soil moisture levels were accumulated in the basin treatment and the lowest under conventional management. Interestingly, the direct seeded treatment had substantially lower soil moisture levels in the 2015/16 El Niño season compared to other seasons. An explanation could be that most of the rainwater efficiently drained beyond 60 cm and maize plants under direct seeding depleted the soil profile even further during the heavy El Niño season, leading to very low soil moisture in this treatment. This led to negative effects on crop performance compared to basin planting which maintained higher levels of soil moisture during the same season. On average, soil moisture was 11%–16% higher in the basin treatment as compared with the conventionally tilled practice at 0–60 cm soil depth in the three cropping seasons. These findings confirm earlier soil moisture results from the same sites, enhancing the time series by adding a strong El Niño season (Thierfelder and Wall, 2009; 2010a).

16.3.4 Yield Response of CA Systems to Climate Stress

While CA systems can improve water infiltration and soil moisture dynamics in a controlled trial environment, it is important to test if this is generalizable and translates into CA yields being more resistant to climate stresses (heat and drought stress) across a range of on-farm and station contexts. Evidence for enhanced CA yield resistance would support the argument that CA enhances adaptive capacity to major climate stresses in southern Africa and is a climate smart practice (Thierfelder *et al.*, 2017) with a strong support case for scaling climate smart agriculture systems. The analysis proving this evidence is published in Steward *et al.* (2018) and here we summarize the key highlights of this study.

The meta-regression found, in general, CA systems better resist drought and heat stress than conventionally tilled systems (Fig. 16.4). Overall the best CA performance under stress conditions (extremes of precipitation balance, PB, or heat stress) was seen on low-clay/sandy soils (left panel, Fig. 16.4), but there was also good performance on medium-textured soil (middle panel, Fig. 16.4).

With low or negative water balance (evapotranspiration is similar to or greater than rainfall) and heat stress (temperatures above 30°C at anthesis), CA systems always outperformed CP systems. On the other hand, a strongly positive water balance (evapotranspiration is substantially lower than rainfall) and low heat stress led to CA performing worse than CP unless the soil contained very little clay (left panel, Fig. 16.4). The effect of heat stress appeared complex: on very clayey soils under drought, heat stress increased the relative performance of CA, but under wet conditions it reduced performance (right panel, Fig. 16.4). On low-clay soils the opposite was true: heat stress reduced CA performance under drought and increased it under wet conditions (left panel, Fig. 16.4).

Under high-clay content there was a positive yield response towards CA under drought stress even with increasing heat stress (right panel, Fig. 16.4). However, under higher PB, the conventional system outperformed the CA systems even with increasing heat stress.

16.3.5 Where Does an Increased Adaptive Capacity of CA Systems Come From?

Our previous findings indicated that higher rainfalls and available moisture can negatively affect CA systems if the soil quality including water permeability has not improved sufficiently to allow improved water flow to deeper soil layers and drainage into the groundwater instead of increased surface run-off (Thierfelder and Wall, 2009). CA is a water-conserving system and works best with physical water drainage systems and improvement in soil infiltration and permeability attained with time due to CA practices. This was clearly confirmed by the results in Fig. 16.4 although it is important to note that soil texture plays a critical role in how the conventional tillage and CA systems will perform under varying climate stresses (drought and flood).

Results obtained are confirmed by other studies which reported greater productivity under CA in lighter-textured soils (Nyamangara *et al.*, 2014), which form the majority of soil

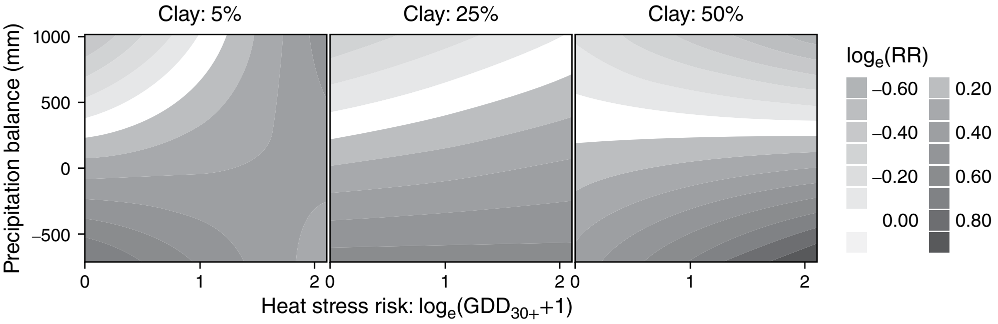

Fig. 16.4. The effect of heat stress at anthesis (log$_e$(GDD$_{30+}$+1)) and growing season precipitation balance (precipitation–potential evapotranspiration) on conservation agriculture yield performance relative to conventional practice (log$_e$(RR)) across low (left), medium (middle) and high (right) soil clay contents. Negative values of precipitation balance, towards the bottom of panels, indicate a rainfall deficit. Shading beneath white bands in the graph indicate conservation agriculture outperforms conventional practice and vice versa. Results are predicted for an intermediate level of fertilizer application. Adapted from Steward *et al*. (2018).

types in southern Africa. Nevertheless, the time of which a cropping system has been under NT management should not be underestimated. Greater yields become apparent in most tested CA systems after 2–5 years, which was confirmed from regional on-farm trials in a previous study from southern Africa (Thierfelder *et al.*, 2015b). Gradually improving soil quality in CA systems in response to NT, residue retention and diversification have been also measured under controlled conditions in on-station long-term trials (Thierfelder *et al.*, 2012; 2013b).

The reasons for an enhanced adaptive capacity are many and stem from improvements in physical soil structure over time (e.g. more continuous soil pore system, increases in organic carbon as a stabilizing factor, aggregate development); an increase in biological soil fertility (e.g. more earthworms, beetles and termites creating a favourable pore structure); and soil cover with mulch which conserves soil moisture and reduces temperature and evapotranspiration. All these factors positively influence water infiltration and soil moisture retention and eventually make CA systems more climate smart (Thierfelder *et al.*, 2017).

16.3.6 How can the Adaptive Capacity be Improved?

While providing greater adaptive capacity to climate stress it was observed that current CA cropping systems as practised in smallholder farms are insufficient to maintain and/or increase soil fertility over time (Thierfelder *et al.*, 2018). Farmers struggle to maintain sufficient crop residues for groundcover due to intensive crop–livestock interactions in Zimbabwe and Zambia with associated trade-offs (Valbuena *et al.*, 2012; Mupangwa *et al.*, 2019). Also the long dry season and volatilization of nitrogen reduce potential fertility benefits of CA systems and rarely contributed to improvements in soil carbon and available soil nitrogen in on-farm trial settings at the onset of the new cropping season (Cheesman *et al.*, 2016).

Future CA interventions, therefore, need to focus more on increasing the biomass production on smallholder farmers' fields for both feed and for mulching (Mupangwa *et al.*, 2018). This could be achieved through adequate fertilization (Mupangwa *et al.*, 2019) and use of animal manure (Rusinamhodzi *et al.*, 2013), optimal plant population (Nyagumbo *et al.*, 2017), growing of drought-tolerant crops (Thierfelder *et al.*, 2016; Setimela *et al.*, 2018), increased diversification and groundcover by leguminous intercrops (pigeon pea, lablab and cowpeas) (Mhlanga *et al.*, 2016) or by introducing tree-based components in CA cropping systems (e.g. *Gliricidia sepium*) (Lewis *et al.*, 2011) to increase biomass production on-site (Mupangwa and Thierfelder, 2014; Thierfelder *et al.*, 2018). This will increase the adaptive capacity of CA systems to climate-related stress as more diversified systems and use of drought-tolerant seed and targeted interventions will likely support greater moisture conservation.

16.4 Conclusions

The results of this study confirm the following main points: (i) CA systems with crop residue retention maintain higher infiltration rates leading to greater soil moisture contents as compared with conventional tilled practices with residue removal. This can lead to increased adaptive capacity of cropping systems to drought and heat stress as the soils managed under CA have greater moisture reserves and buffering capacity against climate stresses; and (ii) the yield analysis highlighted the following aspects: under low-clay (sandy soils), the adaptive capacity of CA systems is much greater than in conventionally tilled systems, especially under heat and drought stress. In situations of low heat and higher PB, CA systems were out-yielded by CP. Under medium clay soils, CA systems were still out-yielding conventional tillage systems under low rainfall but, with increasing rainfall, conventional systems were more beneficial under low and high heat stress. A similar but stronger response was found under higher clay content.

To reap the multiple benefits of climate resilience and maintaining soil fertility, it is important to adapt current smallholder CA systems to the agroecologies of southern Africa. The region is characterized by a unimodal rainfall season and it is likely that current CA systems are not able to provide the multiple benefits reported from elsewhere due to the long dry season of 7 months. To improve climate smartness and increase soil fertility, complimentary agricultural practices are required and can be incorporated into the CA systems. These should be the use of improved stress-tolerant seed, targeted fertilization and manure use, green manure cover crops and incorporation of agroforestry species, appropriate scale mechanization and improved weed control strategies, among others.

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17 What Drives Small-scale Farmers to Adopt Conservation Agriculture Practices in Tanzania?

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Abstract

Conservation Agriculture (CA)-based Sustainable Intensification (CASI) practices in this study comprised minimum soil disturbance, permanent soil cover, intercropping of maize and legumes, and use of improved crop genotypes and fertilizers, and were tested on-farm in different agroecologies in northern and eastern Tanzania. The results for six consecutive years of study indicate increased adoption of CASI practices compared to the baseline year (2010). The major impacts of these practices were reduced production costs, labour savings and overall increased crop and land productivity. The average area allocated to improved maize–legume (ML) intercrop rose during the project period by 5.28 ha per household, of which 15% was under complete CASI practices. Adoption trends show that, on average, 6.5% of adopters across the study and spillover communities started adoption in the 2nd year and about 14% of farmers adopted the practices over the next 3–5 years. Demographic and human capital (family size, education, age and farming experience), on-farm CASI demonstrations, farmer to farmer exchange visits, social capital (farmers' group or a cooperative), access to input and output markets (improved seeds, herbicides, fertilizers, insecticides and equipment) and food security were found to have positive and significant effects on adoption of a range of CASI practices. These results suggest continued and long-term efforts in investments in demonstrations, institutionalizing CASI practices in NARS, and good links to input and output markets, including appropriate machinery, are necessary to achieve sustained adoption.

Keywords: sustainable intensification, adoption, smallholder farmers, scaling

17.1 Introduction

The Sustainable Intensification of Maize–Legume Based Cropping Systems for Food Security in Eastern and Southern Africa (SIMLESA) project was initiated in Tanzania in 2010 to support smallholder farmers to adopt productive, resilient and sustainable maize–legume (ML) cropping systems through adaptive research, community demonstrations and social innovations to facilitate local learning and scaling of new farming practices. At the start of the project, characterization of ML production, input and output value chains and adoption pathways was carried out. Capacity building and skills strengthening of local extension personnel were done in collaboration with the respective national agricultural research centres (NARs). SIMLESA implementation was based on adaptive research at experimental stations which was replicated in villages. The

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project facilitated and sustained demonstrations of Conservation Agriculture for Sustainable Intensification (CASI) practices comprising minimum soil disturbance, permanent soil cover, intercropping of maize and legumes, and use of improved crop genotypes and fertilizers in the project communities and beyond. Partnerships with a range of value chain stakeholders in participating districts and countries were a critical implementation mode including scaling efforts for effective diffusion of CASI practices among smallholder farmers. Selection and recruitment of lead farmers who hosted CASI demonstrations and their inclusion as trainers was critical. Sustained CASI demonstration sites within reach of smallholder farmers became learning centres, providing an opportunity for male and female farmers, including the youth to try and embrace the practices as climate smart, as called for in the Malabo Declaration and Agenda 2063.

Through established monitoring and evaluation systems, the project utilized local resources to reach more farmers. To improve its implementation, a number of adoption surveys were conducted over the years in project areas. A number of on-farm demonstrations were set up in various stations and managed by NARs (Selian and Ilonga) research centres. The research activities were implemented in two contrasting agroecological zones in each of Gairo, Kilosa, Mvomero, Mbulu and Karatu districts.

An adoption survey was conducted between October and December 2018 with the aim of understanding adoption impacts and benefits of CASI practices resulting from the SIMLESA project in the study areas and spillover communities.

17.2 Methodology

The project started in 2010 by involving different partners such as national extension networks and research centres. Awareness campaigns designed to reach smallholder farmers were rolled out through various communication channels such as radio, television, public gatherings and farmers' schools. Farmers who were directly involved in the project were trained on a set of CASI practices and their benefits in natural resource conservation for food security.

17.2.1 Sampling Procedures

Continuous random sampling methodology was adopted to capture SIMLESA farmers within a radius of 25 km. This was a two-stage approach, beginning with the selection of primary sampling units (PSUs) in the district where SIMLESA activities were implemented. Within the PSUs, households were randomly selected as units of analysis. Note that, during the project implementation, the activities were spread in different regions with different farmers hosting demonstration plots. The study therefore limited itself to PSUs that were found to be within 25 km radius of these demonstration sites. Households were randomly selected from communities within the PSUs.

During the household sampling, care was taken to exclude farmers who hosted SIMLESA activities and demonstration plots. However, these farmers were interviewed independently in the main survey across the districts. The study enlisted the help of extension officers from local authorities at the PSU level.

17.2.2 Sample Size

Sample size computation was performed using Eqn 17.1:

$$n = \left[\frac{4\sigma^2 (z_{1-\alpha/2} + z_{1-\beta})^2}{D^2} \right] \left[1 + \rho(m-1) \right] \tag{17.1}$$

where n = sample size; σ = variance in population outcome metric; D = the effect size or how much of an impact the project will have; $z_{1\text{-}\alpha}$ = Z value at 5% significance level/probability of Type 1 error; $z_{1\text{-}\beta}$ = Z value at 80% statistical power/probability of Type 2 error; ρ = the intra-cluster correlation effect; and m = the number of observations in each cluster (village).

A random sample of 20 households was selected and the total sample size was 958 farmers.

17.2.3 Basic Assumptions on Adoption

A number of assumptions were made in computing sample size for the survey:

1. It was assumed that the cluster/community was homogeneous, thus a random sub-sample of

20 households was representative of its farming population. A homogeneous cluster is composed of a target population with a common ethnic, religious, socio-economic or cultural heritage which has not been influenced by external factors and whose members practice a similar livelihood. Random sampling enables a representative selection of smallholder farmers without any prior knowledge or consideration of particular characteristics of the beneficiary population, using the randomly generated numbers from a total amount of names listed. Every village, household and person has an equal chance of being included in the sample.

2. The location of the demonstration plots was assumed to be centrally located within the villages. These plots formed the basis of having a 25 km radius cluster for sampling purposes.

3. It was also assumed that every smallholder within the cluster, notwithstanding their resource endowment, had an equal chance of access to the CASI activities and thus had an equal chance of being sampled.

17.2.4 Computation of Area Under CASI

1. To calculate the area under CASI in each district and SIMLESA zones, the maize area was multiplied by the average proportion of area under full CASI as computed from the SIMLESA benefits survey of 2018, which was 9%. (Note that this was the area under full or partial CASI in the whole district.)

2. The maize area in agroecological zones was assumed to be 35% of arable land in rural areas where SIMLESA was implemented.

3. To compute the area under full CASI in research trial and scaling sites, the maize area under full CASI at district level was multiplied by the proportion of area under CASI in the trial sites as typified by SIMLESA, which was 35% (Mmbando *et al.*, 2016). (Note that this was the area under full CASI in the communities or villages where the trials were established by researchers.)

17.2.5 Computation of CASI Adopters

1. The rural population was summed as reported by FAOSTAT (2017). The average household had five members. Thus, we divided the total rural population by 5 to obtain the total number of households.

2. The farming households were assumed to be 35% of the rural households in agroecological zones where SIMLESA was implemented.

3. To compute the adopters of CASI, the number of farming households was multiplied by the adoption rate of full CASI practices as computed from the SIMLESA benefits survey of 2018.

4. To compute the number of those adopting in each project trial sites and scaling sites, the number of adopters within the country was multiplied by the average proportion of adopters in each trial site. (Note that scaling sites are the areas under CASI established by either full or just a component of CASI chosen by the farmers of the communities in question outside the trial sites or communities.)

17.3 Results and Discussions

The results of this study revealed different factors that drove the adoption of the CASI practices of ML diversification; residue retention; use of herbicides, different types of fertilizers, improved crop varieties; and minimum soil disturbance by small-scale farmers as discussed below.

17.3.1 The Role of Demographic and Human Capital

Family size and human capital (education, age and experience) were found to have a positive and significant effect on adoption of a range of CASI practices. The implication here is that minimum soil disturbance, soil and water conservation, and proper use of improved seeds to establish crops are knowledge-intensive and require some farming experience and management. Where farmers have some levels of education and also have access to family labour it becomes easier to adopt the practices. In a situation of low farmer knowledge of improved farming, and resource constraints – especially labour – farmers opt for poor farming practices that seems cheap to practice but are at the expense of productivity. Similar results were also reported by Kassie *et al.* (2012).

17.3.2 Demonstrations and Farmer to Farmer Exchange as Information Source

As a critical precedent to adoption, information is crucial in the spread of CASI practices, or any other production practice for that matter. The result showed that demonstrations and farmer to farmer interactions were the main sources of information of CASI practices followed by extension services from both government and project staff. Others were platforms used to spread information, such as radio, television and innovation platforms.

17.3.3 Social Capital

Social capital in the form of membership in common interest groups (such as farmers' groups or a cooperative) was generally found to strongly enhance adoption of CASI practices. For example, farmers who belonged to an agriculture-related group had higher adoption of some CASI practices such as minimum soil disturbance and crop rotation at a rate of about 65.4% and 50.6%, respectively. These institutions present alternative remedies to the prevalent local market imperfections. Therefore, collective action accorded through agricultural groups may provide credit, inputs, information and stable market-outlet services to farmers.

17.3.4 Access to Markets

Households located closer to markets were more likely to adopt CASI practices such as ML intercrops and minimum soil disturbance than more distant households because of easy access in terms of availability and price of the agricultural inputs such as improved seeds, fertilizers, herbicides and extension information compared to the distant households.

17.3.5 Contribution of CASI in Production Profitability and Food Security at Household Level

Benefit–cost ratio analyses revealed that production under the full set of CASI practices was more profitable (2.65) than partial combination of CASI practices (1.72 and 1.55 for partial 1 and 2, respectively) (Table 17.1). The results also showed that the full CASI set of combinations were superior yield-wise and in terms of gross margins (Table 17.1). These positive returns accord smallholder farmers' extra income, which may allow them to afford better, higher-yielding crop varieties and production implements that can help improve food security among the rural population.

17.4 Methods Used to Disseminate CASI Practices

A number of channels were used to expose farmers to CASI practices over the project period: on-farm demonstration plots, innovation platform forums, extension services, contact with fellow farmers, radio and television programmes, and field days, and they contributed significantly to CASI adoption (Fig. 17.1).

Table 17.1. Grain yields and economic analysis of different Conservation Agriculture-based sustainable intensification component combinations. Authors' own table.

Harvested quantities (kg ha^{-1})			Gross revenue per hectare (US$)			Cash costs per hectare (US$)			Gross margins (US$)			Benefit–cost ratio		
Partial CASI 1	Partial CASI 2	Full CASI	Partial CASI 1	Partial CASI 2	Full CASI	Partial CASI 1	Partial CASI 2	Full CASI	Partial CASI 1	Partial CASI 2	Full CASI	Partial CASI 1	Partial CAS 2	Full CASI
1800	789	2191	356	156	433	207	101	164	149	55	270	1.72	1.55	2.65

Based on a maize price of US$197.8/tonne (FAOSTAT, 2017).

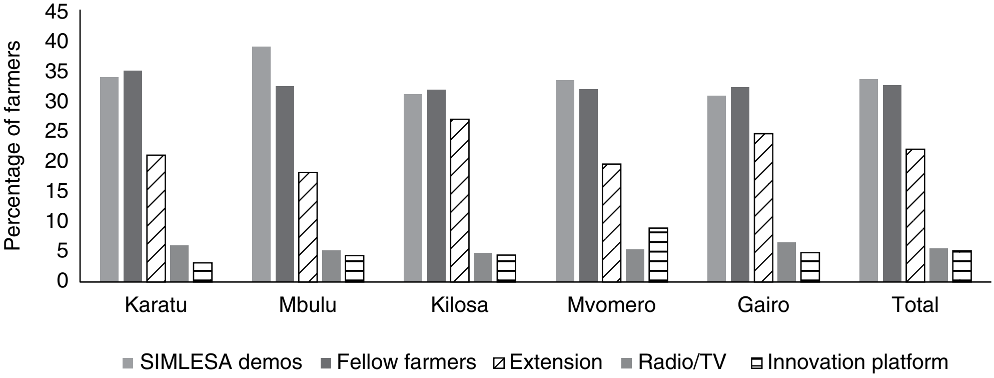

Fig. 17.1. Different methods of dissemination of CASI technologies. From SIMLESA Country Synthesis Report (2018). Authors' own figure.

The number of farmers aware of existing CASI practices increased over time (Table 17.1), from zero awareness during baseline survey leading into its adoption.

17.4.1 Adoption of CASI

Conditional on exposure to CASI practices, there were farmers who decided to adopt but at different points during the project implementation period. Early in the cropping season a year after project intervention (2010/11), CASI adoption by a few farmers near project sites was evident as can be expected (Fig. 17.2). Between 2010 and 2018, there was a 15–16-fold increase in the use of improved intercropping by farmers.

The use of herbicides in crop production remained low (Fig. 17.2), possibly due to unavailability and/or high costs. Past bad experiences with fake or adulterated herbicides may also have contributed to the low rate of adoption of herbicide use by smallholder farmers.

Retention of residue on the farm after harvesting the crop was one of the most challenging decisions faced by smallholder farmers. The need for livestock feed may hamper efforts towards adoption of this practice as shown by the low adoption of this practice. Farmers normally cut and carry the residue or graze on the farm (Rusinamhodzi *et al*., 2015).

Minimum soil disturbance is not a common agricultural practice among most farmers in the region. The adoption of this practice was observed to increase (5%), although not at as high a rate as intercropping and residue retention, which were adopted by 70% and 25% of farmers, respectively. The minimum soil disturbance practice is very much associated with the use of herbicide to control weeds in undisturbed soil. This suggested that the low adoption of herbicide use could be associated with low adoption of minimum soil disturbance practice. The drudgery involved in establishing crops in uncultivated land may also be the cause of low adoption. This calls for the introduction of appropriate small machinery appropriate for CASI practices, especially no-till (NT) seeders. It is apparent that, post-SIMLESA, extension networks need to step up efforts in creating awareness, training and reassuring farmers of the potential benefits of minimum soil disturbance – especially in the light of climate change and variability. The emphasis should be on the benefits (increased natural soil fertility, pests and diseases pressure reduction) that will be realized after continuous application of the CASI practices for about 5 years. There is, however, the immediate benefit (time saving, lower cost of production and timeliness of farm operations) accrued from practising minimum soil disturbance, and this should be made clear to targeted farmers.

17.4.2 Persistence of Adoption

Adoption is only meaningful when sustained over time. This does not prevent farmers changing their choice of practices in future but, in many cases, the benefits of a practice can only be seen when implemented consistently over several seasons. This is especially true of those practices with a strong natural resource component such as CA. To obtain a picture of how consistently farmers were applying the practices, the survey respondents were asked to state the earliest year they had been using the practices consistently (Fig. 17.3).

There had been an increasing percentage of adopters since 2011 with the highest (16%) reached in 2014/15 cropping season. However, the rate of increase decreased between 2014/15 and 2016/17, but then picked up in the 2017/18 cropping season. The reason for this adoption fluctuation was farmers' response to the market and weather. There was a price decrease, especially for maize and legumes, between 2014/15 and 2016/17. A high demand for maize and legumes in 2017/18 led to increased adoption.

17.4.3 Adoption of Various Combinations of CASI Practices

ML diversification (improved intercropping) was the most widely adopted CASI practice combination, adopted by 38% of farmers, whereas adoption of other combinations of CASI practices were below 15%. The adoption of improved

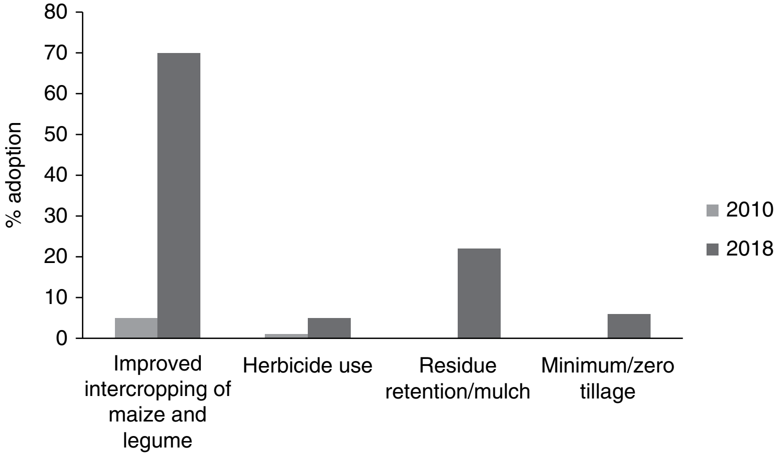

Fig. 17.2. Percentage adoption of CASI practices from 2010 to 2018.

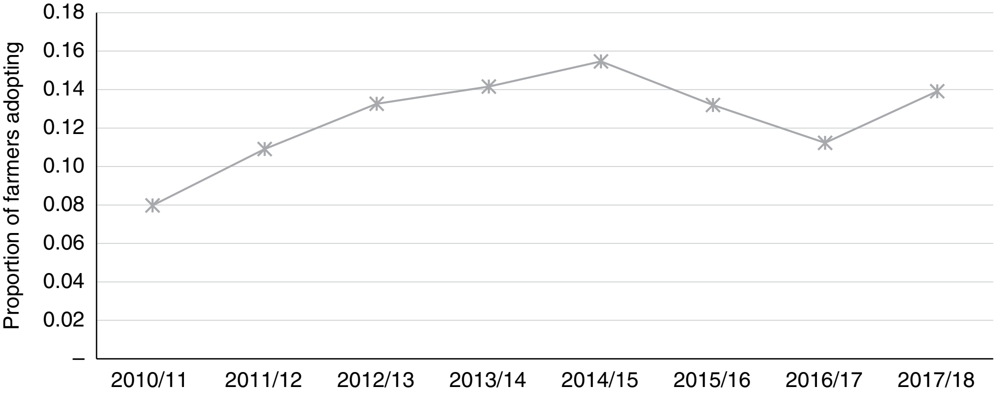

Fig. 17.3. Adoption of CASI practices by year since initial adoption in Tanzania. Authors' own figure.

non-CASI practice was 27% (Fig. 17.4). These results suggest that the two combinations of practices were easily adopted by many farmers because they were familiar to them, whereas other practices trailed behind because of their novelty, although they were more profitable.

17.4.4 Area Under Various Combinations of CASI Practices

In this section the proportion of the farm area of adopting farmers that was under various combinations of CASI practices is summarized. The general trend was that when various combinations were considered, the portion of the farm under CASI practices was fairly large. However, this masks the fact that only a small portion of the farm had full combinations of CASI practices (Fig. 17.5). Generally improved ML intercropping accounted for the larger proportion of the area under CASI practices. Optimal combinations of CASI practices was what was needed for maximum yield and environmental impact (Manda *et al.*, 2015). Seventeen percent of the ML intercrop area was under no CASI practices. Complete CA was on 15% of the ML area, 37% of the area was under two CASI practices and 52% was under 2–3 CASI practices (Fig. 17.5).

17.5 Impacts of the SIMLESA Programme in the Community

The economic impact of CASI practices will only be realized when and if CASI is widely diffused and adopted. Adoption as defined by Rogers (2003) is a decision of full use of an innovation as the best course of action available, while diffusion is the process in which an innovation is communicated through certain channels over time among the members of a social system. Adoption itself emanates from an individual farmer's decisions to accept upon careful comparison of benefits vis-à-vis their costs.

Setting up CASI demonstration plots in the villages provided the necessary information and knowledge about CA and significantly reduced farmers' learning costs. In a couple of seasons, some farmers were persuaded to actively participate in project activities and some hosted the demonstrations on their farms. This helped in publicizing the benefits of CASI in communities, attracting many farmers at the outset and gaining momentum over time with support from the project partners. The rate of adoption of CASI practices varied over time. The few early adopters were mostly opinion leaders and lead farmers in the communities. These were central to the spread of CASI and to influencing early adopters in the communities. However, to achieve adoption by the majority of farmers, there is a need to

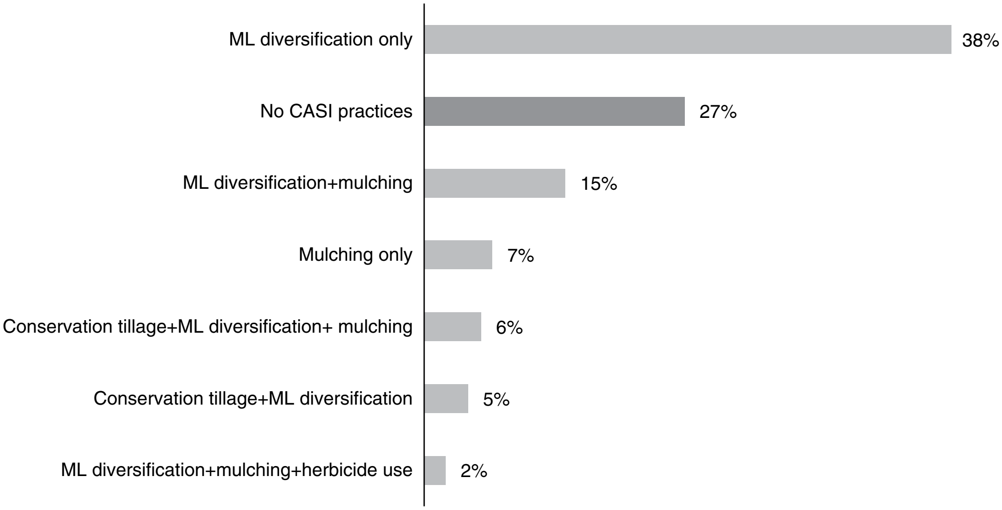

Fig. 17.4. Percentage adopters of combinations of CASI practices during 2017/18. Authors' own figure.

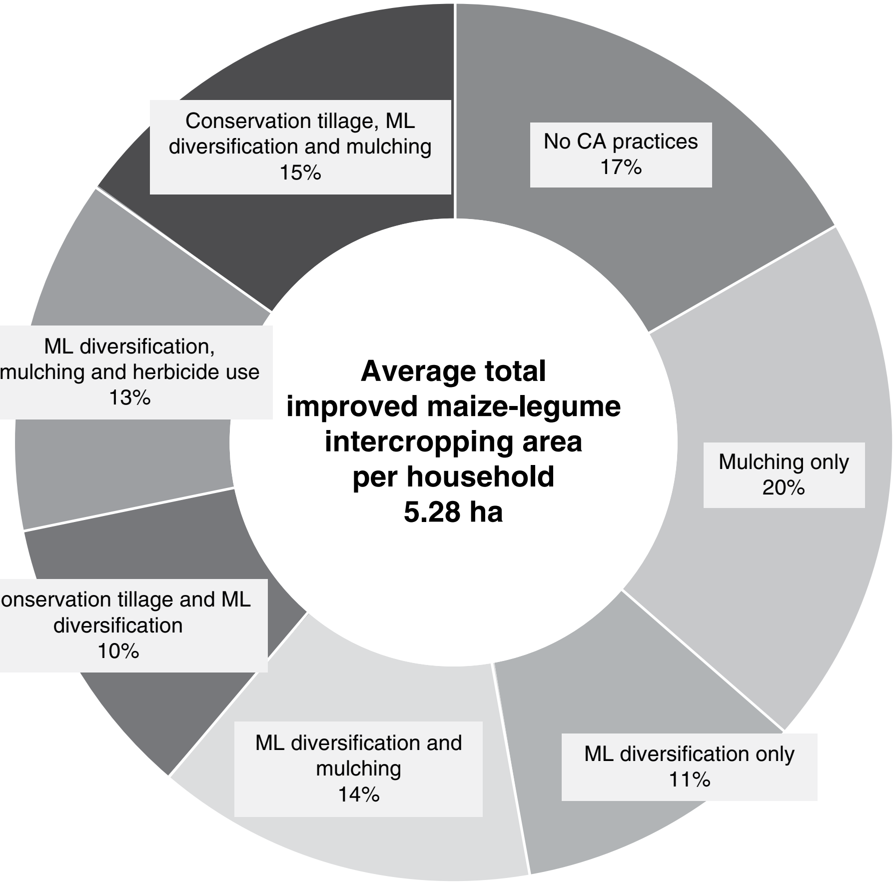

Fig. 17.5. Proportion of maize–legume area under CASI practices in Tanzania. Authors' own figure.

diversify adoption pathway strategies, including sustained investments in scaling out and mainstreaming CASI in national governmental agricultural extension programmes.

17.6 Conclusions

Sustained adoption of CASI practices is imperative for improved productivity, as evidenced by the study findings. However, the optimal combinations of CASI practices needed in different agroecologies may be labour intensive, which escalates the production cost. This could be offset by the introduction of small mechanization to be used at different stages of the production chain (tine ripping, NT seeding, spraying, harvesting, shelling and transportation). To increase permanent soil cover (mulch) adoption, it is necessary to introduce improved livestock feed production (pasture and fodder establishment in the farm border and contours) to offset dependency on crop residues for livestock feed. The evidence generated in this study indicates that the adoption of CASI practices is positively influenced by gender, farm size, number of trainings attended by farmers and farmers' membership in farmer groups/associations. The results imply that, to promote adoption of a complete package of CASI practices and policies that enhance market accessibility to the farming community, CASI training through extension services and membership of farmers' groups/associations should be a priority. Agriculture being the mainstay of Tanzania's economy, CASI offers a pathway to contribute to sustainable production that is resilient to a changing climate and environmental degradation, as called for by the Malabo Declaration and Agenda 2063.

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18 Impact of Conservation Agriculture on Soil Health: Lessons from the University of Fort Hare Trial

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Abstract

Conservation Agriculture (CA) promotes soil health, but issues to do with soil health are poorly researched in the Eastern Cape, South Africa. This study reports on findings from a field trial done on the effects of tillage, crop rotations composed of maize (*Zea mays* L.), wheat (*Triticum aestivum* L.) and soybean (*Glycine max* L.) and residue management on a number of soil health parameters such as carbon (C)-sequestration, CO_2 fluxes, enzyme activities, earthworm biomass and the Soil Management Assessment Framework soil quality index (SMAF-SQI). The field trial was done in a semi-arid region of the Eastern Cape Province, South Africa, over five cropping seasons (2012–2015). It was laid out as a split–split plot with tillage [conventional tillage (CT) and no-till (NT)] as main plot treatment. Sub-treatments were crop rotations: maize–fallow–maize (MFM), maize–fallow–soybean (MFS); maize–wheat–maize (MWM) and maize–wheat–soybean (MWS). Residue management: removal (R−) and retention (R+) were in the sub-sub-plots. Particulate organic matter (POM), soil organic carbon (SOC), microbial biomass carbon (MBC) and enzyme activities were significantly ($p < 0.05$) improved by residue retention and legume rotation compared to residue removal and cereal-only rotations. Also, carbon dioxide (CO_2) fluxes under CT were higher compared to NT. The calculated soil quality index (SQI) was greatly improved by NT and residue retention. MWM and MWS rotations, in conjunction with residue retention under NT, offered the greatest potential for building soil health. Residue retention and inclusion of soybean in crop rotations are recommended for improving soil health under CA systems in the semi-arid regions of South Africa.

Keywords: carbon dioxide (CO_2) fluxes, crop rotation effects, residue retention, no-till, smallholder, soil fertility

18.1 Introduction

World population is expected to double by 2050. In order to avoid famine it will be necessary to increase food production and supply (Dunkelman *et al.*, 2018). The strategy used in industrial agriculture in Africa to increase food production has mainly been intensification, modelled on the ‘Green Revolution’. The successes of the Green Revolution relied on new high-yielding varieties, high dosages of synthetic agrochemicals and intensive inversion tillage of the soil. Although

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this intensification increased crop yields, it came at a cost and resulted in a new set of problems, some of which are currently of global concern. These include increased carbon dioxide (CO_2) emissions with concurrent effects on climate change (Muzangwa, 2016; Pryor *et al*., 2017), loss of topsoil and related soil degradation (Singh *et al*., 2020), pollution of water bodies from the increased use of synthetic fertilizers and herbicides (Singh *et al*., 2019) and loss of plant and animal biodiversity (Giupponi *et al*., 2020). Recognizing these impacts, recent agricultural innovations are promoting alternative agriculture systems that would satisfy the food requirement of a growing population but at the same time minimize damage to the soil, reducing soil degradation and mitigating the impacts of conventional agricultural systems on the environment.

The need to reduce soil degradation is of particular interest to the Eastern Cape Province of South Africa. Soils in the province are fragile and susceptible to erosional forces (Mills and Fey, 2004). With steeply sloping landscapes and overgrazing, the soils are mostly unprotected and predisposed to erosion and, consequently, loss of soil organic carbon (SOC) (Mandiringana *et al*., 2005). Furthermore, the predominantly semi-arid conditions make it difficult to build enough crop and pasture biomass for C-sequestration and restoration. The farmers' practices of continuous maize monocropping and intensive tillage further exacerbates the C losses from cropped lands, resulting in diminishing crop yields (Mandiringana *et al*., 2005; Dube *et al*., 2012). However, current research recognizes soil as an important component of the biosphere that can be managed in a way such that it improves crop production, while concurrently offering ecosystem services and maintaining environmental quality. This multiple capacity of soil is termed 'soil health' (Doran, 2002).

While terms such as soil health and soil quality are often used interchangeably, soil health refers to a holistic approach that considers soil as a vital living ecosystem sustaining all organisms (Lehman *et al*., 2015). On the other hand, soil quality considers the soil's appropriateness for the purpose of crop production. Soil health indicators include physical, biological and chemical properties, all interacting to affect soil quality (Stott *et al*., 2017). Conservation Agriculture (CA) builds and incorporates these concepts into a soil management strategy that promotes soil health. CA is regarded as an ecosystem approach to promote sustainable agriculture through practical application of the context-specific and locally adapted three interlinked principles of: (i) continuous no- or minimum mechanical soil disturbance (no-till [NT] seeding/planting and weeding); (ii) permanent maintenance of soil mulch cover (crop biomass, stubble and cover crops); and (iii) diversification of cropping systems (Kumar *et al*., 2016; Kassam *et al*., 2017). If applied correctly, CA can increase SOC by sequestering atmospheric C, and thereby improving soil health, ameliorating the impacts of soil degradation and increasing crop productivity (Muzangwa, 2016; Thierfelder *et al*., 2017). CA is recognized as a climate smart soil management system as it mitigates the impact of agriculture intensification on climate change by reducing greenhouse gas (GHG) emissions, particularly CO_2 (Muzangwa, 2016; Thierfelder *et al*., 2017).

Several advances have been made in CA research and promotion thereof to the local farmers in South Africa (Swanepoel *et al*., 2018). However, these successes have been reported mainly with commercial farmers but not with smallholder farmers, who still play a significant food security role in the former black homelands of South Africa (Muzangwa *et al*., 2017). A survey study by Muzangwa *et al*. (2017) revealed that the majority of the 'CA' farmers were practising NT, known as *lima lula* in isiXhosa, the native language in the Eastern Cape Province. Of these farmers, 10% practised NT with crop rotation and 18% practised NT with residue retention, while only a small number (3%) did all three CA components. As a result, the adopters are not getting the CA incentives such as improved soil fertility, attainment of high crop yields and profitability (Muzangwa *et al*., 2017). These incentives are key in the acceptability of CA by the farmers. Therefore, it is important to investigate suitable and sustainable components of CA that could be used by the smallholder farmers as key entry practices. The overall objective of the study was, therefore, to evaluate the effect of different tillage systems composed of NT and conventional tillage (CT), crop rotations composed of locally available cash and food crops (maize, wheat and soybean) combined with different residue management options on various soil health parameters which include C-sequestration, CO_2 fluxes, biological activity and calculated SQI. This chapter provides recommendations for best management.

18.2 Materials and Methods

18.2.1 Experimental Site

An experiment (field trial) was carried out at the University of Fort Hare (UFH) (32°47′ S and 27°50′ E) to test various soil management inputs in relation to soil health. The location is at 508 m altitude and average annual rainfall is 575 mm (Muzangwa, 2016). About 30% of the annual rainfall is in winter and the rest in summer. Based on the total rainfall, the site is classified as semi-arid (Palmer and Ainslie, 2006). The surface layer soils are of the Oakleaf form or Eutric Cambisol (Muzangwa, 2016). At the initiation of the trial, before any tillage (December 2012), the soil had average SOC values of 1.58% (standard deviation 0.13%) within the 0–10 cm soil depth. Before the establishment of the trial, the site had been under lucerne (*Medicago sativa*).

18.2.2 Experimental Design

The field trial was a split–split plot design with 16 treatments and 3 replicates. Main plots were allocated to NT and CT. Rotations with four levels were in the sub-plots; maize–fallow–maize (MFM), maize–fallow–soybean (MFS), maize–winter wheat–maize (MWM) and maize–winter wheat–soybean (MWS) (Table 18.1). The sub-sub-plots were allocated to residue management at two levels; residue removal (R−) and residue retention (R+). The sub-sub-plot sizes were 5 × 7 m, but data were collected from net plot sizes of 3 × 4 m.

18.2.3 Crop Management Practices

Before the onset of the field experiment in December 2012, the experimental site was ploughed, disced and harrowed to create uniform conditions. However, thereafter CT plots were tilled before each cropping season while NT plots were maintained strictly NT. A short season and prolific maize cultivar (BG 5785BR) was planted in summer (October–February) targeting a population of 25,000 plants ha^{-1}, recommended for dryland conditions in the central Eastern Cape Province of South Africa. An early maturing, dryland spring wheat cultivar (SST015) was planted in winter (May–August) at a seeding rate of 100 kg ha^{-1}. Soybean cultivar (PAN 5409RG) was sown in summer, targeting a population of 250,000 plants ha^{-1}. Fertilizer was applied to the summer maize crop only at a rate of 90 kg N, 45 kg P and 60 kg ha^{-1} K for a target yield of 5 tonnes ha^{-1}. All the P, K and one-third of the N fertilizer was applied at planting as a compound fertilizer (6.7% N; 10% P; 13.3% K + 0.5% Zn) and the rest (60 kg) as limestone ammonium nitrate (LAN) at 6 weeks after planting by banding. Soybean was inoculated with *Rhizobium leguminosarium* before sowing. Maize was planted by opening holes using a hoe while soybean and wheat were planted after opening 5-cm deep furrows. Crop residues were either retained in the R+ plots or removed in the R−plots after each cropping season. No irrigation was applied to the experimental plots.

18.2.4 Field and Laboratory Measurements

C-sequestration and CO_2 fluxes

Residue dry weights were determined each season at harvest. Plants were cut at ground level and residue was oven-dried at 70°C to a constant mass for dry weight determination and further chemical analysis. Plant residues were also ground to pass through a 1 mm sieve, and C content was determined by dry combustion (LECO Tru-Spec CN Analyzer, St Joseph, MI, USA). Aboveground biomass C inputs were estimated as the product of the residue C content and dry weights. Residue dry weight and C-input from residues was reported after summing the total C-input over the five seasons. Soil samples were collected at the beginning of the study (soon after land preparation) for baseline analysis and in November 2014, just before the last cropping season. Six soil cores were collected randomly to make a composite sample for each

Table 18.1. Summary of the crop rotation treatments (from Muzangwa *et al*., 2020, with permission).

Crop rotation	Summer[a] 2012/13 (Season 1)	Winter[b] 2013 (Season 2)	Summer 2013/14 (Season 3)	Winter 2014 (Season 4)	Summer 2014/15 (Season 5)
MFM	Maize	Fallow	Maize	Fallow	Maize
MFS	Maize	Fallow	Soybean	Fallow	Maize
MWM	Maize	Wheat	Maize	Wheat	Maize
MWS	Maize	Wheat	Soybean	Wheat	Maize

[a]Summer season months are October, November, December, January and February; [b]Winter season months are May, June, July and August.

plot at two depths of 0–5 and 5–10 cm after removing the surface litter layer. Soils were air-dried and passed through a 2-mm sieve. Particulate organic matter (POM) was determined using the weight loss on ignition procedure as described by Cambardella and Elliot (1992). SOC was determined by dry combustion (LECO Tru-Spec CN Analyzer, St Joseph, MI, USA).

CO_2 fluxes were monitored after 2 years of the trial, every 2 weeks between March and April 2015 as well as during the winter and part of spring (June–October, 2015). An automated soil CO_2 flux system (LI-COR, Lincoln, NE, USA) composed of an infrared analyser, multiplexer system (Fig. 18.1A) and 16 LI-COR 8100A long-term chambers (Fig. 18.1B) was used for the CO_2 flux measurements. One PVC collar with a wall thickness of 5 mm, compatible with the LI-COR 8100A long-term chambers, was inserted in each of the plots to a depth of 5 cm, 1 day before the initial measurement, and was kept in the field during the measurement period. In total, there were 16 LI-COR 8100A long-term chambers, each connected with an air temperature sensor as well as with soil temperature probes inserted into the soil to a depth of 5 cm. The automated soil CO_2 flux system was calibrated automatically using the surrounding air as a reference before each measurement. Each measurement was programmed to take 3 min and two measurements were run for each plot. The CO_2 flux (μmol $m^{-2}s^{-1}$) and soil temperature (°C) data collected by the LI-COR 8100A were stored to the instrument's flash memory and transferred to a personal computer.

Biological activity

Soils sampled for SOC were also used for the determination of microbial biomass carbon (MBC) and soil enzyme activities. The chloroform fumigation-extraction procedure was used for determination of MBC as outlined in Muzangwa (2016). Fluorescein diacetate (FDA) activity was determined by measuring the fluorescein released after hydrolysis of fluorescein diacetate following the method outlined by Prosser *et al.* (2011). The β-glucosidase activity was assayed through the colorimetric determination of p-nitrophenyl released after the hydrolysis of p-nitrophenyl – β-D-glucoside (PNG) (Deng and Popova, 2011). Earthworm biomass, numbers and species identification was done from a randomly thrown 35 cm × 35 cm quadrant. Mustard seed solution (*Brassica alba*) was poured into each quadrant to force the earthworms out to the surface. The soil was also excavated to a depth of 50 cm to capture the inactive and deep-surface earthworm dwellers (Mcinga, 2018).

Soil quality index (SQI)

The Soil Management Assessment Framework soil quality index (SMAF-SQI) (Andrews *et al.*, 2004) was used to quantify the impact of tillage, crop rotation and residue retention treatments. Nine soil quality indicators (used in this tool) were transformed via scoring algorithms into unit-less scores (0 to 1) that reflected the level of function of that indicator in a crop or soil management system, taking into account the differing soil and climatic factors that are known to influence the performance of the indicators. A score of 1 for an indicator represents the highest potential that a soil quality parameter could reach in that particular soil and crop management system. The nine soil quality indicators (fast wetting macroaggregate stability (AGS), bulk density, pH, electrical conductivity (EC), extractable phosphorus (P) and potassium (K), SOC, MBC and β-glucosidase activity) were determined as outlined in Gura and Mnkeni (2019) and used to

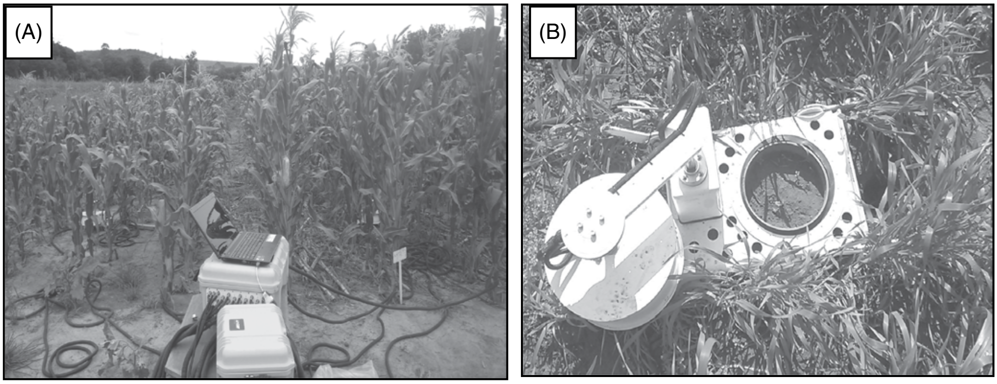

Fig. 18.1. (A) LI-COR 8100A system consisting of the analyser control unit (smaller box) and multiplexer unit (larger box); and (B) LI-COR 8100A gas collection chamber. Authors' own photos.

calculate an SQI after 3 years of applying treatments. The SMAF scores and the SQI were calculated for the 0–5 and 5–10 cm soil depths.

18.2.5 Data Analyses

Analysis of variance (ANOVA) was performed using JMP statistical package version 14.1 (SAS Institute, Cary, NC, USA). Means were separated using the Fisher's least significance difference (LSD) at $\alpha = 0.05$ probability level unless otherwise specified. Orthogonal contrast analyses were performed to find the significance of retaining residues against residue removal as well as inclusion of soybean crop in rotations against cereal-only rotations on significant soil health parameters.

18.3 Results and Discussion

18.3.1 C-sequestration and CO_2 Fluxes

The interaction effects of tillage, crop rotation and residue management are shown in Table 18.2. The treatments were not significant ($p > 0.05$) with respect to cumulative biomass and C output; however, crop rotation was significant ($p < 0.001$). The biomass yields by crop rotations across the treatments followed the order MWM > MWS > MFM > MFS (Muzangwa, 2016). The observed high biomass from MWM and MWS rotations was due to increased cropping intensity associated with these rotations compared to MFS and MFM. Therefore, MWM and MWS rotations can be a solution for the Eastern Cape CA farmers who are often faced with competing needs for residues for retention in their fields and livestock feed.

The average SOC measured from a depth of 0–10 cm after five cropping seasons and application of the treatments was 1.13%, a decline from the baseline average value of (1.58%) (Table 18.2). This could be a result of a shift from the previously more stable ecosystem of the site before the experiment. The average SOC level across the treatments was less than 2% (Table 18.2), thus the plots are still classified as very low in SOC (Landon, 1991) indicating greater C-sequestration potential. POM, which is assumed to be a biologically and chemically active fraction and the easily decomposable pool of soil organic matter, is an early indicator of C-sequestration potential of the tested treatments. Depending on the management practices, POM accounts for about 20% or more of the C in SOC (Carter *et al.*, 2003). In this study, POM after five cropping seasons was more responsive to crop rotation and residue management treatments compared to SOC, but neither parameter was responsive to tillage treatments (Table 18.2). This observation is consistent with earlier research work where POM was found to be a sensitive and appropriate indicator for short-term dynamics of soil organic matter (Liang *et al.*, 2014; Carbonell-Bojollo *et al.*, 2015). Residue management effects on

Table 18.2. Tillage, crop rotation and residue management effects on SOC, POM (0–5 and 5–10 cm depths) and average CO_2 fluxes measured at the UFH experimental site. Authors' own table.

Factor	SOC (%) 0–5 cm	SOC (%) 5–10 cm	POM (g kg^{-1}) 0–5 cm	POM (g kg^{-1}) 5–10 cm	Mean CO_2 fluxes (µmol m^{-2}s^{-1})
Tillage					
CT	1.17	1.15	7.61	5.61	2.26^a
No-till	1.15	1.04	8.36	5.97	1.81^b
p value	ns	ns	ns	ns	**
Crop rotation					
MFM	1.15	1.09	7.50^b	5.89	1.93
MFS	1.16	1.05	8.00^b	5.62	2.04
MWM	1.16	1.15	8.67^a	5.74	2.07
MWS	1.18	1.10	7.78^b	5.93	2.08
p value	ns	ns	**	ns	ns
Residue management					
R-	1.13^b	1.06^b	7.26^b	5.32^b	1.91^b
R+	1.20^a	1.14^a	8.71^a	6.27^a	2.16^a
p value	*	*	***	***	*
CV (%)	8.79	9.31	11.48	13.97	14.75

Different letters in each column and factor indicate significant differences among the treatments. *, significant at 0.05; **, significant at 0.01; ***, significant at 0.001; and ns, not significant ($p > 0.05$). CT, conventional tillage; MFM, maize-fallow-maize; MFS, maize-fallow-soybean; MWM, maize-wheat-maize; MWS, maize-wheat-soybean; POM, particulate organic matter; R-, residue removal; R+, residue retained; SOC, soil organic carbon.

POM were significant ($p < 0.05$) at 0–5 and 5–10 cm depths. SOC levels were only significantly ($p < 0.05$) influenced by residue management at the 0–5 and 5–10 cm depths. Retention of crop residues increased both soil POM and SOC across sampling depths. The observed increase in POM with residue retention is due to the latter being a source of soil organic matter in the soil (Lal, 2010). Maize–wheat–maize (MWM) rotation increased POM compared to the rest of the rotations at the 0–5 cm depth and was consistent with findings by Agomoh *et al.* (2020). Cereal-only rotations such as MWM are suggested to provide greater labile SOM for nutrient cycling. Furthermore, rotations with soybean tend to produce residues with a low C to N ratio, which facilitates fast breakdown of the soil organic matter (Agomoh *et al.*, 2020).

The CO_2 flux across the treatments ranged from 0.28 to 5.47 µmol m^{-2} s^{-1} (Table 18.2) and fell within reported ranges under similar semi-arid climates (Wang *et al.*, 2010). The mean CO_2 flux calculated over the experimental period showed a significant effect ($p < 0.05$) of tillage and residue management, and a higher CO_2 flux was observed with CT than with NT and with residue retention than removal. The observed significant increases in CO_2 flux under CT relative to NT are consistent with the literature (Almaraz *et al.*, 2009; Dendooven *et al.*, 2012). CT is associated with inversion and mixing of the soil, which promotes soil aeration, in turn facilitating the breakdown of soil organic matter and residues by soil microbes (Almaraz *et al.*, 2009; Dendooven *et al.* 2012; Mangalassery *et al.*, 2013). Some research has ascribed the rapid increase in CO_2 flux with tillage to the release of entrapped CO_2 from soil (Reicosky *et al.*, 1997). The retention of residues on the soil surface under NT minimized contact of the residues with soil microbes, reducing decomposition of organic matter and CO_2 flux compared to CT. The observed significant increase in CO_2 flux with residue retention compared to removal is consistent with the findings of Tanveer *et al.* (2013) and Shaaban *et al.* (2015). It was attributed to the availability of easily decomposable organic matter under residue retention, which tends to stimulate microbial activity and CO_2 production (Dyer *et al.*, 2012; Shaaban *et al.*, 2015). The increase in CO_2 flux with residue retention did not, however, lead to a net loss in soil

C-sequestration as the POM and SOC were still significantly increased by residue retention.

18.3.2 Soil Biological Activity

Generally, the findings provided an early indication into the changes in soil health given their variation in response to the CA components compared to SOC (Muzangwa *et al.*, 2020). The tested enzymes and MBC were all more responsive to residue retention than to its removal (Table 18.3). Only FDA was significantly influenced by crop rotation. Crop rotations with high cropping intensity: MWM and MWS increased FDA compared to the other rotations with winter fallows. Tillage practice had a significant effect only on FDA (0–5 cm) and β-glucosidase at both depths. Contrast analysis showed significant ($p < 0.05$) improvement of the MBC and soil enzymes with residue retention and legume rotation compared to residue removal and cereal-only rotations, respectively. This was consistent with the findings of Govaerts *et al.* (2007) who explained the increase as a positive indication of a healthy soil. MBC is often used as an indicator of the overall biological activity as it is central in the transformation of organic matter to plant available elements. Retention of residues provided the extra energy source for microbial growth, hence the increase in MBC. Enzyme assay such as the FDA gives an overall measure of a number of hydrolases such as lipases, proteases and esterases (Green *et al.*, 2006). Therefore, the observed positive changes in FDA with NT compared to CT; certain rotations and residue retention rather than removal give an insight into the potential of these practices to promote soil health (Prosser *et al.*, 2011). β-glucosidase is an important enzyme in the soil agroecology, catalysing the hydrolysis of glycosyl compounds (cellubiose) to labile C and energy sources to support soil microbial life (Prosser

Table 18.3. Tillage, residue management and crop rotation effects on MBC, fluorescein diacetate hydrolysis (FDA) and β-glucosidase at 0–5 and 5–10 cm depths at UFH experimental site. Authors' own table.

Factor	MBC (μg g^{-1} soil)		FDA (mg fluorescein kg^{-1} h^{-1})		β-glucosidase (μmol *p*-nitrophenol kg^{-1} h^{-1})	
Depth (cm)	0–5	5–10	0–5	5–10	0–5	5–10
Tillage						
CT	200.14	135.71	40.92^{b}	29.72	2470.21^{b}	1779.79^{b}
No-till	230.13	147.34	48.92^{a}	27.29	2853.52^{a}	2213.26^{a}
p value	ns	ns	**	ns	*	*
Crop rotation						
MFM	216.02	135.60	39.97^{b}	29.57^{b}	2390.28	2071.11
MFS	223.21	137.92	46.11^{a}	30.78^{b}	2731.11	2058.61
MWM	215.78	143.06	47.09^{a}	33.57^{a}	2705.83	1951.39
MWS	206.49	149.53	46.50^{a}	33.43^{a}	2816.25	1905.00
p value	ns	ns	*	*	ns	ns
Residue management						
R-	194.94^{b}	133.61^{b}	42.59^{b}	29.39^{b}	2210.49^{b}	1750.42^{b}
R+	234.81^{a}	149.45^{a}	47.25^{a}	34.27^{a}	3110.25^{a}	2242.64^{a}
p value	**	*	**	**	**	*
CV (%)	17.48	17.02	8.95	14.52	15.50	16.27

Different letters in each column and factor indicate significant differences among the treatments.

*, significant at 0.05; **, significant at 0.01; ***, significant at 0.001; and ns, not significant ($p > 0.05$).

CT, conventional tillage; FDA, fluorescein diacetate; MBC, microbial biomass carbon; MFM, maize-fallow-maize; MFS, maize-fallow-soybean; MWM, maize-wheat-maize; MWS, maize-wheat-soybean; R- residue removal; R+, residue retained.

et al., 2011). Therefore, the enzyme is critical in the formation of humus, ensuring stability of the soil.

Tillage, crop rotations and residue management consistently interacted in influencing earthworm biomass over the course of this study. Greater earthworm biomass was observed under NT than CT during the first three seasons (2015/2016-summer, 2016-winter and 2016-spring) (Table 18.4). This could be attributed to greater loss of organic matter under CT than under NT due to accelerated oxidation of organic matter during tillage (Crittenden *et al.*, 2014). However, according to van Capelle *et al.* (2012), the positive effect of reduced tillage on earthworms could also be due to the interacting effects of reduced injuries, decreased exposure to predators at the soil surface, microclimate changes and an increased availability of organic matter providing a convenient food source in the upper soil layers. A contrasting trend was observed during the 2016/17-summer season

Table 18.4. Tillage, crop rotation and residue management effects on earthworm biomass measured in 2015/16 summer, 2016 winter, 2016 spring and 2016/17 summer seasons at the UFH experimental site (adapted from Mcinga, 2018).

	CT		No-till		
Factor	R–	R+	R–	R+	Mean
Biomass (g m^{-2}) (2015/16-summer)					
Crop rotation					
MFM	6.16^{h}	13.00^{fgh}	28.02^{cd}	17.51^{ef}	16.17
MFS	10.01^{gh}	18.53^{ef}	14.23^{efg}	31.10^{c}	18.47
MWM	7.91^{gh}	14.74^{efg}	21.46^{de}	41.90^{b}	21.50
MWS	8.63^{gh}	9.97^{gh}	20.51^{e}	50.93^{a}	22.51
Mean	8.18	14.06	21.06	35.36	
Mean	11.12		28.21		
Biomass (g m^{-2}) (2016-winter)					
Crop rotation					
MFM	26.00^{fg}	16.52^{hi}	39.13^{cd}	22.23^{gh}	25.97
MFS	14.34^{i}	16.45^{hi}	24.00^{fg}	30.69^{ef}	21.37
MWM	34.46^{de}	30.25^{ef}	38.27^{cd}	50.78^{b}	38.44
MWS	36.47^{de}	39.38^{cd}	44.68^{bc}	59.35^{a}	44.97
Mean	27.82	25.65	36.52	40.76	
Mean	26.73		38.64		
Biomass (g m^{-2}) (2016-spring)					
Crop rotation					
MFM	26.12^{f}	28.93^{f}	15.65^{g}	62.83^{cd}	33.38
MFS	7.69^{g}	42.67^{e}	33.10^{ef}	53.93^{d}	34.35
MWM	28.61^{f}	74.61^{b}	38.61^{e}	11.63^{a}	38.37
MWS	31.90^{ef}	75.06^{b}	39.32^{e}	117.82^{a}	66.03
Mean	23.58	55.32	31.67	61.55	
Mean	39.45		46.61		
Biomass (g m^{-2}) (2016/17-summer)					
Crop rotation					
FM	59.16^{abc}	64.56^{ab}	29.36^{e}	26.94^{e}	45.01
MFS	51.66^{bcd}	68.70^{ab}	31.81^{e}	28.11^{e}	45.07
MWM	64.18^{ab}	66.97^{ab}	37.52^{de}	37.90^{de}	51.65
MWS	72.68^{a}	77.10^{a}	41.86^{cde}	44.49^{cde}	59.03
Mean	61.93	69.33	3.14	34.36	
Mean	65.63		34.75		

Different letters in each column and factor indicate significant differences amongst the treatments.
CT, conventional tillage; MFS, maize-fallow-soybean; MFM, maize-fallow-maize; MWM, maize-wheat-maize; MWS, maize-wheat-soybean; R- residue removal; R+ residue retained.

where earthworm species biomass was greater under CT than under NT for all three earthworm species observed in this environment. Ernst and Emmerling (2009) observed a similar trend and suggested that the abundance of earthworms under CT in some situations is likely to be related to lower bulk density and increased transport of organic matter to deeper soil layers.

Crop rotations that involved the use of the winter crop (MWM and MWS rotations) resulted in improved earthworm biomass (Table 18.4) as opposed to when the soil was left fallow (MFM and MFS rotations). This was consistent with the findings of Schmidt *et al.* (2003) which indicated that crop rotations involving cereal and legume crops provided food and favourable nutrition which resulted in an increase in earthworm biomass even during the winter season. Fallow periods may render the earthworms inactive as it appears that even under NT (where conditions are assumed favourable), there is low earthworm biomass. Earthworms positively responded to residue retention treatments irrespective of tillage management (Table 18.4). This could be due to the short-term influence of residue retention on moisture availability as well as to organic matter improvement (Riley *et al.*, 2008). Moisture under residue retention treatments is generally more conducive for earthworms, providing stable growth.

18.3.3 Soil Quality

The SQI obtained from the SMAF scoring of nine soil quality attributes showed significant improvement in soil performance with NT and residue retention at both 0–5 cm (Fig. 18.2) and 5–10 cm (Fig. 18.3). No significant influence of crop rotation was observed. Crops under NT with residue retention performed much better under severe drought than those under CT. This observation indicates capacity of NT combined with residue retention in registering significant soil quality improvement in the long term. Aziz *et al.* (2011) explained that soil quality is influenced by the interaction of soil biological, chemical and physical characteristics. Therefore, any changes brought by the CA components resulting in changes in the soil physical, chemical and biological properties is bound to have a compound effect on soil quality, as earlier reported by Islam and Weil (2000).

18.4 Conclusions

The results from the study demonstrated the significance of crop rotations of MWM and MWS and of residue retention without tillage in sustaining soil health under the semi-arid conditions of the Eastern Cape Province. Generally,

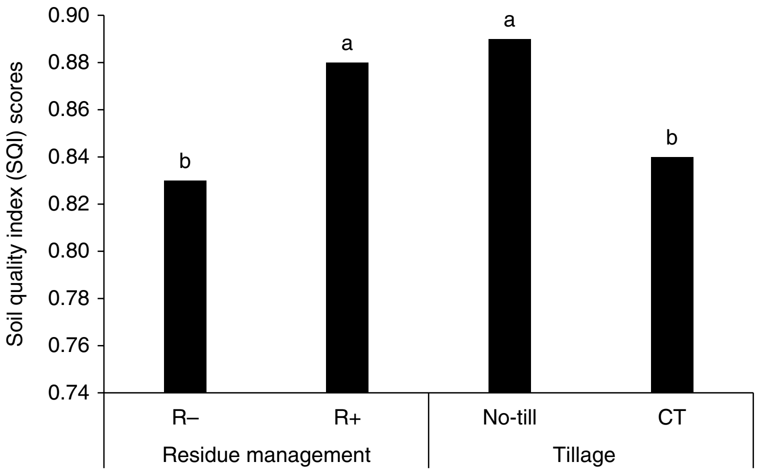

Fig. 18.2. Tillage and residue management on soil quality index (SQI) scores at 0–5 cm soil depth. Different letters indicate significant differences amongst the treatments. Authors' own figure.

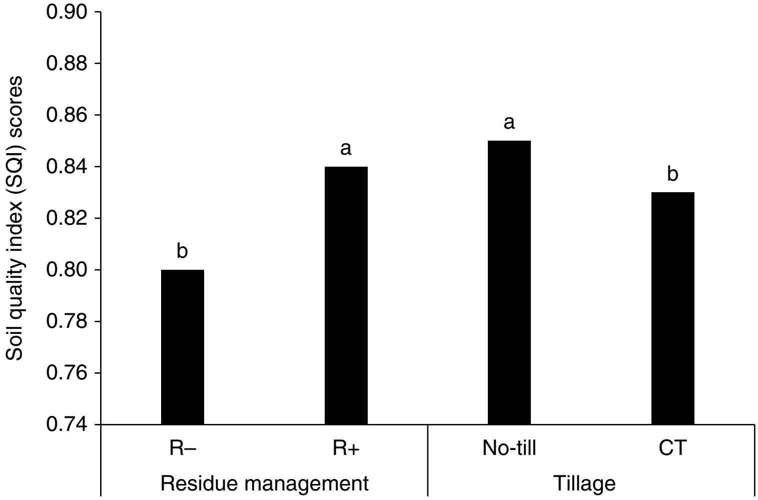

Fig. 18.3. Tillage and residue management on soil quality indexes (SQI) scores at 5–10 cm soil depth. Different letters indicate significant differences amongst the treatments. Authors' own figure.

biomass and C-input were greatly increased by MWM and MWS, hence the rotations may provide a solution to the low biomass production under CA smallholder farms. POM was more sensitive to management changes than SOC. MWM rotation and residue retention had the greatest potential for C-sequestration demonstrated by increased POM values after 3 years of CA treatment application. However, residue retention was the only factor to significantly improve SOC in the duration of the experiment. Soil tillage, which involves ploughing, discing and harrowing, increased CO_2 flux by over 20% compared to NT, underscoring the importance of NT as a climate smart agriculture tool. Residue retention combined with rotations that involve soybean were effective in increasing the MBC and the activities of β-glucosidase and FDA. The response of the biological indicators to crop rotation and residue retention underscores the importance of these management interventions in the maintenance of soil health. On the other hand, earthworm biomass was improved more by NT and residue retention than by CT and residue removal. The calculated SMAF-SQI was significantly improved by residue retention and NT, therefore the practices are considered key in the general improvement of soil quality of CA systems falling under similar geoclimatic conditions.

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19 Formal Education and Training for Conservation Agriculture in Africa

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Abstract

This chapter examines the role of formal education, training and skills development in Conservation Agriculture (CA) in Sub-Saharan Africa (SSA) in the context of the region's agricultural transformation systems. It explores nascent literature on potential reforms that include development of CA educational programmes and linkages that are more strategically attuned to national agriculture development aspirations. The chapter highlights theoretical grounds and practical examples for the multi-level strategies with complementary relationships aimed at facilitating systemic CA-related education, training and skills development to accelerate and expand its uptake in Africa. The chapter has advocated educational institutions and the university in particular to orchestrate the CA innovation value chain through 'internal' alignment of actors at institutional level (i.e. intra-organizational mainstreaming). The success of an innovation also depends on its 'external' viability. This was illustrated by proposing inter-organizational mainstreaming and a triple helix model where government and industry, respectively, are the principal actors towards increase in sociotechnical viability of the CA innovation system. There are obvious hurdles related to the interactions and coordination between stakeholders, as well as the integration of value complementarities across the value chain. Probable corrective strategies have been exhaustively interrogated and they are, for instance, manifested through technical and organizational adaptations as they summarize and compare systematically their contributions, arguments, assumptions and limitations in the process of creating and harnessing economies of scope in innovation. There may not be any ideal model for demand-led, CA-related education, training and skills development. A number of strategic options present themselves and, in a dynamic world, all strategies are relatively short-lived but must yield outcomes that contribute to longer-term goals. The educational institutions should find appropriate themes and avenues worthy of support in their own right, and projects that invite collaboration on their own terms.

Keywords: agrarian change, agricultural transformation, innovation, mainstreaming, triple helix model

19.1 Introduction

By 2050, Africa must double food production to feed its population, which is expected to increase by some 115% within the same period. Thus, urgent efforts are needed to transform agricultural production on the continent, in line with the Comprehensive Africa Agriculture Development Programme (CAADP) framework and the Malabo Declaration to which African governments have pledged their support. The new interventions will need to take into account the challenges to increase agricultural productivity in a sustainable manner to meet the growing global

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demand, while at the same time adapting to a changing climate.

Agriculture is the main user of land and water, a major source of greenhouse gas (GHG) emissions and the main cause of human-induced conversion of natural ecosystems and the loss of biodiversity. Agriculture accounts for around 14% emissions globally, but combined with forestry (17%), they add up to almost one-third of total global emissions (International Energy Agency, 2008). Conservation Agriculture (CA), among other avenues for environmental action, is considered one of the recipes for raising productivity sustainably while reducing the large 'environmental footprint' of agriculture. This new transformational agriculture has been spreading globally over the past two to three decades, including in Africa, but its uptake and spread needs to be accelerated and especially in Africa. In 2015/16 the cropland area of CA in Africa was estimated at 1.5 million ha, which amounted to more than double its area since 2008/09 (Kassam *et al*., 2018). However, given the modest but encouraging gains so far, the uptake and spread of CA in Africa has to be accelerated to ensure that it is able to contribute fully to the sustainable development Agenda 2063 as envisaged in the Malabo Declaration. Since 2015/16, the CA area in Africa has continued to expand at an increased rate in countries both north and south of the equator, including in the dry semi-arid and Sahelian areas, in cropping areas with shrubs and trees. This progress must be accelerated in the coming decades, calling for greater support from Africa's growing network of education and training institutions.

CA has already been shown to be relevant and appropriate for all farmer typologies and mechanization levels in Africa as well as internationally. For Africa, the African Conservation Tillage Network (ACT) and other continental organizations, as well as international organizations such as FAO, have identified several constraints that must be addressed in order to accelerate the uptake of CA. According to ACT (2017a), the creation of an enabling environment must include: (i) the continued expansion of promotion and support of CA-based systems by national public and private institutions; (ii) effective policies and regulatory frameworks and institutional arrangements to support the promotion and mainstreaming of CA; (iii) generation of adequate knowledge about CA systems among policy makers, extension and technical staff; (iv) appropriate CA technology packaging and dissemination; (v) adequate CA-based enterprise diversification and integration in farming systems; (vi) strengthening farmers' ability to diversify crop rotations, sequences and combinations with adequate new knowledge, experience and seeds; (vii) adequate skills and competencies among the farmers and other CA practitioners; (viii) improving farmers' ability or knowledge to generate extra biomass and maintain year-round soil cover through the use of specially introduced cover crops, intercrops and residue; (ix) the availability and affordable access to the required CA equipment, machinery and inputs; and (x) development of a strong continental strategic and policy framework to guide the promotion and mainstreaming of CA-based sustainable agriculture.

It is evident from the needs identified above that the role of education, learning, skills development, innovations and systemic capacity development is of paramount importance to accelerate not only the adaptation and adoption of CA, but also in transforming smallholder farming in Africa from a social sector for alleviating poverty into successful wealth-creating livelihoods and businesses. In their elaboration of enhancing agricultural innovation, Rajalahti *et al.* (2008) presented a framework that places the education and research domain as a primary enabling intervention for change.

A disconnect between academics and/or research in agriculture and the practical realities of its impact to rural farming communities remains a huge paradox on the African continent. The authors have made personal observations of agricultural universities and colleges surrounded by very poor small-scale farmers. While smallholder farmers produce 80% of the food consumed and contribute 15% of the GDP in Africa, most of the poor (82%) live in rural areas, earning their living primarily in farming (Beegle *et al*., 2019). Over three-quarters of the economically active extreme rural poor engage in agriculture as a primary activity (Castaneda *et al*., 2018), while 20.1% of the small-scale producers owning some form of land are extremely poor (De la O Campos *et al*., 2018; FAO, 2018). 280 million of the 780 million poorest people live in high-potential agricultural areas that can be highly responsive to modern production-increasing technologies. ACT strongly advances that, for a prosperous Africa based on inclusive growth and sustainable development as envisioned by the African Union Commission (AUC) in Agenda 2063, education, training and skill development approaches and programmes must be designed to exclusively and mutually contribute to the different critical levels illustrated in Fig. 19.1. The projection by the First Africa Congress on Conservation Agriculture (1ACCA) declaration of reaching 25 million farmers across Africa by 2025 (ACT, 2015), requires knowledgeable and skilled individuals and institutions with access to contextualized and purposefully packaged CA technologies, innovations and services in overcoming adoption constraints.

Articles 14 and 72 (c) of *Agenda 2063 – The Africa We Want* hails Africa's human capital as its most precious resource, to be fully developed through sustained investments based on universal early childhood development and basic education, sustained investments in higher education, science, technology, research and innovation, and the elimination of gender disparities at all levels of education. The vision and roadmap commits to speeding up actions to

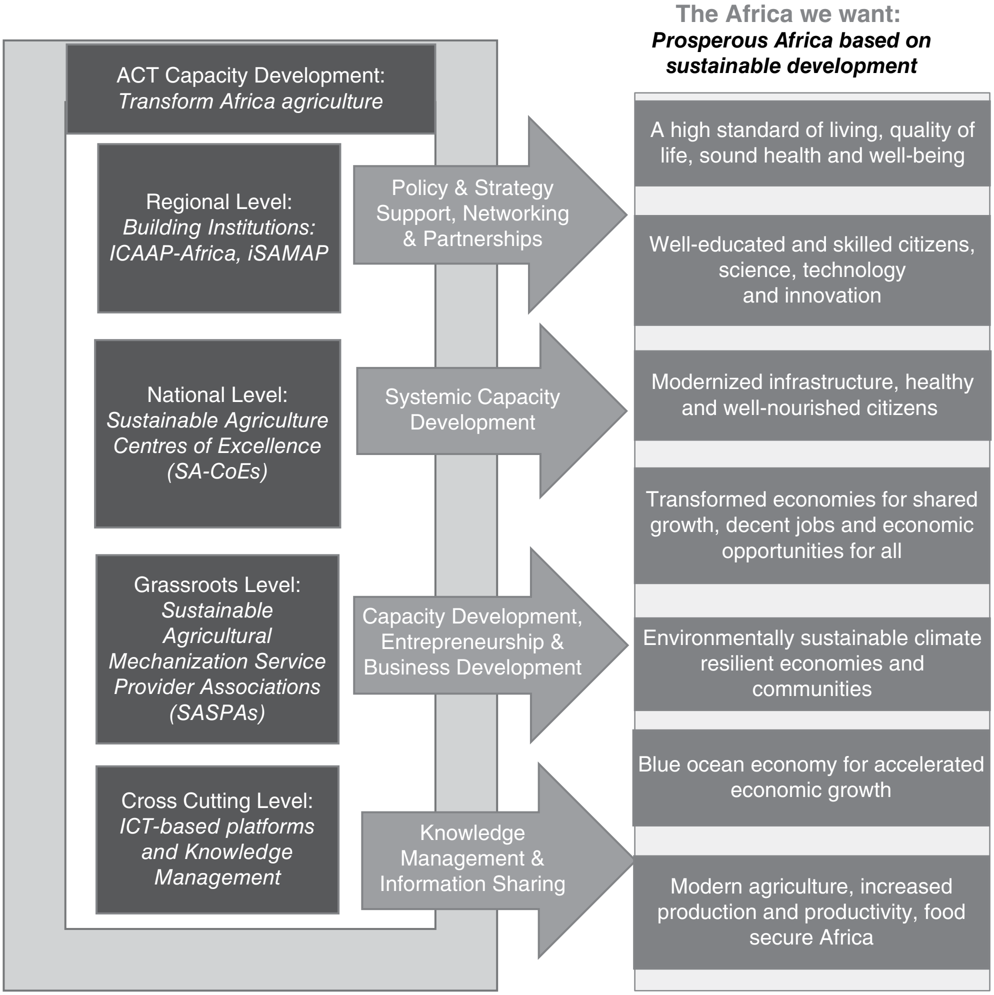

Fig. 19.1. Systemic capacity building elements of the African Conservation Tillage Network (ACT). Adapted from the ACT Strategic Plan (ACT, 2012).

catalyse an education and skills revolution and actively promote science, technology, research and innovation, to build client-focused knowledge, human capital, capabilities and skills to drive innovations for the 'African century' (AUC, 2015).

This chapter examines the role of formal education, training and skills development in CA in Sub-Saharan Africa (SSA) in the context of the region's agricultural transformation and institutional development. It explores nascent literature on potential systemic reforms that include development of CA-based educational programmes and linkages that are more strategically attuned to national agriculture development aspirations. The chapter's main thesis is that embracing shared perspectives, new understanding, and collective commitment for action at intra- and inter-institutional levels (including formal educational institutions) can cultivate favourable environments that yield CA-led agricultural development values. CA must be integral to public and private investments in a unified framework with agricultural-related sectors using innovation capacities of a multi-layered innovation ecosystem involving science and technology, business and national development.

We offer two main contributions: (i) narrative accounts of underemphasized perspective of entry points for formal CA education, training and skills development. A variety of institutional contexts and what they imply for CA education, training and skills development are elaborated; and (ii) forms of stakeholder interaction that may enable a more comprehensive and systematic way to develop strategic relationships for economic and political support of CA. It is expected that formal education and training institutions will find related and other diverse approaches that suit them in order to respond to demands for 'a quality education and training that understands the past, is relevant to the present, and has a view to the future' (Piggozi, 2003).

19.2 Current State of Formal Conservation Agriculture (CA) Education and Training in Africa

There have been calls for an African agricultural university to build a new cadre of agricultural graduates who will go on to become entrepreneurs and wealth creators rather than cogs in the wheels of existing agricultural and related organizations (Davis *et al.*, 2007). There has been gradual progress where universities and other training institutions have established partnership programmes that link young people into training pathways in local industries and enhance their overall workplace knowledge, aptitudes and skills (Minde *et al.*, 2015). Such agricultural-related placements offer increased opportunities for graduates who will be self-employed or embrace start-ups that will offer employment to others along the CA value chains.

Nonetheless, given its relatively recent entry into the knowledge systems in Africa, formal CA education is being offered largely in piecemeal fashion in some education establishments at university and college or institute levels, including formal training establishments. It may be taught as part of the degree or diploma education in agriculture and related fields under the broader subjects such as sustainable production or sustainable development. Often, modules may comprise a few hours of lectures on the components of CA under thematic subject areas such as agronomy, nutrient and water management, pest and disease management and mechanization. CA is rarely taught as a system that integrates the three interlinked principles and is usually side by side or in a continuum to the conventional tillage-based agricultural system practices. All this needs to be brought under a more systematic Africa-wide approach at various levels.

An online search from prominent formal CA knowledge resources for Africa including the ACT (ACT, 2021), Cornell University (Cornell University, 2015) and the Regional Universities Forum for Capacity Building in Agriculture (RUFORUM) (RUFORUM, 2021) showed that there are hundreds of Masters' and PhD theses on CA and related fields that have been conducted in Africa over the past two decades. A few of these theses and aligned publications are available to the public at no cost. Access to the majority requires personal requests from publishers or purchases, which limits access to these very valuable resources for the majority of those in need in Africa. RUFORUM, with an intellectual output materials repository, either in open access or open educational resources, is an exception. It provides free access to postgraduate training and research resources in the agricultural sciences in Africa.

More recently, there has been a move to establishing CA-dedicated formal education institutes and training centres. The Rwanda Institute for Conservation Agriculture (https://www.rica.rw/, accessed 5 August 2021), initiated in 2017, is the first institute in Africa offering a degree course specializing in CA. The institute is a catalyst for CA innovation by committing access to a comprehensive and integrated range of support including space, mentoring, training research and networking to emerging CA professionals. The ACT has also evolved from a focus on capacity building of smallholder farmers, extension and research workers, to building capacity on CA of its institutional membership including researchers and the academia. In the initial 10 years of its operations (2000–2010), ACT focused on capacity development through training of agricultural extension workers and research officers. The focus changed from 2010 to include support to formal agricultural education as well as knowledge management to influence policy change toward CA. To this end, ACT has since directly aided 42 graduates (16 BSc, 23 MSc and 3 PhD) to undertake CA-related studies (Fig. 19.2). Assistance varied from scholarships, internships and external supervision. The African graduate students came mainly from Burkina Faso, Guinea, Kenya, Niger, Madagascar, South Africa, Tanzania and Zimbabwe. Eight of the graduates were from outside Africa: Canada, The Netherlands, UK and USA.

ACT is supporting the expansion and mainstreaming of formal CA education and training through support to tertiary education curriculum development (ACT and ANAFE, 2018) and its CA Centres of Excellence (CA-CoEs) thrust (ACT, 2017b). Development of the curriculum guide involved 15 universities and three national research institutions from 11 countries across Africa. The CA-CoEs initiative has commenced with five centres with a target of 25 centres by 2025. The training functions of the CA-CoEs underscore the need for establishing a quality assurance system for CA training as well as improving the technical knowledge and skills of current and future extension agents (Fig. 19.3). The major development partners to these initiatives include the European Union (ABACO Project in Burkina Faso, Kenya, Tanzania, Madagascar and Zimbabwe), IFAD (SCAP project in Burkina Faso, Guinea and Niger) and the Norwegian Agency for Development Corporation (NORAD) projects in Kenya, Tanzania and Zimbabwe.

Over the past 20 years, several CA projects and research in Africa have generated new knowledge shared using various platforms and publications. Notable platforms are the FAO-operated Conservation Agriculture Community of Practice (CA-CoP), the ACT library and the Africa CA Congresses website (https://africacacongress.org/, accessed 5 August 2021). The first and second congresses on CA have consolidated research experiences from across the continent summarized in their books of condensed papers (ACT, 2014; ACT, 2018a) and book publications (Kassam *et al*., 2017; Mkomwa and Kassam, this volume). The Howard G. Buffett Foundation Centre for No-Till Agriculture, Amanchia, Ghana, is dedicated to CA research and skills development, providing much-needed scientific evidence to inform curricula development.

19.3 Broadening Perspectives on Formal Conservation Agriculture (CA) Education, Training and Skills Development

19.3.1 Cross-sector issues and Conservation Agriculture (CA)-led Agricultural Transformation

In SSA, the estimated structure of employment in the past decade comprised agriculture (58%), household enterprises (22%), wage services (13%), wage industry (3%) and 4% unemployed (Filmer and Fox, 2014). Given the low base and contribution of wage sectors against the millions of young people entering the labour force each year, the projection was that agriculture will continue to dominate the employment pattern. The agriculture workforce is, however, increasingly requiring higher skill levels and qualifications in response to a range of economic, environmental and market challenges (Acker and Gasperini, 2009; UNESCO, 2012). These challenges include: (i) more onerous quality assurance standards; (ii) the use of more complex and ICT technologies on farms; (iii) natural resource constraints; (iv) increased climate variability; and (v) biosecurity requirements. CA education, training and skills development is a

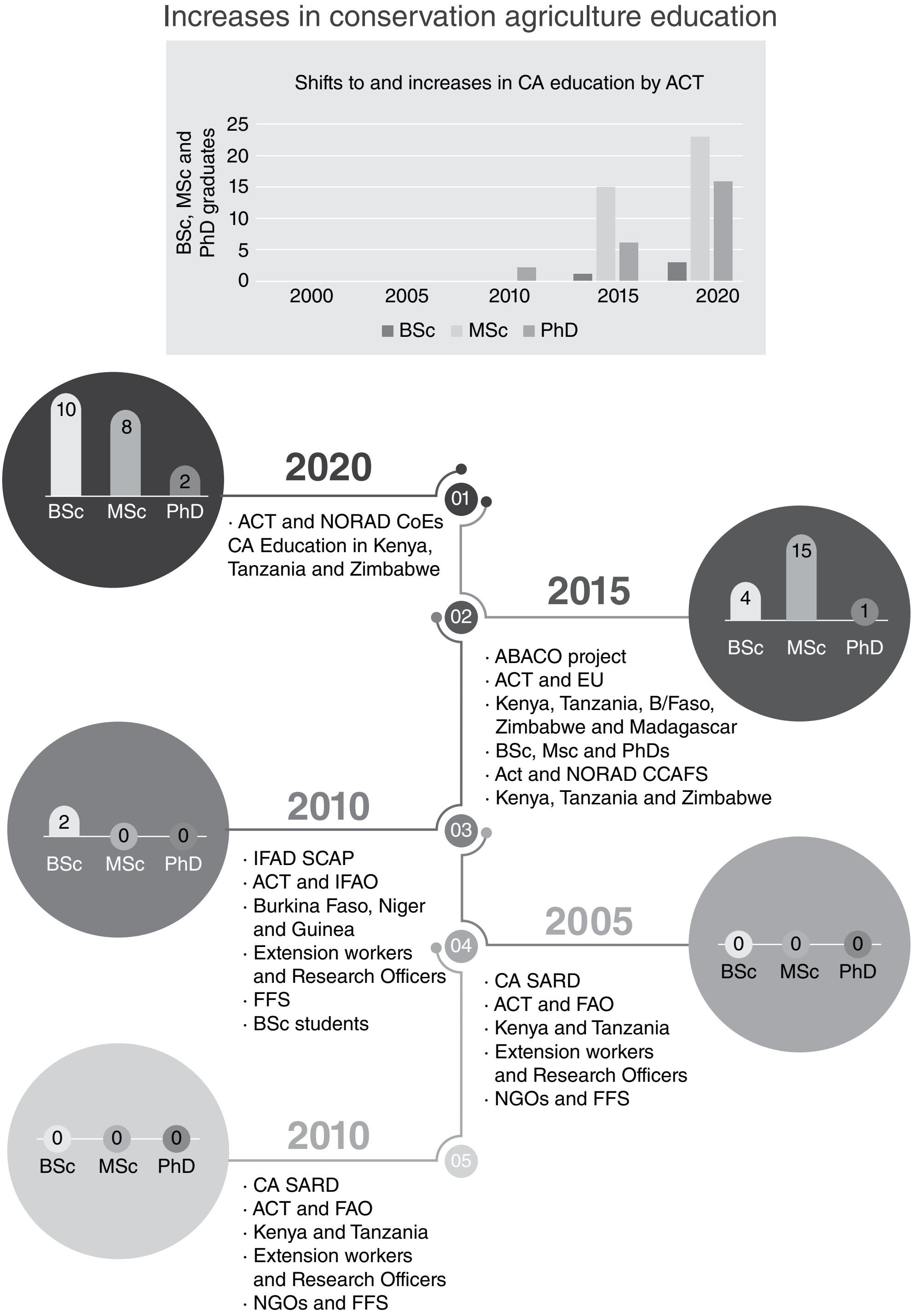

Fig. 19.2. Shifts to and increasing trends in Conservation Agriculture education support by the African Conservation Tillage Network (ACT).

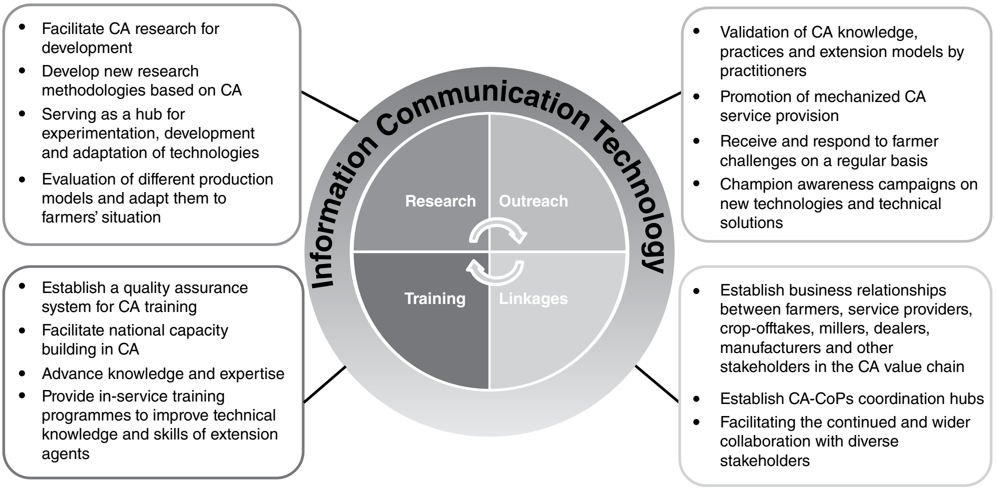

Fig. 19.3. The five key mandates of Conservation Agriculture Centres of Excellence.

critical component of the total effort to bring about agricultural transformation, but it is not sufficient by itself. Programmes and strategies for CA education, training and skills development can be effective when they are nested in a supportive environment of broader national development goals and policy which accord a high priority to and are consistent with the aims of poverty reduction. The damaging compartmentalization of agriculture, education, labour, development planning and other allied sectors need redress to take advantage of the technical dynamism and recognized opportunity for engaging current sustainable agriculture archetypes.

The International Standard Classification of Occupations classifies skill specialization in terms of four conceptual areas: (i) the field of knowledge required; (ii) the tools and machinery used; (iii) the materials worked on or with; and (iv) the kind of goods and services produced (ILO, 2012). This presupposes identification of education, training and skills development processes entrained to the CA value chain in which knowledge, tools, materials, outputs and outcomes are elaborated. Further, the identification of skills to inform occupations is a prerequisite in the design, development and implementation of competence-based CA curricula for different learning cycles (primary to tertiary). Such approaches in curricula development guard against common observations where many agricultural education curricula have been deemed to be unresponsive to socio-economic, technological, physical and environmental changes (DoA, 2007).

Teachers are vital to the success of CA education in schools and they also play a key role in influencing students' attitudes towards sustainable agriculture. In countries where teachers are not registered according to their specialist areas, there is no means to measure whether there are adequate numbers of agriculture teachers and trainers to satisfy the need to update the skills of large and growing workforces, including a need to systemically incorporate sustainable agriculture course content and update curricula in schools and adult education training (Acker and Gasperini, 2009; UNESCO, 2012). To this end, teaching and training personnel in agriculture-related curricula need re-tooling for them to command necessary emergent agriculture discipline content such as CA knowledge, aptitudes and skills. In fact, the changing role of knowledge in contemporary society, which requires the ability to acquire the appropriate knowledge and translate it when needed on the spot, has become more and more important (Gibbons, 1998). Agricultural universities remain well poised to contribute towards retooling the current crop of teachers and tutors through – for instance – training of trainers' initiatives. A range of high-quality teaching resources are available to assist trainers and trainees incorporate CA as a context in the mainstream curriculum. These resources need to be better promoted and coordinated to ensure wider use.

19.3.2 Conservation Agriculture (CA) in Tertiary Education

The constraints to attaining the full potential of CA performance are known and have been for a while but there has not been an appropriate response in research, education and training curriculum content to address the required improvement in the entire CA value chain. There is urgent need for tertiary R&D to position CA as a market-driven agribusiness which can be profitable and dynamic as opposed to being addressed only as an age-old production enterprise. Africa's youth have energy, creativity and strengths in abundance; yet, agricultural programmes have delivered too little and too slowly to meet the needs of Africa's young people (Filmer and Fox, 2014). Given the multiple dimensions of agricultural transformation and the broad range of knowledge, research and capacity building needs for this purpose, the contribution of higher education in this respect cannot be underestimated. The rising cost of graduate education and colossal technological advancement of first world agriculture has rendered untenable the reliance on overseas postgraduate training to educate staff for positions in agricultural education, research and extension. This provides an opportunity to tailor national tertiary curricula to be in tandem with topical agri-environmental issues such as climate smart cropping systems which, fortuitously, are endowed with profuse funding from developed countries and related multilateral agencies.

Tertiary institutions are well positioned to use their resources to assist the public and private sectors to develop strategies to address the opportunities provided by CA training. These resources include a range of academic programmes that are relevant to present and emerging needs of higher level professional and technical personnel for agricultural transformation, including needs of teachers and trainers and designing curriculum and learning content of middle-level institutions. These also include, in the case of agricultural universities, their ability to coordinate and support research that improves the understanding of economic, environmental and social issues, problems and opportunities in current and emerging practices. Filmer and Fox (2014) write that 'Africa's complex agro-ecologies and highly diverse production systems demand a level of original research comparable to that undertaken elsewhere in the world'. The continent is still reeling from decades of neglect and underinvestment in agricultural research though there has been marginal increase in resources devoted to research in some countries (AGRA, 2013).

19.3.3 Conservation Agriculture (CA) in Schools

Agriculture has been reported to have a negative image as a career choice in the eyes of youth who see it as the work of the poor and the elderly (Mafunzwaini *et al.*, 2003). Filmer and Fox (2014: page 117) writes that to attract young people, agriculture will need to be more dynamic and appealing than it is now, and young people will need to view the sector more positively. The farms that offer attractive opportunities will have to be quite different from those that young Africans know. To this end, there should be a greater focus on improving the agricultural literacy of all learners in primary and secondary schools and supporting existing schools to deliver high-quality sustainable agriculture education programmes. It is not sufficient to use agriculture as an elective or for it to provide context for teaching subjects such as geography or science. An accurate and balanced curriculum in agriculture, comprising tenets of CA farming practices, should be promoted within the discipline-based learning strand which contains the subject areas in which students are expected to develop a knowledge and understanding.

Second, the inability to address the unemployment of primary and secondary school leavers and the need to develop the curricula to begin preparing them for alternative careers remains a challenge yet to be addressed by educational systems (African Union, 2014). Further, there appears no recource for the dropout population, which refers to learners who were enrolled in school but never finished their education, or for out-of-school youth who never enrolled in schools. Using South Africa as an example, Minde *et al.* (2015) reported that demand for university graduates accounts for only 6% of the agri-food system labour force. They suggested that building agri-business career skills in the early stages of the educational system is of paramount importance for agriculture's contribution to national economies. It is accepted that general primary and secondary education is the foundation upon which young people, will build their livelihoods and acquire the vocational and technical knowledge and skills that they need to take advantage of the new opportunities (Acker and Gasperini, 2009; UNESCO, 2012). School farms at these levels help to enhance a learner's engagement in agricultural education and practice. There is a need to support schools to maintain existing farms and agricultural facilities and to encourage schools to link with local farmers and industry.

An effective approach to meeting skills needs of practising young farmers has been through the Junior Farmer Field School (JFFS), advocated by FAO, and piloted in several African countries with varying levels of adoption by public and private institutions (FAO, 2007). In retrospect, the JFFS further represents added value as an avenue for bridging the intergenerational learning gap between the agriculture offered in time-bound curricula in schools against the real-time agriculture that farmers are exposed to by various extension agents. Temu *et al.* (2010) noted that farmers' knowledge is acquired through life experiences in the farming landscape and enables development of an intuitive sense of how the integrated system works and how to make decisions. In contrast, formal education is offered in discipline-specific courses or programmes where graduates are often unprepared for a reality that is dynamic, complex and uncertain in rural settings post-school.

19.3.4 Conservation Agriculture (CA) Learning Community

Tertiary institutions could also support development of need-based value-added services like identification of user groups, innovators and entrepreneurs in various CA functional areas. Education, training and skills development is needed, to stimulate a suitable CA-led entrepreneurial environment which will allow second-chance youth and adult learners to enter the agricultural sector and undertake attractive, profitable and sustainable enterprises. Education and training is not a preserve for those who traversed the corridors of schools and colleges. Mulder and Kupper (2006) suggest that if critical sustainable agriculture and natural resources messages are to be widely disseminated in society, the content of these must be researched and packaged for second-chance learners and vulnerable members of society who are constituents of a learning society (Box 19.1). Other principal components of lifelong learning, considered in the context of this chapter, include second-chance non-formal basic education, adult literacy, vocational training, and farmer training, with support of community-based multi-media training facilities. Farmers are an important niche where learning occurs through a number of ways that continue to evolve and perplex scholars (Lunn-Rockliffe, 2020). They are endowed with limited resources and in their quest to optimize the same, bottom-up and peer-sought solutions which respond to local interests and values are produced. In pursuant of sustainable production systems, adoption of farmer field school approach is favoured against what have been characterized as 'soft-instructions' methods (Putter *et al.*, 2011).

Intensive vocational training courses are considered the most effective way of delivering retraining for specific new tasks or job opportunities (ILO, 2011). To function effectively and to become the building blocks for lifelong learning in a CA learning society, these must have technical support in designing programmes, training personnel and evaluating the effectiveness of activities (Ahmed, 2014). Thus, opportunities to

Box 19.1. Rights-based education and training

Civil society organizations have been pivotal in identifying vulnerable sections of society to be empowered, to defend their right and to enhance their quality of life. Attention is drawn to responsible stakeholders in the CA value chain to address the educational and training needs of orphaned and vulnerable children, the physically challenged, single- or grandparent-headed households, or households affected by HIV and AIDS.

participate in or interact with tertiary agricultural education programmes and institutions would be an advantage for either institution. A key feature of such institutional interface would be the development of content that enables learners to design, develop and manage their own business along the CA value chain. For example, a vocational centre may be delivering curriculum in mobile power and machinery that could iteratively be pivoted to CA mechanization needs and entrepreneurship. NEPAD and CAADP (2013) reported on a project that integrated sustainable vocational training for the agriculture sector aimed at young people across Africa. The work illustrated an implementation process to establish expertise required for developing successful CA value chains using farmer training centres or technical and vocational training (TVET) centres. TVET qualifications are often issued by registered training organizations and can be delivered in a range of ways. Minde *et al.* (2015) bemoaned the lack of agricultural curricula in TVET colleges in most countries in southern Africa compared to South Africa where ten (out of 50) TVET colleges offer agricultural programmes, thereby meeting the skills needs of the agriculture sector.

19.3.5 Information and Communication Technology (ICT) and Media

Advances in ICT have opened new frontiers, not just in delivering learning content in new ways, but also in meeting the prevailing challenges related to sharing, exchanging and disseminating knowledge and technologies. Rasoanindrainy (2017) noted that on the continent, radio penetration is at 75%, mobile phone penetration rate at 43%, while mobile internet penetration is at 26%. Some African countries are advanced, with internet users reaching more than 50%, while many are still lagging behind at less than 10%. In respect of skills development, some of the areas of interest are delivering content in creative ways, reaching new groups of learners at a time and place of their own choice, enriching the teaching and learning process, improving management information and upgrading teaching personnel.

In a study on how ICTs are used in the CA knowledge pathways in Laikipia County, Kenya, Achora *et al.* (2018) concluded that new emerging and existing communication technologies have a very high potential to improve agricultural knowledge flows if taken advantage of by the 'change agents' in the diffusion process of new innovations. New online technologies and social media have emerged as platforms for collaboration and for sharing of product and market information. The opportunity of using real-time communication tools has been greatly embraced, especially by youthful farmers, and the advantage of these new emerging tools is their unique attributes. They are similar to the traditional oral cultures of communication seen in African social systems where one can see, hold a discussion, get immediate feedback and use the written media to convey messages.

One influence on agricultural career aspirations is the poor image of agriculture among the youth. Information and communication technologies are important to promote a more professional and modern image of farming. The industry associations within the agriculture sector could work collaboratively at the national level to develop comprehensive online agricultural careers hubs that improve the profile and image of agriculture. Henceforth, exploiting existing infrastructures, targeting more youth, and creating and disseminating more content are considered pivotal in scaling up ICT innovations for CA. Database and data warehousing technologies can be used to store and retrieve large amounts of information and also can be coupled with mobile and internet technologies to deliver information instantaneously to users in the CA value chain.

People not involved in farming remain almost invisible to agricultural researchers, policy makers and agrarian movement activists, but can be very powerful in transforming national policies. The media community remains an important constituency that entrains the public conscience on topical issues through learning, understanding and imparting knowledge on social, economic and environmental platforms (Javier, 2018). The media profiles developmental interventions to a broader audience, creates awareness, and shares and promotes the adoption of new innovations and lessons learnt. Joubert *et al.* (2011) writes that science is not always easy to understand, and making sense of conflicting scientific or technological claims can make it even more of a challenge. Science and technology developments often include elements of risk, controversy or uncertainty and CA breeds the same (Giller *et al*., 2009; 2015). Given responsible conduct in knowledge valorisation, universities and researchers are strategic conveners and often serve as a neutral space for partners to share strategies and results. These elements should form the basis for effective and systemic development and implementation of CA training and learning programmes or projects with journalists and media houses, who often consider factors outside agricultural production paradigms.

In many contexts, media workshops and toolkits have been developed for a network of journalists and media at the exclusion of researchers or intended public recipients. The African Technology and Policy Studies Network (ATPS) challenged this notion when it held a ‘write-shop’ on maximizing the impact of research through science communication at Naivasha, Kenya, on 18–20 June 2007. The write-shop was attended by over 40 researchers, artists, journalists and policy makers from more than 14 African countries, as well as by experts from Europe. The desired outcome was to create understanding between the technical language of scientists and the simple language of artists, journalists and policy makers. This model of communication transformation provides a format where individual, organizational and institutional functional capacities can enable collective learning, joint analysis and collaboration without ambiguity in various settings and contexts.

19.3.6 Resource Mobilization and Cooperation

A greater effort has to be made to mobilize domestic resources, while better allocation and use must be a key element in the effort to close the educational resource gap in general, while directing resources to achieving agricultural transformation through CA-based investments. The longstanding target of devoting a minimum of 0.7% of GDP as international assistance for poor countries appears to have receded for many of the largest industrialized economies. Nevertheless, agriculture is the entry point for interventions in environmental protection in African countries. The large ‘environmental footprint’ of agriculture continues to provide many avenues for environmental action. Environmental protection and climate change financing should be designed and utilized for education, training and capacity building, as these provide synergy in the objectives and strategies of enhancing skills and capacities, while coping with vulnerabilities from land degradation and climate change – the tenets of CA. Resources could be deliberately devoted to incentives for CA teaching, training, action research, case studies, performance standards and assessment of CA work.

Ekboir (2003) and Kuehne *et al*. (2017) noted changes sought to increase research impacts through the introduction of more formal planning methods; management by objectives; and new funding procedures, especially competitive grants and sales of goods and services. These changes have tended to weaken research systems because such funding procedures are better suited to repetitive tasks than to highly uncertain and changing research processes. Non-governmental organizations (NGOs), rather than structured research institutions, appear better at such tasks and show a propensity to scale-out complex and novel technologies such as CA that require substantial biophysical and socio-economic adaptations. It is considered that informal or direct interactions are more important in the early stages of a technology because there is greater uncertainty about the market potential, technical standards, the assets commanded by other agents and network participation (Ekboir, 2003). In this respect, the National Task Forces on Conservation Agriculture (NCATF) established a decade ago under the aegis of FAO should have provided an optimal investment framework. At the inception of NCATF a work-package funding framework for more concerted networked interventions and field actions integrating policies, educational and research programmes favoured by multilateral agencies was anticipated. To date, across Africa, there is an inordinate reliance on funding sourced by individual researchers and foreign institutions, albeit underlain by incongruent perceptions of the place of CA in agrarian change.

Indeed, while research institutions decry a paucity of grants for research and ancillary infrastructure, there appears a windfall of support for CA-related social research founded on settling dichotomous theoretical perspectives on development trajectories. According to Borras (2009: page 13), the first theory holds that the 'cause of poverty of the rural poor is their being excluded from the market and its benefits; the solution is to bring the market to the rural poor, or the rural poor to the market'. The other perspective which Borras (2009: page 13) elaborates is where the 'cause of poverty is attributed to poor people's insertion into particular patterns of social relations; the solutions therefore are transformative policies and political processes that restructure such social relations'. The development policy interpretation of CA has covered much ground in SSA in the past two decades, almost aligned to these twin political economy trajectories. In retrospect, this has allowed R&D priorities related to the emerging CA paradigm to be set by the theoretical arguments that development involves. Yet, investments in CA-led agrarian transformation aimed at an end-to-end value chain approach remain at low ebb. Further, outcomes will ever remain at sharp variance with the value proposition for agrarian change if CA is viewed as epitomizing 'projects' that generate 'high visibility and quick returns' and are summarily evaluated (Mloza-Banda and Nathambwe, 2010).

ACT, through international, regional and institutional cooperation, could collate and broker the role of CA financing in the diffused undefined landscape of skills development, where it is almost impossible for stakeholders to estimate what resources are available for what purposes and how these could be utilized. The existing regional structures of cooperation and exchange in education such as the Association of African Universities (AAU) should be mobilized to play their role in promoting a CA-led sustainable agriculture agenda. The AAU, for instance, in collaboration with UNESCO and UNEP, holds a rich experience in mainstreaming environmental education in higher education institutions. There are many regional agencies and networks in the education sector of SSA that could be encouraged to embrace their special responsibility that will bring out the common regional characteristics of situating emerging agricultural paradigms in education, training and skills development.

19.4 Transition to Conservation Agriculture (CA)-led Systemic Change in Education, Training and Skills Development

Numerous models have been proposed to respond to the institutionalized divisions between research, teaching and extension that continue to obstruct adaptation and success of agricultural education and training in Africa. On one hand, education and training institutions – with their mission of developing human capital – need to be adept at adapting to new patterns of demand. They need to provide proper mechanisms for identifying emerging needs towards reforming curricula and academic management through tested methodologies. The other call is for restructuring institutions to achieve collective goals of preparing professionals to operate in complex environments, offering access to a network of scientific and technical information, and disseminating new technological advances (Davis *et al.*, 2008). In either case, it appears that if the institutions change or are restructured, then they will ameliorate knowledge performance and help those who demand knowledge products and services from the institutions. The converging view is that whereas stronger or restructured institutions may increase the supply of new knowledge and new technologies, the effort may not necessarily correlate very well with the capacity to innovate and adopt innovations throughout the agricultural sector or with economic growth (Rajalahti *et al.*, 2008). Rather, effort towards building capacities in agriculture to identify linkages between agriculture and other sectors will be important in obtaining educational and training outcomes that support resilient ecosystems and sustainable economic development (AGRA, 2013).

This chapter proposes three models for enhancing systemic CA-related education, training and skills development to accelerate and expand its uptake in Africa. The first and second models may be referred to as intra- and inter-organizational mainstreaming, respectively. They comprise collaboration and networking with other departments, individual sections or, outwardly, with stakeholders. The third strategy is the triple helix model which focuses on the interaction between university, government and industry. The agricultural development agenda in many African countries remains uncertain owing to one development perspective being strongly promoted against another and the resultant unfulfilled promises of globalization, decentralization and privatization in agrarian economies (Ndhlovu, 2020). The failure of these development models to make systemic improvements in Africa have now had untold intractable and debilitating consequences for more than half a century. Education and training institutions, which have since been largely recalcitrant in the national development landscape, need to challenge all forms of dysfunctional ecosystems. They need to use their privilege and opportunities to affiliate or orchestrate alliances and partnerships, inspired by the principle that success in agrarian transformation depends upon the collective impact of multi-sector partnerships which have mission alignment or synergy informed by emerging sustainable practices (Rajalahti *et al.*, 2008). In illustrating this call to challenge the status quo, a strengths model is recognized that countries already have various robust initiatives linked to CA and on whose basis they shall further develop impetus towards the objectives of integrating CA into educational programmes, sectors and industry.

19.4.1 Intra-organizational Mainstreaming of Conservation Agriculture (CA) into Education, Training and Skills Development at Universities, Colleges and Schools

The sustainable crop production intensification approach elaborated by FAO (2011) focuses on 'opportunities for optimizing crop production per unit area, taking into consideration the range of sustainability aspects including potential and/or real social, political, economic and environmental impacts'. These are complex issues which require trans-disciplinary examination involving researchers, managers, planners, policy makers and end-users. Success in trans-disciplinary knowledge valorisation demands leadership, scientific competence, shared goals and strategic planning, continuity, flexibility in action, adaptability and proficient programme management. Elsewhere, these elements have been summarized as endogenous capacities to generate, systematize and adapt knowledge, and to adopt and up-scale new practices (Nichterlein *et al.*, 2015).

Such qualities cannot be provided elsewhere by educational institutions without themselves undergoing personal and institutional transformation and henceforth exhibit credibility and legitimacy. One way institutions can project such sincerity is by engaging academic management aimed at educating their students and staff to inspire CA-led production paradigms. In addition, credibility is also based on judgments of the product (e.g. skills set of graduates) and associated services promoted. To this end, educational institutions are beholden to promote, catalyse and support the mainstreaming of CA into their teaching, research, academic management and community engagement curricula. There are a number of practical reasons why integrating CA education and training into institutional norms and practices has become increasingly relevant. Five key motivations include: (i) a university's recognized role in a knowledge-based society; (ii) building social capital and improving employability of graduates; (iii) reduction in financial support for academics and research; (iv) addressing socio-economic and biophysical complexity of agrarian change; and (v) gaining public trust in science and technology as a vehicle for societal development. It is beyond the scope of this article to provide a full analysis of all relevant factors pertinent to change in curriculum, management and other practices through mainstreaming process in educational institutions. Intra- and inter-organizational mainstreaming is considered to be context-specific, depending on challenges facing an entity or country, and the capacities of cooperating partners.

There are different possibilities for analysing policy or strategy integration, ranging from an in-depth investigation of policy/strategy processes in the social science research tradition, or analytical approaches based on a set of integration criteria, to a pragmatic analysis of the targeting of policy/strategy instruments on the issues to be addressed in a given sector. Additionally, there is also need to evaluate the usefulness of the currently available information framework itself to support the assessment for integration (Basch *et al*., 2006; European Environment Agency (EEA), 2006). For instance, the ACT established a quality assurance framework for CA training and practising institutions in Africa that contributes to an information framework which enables a systematic approach to modernizing education systems by improving the effectiveness of CA programmes and projects (ACT, 2018). The quality assurance components for CA-practising organizations include those in Fig. 19.4.

At the Africa region level, NEPAD's Agricultural Education and Skills Improvement Framework 2015–2025 recognizes the need for a quality assurance framework with appropriate monitoring and evaluation, self-assessment, accreditation mechanism and the dynamic development of training that responds to the different demands of various target groups. At the Regional Conservation Agriculture Symposium, Johannesburg, South Africa, 8–10 February 2011, it was argued that CA education and training is conducted almost entirely outside the formal frameworks of education management systems that are governed by laws and regulations determining the nature and scope of national qualification frameworks and their associated national qualification authorities. The Conservation Agriculture Academy, a private sector service provider, initiated a CA curriculum design and resource development project. Courses were designed for season-long in-service clientele and based on farmer field school approaches (Putter *et al*., 2011). The task was steered through global collaboration based on baseline standards for the South African formal education framework with potential for recognition within the Southern African Development Community (SADC) Transnational Qualifications Framework. The ultimate goal was to enable independent projects and institutions to adapt these model resources to award accredited CA-specific qualifications. In 2018, a master CA curriculum guide for Africa for tertiary agricultural institutions was developed by ACT in partnership with NORAD and collaborating academia and research institutions. The free-to-adapt curriculum has since been followed by development of national university CA training modules that

Fig. 19.4. Components of standards and indicators for Conservation Agriculture-practising organizations (from ACT, 2018).

are adapted and dedicated to flexible training needs and agroecologies (ACT and ANAFE, 2018).

There exists a rich exemplar resource originated in the programme for Mainstreaming Environment and Sustainability in African Universities (MESA) (Lotz-Sisitka *et al.*, 2015). It was established to strengthen capacity development and environmental innovation through practical education, training and networking in African universities supported by a 10-year action plan. A change-oriented learning model was used to interrogate curriculum, management, policy, research and community outreach changes and developments in 66 Higher Education Institutions in 25 countries in Africa. Box 19.2 summarizes the pillars of the MESA's partnership programme.

The programme also identified constraints to implementation of action plans abridged in Box 19.3. The issues appear typical but they are highlighted to show that participating agents in the CA education and training undertaking, through adoption of a diversity of change-oriented practices over time, effect new or refined or reconstructed conditions that can negate the identified constraints (Lotz-Sisitka *et al.*, 2015).

Box 19.2. Summary of elements of the MESA's partnership programme

Environment and sustainable development (ESD) innovations course developed and implemented by partners.

Pilot courses held for university professors from African universities.

Seminar for university leaders to develop a common understanding about the MESA universities programme.

Student environmental leadership workshops to raise awareness and spread new thinking about environment, development and society among students.

A biennial conference providing an opportunity for universities to report on ESD innovations.

Pilot programmes linking universities, communities, business and industry in sustainable development partnerships.

Dialogue sessions with corporate sector and government to link them up with universities on research and pilot projects, and aimed at solving specific environment and development issues.

An annual innovation award for participating universities and awards for students.

This chapter challenges agricultural universities and colleges in Africa to step up and revolutionize the mainstreaming rhetoric that appears in workshop reports, and to adopt transformative mainstreaming models that translate into land-based CA interventions. For instance, on the continent, the historical development of the practice of CA (then termed conservation farming) is traced to Brian Oldrieve at Hinton Estates in north-eastern Zimbabwe in the late 1980s. The emphasis was reduced tillage and mulch retention, and the owner is credited with a publication on the practice (Oldrieve, 1993). Experiences at this estate and at any other, witnessed by visiting academics, researchers, extensionists and policy makers, are not only of historical interest in terms of processes of innovation and adoption that they involved. They may also have relevance for agricultural universities and colleges to mainstream CA modelled using an 'own-farm approach'. The modest suggestion is for university institutions to secede part of their teaching or commercial farmland and implement CA tenets based on a holistic CA value chain or ecosystem approach. Elsewhere, such systemic campus-based eco-innovations have been termed 'green campuses' (Sharp, 2002), 'green growth strategies' (Beltramello *et al.*, 2013) or 'sustainability in higher education' (Lozano *et al.*, 2011). It is time public and private

Box 19.3. Constraints to implementation of MESA action plans

Institutional constraints: rigid institutional structures, unsupportive administrators and colleagues, inability to bring in other stakeholders from outside the universities due to inhibiting structures and lack of qualified/enthusiastic staff.

Monitoring and Evaluation (M&E): M&E needs to be well thought through at project design level. Most projects that were not doing well seem not to have incorporated this aspect into their planning.

Knowledge gap in environmental field: In some institutions the project could not take off due to lack of knowledge about ESD; environment-related activities were considered a luxury. Students also needed more depth of what ESD and sustainable development meant to their lives.

Resource constraints: lack of finances, materials and human resources; inadequate financing from regional and global agencies.

sector teams, decision and policy makers, journalists and farmers visited universities to appraise a microcosm of agrarian change. At school level, perhaps few models supersede the JFFS Approach (FAO, 2007). At its onset, it integrated into practice intergenerational knowledge transfer for sustainable agriculture by connecting the learners with agricultural teachers, curricula and school gardens on one hand, with their guardians, farming enterprises and extension agents on the other. It thus approached mainstreaming, taking into account the learner's ecosystem through bridging or creating a systemic theoretical, practical and entrepreneurial learning environment across the school and homestead landscape.

19.4.2 Inter-organizational Mainstreaming of Conservation Agriculture (CA) into Cross-sector Programmes With University Brokerage

The current trajectory of agricultural education and training can largely be attributed to colonial systems that focused heavily on formal education as a means of preparing a corps of professionals and civil servants to staff administrative ranks (Cletzer *et al.*, 2016). These dissected administrative sectors have largely been maintained post-independence in many countries as ministries or departments, or else modified into authorities or parastatals underlain with a strict code of ownership, administration and management of sector missions. The duty rests on the instigator of a new vision to navigate their way through this triad of codes to engage agrarian development processes. It remains a truism that, for more than a century, our immediate world (made up of farming families on one hand and government on the other) has grown up under the aegis of what is termed conventional tillage-based agrarian terrain. Alarming environmental and climate-related problems affecting agricultural production have provided the impetus for inquiry into the current and alternative nature, scope, pace and direction of agrarian transformations and development.

Boras (2009) writes that the development policy and academic world do not have consensus about the causes and consequences of agrarian development processes. This chapter adds that even within each camp, there is disparate discourse, often leading to desperate measures in supporting agrarian change. Further, the scientist–policy interface lacks trust; and, to build trust, durable relationships and synergy among researchers, professional institutes and political leadership are needed. The stakeholders of agricultural development are often many and diverse. Government agencies, NGOs, civil society organizations, local self-governments, banks and the corporate sector all have a role to play in fomenting CA education, training and skills development. The major objective of the dialogue within and among stakeholders is to engage in analytical thinking and consultations on understanding and diagnosing opportunities for practical sustainable agriculture interventions led by education, training and skills development (Kassam *et al.*, 2011; Kassam *et al.*, 2014).

National Task Forces on Conservation Agriculture (NCATF) were established through the support of FAO, to facilitate and institutionalize processes through which different stakeholders themselves customized the CA agenda to play their roles. The task forces were to guide the development and provision of a nationally coordinated, effective, responsive and quality-assured CA. In varying ways, educational institutions were sought to carry out the R&D activities and programmes as well as education, training and skills development for CA. These national task forces evolved in a number of ways in different countries in response to renewed strategic directions for agricultural development, or determined priorities of national CA initiatives, or to address attendant challenges (Box 19.4). Evidence, however, points at these new forums as suffering from a work culture that does not promote intensive networking as part of common practice, as exemplified by NCATF experiences in Malawi summarized in Box 19.4 (MAIWD/COMESA, 2011). Rajalahti *et al.* (2008) write that, when networks develop formal structures, they may become absorbed in organizational and administrative issues at the expense of conducting the strategic business for which they were conceived.

More recently, under the aegis of ACT, cooperating partners, national and regional governments/research and educational institutions, there has been an emergence of new mechanisms and cultures aimed at facilitating greater network formation. CA Centres of Excellence

Box 19.4. NCATF experiences in Malawi

Experience in Malawi showed that the NCATF were a coalition made up of individuals and institutions that volunteered to subscribe to the NCATF. The NCATF therefore attracted some, but not all, CA providers in the value chain. CA providers sent representatives with varying levels of expertise and authority to the NCATF strategic meetings. Some institutions sent different representatives to consecutive meetings. It had neither functional representation of other departments in ministries of agriculture or in other key ministries nor in the private sector. They exhibited lack of disposition and capacity for networking.

(CA-CoEs) or CoPs have been proposed and/or established as public research and/or training institutions dedicated to the goals and showcasing the widespread adaptation and adoption of CA (ACT, 2017; Mampholo, 2017). Key areas of their contribution have included (but not limited to) research, outreach, linkages, education and training, and IT-supported M&E and knowledge management (Mampholo, 2017). Whether CA-CoEs or CoPs are complementary to NCATF or their successors, the poor mechanisms and infrastructures for sharing and exchanging agriculture knowledge generated from research or university outreach educational programmes at national and regional levels remain entrenched.

The multi-functionality of CA reinforces the obligation to integrate it into mainstream agriculture and to other sectors allied to agricultural development. The potential of integration has been recognized as a way of leveraging what exists, adding value and seeking inclusion in development paradigms. Yet, there remains the serious challenge of how to make it happen systematically, at much greater scale and with much greater effectiveness even within the sector itself, as is the case in point for CA whose integration has been riddled with false starts. The First African Congress on Conservation Agriculture of 2014 recommended 'governments to create conducive environment for the adoption and development of CA by investing more in CA education and extension; integrating CA training in educational curricula, and supporting CA farmers and their organizations'. In line with this proposition, this chapter argues that universities champion agrarian change through brokerage of CA mainstreaming in agriculture-related governance arrangements. The university institution needs a sustained relationship with government and allied institutions, being a key domain in the creation, mobilization and utilization of knowledge for development.

It is beyond scope of this chapter to arbitrate amongst the various schools of thought or interrogate the many studies that have offered advice for increasing the efficiency and effectiveness of inter-organizational science–policy interfaces leading to sustainable (agricultural) development. Nonetheless, in addition to policy or strategy integration frameworks (European Environment Agency, 2006), both scope and entry point are highlighted to emphasize the need for clarity in discussions about integration as well as systematic interaction approaches. In terms of establishing scope and mandate, Wamsler and Pauleit (2016) recounted that sustainable change will remain elusive as long as understanding of mainstreaming remains naive among protagonists. They identified normative (e.g. political leadership, overall policy frameworks, policy-making culture), organizational (e.g. integrated departments, new coordination mechanisms) and procedural (e.g. assessment procedures) factors at different policy-making stages of the mainstreaming process. In turn, these factors embody different mainstreaming strategies or levels that are complementary to achieving sustainable transformation. They were identified as add-on, programmatic, managerial, inter- and intra-organizational, regulatory and directed mainstreaming strategies. Each of these strategies is supported by core principles, tools and considerations needed to optimize engagement critical for success.

Termeer *et al.* (2018) elaborated a systems-based problem framing where the nature of change being sought 'consists of interconnected activities and outcomes embedded in a dynamic environment driven by social-ecological change and leading to multiple feed-forward and feedback signals'. van der Molen (2018) summarized a framework for enabling well-informed governance arrangements that recognizes regulatory, adaptive and integrative elements of governance capacities. Regulatory capacity infers knowledge creation and mobilization as enablers or constituents of regulation; and monitoring and iterative processes permit adaptive capacity and governance renewal in non-linear systems. Integrative capacity is built by incorporation of a variety of knowledge forms and diverging knowledge systems. A related principle, transformative capacity, addresses the challenge of transformative change (Termeer *et al.*, 2018). The present agricultural economies based on precepts of conventional tillage-based production edifices have in place a time-honoured set of regulatory, adaptive and integrative structures. Governance institutions are known to be highly resistant to transformative change, owing to mechanisms where current decisions are determined or limited by decisions in the past, reflecting vested interests and historically grown power positions (termed path dependencies) (Sehring, 2009). If a university must competently support groups of actors to connect knowledge with action, it needs to be flawless in the skills and roles of knowledge (regulatory, adaptive, integrative, or transformative) it brings for CA-led agrarian transformation.

Rose *et al.* (2017) suggested that there exist specific moments in which the ground is fertile for the uptake of scientific knowledge into policy, otherwise a process may fail or take longer outside these windows. As a broker, the university should, therefore, undertake an initial situation analysis of the dynamics of stakeholders, issues, institutions, power and politics to identify engagement entry points or triggers. These underlying forces are summarized as problem streams (e.g. crisis events or lethargic patterns), policy streams (e.g. new technologies) and politics streams (e.g. change in administration). Proactive vigilance is required since windows of opportunity are usually short-lived and open only occasionally, and issues rise and fall regularly from a government's agenda. Elsewhere, efforts have been undertaken to compile guidelines and checklists as well as translate general principles into consecutive steps for multi-sector integration programmes (UNDG, 2009; OECD, 2014).

19.4.3 Triple Helix or Learning Alliance Model of Collaboration

In a knowledge economy, universities are instrumental in knowledge valorisation at the centre of which is the triple helix model or learning alliance that advocates strategic interactions and collaboration between universities, industry (or with societal/not for profit organizations) and a government body or agencies to drive commercial and social innovation (Draghicia *et al.*, 2015; Sarpong *et al.*, 2017). The argument is that knowledge production does not take place only at the university but in a complex relationship between the three entities. Rajalahti *et al.* (2008: pp. 21–23) qualified the term 'learning alliance', stating that whereas other multi-stakeholder platforms (mainstreaming) focus on co-ordination or joint programmes, they rarely have a clear central focus on knowledge generation and management. The learning alliance incorporates knowledge and experiences from a range of sources and recombines this content into a shared prototype to test and improve leading to locally captured mutual outcomes.

Termeer *et al.* (2018) observed that agri-food systems inherently involve many subsystems that impact activities and outcomes across a range of spatial, temporal and jurisdictional scales, and involve a wide range of public and private actors. University–industry–government partnerships have emerged as one way of connecting different policy/strategy subsystems and increased market participation by those that create, mobilize and utilize knowledge products and services reminiscent of actors in the CA value chain. Cooperating actors achieve a certain level of integration concerned with joint identity, joint strategy and joint goals that maximize exchange of information and knowledge, co-creation of new knowledge and innovation. The model yields collective entrepreneurship where the three institutions work collectively to learn and (re)direct science and technology research attention to productive and predefined outcomes.

The value proposition herein is that a university must immerse itself in industry-linked solutions where it promotes CA-led education and training as vital to industry, and with a proven potential impact on the economy. In fact, at all levels of education, institutions should evolve into organizations that federate and co-ordinate constitutive agents who can innovate and foment CA-led agricultural production through the CA value chain relationships in which industry is an integral player. For instance, at local level, the executing agencies of this model would involve schools and colleges (education), agrodealers (industry) and agricultural extension agents (government). The Sasakawa Global 2000 programme (SG2000) that ran for about 15 years across 12 countries in southern, East, and West Africa illustrates a pragmatic grassroot triple helix model of innovation. In all countries, SG2000 followed a development pathway approach where projects were aligned with national agricultural programmes while working within governmental structures, with an extension staff provided and paid for by the government. Agrochemical and/or seed companies were courted and became integral to these partnerships. In Malawi, for example, Mloza-Banda and Nathambwe (2010) wrote that the programme heralded the first attempt to promote CA at broad scale at smallholder level and remains the reference point for serious CA promotion in the country. The agricultural university began to address new research agendas such as biophysical and socio-economic *ex ante* and *ex post* evaluations and equipment needs and portfolios through bespoke partnerships. The SG2000 partnership runs against the notion that the triple helix model focuses predominantly on macro-level theorizing at the expense of micro-foundations required to institutionalize the concept (Sarpong *et al.*, 2017).

The success of the university in valorisation of the triple helix model should not absolutely lie in the commercialization of academic work or creating external income streams through reshaping research agendas that exploit industry sources of funding (Salleh and Omar 2013; USAID, 2015). Rather, it should partner development of a skills set that empowers intersectoral alliances or subsystems that can innovate politico-economic dimensions of agriculture where CA is embedded as a catalyst for competitiveness at micro- and macro-levels. The following examples, related to input–output patterns and agricultural mechanization contexts integral to CA innovations, are intended to illustrate entry points for the relationship between business practitioners, academic researchers and government in innovation collaboration.

The first example relates to farmers' adoption of CA. Similar to other innovations, it has been wrought with challenge related to inputs – labour, machines and equipment, fertilizers and herbicides – that are all industry-based. Addressing changes in agrarian structure over the last six decades, Yogeshwari (2013) writes that developing countries are still supporting parasitic structures and interventions which extract surpluses from poor farmers through organizations, credit or other market operations, but they are not in the first place supportive of lessening the input burden. Farmers are unable to break their subordinate position in the input–product market, and the market or the states are unable to prevail against intermediaries.

A university could place before government and industry a CA-led tripartite model that addresses the input dilemma with concomitant investments in secondary products, crop–livestock integration or industry-linked commodities against the current preponderance of actors all supporting local primary production. Value chain innovations from sustainable agricultural intensification practices to support recalcitrant livestock sectors, or steering production paradigms linked to food manufacturing sectors, remain muted at best with rudimentary displays of cottage-level processed products at field days and agricultural fairs. Lessons addressing the agrarian change debate abound, with some showing that the greater the distance to the major market, the lower the propensity for farmers to intensify or diversify (Djurfeldt *et al.*, 2018). Non-staple food and cash crops have often been deemed sensitive to markets over long distances, especially under African conditions. Production of such crops, forlornly under the aegis of government or NGOs, is thus mistakenly directed towards volatile or unavailable local markets, instead of national or international ones. Academia should argue pragmatically whether CA-led agrarian change is a case of new wine in old bottles with respect to the ceaseless input–product market dilemma. Will the CA-led production paradigm address the prevalence of the semi-servile condition of the majority of the agrarian population?

Another example is where the university is being encouraged to pursue CA-led national perspectives on farm power and machinery/equipment/energy use and management aspects under the aegis of the triple helix model of innovation. There is a critical shortage of professionals with interdisciplinary orientation and possessing professional skills at different levels of agricultural mechanization to support innovation systems that transcend technological and socio-political landscapes. The South African higher education system is credited as an example of good practice for the continent in general when, in 2012, students studying science, engineering and technology accounted for more than one-quarter of all university enrolments (African Union, 2014).

ILO (2014) revealed that 70% of power on SSA's farms comes from manual labour and that agriculture alone represents 60% of all child labour. Women comprised about 33% of the agricultural labour force worldwide, ranging from less than 10% in Latin America and the Caribbean to more than 60% in South Asia and SSA (Verschuur, 2019). These alarming statistics call for contextual conceptualization and operationalization of household labour roles that mechanization will unearth or unbound. For instance, while it is acknowledged that not all women will benefit equally from labour-saving technologies, introducing culturally appropriate labour-saving technologies that reduce women's time and energy burden is a means of promoting economic growth and reducing poverty (Kienzle *et al*., 2009; Carr and Hartl, 2010). CA changes the organization of work at the household level and there is need to understand and implement complementary inputs in an optimal manner in order to yield labour-saving benefits that CA may bring (Wall, 2007).

Perhaps the question of who is disproportionately affected by the drudgery of conventional manual labour and who may stand to benefit from tools and equipment has failed to find the appropriate answers that should be sought from providers or lead policy makers of mechanization. For instance, mechanization is often equated to implements for ploughing or weed control. Biggs and Justice (2016) reported that the spread of smaller-scale equipment in Bangladesh, such as two-wheeled tractors which make up 46% of the total tractor horse power engines, was their use as mobile multipurpose power units. Rural entrepreneurs used them on their own holdings and hired them out for multiple services such as no-till (NT) operations, transport of people or goods, pumping water and powering threshers. Thus, small-scale equipment in rural economies is used in multi-sector ways which bureaucracies and policy frameworks that dominate planning fail to conceive. The engineering units of the universities and technical colleges that produce the professionals who generate and disseminate agricultural and related engineering knowledge and technologies are central to developing institutional models of CA equipment value chains based on new synergies among university, industry and government over the foregoing conventional agrarian system. Beyond models, the education institutions need to support performance-based education and skills curricula alongside the long-held education legacy of science and arts. Aligning youth engagement in agriculture and allied sectors through formalized and supported education and training in engineering with mechanization provides the creation of safe, decent and competitive agricultural careers for the youth and intergenerational development dividends. The plan of action for a sustainable agricultural mechanization initiative for Africa led by AUC-DREA with technical support of FAO and ACT as Secretariat (AUC, 2017) needs to consider the university–industry–government nexus as a critical value driver.

19.5 Summary and Conclusions

19.5.1 At Institutional Level

CA knowledge valorisation requires the application of coherent interventions that would increase both the income and adaptive capacity of farmers for diversified, as well as resilient, agriculture. Out-scaling of CA practices requires farmers' participation for effective technology transfer, besides validation, refinement and adoption. In this context, convincing farmers (which goes beyond filling the knowledge gap) would require linking science to society. In pursuance of this, a paradigm shift from routine, component-based short-term investigations to innovative, result-oriented, system-wide long-term research technology development is warranted. Curricula and pedagogical changes are necessary for educational systems to produce learners/graduates with the knowledge, skills and attitudes that enable sustainable food security, improve livelihoods and facilitate natural resource conservation that CA represents. There is a need to undertake processes for updating agriculture education and training curricula at primary, secondary, vocational and tertiary institutions, juxtaposed with improvements currently delivered to farmers. The capacity to integrate CA considerations into agriculture and related education and development programmes and policies is improving, but the need for additional entry points has been identified.

19.5.2 At National Level

Strong universities that can successfully collaborate in delivering CA-led systems of production and economic governance are needed. Africa has 15% of the number of Asia's researchers and only 3% of North America's researchers and is thus consequently subject to externally driven agriculture R&D agendas. Agriculture must be placed distinctively and decisively within a political economy framework at the highest level of practical, methodological and operational processes governments follow in effecting people's sovereign livelihoods (van der Ploeg, 2020). To this effect, both the inter-organizational mainstreaming and the triple helix models place CA in a politico-economic dimension. It is considered that the ideal typical interaction model of stakeholder interaction builds on different perceptions of science and innovation and their roles in society that must be reconciled according to context (Rajalo and Vadi, 2017; Sarpong *et al.*, 2017, Knaggårda *et al.*, 2019). Nonetheless, the innovation ecosystem concept emphasizes the integration of value complementariness across the value chain which enriches the ecosystem as a whole (Xu *et al.*, 2018). That is why universities must shore up their competences through intra-institutional CA mainstreaming so they present specific 'niches' or strong links to the CA-led value chains.

19.5.3 At Regional Level

It is estimated that, in 2015/16, CA was practised on 1.51% of total cropland area in SSA compared to 63.2% in South America, 28.1% in North America, 45.5% in Australia/New Zealand, 4.1% in Asia and 4.3% in Europe (Kassam *et al.*, 2018). African agrarian economies are thus presently being driven by conventional tillage-based agriculture which shares certain assets (components, processes, knowledge, people or relationships) with CA. These shared assets and subsystems could allow the principle of 'economies of scope' and 'economies of substitution' to prevail as robust CA developments on the continent allay the disinclinations of socio-political and economic perspectives of CA-led agricultural development (Panzar and Willig, 1981; Garud and Kumaraswamy, 1995). Academia remains integral to identifying interconnectivity between subsystems of the two agrarian systems and to facilitate innovative recombination of the same in order for CA to make a quick difference to Africa's agricultural malaise. This is premised on the commitment of African governments to spending at least 10% of their national budgets on agriculture to raise agricultural productivity to at least 6%, and for investments in agricultural trade-related capacities (NEPAD, 2003). ACT should endeavour to place CA-related education, training and skills development at continental political level through the African Regional Flagship Programmes, the Action Plan of NEPAD, Africa Union Agenda 2063 and the Post 2015 SGD – Goal 4 (Education). The Action Plan seeks 'to generate and scale-up action in all levels and areas of education and learning in order to accelerate progress towards sustainable development'.

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20 Strengthening Conservation Agriculture Education in Africa

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Abstract

This chapter brings together recent developments and ongoing efforts in Conservation Agriculture (CA) education in Africa. It covers areas related to online education and training including CA Massive Open Online Courses (MOOCs), CA-based education and training capacity, CA curriculum development and CA quality assurance. An overview of emerging opportunities in CA education and training are elaborated in general, as well as through specific efforts of institutions such as the African Conservation Tillage Network. CA-based land use transformation occurring in Africa, and the growth of related supporting activities in public and private sectors, represent an important area of opportunity for education and training. It also offers opportunity for youth to develop their vocational and professional careers in the food and agriculture sector.

Keywords: MOOC, online learning, mainstreaming, open source, capacity development, curriculum development, quality assurance

20.1 Introduction

New and innovative ways of delivering education and creating online Conservation Agriculture (CA) communities of practice for a regional and global student population take advantage of web-based communication technology. A recent attitude of democratizing education has spawned the dawn of free web-based courses referred to as Massive Open Online Courses (MOOCs). Although the concept of distance learning has been around in the Western hemisphere since 1728, the students and size of courses delivered outside of high school and university campuses has grown phenomenally, thanks to the arrival of the internet. Just one of several educational technology (EdTech) companies offering MOOCs, Coursera.com, has over 70 million subscribers today. This technology-based education distribution system can now offer quality CA education and training opportunities to a much wider and more globally dispersed audience.

The questions we set ourselves for this chapter are: through MOOCs, does the general public have an opportunity to learn about CA? Is CA education represented in this unfolding teaching/learning pathway? If CA education is not presented and agriculture MOOCs are promoting conventional agriculture, could this be hindering the uptake of CA? Could the CA farming system, if mentioned, be misrepresented?

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Another set of CA education issues relates to progress occurring in Africa in the area of CA curriculum development for tertiary education in Africa, and the resources and capacity available to develop CA-focused courses and modules. CA-related research and knowledge in Africa and globally has been growing at an accelerated speed as more investment is directed towards CA research. Equally important and related development activity in Africa has been the development of CA education capacity at the tertiary level. Along with this has been the appreciation that there is a need to integrate and exercise quality assurance due diligence responsibility by stakeholders dealing with the CA education and training development in Africa. This chapter outlines some of the related developments in the area of CA curriculum, curriculum resources and capacity, and quality assurance. These aspects of CA education and training are important and support the implementation of the Malabo Declaration and Agenda 2063.

The section on MOOC in this chapter is based on the findings of a literature survey of English and Spanish language web-based open source free courses hosted on EdTech companies and international institutions. We searched for MOOCs teaching about climate smart agriculture (CSA) and sustainable agriculture, broadly defined. Course listings from university websites were not included because MOOCs are distinct from online university courses. Although MOOCs are created and facilitated by universities or training institutions, they are designed for a global audience that chooses not to or cannot attend university or that wants a general introduction to a subject. MOOCs are offered for free. They range from 3 to 9 weeks long. There are several models depending upon the subject, the university and the rules of the EdTech company. University online courses, on the other hand, are fee-based.

The major EdTech companies host course management systems (CMS) within which universities create MOOCs. Among these companies are Coursera.com (www.coursera.com, accessed 5 August 2021), edX.com (www.edX.org, accessed 5 August 2021) and Futurelearn.com (www.futurelearn.com, accessed 5 August 2021). Many development-related institutions are also creating agriculture and environmental sustainability MOOCs; among these are FAO, World Bank Group, Sustainable Development Goals Academy (SDG), Inter-American Development Bank and United Nations Institute for Training and Research (UNITAR).

In the survey, which was intended to locate teaching material about CA in MOOC format, we also studied the course content of many agriculture-related MOOCs to ascertain if information about CA principles and systems were included and/or explained in any part of the course material as part of sustainable solutions to agricultural and environmental issues.

The information on CA education capacity development and curriculum development, as well as the information on quality assurance, is based on the work of the African Conservation Tillage (ACT) Network. Over the past 5–7 years, ACT has been active in these activities, as part of its strategic plan, in collaboration with many African education and training (as well as public and private sector) organizations. ACT has promoted the concept and strategy of the development of CA Centres of Excellence (CA-CoEs) across Africa in collaboration with universities, research institutes, extension programmes and private sector organizations (ACT, 2017). This experience provided the useful information shared in this chapter.

Given that there are now attempts to integrate formal CA education in colleges and universities in Africa, curriculum development activities are becoming increasingly organized. CA-based development of the food and agriculture system would require a constant supply and availability of well-educated graduates and postgraduates who have basic knowledge and understanding about CA and are specialized in conducting good-quality scientific research on CA systems and practices across Africa. Thus, ACT has been investing its efforts in the area of CA curriculum development for Africa (ACT and ANAFE, 2018). This information is included in this chapter.

ACT has also promoted the idea of self-regulating quality assurance (QA) responsibility for all stakeholders promoting CA education and related activities (ACT, 2018). Their work, done on the development of QA and its application, provides useful information that is included in this chapter.

20.2 Education Opportunity Offered by MOOCs

We canvassed the web landscape of major EdTech companies hosting MOOCs from many universities, analysing courses in English and Spanish related to agriculture, especially sustainable farming or CSA (Shah, 2018). We found that there were dozens of MOOCs on agriculture, soils, sustainable development, water management, soil health, the future of farming, etc. – all created by leading universities claiming to educate the student in issues of sustainable agriculture and possible solutions (e.g. Wageningen University, University of Western Australia, University of Florida, University of Lancaster and University of Reading).

We were unable to locate any MOOC on CA *per se*, except one MOOC in Spanish being offered recently from the Universidad Nacional de Cordoba, Argentina, 'Introduccion a la Siembra Directa' (https://courses.edx.org/courses/course-v1:UNCordobaX+AG001x+2T2018/course, access available only on registering).

However, we located several instances of CA being mentioned in sustainable agriculture-related MOOCs. For example, one mention of the need to reduce the amount of tillage occurring in vineyards was in a MOOC from the University of Reading, 'The Future of Farming'. Another instance was a case study evaluating the economics of land conservation in a MOOC from the University of Western Australia in 'Agriculture, Economics and Nature' (UWA, 2018).

In the University of Reading MOOC, no explanation of CA was given; rather, it was mentioned as a 'minimum soil disturbance' method for maintaining soil health in vineyards. The explanation of CA and its three interlinked principles were not explained. In the University of Western Australia, CA was presented as a 'package of farming tools' (no-till [NT], cover crops, crop rotation) which farmers tended to choose from and not to adopt in their entirety. As can be seen from the quotation below, the overall impression given about CA is not positive and would not likely inspire students who want to explore more into the benefits of CA.

> While though this (CA) is being quite widely promoted throughout developing countries, particularly in Africa and South Asia, it really hasn't been that widely adopted in those countries. And this is a bit of a contrast to at least some parts of the developed world. There's quite a bit of this type of agriculture in Australia and in North America, some in South America. But in the small holder type areas, areas with smaller farmers, smaller farms in Africa – southern Africa, particularly – and South Asia, **the adoption of these practices has been quite disappointing**...The yields may get worse before they get better, particularly if nutrients are not added and that crop residues that are retained and left on the soil surface are not available to be used for other things.
>
> Professor David Pannell, University of Western Australia

There were also instances within a MOOC where solutions to environmental problems such as soil erosion were being discussed and would have been a logical place to insert the benefits of CA. However, specific non-CA solutions were explained. Here are two examples: The solution for soil erosion given by the University of Lancaster is for farmers 'to flatten their fields as much as possible'. Their solution to stopping the run-off of chemical pollutants into waterways is to dig deep ditches and/or canals along the sides of the fields into which the pollutants and sludge will collect. They do not explain what to do with those pollutants once the channels are filled. ('Soils', University of Lancaster, coursera.com.)

These examples are indicative of how 'disputed' information can be disseminated through a MOOC to an audience that may be looking at the world of farming for the first time. MOOCs have the potential to broadcast globally to thousands of students a misrepresentation of the reality on the ground. Regarding the comments given from the University of Western Australia: if truth be told, globally, CA was being practised in 2015/16 on more than 180 M ha of cropland, with South America having the largest CA area, not just 'some in South America', as Professor Pannell indicates.

The teaching content in two MOOCs from two other major and influential agricultural institutions (Rothamsted and Wageningen) discussed solutions to unsustainable land use along the lines of updating the tillage-based 'Green Revolution' agriculture. One example is that increasing yields and combating degradation and loss of soil health are to be found in 'a basket' of solutions – modern seeds, modernized agrochemicals, min-till, contour ploughing, bunding, terracing, planting trees, agroforestry practices, etc. Several of the lectures are presented outside, with a backdrop of a deeply ploughed field. In course material from these two institutions there is no mention of a CA or NT farming system, no recognition that maybe a new system of farming might be needed or even considered.

We have established that there is disinformation from even highly regarded agriculture departments and institutions which will be taken on board by people who have no background in agriculture nor knowledge against which to judge the Green Revolution recycled solutions, systems and practices with which they are being presented.

The spread of internet-based communication technology has been accelerated by the COVID-19 pandemic. The virus forced many to work from home, attending meetings, conferences, training workshops and even more university courses via the internet. Such web-based communication does not have the same quality as face-to-face interaction, but it has proven to be very cost-effective, underscoring further the usefulness of MOOCs.

Internet users' statistics for Africa (https://www.internetworldstats.com/stats1.htm, accessed 5 August 2021) indicate that internet penetration as a percentage of the population in March 2020 was 39.3% compared to 62.7% in the rest of the world, although there is immense variation among countries (ranging from 89.8% in Kenya to 5.3% in Burundi). On the bright side, the region has shown a readiness to embrace full digitization. It has seen the highest rate of increase in internet use and connectivity in the world over the last two decades and is home to a young and dynamic population. Over the same time period, the number of internet users in Africa has increased more than 116-fold, from 4.5 million to 523 million, while that in the rest of the world did not even double (Ghanem, 2019). With its large numbers of imaginative and creative youth, Africa stands to benefit immensely from MOOC-based CA learning.

In conclusion, from this general internet search which found no English language MOOC-CA specific courses on offer, there is obviously opportunity for taking CA education to another level, another boundary, beyond standard institutional teaching of out-of-date agriculture, and into the EdTech realm of globally offered MOOCs. Making available to the CA community, particularly African CA Centres of Excellence (CA-CoEs) promoted by ACT (ACT, 2017) and their national and international collaborators, the opportunity to add CA introductory information to their curriculum in MOOC format, would offer the following benefits:

1. Provide to a wide audience correct information about CA systems and their adoption process. The correct information would help to combat and expose messages of misinformation.
2. Facilitate networking among the CA-CoEs and share curricula to help equip the next generation of workers with the knowledge and practice of CA.
3. Provide a platform, enabling responses to questions by experts, and encourage discussion in the general public to include broader and on-demand CA-based elements of rural development.
4. Educate the public; this would also contribute to putting pressure on policy makers to change agriculture policy to support CA.
5. Provide affordable and easily accessible agriculture education.
6. Expose students and educators to modern, web-based teaching and learning methods.

We wanted to get an idea of the number of people enrolling in these MOOCs, but were informed by the companies involved that the number of enrolled MOOC participants and their profiles is confidential information of each university or institution, thus there was no way to have information about the extent to which an education opportunity of this kind would benefit women and youth. However, when enrolling in the MOOCs in order to view the course content, one can see on the forums that there are thousands of posts from all around the globe. Thus an assumption may be made that there is an interest in and demand for information about the challenges and solutions to environment and agriculture issues.

MOOCs are now a powerful and impacting source of education globally. They have the potential to influence the public's attitudes towards the role that agriculture plays in environmental issues and, more importantly, attitudes and knowledge about solutions to develop sustainable agriculture which are of interest to policy makers. The vast knowledge and experiences from the farmers who are successfully practising CA can be freely shared to a global audience of all ages.

African-produced MOOCs can be a pathway to African universities debuting on the global stage with proven case studies and introduction of African CA experts. Following up on these ideas would be to build on the eLearning platform that ACT has already created.

20.3 CA Education and Training Capacity Development

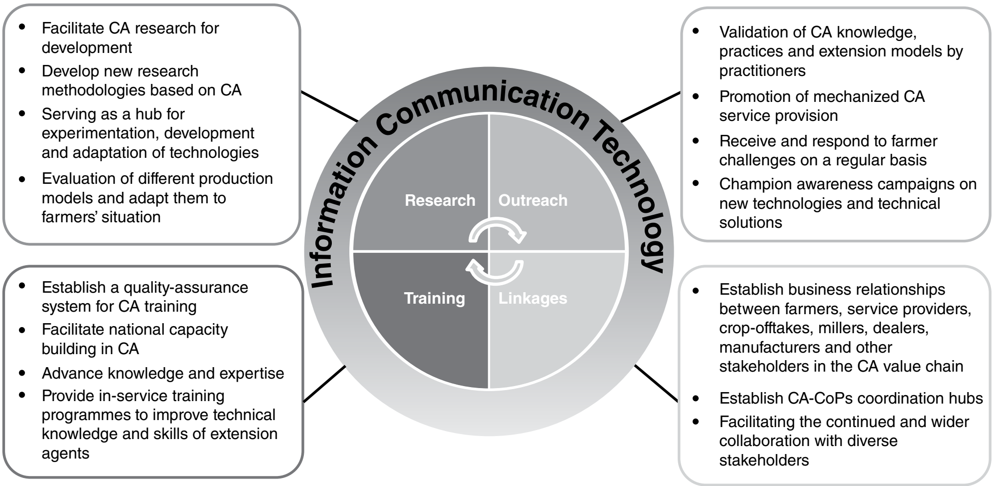
ACT is a pan-African not-for-profit organization that has evolved into an open platform for stimulating and facilitating the sharing of information and knowledge on experiences and lessons in promoting CA. ACT brings together stakeholders in the public, private and civil sectors dedicated to improving agricultural productivity and resilience in Africa's farming systems through the sustainable use of production inputs, and of natural resources of land, water and biodiversity. ACT's thrust is to add value to local, national and international efforts to scale CA. It does this through strategic partnerships that identify, adapt, adopt and scale up CA practices.

The ACT partnership strategy provides the basis of collaborating with various agriculture-based organizations or institutions in different regions explicitly to promote CSA. No single actor, no matter how effective they are, can tackle today's agricultural productivity and environmental challenges alone. ACT strongly believes in growth of partnerships for enhancing its effectiveness in scaling up adaptation and adoption of CA and natural resource management sectors. Effective networking between ACT and its partners continues to allow lesson learning that leads to impact, is beneficial and sustainable. Its head office is in Nairobi, Kenya, and it has a sub-regional presence in southern, eastern, West, Central and northern Africa. ACT works in partnership with national agricultural research institutions and academia across Africa, commonly identified as future Conservation Agriculture Centres of Excellence (CA-CoEs).

Partnership building is emphasized in the ACT 2013–2022 strategic plan (ACT, 2012), which identifies capacity building and partnership as one of the six thematic areas. Strengthening institutional, individual and corporate private sector players and the farming communities' capacities in the uptake and use of CA is essential. One of the pillars identified to enhance this strategic focus is through partnering with CA-CoEs, where demonstrations, research, education and training on CA are being carried out. The ACT CA-CoEs (ACT, 2017) have five key thrusts: research, outreach, linkages, information technology and training (Rolitt) (Fig. 20.1).

20.3.1 Relevance of the Conservation Agriculture (CA) Centres of Excellence

A centre of excellence is an organization that focuses on optimizing application or service characteristics such as quality, performance or



- Facilitate CA research for development
- Develop new research methodologies based on CA
- Serving as a hub for experimentation, development and adaptation of technologies
- Evaluation of different production models and adapt them to farmers' situation

- Validation of CA knowledge, practices and extension models by practitioners
- Promotion of mechanized CA service provision
- Receive and respond to farmer challenges on a regular basis
- Champion awareness campaigns on new technologies and technical solutions

- Establish a quality-assurance system for CA training
- Facilitate national capacity building in CA
- Advance knowledge and expertise
- Provide in-service training programmes to improve technical knowledge and skills of extension agents

- Establish business relationships between farmers, service providers, crop-offtakes, millers, dealers, manufacturers and other stakeholders in the CA value chain
- Establish CA-CoPs coordination hubs
- Facilitating the continued and wider collaboration with diverse stakeholders

Fig. 20.1. The five key thrusts of Centres of Excellence: research, outreach, linkages, information technology and training. Figure courtesy of African Conservation Tillage Network (ACT, 2017).

availability. In today's world, a CoE applies to any organization committed to continuous creation, use and showcasing of its technological, service and business-oriented capabilities to stakeholders in a competitive environment to acceptable international standards.

In 2012, ACT initiated recognition of CA-CoEs in various parts of Africa. CA-CoEs are public research and/or training institutions dedicated to the goals and showcasing the widespread adaptation and adoption of CA at the national level. Some key areas of their contribution include:

- **Research.** Forefront CA research in the region. Creating new impact pathways and applications of the findings. Develop and pilot new research methodologies based on CA. Produce operation manuals and guidelines to support aspects of CA such as production, adaptation and mitigation.
- **Outreach**. Co-generation, validation and dissemination of CA innovations and practices. Promote mechanized CA service provision. Share evidence-based knowledge and information across local, state and national contexts.
- **Linkages.** Establish business relationships among CA stakeholders in targeted value chains. Establish CA Communities of Practices (CA-CoPs) coordination hubs. Serve as a platform for public policy consultation.
- **Education and Training**. Formation and capacity building of CA CoE core team. Facilitate capacity building on CA technologies for farmers, farmer groups, mechanized CA service providers, agro-dealers, farmer organizations and NGOs. Develop training modules for all levels and training trainers and practitioners.
- **Information Technology.** Support monitoring and evaluation (M&E) and knowledge management. Enhance knowledge management and information sharing for effective CA adoption on the ground across vertical and horizontal scales. Establish e-based knowledge sharing platforms across state, national and global contexts. Identify and document best practices and develop local resources for their implementation. Support entrepreneurial mechanized CA service provision. Enhance M&E and impact documentation of CA at continental level.

20.3.2 ACT's Conservation Agriculture (CA)-CoE Strategic Growth Vision

Through collaboration and strategic partnerships, ACT has a strategic vision to establish 25 CA-CoEs in Africa by 2025, accomplished through a phased approach. Each centre will be expected to have impact on the wider community through interaction with research and training institutes, governments, the private sector and non-profit sector. In the initial phase ACT has initiated the establishment of seven CoEs in different countries and regions in Africa. This approach will contribute to operationalization of Vision 25×25 of the 1st Africa Congress on Conservation Agriculture (1ACCA), Lusaka Declaration target of reaching 25 million farm households with CA systems and practices by 2025.

Currently, seven CA-CoEs have been initiated. They are:

1. Tanzania Agricultural Research Institute (TARI), Uyole, Tanzania.
2. Gwebi Agricultural College, Zimbabwe.
3. Kenya Agricultural and Livestock Research Organization (KALRO), Njoro, Kenya.
4. National Institute of Agronomic Research, Morocco (discussions are ongoing).
5. University of Nazi Boni (formerly Université Polytechnique De Bobodioulasso), Burkina Faso.
6. Yei Crop Training Centre, South Sudan (disrupted by the internal security skirmishes).
7. Haramaya University, Ethiopia (MoU signed, formal programme yet to start).

20.3.3 CA-CoE Impact Vision

The expected impact of the CA-CoEs model is to deliver coordinated, demand-driven CA-based agricultural technologies, information services and knowledge to farmers and other stakeholders, for increased agricultural productivity, profitability, competitiveness and sustainable use of natural resources. This is envisioned to develop infrastructure of services and human resources which will trigger an exponential increase in the number of entrepreneurs providing sustainable mechanized CA services to farmers and other actors along relevant value chains. This should, in turn, lead to making CA an agribusiness as it relates to farmer practices and to farmers as users of CA, as well as to service providers as suppliers of services. The infrastructure of services and human resources includes: support for research and development, development of standard curricula for the training of farmers and key actors along the value chain, mainstreaming CA in agricultural training institutions and capacity building of existing and potential CA-based mechanization service providers. Others include establishing strategic linkages with key support services (e.g. financial, insurance and manufacturing institutions) and the targeting and engagement of youths to inculcate CA thinking and practices for posterity. At the heart of this strategic framework is a capacity-building model for extension workers and service providers to establish themselves as communities of practice and/or commercially viable entities providing CA services along the value chain.

At a higher regional level, the model forms a coordinated network for policy engagement, training/capacity building, agribusiness development, end-to-end linkages to output and input markets.

Specific outputs of the CA-CoEs include: awareness to CA increased, knowledge and skills on CA among value chain actors increased, CA stakeholders' capacities increased, availability and accessibility of CA agro-inputs and implements increased, R&D on CA enhanced, policy environment and frameworks for up-scaling CA improved, CA programme management enhanced and a regulatory framework in place to ensure that all value chain operators benefit and make profit out of their businesses.

The CA-CoEs model for supporting integrated CA systems development across Africa is poised to leverage the contribution of national and international intellectuals and academia as well as development stakeholders to strategically participate and contribute towards solving smallholder farmers' challenges in Africa.

20.4 CA Curriculum Development

In 2018 ACT, in collaboration with the African Network for Agriculture, Agroforestry and Natural Resources Education (ANAFE), developed the Conservation Agriculture Curriculum Guide for Africa (ACT and ANAFE, 2018). The curriculum was developed as a compliance response to the Lusaka Declaration of the 1st Africa Congress on Conservation Agriculture, which in its 6th resolve urged 'ACT is to establish a quality-assurance system for accredited agricultural training institutions to provide CA training certificates. Furthermore, ACT will collaborate with relevant stakeholders for the harmonization of CA training curricula'. Furthermore, in its eighth resolve, the declaration requested 'Agricultural training institutions to take up CA as an integral part of their training programmes and take part in farmer sensitization and training efforts' (ACT, 2015).

Africa's agriculture is in great need of reform to minimize and eventually eliminate land degradation, improve yields per unit area, reduce the drudgery especially for smallholder farmers, sustain productivity and profitability, and enhance environmental conservation. These aspirations are elaborated in the Comprehensive Africa Agricultural Development Programme (CAADP) adopted by the African Union Commission. The companion document, dubbed the Science Technology and Innovation Strategy for Africa (STISA) emphasizes modernization of agriculture while relegating traditional practices to history. However, according to ACT and ANAFE (2018), our ambitions to make big gains in agriculture are unlikely to be achieved any time soon because we are dealing with millions of smallholder farmers whose traditional practices (even where effective) are largely ignored or underrepresented in what is called innovations. CA requires low investment, minimizes labour and is close to current smallholder practices. Yet its impact has been shown to be huge on both production and ecological sustainability, providing an opportunity to enhance its practice by providing expertise through education and training.

The curriculum structure is versatile, enabling agricultural learning institutions to select and use modules or topics that enhance their current agricultural curricula. The goal is to support agricultural learning institutions to impart the science and innovations in CA to enhance productivity while meeting the conservation and sustainability needs, with a special focus on smallholders. The curriculum is thus a source of ideas that can be adopted and adapted to meet the specific needs of farming communities and of teaching institutions. Educators and researchers are expected to further develop the ideas contained in the curriculum to strengthen the science and innovations in CA.

20.4.1 Methodology

The impetus to develop the curriculum arose from an intensive workshop held in Nairobi Kenya from 4–6 December 2017 for researchers, educators and practitioners of CA. The workshop participants came from the ACT Secretariat; ANAFE Secretariat; Capacity Development Resources (CDR), School of Agriculture, Policy and Development, University of Reading, UK; School of Environmental Studies, Kenyatta University; and Land Resource Management & Agricultural Technology (LARMAT), University of Nairobi, Kenya. Others attending were Nsuka University, Nigeria; Botswana College of Agriculture; Mekelle University, Ethiopia; Sokoine University of Agriculture, Tanzania; College of Agriculture Makerere University, Uganda; Zambia Virtual University; Egerton University, Kenya; Ekiti State University, Nigeria; Rongo University, Kenya; Copper Belt University, Zambia; University of Limpopo, South Africa; University of Swaziland; Uyole Agricultural Research Institute, Tanzania; Gwebi College of Agriculture, Zimbabwe; and Kenya Agricultural and Livestock Research Organization Njoro, in Kenya.

Professor August B. Temu, former Deputy Director General of the World Agroforestry Centre (ICRAF), led the curriculum development process. Special contributions were also made by Professor Amir Kassam, International Conservation Agriculture Advisory Panel for Africa (ICAAP-Africa), Chair. The work was undertaken with the financial support of NORAD.

20.4.2 How Conservation Agriculture (CA) Responds to Development Needs

CA practices hinge on three interlinked principles: minimizing or avoiding soil disturbance, maintaining a permanent soil cover with mulch and crop diversification through rotations and associations. The combined effects of these practices, when applied along with other complementary good agricultural practices, leads to benefits including: increased productivity, improved biodiversity and a number of ecological benefits. These results contribute to agricultural and human developments and environmental amelioration and protection, including the potential of CA to contribute to the achievement of nine SDGs and 22 targets, elaborated in the curriculum guide (ACT and ANAFE, 2018).

It is important when teaching CA to demonstrate how best to achieve these goals and targets. It is noteworthy that the goals and targets also respond to the challenges identified in agreements and protocols relating to the United Nations Framework Convention on Climate Change (UNFCCC), United Nations Convention on Biodiversity (CBD) and United Nations Convention to Combat Desertification (UNCCD). Very similar goals and targets are identified by CAADP and the accompanying STISA.

20.4.3 Job Areas for Conservation Agriculture Experts

Graduates with CA-related knowledge and skills are expected to apply their knowledge in farming, extension, training and research. Thus, they may take job positions such as farmers, farm managers, agronomists, agro-mechanics, extension officers, trainers for farmers or technicians, conservators, ecologists and natural resource managers. They are expected to understand the local, regional and global implications of farming practices on livelihoods, ecosystems, water, greenhouse gas (GHG) emissions and overall long-term development aspirations of communities; the interaction between crops, livestock and trees in farming systems; and be able to balance farming productivity with landscape restoration.

The purpose of the curriculum is not to separate CA from conventional agriculture. Rather, it seeks to enhance the knowledge and skills of (among others) farmers, agronomists, soil specialists, irrigation experts, mechanization engineers, agricultural economists and policy makers to appreciate and apply the knowledge currently available on CA to tap its benefits. It is, therefore, important that currently serving officers in agriculture attend refresher courses where CA will be a focal point. This curriculum can therefore be adapted to fit into short courses in CA, targeted at different stakeholders according to identified needs.

Another important consideration is the capacity to evaluate an agricultural production system regarding whether or not it meets CA criteria and indicators. By being able to score farming practices and farms we can establish the tendency towards CA and thereby map whole agricultural landscapes showing the stages of transition.

20.4.4 The Conservation Agriculture (CA) Curriculum

The curriculum is organized in six modules, listed below, which are logically linked. Institutions aspiring to produce CA specialists can adopt all six modules. However, when used by institutions that are already teaching various aspects of agriculture, it is advised that they mainstream CA into the existing curriculum by identifying the topics they consider useful in meeting their needs.

- Module 1: Introduction to CA.
- Module 2: Natural resource characterization.
- Module 3: Agro-ecosystems, biodiversity and climate change.
- Module 4: CA practices, innovations and technologies.
- Module 5: Economics and business of CA.
- Module 6: Cross-cutting aspects.

This curriculum guide is a living/dynamic document which is expected to transform according to the institutional environment where it is applied in the light of experience, and as new information becomes available. It is recommended that it is fully reviewed within 5 years, based on assessments by institutions that use it wholly or in part.

20.5 Conservation Agriculture (CA) Quality Assurance Framework

During the 1st Africa Congress on Conservation Agriculture (1ACCA) that was held in Zambia in 2014 (ACT, 2014), stakeholders resolved and mandated ACT to establish a quality assurance framework for CA training and practising institutions in Africa. Quality is defined as the ability or degree to which a product, service or phenomenon conforms to an established standard, and which makes it relatively superior to others. It is not just a feature of a finished product or services but involves a focus on internal processes and outputs. Quality assurance can be described as the process of verifying or determining whether products or services meet or exceed customer expectations. Quality assurance as applied in education refers to all forms of internal and external quality monitoring, evaluation or review, or the systematic review of educational programmes to ensure that acceptable standards of education, scholarship and infrastructure are being maintained. In common usage, the term quality assurance means the maintenance of a desired level of quality in a service or product, especially by means of attention to every stage of the process of delivery or production. CA production is part of a chain of activities that starts from land preparation, seeding and planting, weed management, soil management, conserving soil and water, managing livestock, harvesting, marketing and input supplies, and stretches all the way to the consumer. These activities should meet quality standards during implementation.

20.5.1 Scope and Purpose of the Framework

The framework aims to support and guide initiatives in relation to CA quality assurance at the national agency level. It will function as a common reference framework that will help African countries assess, develop and improve the quality of their CA education, training, research and practice systems; guide the design and implementation of measures to strengthen quality assurance at the country level; provide the basis for alignment between national education and training systems across the region; and increase transparency of and consistency in CA training and practice policy developments. The purpose is to assist African countries including their accredited training and practising institutions that are promoting CA best practices (NGOs, private sector, companies, projects, national and local governments and CA Centres of Excellence) to promote and monitor the improvement of their systems of CA education and training and programme delivery. This tool can be used as a systematic approach to modernize education systems by improving the effectiveness of CA programmes and projects. The framework has to be used on a purely voluntary basis, taking account of its potential added value and in accordance with national legislation and practice. It should not be considered as a benchmark, as a means of reporting on, or of drawing comparisons among different national systems in their quality and efficiency.

From time to time ACT will provide feedback on the framework compliance to institutions participating in the implementation of the CA quality assurance framework. The framework is intended to facilitate the sharing of information on good CA systems and practices; provide for concrete means to support an evaluation and quality improvement culture at all levels; support and promote lifelong learning; and contribute to evidence-based CA policy and practice.

20.5.2 Components of Standards and Indicators for Conservation Agriculture (CA) Training Institutions

The educational quality standards define the quality characteristics required for each education institution. The standards are intended to improve the quality of the education institution, and are to be built into the institution's delivery and learning objectives. Providers of CA training should meet the minimum quality assurance standards for education and training. The training provider should capture how these standards are observed in practice. Each quality standard has sets of indicators useful in monitoring the performance of the standard.

Vision, mission and objective statements

The purpose of quality management unit is to develop policies and procedures by which the institution can measure its progress in all domains like education, training, research and services to achieve its mission, using the established standards. Experience in education from Ghana, for example, shows that several committees have been established with different functions related to training quality assurance.

Conservation Agriculture (CA) curriculum and teaching/learning delivery

The CA education programmes should be designed so that they meet the objectives set for them, including the intended learning outcomes. CA study programmes provide students with both academic knowledge and skills, supporting their personal development.

Inputs

The key inputs for a CA training institution include staff management and development. It is essential that every provider has a systematic approach to the recruitment and further professional development of people engaged in education programmes and service delivery. It is important to ensure that the institution has the necessary facilities and environment in which training is being offered. Different types of training may require specific resources such as laboratories, workshops, ICT laboratories and experimentation field sites in order to guarantee quality.

Outputs

Support of learners and graduates is a key component and involves those actions that provide the ability to review the CA training courses provided by the training institutions. It is about how the training offered meets self-employment and the labour market requirements. It is about meetings with students, mainly with regard to feedback on students' perspectives with respect to quality assurance mechanisms that are being implemented. It is important that institutions have the means of collecting and analysing information about their own activities. Without this, they will not know what is working well and what needs attention, or the results of innovative practices. CA training institutions have a responsibility to provide information to the public about the programmes they are offering; the intended learning outcomes of these; the qualifications they award; the teaching, learning and assessment procedures used; and the learning opportunities available to their students. Published information might also include the views and employment destinations of past students and the profile of the current student population.

20.5.3 Components of Standards and Indicators for Conservation Agriculture (CA)-practising Organizations

The quality assurance components for best-practising organizations include those in Fig. 19.4. CA-practising institutions need to demonstrate tillage practices that do not damage the soil, leading to compacted soils and hard pans. Conventional tillage – with hand hoes, discs or mouldboard ploughs – damages the soil structure and leaves it exposed to the wind and rain. A healthy soil, for example, has many different living organisms in it: earthworms, ants, beetles, spiders, termites and many tiny organisms that are so small they cannot be seen with the naked eye. It is high in organic matter. It is rich in nutrients that plants can use as food, primarily nitrogen (N), phosphorus (P) and potassium (K). It is deep enough for plant roots to grow properly. Providing adequate soil organic cover is a cornerstone of CA. There are a number of cover crops that do better under different climatic conditions and altitude. Legume–cereal crop rotations form an important component of smallholder farming systems in Africa.

Best-practising organizations promote weed management in many different ways, for example: using crops and other forms of soil cover, by hand weeding or using equipment to cut or crush the weeds and using herbicides. When production and yield increases, it means that labour required to harvest and handle the crops also increases. Farmers have, therefore, to adopt harvesting techniques and methods that will handle the situation but also need to prepare good storage facilities that are big enough to store the higher yields. Proper marketing of agricultural produce is essential to generate returns that can be used for many farmer requirements such as household consumption and buying inputs for the next season. CA-practising organizations should provide for mechanisms that allow farmers to have access to CA inputs. The main inputs that farmers need for CA are information, equipment, seed, fertilizers, herbicides, pesticides and credit. Farmers need to have easy access to seed, fertilizers and other inputs if they are to adopt and scale up CA. Although livestock are important for many farmers since they provide meat, milk, hides and manure, and pull farm implements and carts, they should be properly managed to keep them from grazing on crop residues in fields after the harvest. If the animals eat all the cover crops or stalks from the previous crop, the soil surface will be bare and exposed to heavy rain and to the wind. Fodder should be grown in the CA field, cut and carried to the animals.

The social economic aspects for widescale adoption of CA include formation and maintenance of market-led producers and farmer organizations. Farmer organizations are important communities of practice in addressing the market constraints. Farmer organizations play an important role in tackling the systemic causes of poverty, because they give farmers – men and women – a legitimate voice in shaping pro-poor rural policies. One of the major constraints to scaling up of sustainable farming practices including CA is lack of availability and access to CA inputs and services including the ones for land preparation, planting, spraying, threshing, shelling and transportation by smallholder farmers, hence leading to a decline in production and consequently farm output. Smallholder farmers will be propelled faster towards mainstreaming CA practice; for example, by providing access to such implements and services as jab-planters, herbicide sprayers, animal drawn NT direct seeders, cover crop seed and other inputs through CA service providers. CA platforms to support coordination and grassroots activities are critical. The mission of a CA platform is to provide coordination of stakeholders working within a particular country or location to address the constraints on the adoption of CA in order to achieve the vision of scaling up CA. The platform raises awareness and lobbies at all levels to ensure that CA becomes a leading farming practice. Creating awareness in CA, good agronomic practices, use of improved seed and keeping farmers up to date on new products, technologies and on-farm practices is a prerequisite for enhanced adoption of CA.

20.5.4 Self-assessment, Objectives and Approaches

Both education/training institutions and practising organizations should be engaged in self-assessment as part of quality assurance procedures. Self-assessment attains several objectives (Fig. 20.2). This process ends in the development of a programme improvement plan (PIP) that institutions and organizations will use for implementation of the action plans. The self-assessment by a training provider, or a practising organization, of its programmes and services is a fundamental part of its quality assurance system. It is an

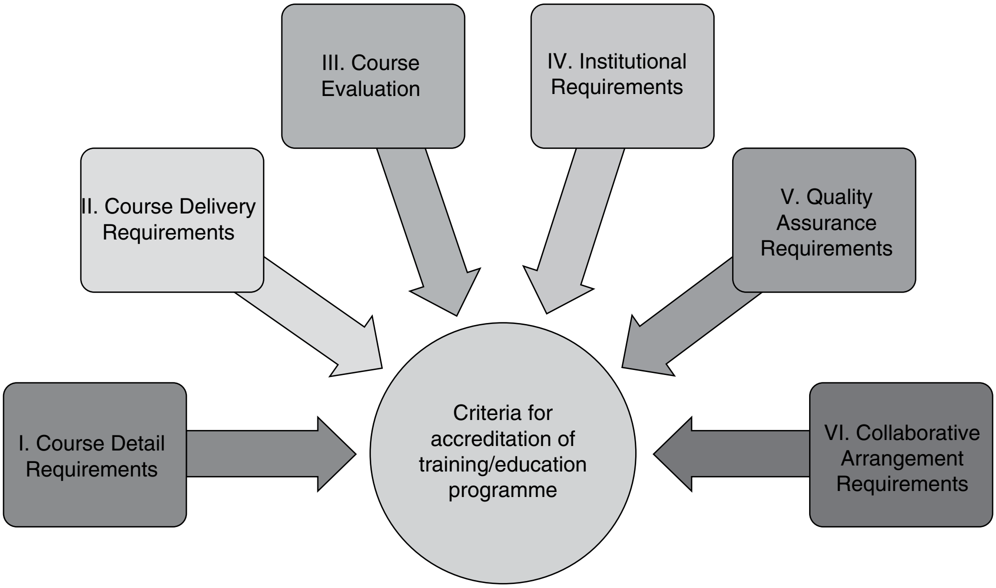


Fig. 20.2. Criteria for accreditation of training and education programme. Authors' own figure.

important mechanism to improve institutional education quality and quality of the programme delivery and implementation. It involves quality evaluation by the institution or organization itself to promote, develop and improve quality and to be ready for internal assessment, external assessment and quality accreditation. Self-assessment is a structured and systematic process to explore, reflect and report on the effectiveness of an activity. It aims to capture, interpret and disseminate learning from any actions undertaken. It seeks to identify good CA practice and to use the findings to inform future policy and practices. It seeks to engage stakeholders, gather credible evidence from a range of sources, draw and justify conclusions, make recommendations for improvement and ensure the use and sharing of lessons learned.

The self-assessment serves, at least, the following objectives:

1. Motivate the institution to develop further.
2. Create confidence among students, and among society, by demonstrating a focus on educational quality.
3. Build trust about educational products and services within society.
4. Provide learners with information about education quality.
5. Provide information about processes or activities of the institution.
6. The outcome is an important document for institutional administrators to be used in development planning.

Two common approaches to conducting self-evaluations are available: the training provider or CA-practising organization conducts an initial self-evaluation by applying the evaluation checklist separately to each of the programmes being evaluated; and the evaluation is conducted with the involvement of the external evaluator from the start. The self-evaluation activity should produce a constructive report, which will help the training provider or the CA-practising organization to maintain and improve the quality of its programme and services.

20.5.5 Accreditation of Conservation Agriculture (CA) Training Institutions and Practising Organizations

ACT will provide accreditation to the individuals who provide training in their respective fields as being the experts and authorized (if under regulated professions) to provide such training. Also, the trainers who qualify for accreditation are providing training in non-regulated subject materials and are engaged in coaching or grooming courses (at personal or professional levels). ACT will also provide accreditation services to training providers; that is, companies that are not engaged in formal education or training. These companies might be a small- or large-scale organizations but need to have their training processes assessed and accredited. The criteria for accreditation of training and education programme is outlined in Fig. 20.2.

ACT will not offer the accreditation services to any organization engaged in formal training or education from primary to postgraduate level. Any school, college, vocational college or university is considered as a formal education provider and ACT will not accredit such entities since they have their respective accreditation organizations at national and international levels. ACT agrees to work with such institutions to provide formal education qualifications that are accepted by the national or international accreditation organizations.

20.5.6 Sustaining the Conservation Agriculture (CA) Quality Assurance System

Sustaining the quality assurance system requires continuous application of the QA framework within the organization or system (internal environment), which is conducive to initiating, expanding and sustaining QA. Sustainable QA requires a policy environment that explicitly recognizes the importance of quality for reaching organizational or system goals, and that provides support, guidance and reinforcement for QA implementation. Leadership is critical to help the organization see where it needs to go (vision). QA cannot be sustained if there are inadequate resources allocated for QA, and also resources for capacity building, communication and other key support functions. Delineation of responsibilities and accountability for oversight, coordination and implementation of QA in the organization is necessary. Capacity building, which ensures that staff have the necessary technical, managerial, and leadership knowledge and skills to carry out their QA responsibilities and that they know when and how to use these skills best, is required.

20.6 Concluding Remarks

During the past 5 years, and particularly since the time of the curriculum development conference in Nairobi in 2017, more CA teaching resources from Africa and around the world have become available, especially in the form of textbooks (e.g. Farooq and Siddique, 2015; Jat *et al.*, 2015; Kassam *et al.*, 2017; Dang *et al.*, 2020; Kassam, 2020; Kassam and Kassam, 2020). Also, many special issues of journals, journal articles, reviews and case studies and modelling initiatives on all aspects of CA systems and science, practice, benefits, adoption and spread are becoming available for designing and developing CA curricula and modules for both face-to-face and online teaching.

At the practical level more manuals and guides are becoming available as source materials for designing and developing extension courses and field training materials to strengthen participatory training programmes for extension staff, farmers and service providers.

An exciting development in terms of education and training has been the establishment of the Rwanda Institute of Conservation Agriculture (RICA) and the strengthening of the CA training centre in Ghana. Also, CA experience and learnings in the field in Africa has expanded to cover more countries, attracting greater development investments from international and regional development assistance agencies including FAO, IFAD, EU, AfDB and bilateral aid agencies including through South–South and triangular cooperation.

There is now ample material coming onstream to support CA curriculum and course development, as well as production of online teaching modules and MOOCs. However, there is a shortage of experienced lecturers and trainers, and field facilities. There is also a real need for university and training institutions to establish campus farms for education and training, research and extension based on CA.

There are also good opportunities for online teaching and learning through webinars, virtual group meetings and interactive teaching and learning at individual and group level, and self-taught and facilitated online courses from local or international sources.

Special attention must continue to be paid to the education and training of smallholder farmers, both men and women, and for attracting youth into the future food and agriculture system. Both CA-based farming and a CA-based food and agriculture system is a source of economic, environmental and social opportunity for farmers, women, youth and professionals in the public, private and civil sectors. The potential for reviving and regenerating rural economies and communities, and for strengthening the synergies across the rural-to-urban continuum, is a real opportunity for sustainable development in Africa in the coming decades and within the framework of the Malabo Declaration and Agenda 2063.

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21 Conservation Agriculture Innovation Systems Build Climate Resilience for Smallholder Farmers in South Africa

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Abstract

Introduction of Conservation Agriculture (CA) and associated climate-resilient agriculture practices within an innovation system approach, and using farmer-level experimentation and learning groups as the primary learning and social empowerment processes, has created a sustainable and expanding farming alternative for smallholders that is improving their resilience to climate change substantially.

Through a knowledge co-creation process, smallholder farmers in the programme have adapted and incorporated a wide range of practices into their farming system, including minimum soil disturbance, close spacing, improved varieties, judicious use of fertilizer, pesticides and herbicides, crop diversification, intercropping and crop rotation as well as fodder production and livestock integration. They have organized themselves into learning groups, local savings and loan associations, water committees, farmer centres and cooperatives and in so doing have created innovation platforms for local value chain development. They have built ongoing relationships with other smallholders, NGOs, academic institutions, government extension services and agribusiness suppliers, and have promoted CA tirelessly within their local communities and social networks.

To date, this is the most successful model for implementation of CA in smallholder farming in South Africa and, through networking and upscaling activities, is being promoted nationally as a strategic approach to smallholder adaptation and mitigation programming, in line with the Africa climate smart agriculture (CSA) Vision 25×25 (NEPAD, Malabo, June 2014).

Keywords: participatory impact assessment, climate change adaptation, scaling, KwaZulu-Natal, Southern Africa

21.1 Introduction

Sustainable and regenerative agricultural practices such as Conservation Agriculture (CA), that conserve and increase soil organic carbon (SOC) and improve soil health, are increasingly promoted in southern Africa as an alternative to conventional farming systems (Smith *et al.*, 2017). CA depends on the simultaneous implementation of three linked principles: (i) continuous zero or minimal soil disturbance; (ii) permanent organic soil cover; and (iii) crop diversification (FAO, 2013). The latter usually entails crop rotation and the inclusion of legumes and/or cover crops.

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Complementary practices supporting CA implementation in smallholder farming systems include appropriate nutrient management and stress-tolerant crop varieties, increased efficiency of planting and mechanization, integrated pest, disease and weed management, livestock integration and enabling political and social environments (Thierfelder *et al*., 2018).

The Maize Trust-funded CA Smallholder Farmer Innovation Programme (SFIP) in South Africa, as conceptualized and implemented through the Mahlathini Development Foundation (MDF), has pioneered the use of agricultural innovation systems as a methodological approach for the promotion of an appropriate smallholder CA farming system, as well as awareness-raising and adaptive research into specific elements of this system (Kruger and Smith, 2019). This approach takes cognizance of the complexity of introducing CA into a farming system, including working with smallholder farmers as partners in the knowledge co-creation process through on-farm research and experiential learning, as well as embedding the process into the existing socio-political environments and economic value chains. The overall goal of the CA-SFIP is the mainstreaming of CA by grain farmers to ensure sustainable use and management of natural resources while enhancing national and household food security and income.

Specific objectives of the programme include also increasing the sustainability and efficiency of CA systems in the study areas giving specific attention to the value chain and incorporation into the broader agribusiness environment, and strengthening and using different innovation platforms such as social institutions as avenues to scale out sustained collective action and CA practices. Figure 21.1 outlines the elements of the CA-SFIP in South Africa (2013–2019) (Smith and Visser, 2014).

This chapter considers the building blocks of an innovation systems approach, issues of horizontal or out-scaling and three different sets of indicators (innovation system indicators, soil health indicators and resilience indicators) that have been developed to monitor and track progress within the system.

In the smallholder context, introduction of CA into the farming system requires the design, introduction and facilitation of a reasonably complex innovation system (IS) approach by the implementers, as well as practice, labour and resources (including natural and financial resources) by the farmers that have system-wide implications. In the SFIP, on-farm, farmer-led research is the most central component of the IS, supported by learning, awareness-raising and economic elements (Smith *et al*., 2017; Swanepoel *et al*., 2018). Different activities are undertaken within each of these elements. A strongly participatory facilitation process is required to ensure synergies across the activities and the knowledge co-creation that is crucial to the success of the process. To date the introduction of CA into smallholder farming systems has mainly consisted of researcher- or extension-led CA trials and demonstrations, and uptake has been extremely limited (Swanepoel *et al*., 2018).

Interested individuals in a local area or village come together to form a learning group. Several farmers in that group then volunteer to undertake on-farm experimentation, which creates an environment where the whole group learns throughout the season through observations and reflections on the trials' implementation and results. They compare various CA treatments with their standard practices, which are planted as control plots. This provides an opportunity to explore all aspects of the cropping system, its socio-economic context and feasibility, as well as the grain and legume value chain in the area. Over a period of 4–6 years, farmers develop their ability to define their own farm-level experimental processes, which increase in complexity and design to incorporate different aspects of the cropping system. They work together to share labour and equipment, set up village savings and loan associations (VSLAs), do bulk buying, set up farmer centres and arrange for local processing and marketing options. They bring new farmers interested in CA on board throughout the process.

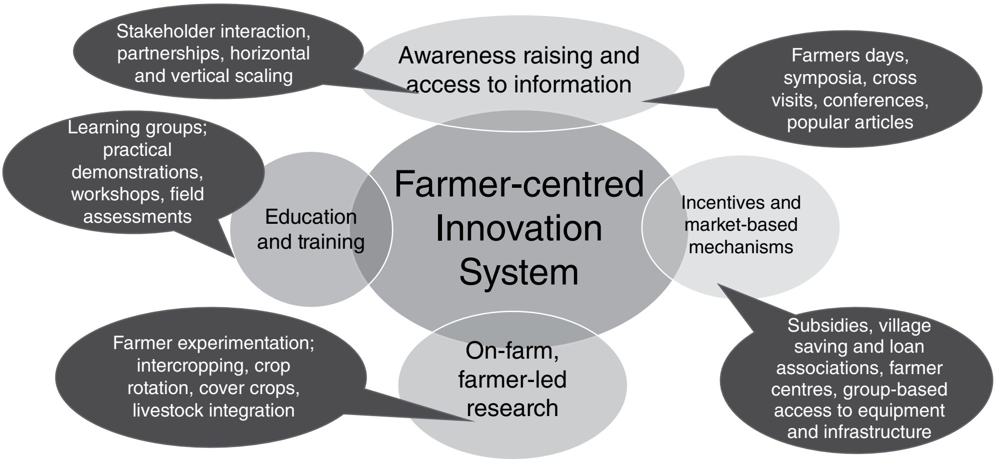

Fig. 21.1. Elements of the CA-SFIP innovation system. Authors' own figure.

This process also allows for longer-term monitoring and research into biophysical and socio-economic changes in the areas of operation, allowing the smallholder farming sector in South Africa to benefit from CSA as envisaged by the Malabo Declaration and the implementation of Agenda 2063.

21.2 Smallholder Farming System and Participants

The majority of smallholder farmers in South Africa live in scattered communal tenure communities, more often than not in agriculturally marginal production areas. They suffer under the yoke of extreme poverty and highly degraded natural environments, and are very vulnerable to the effects of climate change.

Agricultural production is central to rural livelihoods and food production and is undertaken as a mixed farming system approach that typically includes vegetable production in small household gardens, field cropping in dryland fields of between 0.1 and 2 ha and livestock rearing – mostly cattle, goats and sheep in village-based commonages (De Wit *et al.*, 2015).

There are an estimated 3 million smallholder farmers in South Africa, of whom around 72% fall within a non-commercial category consisting primarily of unemployed women who rely on social grants (89%), who farm for household food purposes on small plots (0.1–1ha), with very low household incomes (~ZAR2,000/month), with low productivity (maize yields of between 0.1–2t/ha) and with negligible external support. A further 23% are considered semi-commercial, as they produce for both household consumption and sale and are slightly better resourced. Commercial smallholders make up the remaining 5% and are often supported through employment in the family (Cousins, 2015).

Though a focus on the rural poor, this programme has worked primarily with the non-commercial and semi-commercial smallholders in the Eastern Cape and KwaZulu-Natal (KZN) provinces of South Africa. The focus has been on three distinct agroecological zones within KZN: Bergville, in the Drakensberg mountain foothills, with an average annual rainfall of between 650 and 750 mm per annum, with high percentage clay soils; southern KZN and the northern reaches of the Eastern Cape (EC & SKZN), also in the Drakensberg foothills, but with more variable rainfall (450–750 mm/annum) and much sandier soils; and the Midlands, in the more coastal region of southern KZN, with a higher average annual rainfall of between 750 and 850 mm and a wide range of soil types.

21.3 Aspects of the CA-SFIP Innovation System

In broadening the introduction of CA beyond the scope of researcher-managed trial plots and commercial cropping advice, the following aspects have been included in the agricultural innovation process:

- Collaborative and participatory research for knowledge co-creation in terms of applying CA principles to smallholder farming systems.
- Farmer-level experimentation.
- Introduction of crop rotation, intercropping, cover crops and fodder crops into the smallholder farming system.
- A focus on livestock integration.
- A focus on new cover crops and planting options such as strip cropping.
- Inclusion of quantitative research elements into the experimentation process: soil fertility, soil health (including carbon sequestration), run-off, infiltration and water productivity.
- Adaptive and localized research into aspects such as soil and water conservation, spacing, varieties, herbicide and weeding regimes, pest control and local breeding options.
- A maize commodity value chain focus including relationships with agribusiness, bulk buying, farmer centres and local marketing initiatives.
- Support for microfinance and small business development in the CA system.
- Learning and mentorship for community-level facilitators and lead farmers; internships for agriculture and rural development studies graduates; postgraduate (MSc and PhD) opportunities in CA; and short learning programmes for stakeholders, including other NGOs, research organizations and government.
- Development of visual and proxy indicators suitable for local-level implementation.
- Cost–benefit and livelihoods improvement analysis for the CA systems at local levels.
- A focus on the post-harvest aspects of storage, threshing and milling.
- Brokering of partnerships in agribusiness, research and implementation.
- Exploration of alternative financing models, including payment for ecosystem services and climate change adaptation incentives.
- Production of a CA manual for smallholder farmers (in English and isiZulu).
- Production of articles, conference papers and presentations by all members of the implementation team.
- Setting up of innovation platforms and forums that include all role players.

The combination of all these aspects has provided a coherent CA implementation process for smallholder farmers. The primary organizational structures through which all the aspects of learning, experimentation, implementation and value chain development are negotiated are village-based farmer learning groups. Individual farmers undertake experimentation suited to their own needs and farming process. Subgroups of farmers undertake different experiments, for example new crop varieties and cover crop combinations, and the results are fed back into the learning groups and innovation platforms, allowing for a cyclical increase in complexity of the system.

21.4 Horizontal Scaling

This aspect of the process relies on verbal communication between smallholder farmers as the basis for awareness-raising and spread of CA in and between these communal tenure villages. It is based on communication in learning groups and also on open days and stakeholder forums, given that smallholders rarely rely on printed information for their farming decisions (Smith *et al*., 2017).

This section outlines the uptake of the CA process across the three areas for the 6 years of implementation. The numbers indicated (Table 21.1) are those participants within the learning groups who undertake the farmer-level experimentation. For the CA trial, each farmer signs a contract indicating their willingness and ability to undertake the trial as well as the control. Participant farmers plant a CA trial (100m^2, 400m^2 or 1000m^2) alongside their normal maize plantings (controls). Their control plot has to be at least the same size as their trial.

Table 21.1. Participants in the CA farmer-level trials for the CA-SFIP (2013–2018). Authors' own table.

	2013–2014	2014–2015	2015–2016	2016–2017	2017–2018	2018–2019		
	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Area under trials (2018)	Total area planted[a]
Bergville	19 (12)	59 (27)	81 (55)	106 (115)	270 (252)	291 (207)	17.4 ha	49.4 ha
EC + SKZN	23 (22)	48 (16)	43 (29)	68 (54)	120 (84)	111 (83)	3.6 ha	8 ha
Midlands				30 (18)	75 (47)	85 (82)	2.2 ha	4.6 ha
TOTAL	42	107	124	204	383	487	23.2 ha	62 ha

[a] Control plot sizes have been measured accurately only for a proportion of the participants. This value is thus an estimate. The numbers in each column are the number of smallholders registered each year (at the beginning of the season) to do their farmer-level trials. The numbers in brackets are the farmers who managed to plant and harvest their trials.

Reasons provided by farmers for not planting have included:

- Season too dry and opted not to plant.
- Waited too long and then could not plant.
- Lack of labour.
- Cattle not sent into the mountains for summer grazing in time to plant.
- Non-payment of subsidy amount.
- Ill-health, migration of family members.
- Inability to plant the control plots as per the agreement.

Table 21.1 indicates that there is a gradual yearly increase in the number of participants practising CA, despite adverse weather conditions and the many constraints smallholder farmers face.

Monitoring of the number of participants who continue with CA implementation after their first year indicates different trends for the three different regions in the province (Bergville, EC and SKZN, and Midlands) (Table 21.2). Continuation depended to a large extent on a positive outcome for their first season of experimentation, which in turn is related both to the local climatic and soil conditions and the farmer's own practice.

For Bergville, 31% of participants who started CA experimentation continued for five consecutive years, 58% continued for 5 years, 41% for 4 years, 85% for 3 years and 100% for 2 years. This is not a linear process of uptake, which again is influenced by climatic conditions, as some farmers opt not to plant if seasonal rainfall is very late, but will take up the practice again in more conducive seasons. In all three areas the numbers also indicate that there is increased uptake in an area after 2–3 years of farmers being active in CA, jumping from 24 to 180 participants in the EC&SKZN and from 18 to 102 participants in the Midlands, for example.

Soil type and adverse weather conditions play a large part in longer-term adoption of CA and uptake is predictably lower in areas with very sandy soils, low soil organic matter (SOM) and high weather variability (hot, dry conditions interspersed with high-intensity storms). Favourable institutional arrangements and social organization have also been important contributing factors. Similar trends have been noted in recent reviews (Giller *et al*., 2009; Swanepoel *et al*., 2018; Thierfelder *et al*., 2018).

What is significant is that every year new participants are brought on board and that, overall, the number of farmer participants undertaking trials and continuing with the CA is growing steadily.

21.5 System Indicators

On a project level, an intensive monitoring process is undertaken by the MDF teams in the three different areas, using a participatory monitoring and evaluation (PM&E) framework that includes social agency (social and organizational), value chain (socio-economic) and productivity (agricultural and environmental) indicators. Table 21.3 indicates the values for some of these indicators between 2013 and 2018.

Table 21.2. Horizontal scaling for the CA-SFIP programme between 2013 and 2018/19. Authors' own table.

Number of years CA	Number of participants	% Who continued	Number of participants	% Who continued	Number of participants	% Who continued
	Bergville		EC&SKZN		Midlands	
1	291		180		102	
2	291	100	86	48	52	51
3	247	85	34	40	18	35
4	101	41	4	12		
5	59	58				
6	18	31				

Note: Empty cells denote shorter overall period of implementation for the different regions.

The information for this dashboard is gleaned from several sources. There are planting and growth monitoring forms that are filled in for a selection of individuals undertaking the CA farmer experimentation process (30% of total participants), mostly for the production indicators such as size of field, inputs used, crops planted, weeding, growth, soil cover, soil fertility, soil health and yields. The more social indicators are gathered through focus group discussions (yearly review sessions with each learning group) as well as individual questionnaires.

In this way, the programme is able to track and analyse the impact of the CA farmer-level experimentation process on the whole livelihood system of these smallholder farmers. Trends in the last few years are discussed below.

21.5.1 Social Agency Indicators

1. The total number of participants in the CA experimentation process increased from 51 between 2013/14 to 487 between 2018/19. This indicates that the horizontal scaling process of bringing in new participants from existing and neighbouring villages in each successive season has worked extremely well as a process for introducing CA into the smallholder sector, as does the increase from 5 to 31 villages in this 5-year period. The ISs model provides a solid foundation for the learning and co-creation function in an out-scaling process and also provides a foundation for upscaling through the multi-stakeholder innovation platforms (Herman *et al*., 2013). *This model has the potential to double the number of smallholders implementing CA on a yearly basis.*

2. The number of female farmers has declined from 89% of the total number of participants to 75%. This indicates that the number of male farmers has increased from around 12 to 58 in total. Within the socio-cultural context of the rural Zulu population in KZN, this means that the community is taking the CA process – specifically its potential to provide an income over and above food provision – more seriously. The pattern is for men to only become involved in agricultural activities that provide an income, as the women's role in household food production activities is still very dominant.

3. VSLAs have been introduced for learning groups that have shown an interest, to assist participants in consumption smoothing, cash flow management and procurement of inputs for productive activities. In the 5-year period of implementation, 58% of participants have joined VSLAs. And 28% of all participants are now saving and taking out small loans for agricultural inputs. *VSLAs are central to ensuring continuity and sustainability of CA implementation and are crucial for improving resilience of smallholder households.*

4. The learning groups are considered to be local innovation platforms, where innovation is the result of a process of networking, interactive learning and negotiation among a heterogeneous set of actors (Hellin *et al*., 2014). Learning group members plan, implement and review their progress together. These learning groups also host farmers' days and bring together community members from their own and neighbouring villages for these events. They invite local stakeholders such as the traditional authorities, local municipal officials and extension officers to these events and, with support from

Table 21.3. CA Innovation system indicators for the CA-SFIP (2013–2018). Authors' own table.

Indicator	2013/14	2018/19	Description/comments
Social agency indicators			
Participants	41	487	No. of CA experimentation participants, from farmer registration lists across all three areas
Learning groups	4	31	No. of village-based learning groups
Gender	89%	75%	Percentage of women undertaking CA experimentation. Obtained from farmer participation lists across all three areas
Local savings and loan associations	0%	58%	Percentage of all learning group members involved in VSLAs; from savings groups registers and learning group membership lists
Innovation platforms	0	6	No. of platforms set up that include farmers and external stakeholders
Value chain indicators			
Months of food provisioning			No. of participants, shown as a percentage who can provide enough maize meal for their family for different month-based categories; from annual review interviews for an average of 50 participants annually
1 to 3	100%	8%	
4 to 6	0%	39%	
7 to 9	0%	38%	
10 to 12	0%	15%	
Local sale of crops	0%	15%	No. of participants, shown as a percentage who sell maize, beans, cowpeas and sunflower produced locally; from annual review interviews for an average of 50 participants
Saving for inputs	0%	28%	No. of VSLA members who used their savings and small loans for agricultural inputs, shown as a percentage; from savings group records for 150 participants, averaged for a 3-year period
Farmer centres	0	6	No. of farmer centres set up for sharing CA equipment, providing advice and sale of agricultural inputs and produce between 2013 and 2018
Cooperatives	0	3	No. of cooperatives registered for CA smallholders between 2013 and 2018
Co-financing of local infrastructure	0	3	No. of learning groups who took advantage of the matching grant funding to finance local mills, threshers and water infrastructure or supplementary irrigation
Productivity indicators			
Reduced labour in CA plots	0%	78%	No. of participants, shown as a percentage, who indicated a reduction of labour throughout the cropping season; from annual review interviews for an average of 50 participants annually, across all three areas
Reduced weeding in CA plots	0%	39%	No. of participants, shown as a percentage, who indicated reduced weeding in CA plots compared to conventionally cropped plots; from annual review interviews for an average of 50 participants annually, across all three areas
Use of CA planters			
Hand hoes	97%	26%	No. of participants, shown as a percentage using different CA planters introduced through the programme; from planting and crop monitoring forms, completed for between 50 and 200 participants annually, across all three areas
Hand planters	0%	69%	

Continued

Table 21.3. Continued.

Indicator	2013/14	2018/19	Description/comments
Animal-drawn planters	3%	5%	
Tractor-drawn planters	0%	0.5%	
Maize yield for CA plots (t/ha)	2.3	3.3	Yield data measured and averaged for between 50 and 200 participants annually across all three areas
Crop rotation	0%	20%	No. of participants, shown as a percentage, who practised intercropping of maize and beans; from planting and crop monitoring forms, completed for between 50 and 200 participants annually, across all three areas
Intercropping - maize and beans	0%	92%	No. of participants, shown as a percentage, who practised intercropping of maize and beans; from planting and crop monitoring forms, completed for between 50 and 200 participants annually, across all three areas
Intercropping maize and other legumes	0%	17%	No. of participants, shown as a percentage, who practised intercropping of maize and other legumes such as cowpeas and Dolichos beans; from planting and crop monitoring forms, completed for between 50 and 200 participants annually, across all three areas
Winter cover crops	0%	31%	No. of participants, shown as a percentage, who undertook planting of a winter cover crop mixes (Saia oats, fodder rye, fodder radish, vetch, fodder peas) from planting and crop monitoring forms, completed for between 50 and 200 participants annually, across all three areas
Cover crops: summer mix	0%	26%	No. of participants, shown as a percentage, who undertook planting of a summer cover crop mixes sunflower, millet, sunn hemp, sorghum) from planting and crop monitoring forms, completed for between 50 and 200 participants annually, across all three areas
Seed saving	0%	11%	No. of participants, shown as a percentage who undertook seed saving of OPV maize, legumes and cover crops; from planting and crop monitoring forms, completed for between 50 and 200 participants annually, across all three areas
Fodder: provisioning for livestock through cut and carry, hay	0%	5%	No. of participants, shown as a percentage, who cut and baled hay from their CA plots and veld grass for winter feeding of livestock; from planting and crop monitoring forms, completed for between 50 and 200 participants annually, across all three areas
Reduced run-off in CA plots	0%	92%	No. of participants, shown as a percentage, who saw less run-off in their CA plots when compared to their control plots; from planting and crop monitoring forms, completed for between 50 and 200 participants annually, across all three areas
Increase in percentage organic carbon			Percentage organic carbon measured and calculated for five participants from each area, annually, after being averaged across all CA plots for each participant
Midlands (2017–2018)	0%	0%	
SKZN (2016–2018)	0%	24%	
Bergville (2015–2018)	0%	1%	

CA, Conservation Agriculture; VSLA, village savings and loan associations.

MDF, a wide range of other external stakeholders also participate – including, for example, community-based organizations (CBOs), NGOs, farmers' unions, universities (lecturers and students), input and mechanization suppliers, national and provincial government officials and research organizations. In this way six innovation platforms have been built across KZN. Around 3000 people have been involved in these awareness-raising and information-provision events to date. These platforms have also provided for negotiation of funding opportunities and support for the farmers and introduction of new ideas into the CA farming systems in these areas and have provided the learning groups with enough exposure to allow them to be included in the local economic development agendas for their regions. *Innovation platforms are crucial for awareness-raising, development of social agency, and inclusion in local and regional development initiatives.*

21.5.2 Value Chain Indicators

1. Food production for household consumption is the primary aim of these smallholder farmers. At the start of the programme, 100% of participants were able to produce only enough of their staple maize to feed their families for 1–3 months of the year. After 5 years, 38% of participants produced enough maize to last their families for 4–6 months and 53% produced enough to last their families for 6–12 months. Ten percent of participants produced enough to feed their families and sell surplus produce. They have done this by improving the productivity in their existing fields, as very few have increased the size of their fields. *CA can improve food production by between 200% and 400% over a period of 4–5 years.*

2. Local farmer centres have been introduced to provide the functions of coordination of shared equipment, an advice centre for CA implementers, and a local input-supply option for ease of access to inputs in small quantities. Decisions about the ownership and management processes of these centres were left to the learning groups. All four centres presently in operation are being managed by one or two individuals and all have managed to make a small profit of around ZAR400/month. In all four centres the owners have opted to include a range of products to accommodate for the lack of input sales in the off-season. Secondary cooperatives – linked to these farmer centres – have been registered. *Farmer centres play an important role in building social agency and local economic development options in the villages and are crucial to supporting the CA implementation process.*

3. A matching grant system has been put in place for development of infrastructure and processing (threshers, local grain mills, agricultural water supply for supplementary irrigation). To date three learning groups have taken advantage of these grants. *Matching grant funding provides some opportunities for development of agricultural infrastructure. Most smallholders still find the outlay of 50% too onerous.*

21.5.3 Productivity Indicators

1. Reduction in the labour requirements of smallholder farming systems is an important aspect and proxy indicator of the sustainability of the system. Increasingly, smallholders are limited by labour constraints as family labour is systematically decreasing and farmers have to pay for extra labour. Seventy-eight percent of the CA participants have indicated a reduction in the need for labour throughout the season in their CA plots, compared to their normal farming system plots, and this is an important reason for continuation with the CA approach. Weeding falls into a similar category as a large proportion of their labour requirement is for weeding. In cases where herbicides or mechanical weeding are employed, extra costs are incurred. Thirty-nine percent of the CA participants have indicated a reduction in weeding requirements in their CA plots. *CA linked to close spacing and intercropping reduces labour and weeding requirements for smallholder farmers.*

2. Introduction and promotion of a range of CA planters (hand planters, animal-drawn planters and tractor-drawn planters) have been central to this innovation system. At the start of the process most of the smallholders involved (97%) were using hand hoes for planting. Around 3% of the farmers used animal traction. Use of CA hand planters has increased to 69% of participants, animal-drawn CA planters to 5%, and tractor-drawn CA planters to 0.5% for those few farmers with plot sizes that justify this form of traction. Around 26% of participants still use hand hoes for their CA planting. The latter has to do both with the reluctance of older participants to embrace new ideas and work with 'fancy' equipment, and with soil conditions in some areas, where very high clay percentages make using the planters difficult.

3. Maize yields for both CA experimentation and control plots have been measured annually for around 70% of the participants. Average maize yields for the CA plots have increased from 2.3 t/ha in 2013 to 3.3 t/ha in 2018. These averages include all the participants, whether they are only starting to implement CA or have been implementing for several years. Maximum yields increased from 4.4 t/ha to 8.5 t/ha during this time. Maize yield averages for the control plots averaged 1.8 t/ha for the entire period and did not increase, although there were annual fluctuations. The 2018 season saw a 30% drop in yield averages when compared to the 2017 season. This was due to the third consecutive year of extremely difficult weather conditions – late onset of rains, mid-season drought, extreme temperatures and then above-average rainfall late in the season. *CA implementation assists in maintaining or stabilizing crop yields for 2–3 seasons under extremely variable climatic conditions.*

4. Several indicators look at the implementation of the diversified cropping principle in CA. We thus track the number of participants using intercropping (92%), crop rotation (20%), planting cover crops (31%), fodder provisioning for livestock (5%) and saving seed locally for replanting (11%). This indicates a strong uptake of the diversification principle, given that prior to this programme, 95% of participants were producing only maize in their field plots. *Crop diversification in CA implementation improves food security by providing access to a wider range of food crops as well as feed and fodder for poultry and livestock.*

5. Ninety-two percent of participants have reported reduced run-off in their CA plots compared to their control plots. They have also reported improved moisture in their soils under CA, as well as improved friability and a reduction in compaction.

6. Increase in percentage SOC has been measured for around 10% of the participants; comparing these values when they started CA implementation with values 2–5 years into the implementation process. For the Bergville area (2015–2018) there has been no significant increase in the percentage SOC in the soil (1%). Likely causes were significantly more extreme climatic conditions over the last 3–4 seasons (compared to southern KZN) and heavy grazing of the CA plots in the dry winter seasons, which left little or no soil cover. The average percentage SOC for the control plots in Bergville during this time was 30% lower than the CA plot values. For southern KZN (2016–2018), the increase has been significant at 24%, and for Midlands (2017–2018) no increases have been noted yet. *Increases in SOC are only possible in smallholder CA systems where the variability in climatic conditions is not extreme. It is possible to maintain reasonable levels of SOC in the more extreme situations.*

21.6 Soil Health Indicators

Biological changes in soil properties, such as population and diversity of soil organisms, soil aggregation, and the interplay between the carbon, nitrogen, and phosphate cycles are strongly linked to SOM (Swanepoel *et al*., 2018).

Just considering average increases in SOC over time within a CA system can, however, obscure some interesting and significant trends in soil health at a local level.

In Bergville, over a period of four cropping seasons, soil health indicators have been monitored for different cropping options within the CA system. These were compared to undisturbed veld samples in the vicinity as a benchmark. Below the combined results for three participants from Ezibomvini village, who have all been implementing CA for a 5- year period is presented as an example.

The results indicate:

- Percentage SOM is highest for SCC plots, followed by M+CP, M+B, single-cropped maize and Dolichos.
- Carbon sequestration in the CA mixed crop plots is between 0.75 and 1.5 t/ha more than the single crop plots .
- Overall carbon sequestration is on average around 2–3 t/ha for CA plots and 1.8 t/ha for the conventionally tilled plot.

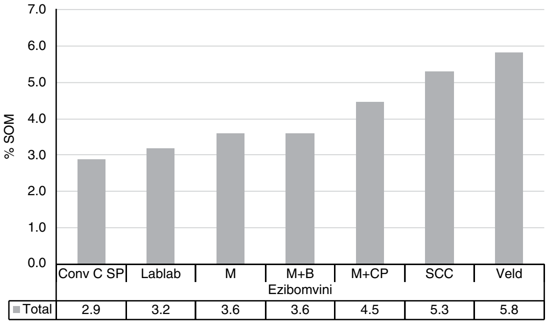

Fig. 21.2. %SOM for different CA cropping options in Bergville (2018) for three participants from Ezibomvini in their 5th year of implementation. Authors' own figure. Conv C SP, conventionally tilled control plot planted to sweet potato; Lablab, CA plot planted to Dolichos beans; M, Ca plot planted to maize only; M+B, CA plot planted to a maize and bean intercrop; M+CP, CA plot planted to a maize and cowpea intercrop; SCC, CA plot planted to a summer cover crop mix of sunflower, millet and sun hemp; Veld, undisturbed veld plot within the homestead boundaries. This is used as a benchmark for an 'ideal soil' in the locality.

This provides an indication of the advantages of multiple cropping options within the CA system in the build-up of SOM and SOC over time, despite the fact that the average %SOM for the area has not increased across seasons. It indicates the advantages of using multi-crop cover crop options and intercrops with cowpea in building carbon in the soil.

21.7 Climate Resilience Indicators

Resilience is the ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organization, and the capacity to adapt to stress and change (IPCC definition in Bizikova *et al.*, 2019).

Various frameworks have been suggested for developing indicators to assess agricultural system resilience to climate change (Bizikova *et al.*, 2019). Indicator sets are divided into five broad thematic areas: social, environmental services, economic, physical and institutional. Specific indicators within these categories are flexible and dependent on the local and policy context, as well as measurability (Ellis, 2014; Engle *et al.*, 2014; Bizikova *et al.*, 2019). Frameworks used to develop the set of indicators used in this process are based on vulnerability and adaptive capacity (OXFAM, 2012; Ziervogel *et al.*, 2014), typically used to assess the impacts of projects and processes (FAO, 2013; Bizikova *et al.*, 2019). Individual questionnaires have been developed that incorporate scales to provide weighted answers for some of the indicators (Kruger *et al.*, 2019). Participatory impact assessments (Catley *et al.*, 2014) have been designed for focus group discussions to augment the information from interviews (Kruger *et al.*, 2019).

A combination of resilience snapshots and participatory impact assessments (PIAs) have been used to build a picture in these villages of factors to assess for resilience and assessment of improved resilience status for the programme participants, comparing their situations at the start of their involvement with their situations 1–3 years later.

21.7.1 Resilience Snapshots

Resilience indicators appropriate to smallholder farmers have been developed in dialogue with farmers over a period of 2–3 years. These are used to create snapshots of resilience, understanding that building resilience is an ongoing process of adaptation and improvement.

Individual interviews with smallholders are conducted seasonally and then compiled in a dashboard format of averaged and aggregated indicators. All aspects of their farming systems are considered. An example for Bergville participants for April 2019 is shown in Table 21.4.

21.7.2 Participatory Impact Assessments (PIAs)

Through a PIA process, farmers developed their own set of resilience indicators which were used to assess the impact of their climate-resilient agriculture (CRA) activities, comparing their situation before their involvement with their situation during the process (after between 1 and 3 years of implementation).

One of the exercises in this process consisted of doing a matrix ranking of practices farmers had used in the past year, incorporating gardening, field cropping, livestock management, soil and water conservation and water issues (access, availability). Impact indicators for this exercise were developed by asking participants to outline how they made decisions about which practices to use and what changes they would observe. A process of proportional piling was used for the scoring of each practice and indicator, where 100 counters were provided for each indicator and the group decided how these would be placed proportionally for each practice.

Participants conflated practices in the following way:

- *CA* includes minimal soil disturbance (0%–15% soil disturbance), soil cover and crop diversification.
- *Savings* includes VSLAs, rotational saving in small groups towards specific infrastructural needs and personal savings.
- *Livestock* includes fodder production, vaccinations, dipping and supplementation.
- *Gardening* includes bed design (trench beds, eco-circles, raised beds), tower gardens, tunnels, mulching, mixed cropping, crop diversification, inclusion of herbs, infiltration pits and water conservation furrows.
- *Crop rotation* includes rotations with three to four crops, in field cropping.
- *Intercropping* includes grain–legume and grain–cover crop intercropping options in field cropping.
- *Small businesses* include agricultural and non-agricultural businesses, sale of snacks in schools, sewing, baking, poultry production and maize milling.

The impact indicators developed by this group (Table 21.5) are of particular interest as they are multi-dimensional, taking into account at least two different aspects for each indicator.

Table 21.5 shows that:

- The participants clearly consider the use of CA in field cropping as the most significant practice, followed by gardening, small businesses, savings and livestock, in decreasing order.
- Participants consider CA, compared to the other activities and processes, to have the greatest potential for improving soil condition, incomes, productivity and social empowerment.
- Crop rotation is considered to be better at increasing soil health and soil fertility than intercropping, showing an internalization by the group of the positive effects of rotation of the main grain crops with legumes and cover crop combinations (winter and summer cover crop mixes), as well as an observation that this works better than intercropping by itself.
- Income, savings and productivity are considered to be somewhat higher for intercropping compared to crop rotation; again, a very astute observation from the group. Generally, participants prefer crop rotation to intercropping, but are able to appreciate the increases in productivity and potential income due to intercropping options.
- Water use and access is considered by this group to be significantly better for crop rotation than intercropping. They have noticed the potential of intercropped grain and legume plots as well as grain and cover crop plots to show signs of water stress and competition for water (and potentially nutrients) between the crops. Although in principle this is not the case in well-managed fields, it is quite likely in more infertile plots and in adverse weather conditions.

Table 21.4. Resilience snapshots for seven individuals in Bergville who are actively implementing climate-resilient agriculture strategies (April 2019). Authors' own table.

Resilience indicators	Rating for increase	Comment
Increase in size of farming activities (% increase in land area and number of livestock)	Gardening 18% Field cropping 63% Livestock 31%	Cropping areas measured, no. of livestock assessed
Increased farming activities (number of activity types)	No	Most participants involved in gardening, field cropping and livestock management
Increased season (Increased number of months in the year where cropping is undertaken)	Yes	For field cropping and gardening – autumn and winter options
Increased crop diversity (Number of new crops and agricultural practices)	12 new crops 8 new practices	Management options include drip irrigation, tunnels, no-till planters, water storage tanks, rainwater harvesting drums
Increased productivity (% increase in yield)	Gardening 72% Field cropping 79% Livestock 25%	Based on increase in yields
Increased water use efficiency	1	Scale:
Water access	1	0 = same or worse than before; 1 = somewhat better than before,
Rainwater harvesting	2	2 = much better than before
Water-holding capacity	1	
Irrigation efficiency		
Increased income	13%	Based on average monthly incomes
Increased household food provisioning (weight of all crops produced, averaged across the no. of weeks/year)	Maize 15 kg/week Vegetables 7 kg/week	Food produced and consumed in the household. NOTE: This indicator was not related to a baseline amount. Vegetable production was not undertaken prior to programme initiation. Maize production was only enough to feed households for 1–3 months of the year
Increased savings	R150/month	Average of savings now undertaken
Increased social agency (Number of new group activities)	2	Village savings and loan associations and learning groups. No. of group activities before programme initiation average 1
Increased informed decision making (number of sources of information used to make decisions)	5	Own experience, local facilitators, other farmers, facilitators, extension officers. No. of sources of information used before programme initiation were 2
Positive mindsets	2.2	More to much more positive about the future; much improved household food security and food availability. SCALE:0 = less positive about the future; 1 = the same; 2 = more positive about the future; 3 = much more positive

Table 21.5. Participatory Impact Assessment matrix for climate change resilience related to different interventions and activities for Bergville participants. N = 35 (July 2019). Authors' own table.

	Soil: health and fertility	Money: income and savings	Productivity: acceptance of practice, saving in farming – equipment, labour	Knowledge: increased knowledge and ability to use	Food: how much produced and how healthy	Water: use and access	Social agency: support, empowerment	Total
Conservation Agriculture	22	21	26	28	18	23	18	156
Crop rotation	16	12	13	12	12	15	10	90
Intercropping	12	13	15	12	11	11	9	83
Gardening	14	15	12	13	15	17	21	107
Livestock	19	11	18	7	5	12	11	83
Savings	6	15	14	15	12	11	15	88
Small businesses	11	17	15	10	20	11	9	93

21.8 In Conclusion

Introduction of CA and associated CRA practices within an IS approach and using farmer-level experimentation and learning groups as the primary learning and social empowerment processes, has created a sustainable and expanding farming alternative for smallholders that is improving their resilience to climate change substantially.

Through a knowledge co-creation process, smallholder farmers in the programme have adapted and incorporated a wide range of practices into their farming system, including minimum soil disturbance, close spacing, improved varieties, judicious use of fertilizer, pesticides and herbicides, crop diversification, intercropping and crop rotation as well as fodder production and livestock integration. They have organized themselves into learning groups, local savings and loan associations, water committees, farmer centres and cooperatives and in so doing have created innovation platforms for local value chain development. They have built ongoing relationships with other smallholders, NGOs, academic institutions, government extension services and agribusiness suppliers and have promoted CA tirelessly within their local communities and social networks.

To date, this is the most successful model for implementation of CA in smallholder farming in South Africa and, through networking and upscaling activities, is being promoted nationally as a strategic approach to smallholder adaptation and mitigation programming. Malabo Declaration and Agenda 2063 have a particular focus on the need to help smallholders and their children to benefit from such transformational activities related to CSA.

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22 Lessons Learnt from Concern Worldwide's Conservation Agriculture Interventions in Malawi and Zambia, 2010–2018

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Abstract
Conservation Agriculture (CA) is a gateway technology intended to build both the productivity and resilience of smallholder farmers. Since 2010, the Ireland-based NGO Concern Worldwide has been promoting CA with extremely poor farmers in Malawi and Zambia. In the context of the specific regions within both countries, similar conditions of limited labour capacity, low financial capacity, poor soil health and constrained agriculture extension services were the primary barriers to the poorest farmers. Initial CA projects utilized broad, standardized approaches to CA with subsidized inputs that led to yield increases, but saw limited non-subsidized adoption. As a result, Concern has adapted its approaches to CA to better accommodate and embrace innovation by lead farmers, understanding different adoption strategies for follower farmers and working to improve input supply systems to meet farmers' needs. However, major constraints to adoption remain for the poorest and, going forward, CA projects will need to incorporate robust strategies for household financial stability such as the graduation model; fostering greater innovation by lead farmers within CA principles to meet local contexts; and integrating seed selection and saving for non-commercialized food crops to spur large-scale adoption of CA by the poorest farmers.

Keywords: farmer innovation, adoption-diffusion, smallholder farmers, consumption support, appropriate technology

22.1 Introduction

Conservation Agriculture (CA) has featured prominently in agriculture development programmes in southern Africa since 2004 due to its capacity to conserve and improve soil health, thereby improving farm productivity and resiliency to climate shocks (Thierfelder and Wall, 2010). The achievement of these outcomes relies on the application of good agronomic practices and the application of three guiding principles: (i) minimum soil disturbance; (ii) permanent soil cover; and (iii) diversified crop associations and rotations. Achievement of these three principles leads to a more resilient soil base that is more productive for farmers, making CA a key component of climate smart agriculture interventions around productivity and adaptation (Thierfelder *et al.*, 2017).

Concern Worldwide is an Irish NGO founded in 1968 that currently works in 22 countries

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around the world, with a specific mission focused on helping people who are living in extreme poverty achieve major and sustainable improvements in their lives (Concern Worldwide, 2016). A significant portion of the interventions carried out by Concern are centred on bettering rural livelihoods, of which agriculture is often the primary livelihood activity. Concern began implementing dedicated CA projects starting in 2008 in Zimbabwe, and in Malawi and Zambia in 2010. Concern's CA projects in those countries have dealt with the challenges around implementation of CA projects with the extreme poor. This chapter provides a narrative around Concern's CA activities in marginal areas of Malawi and Zambia, how these activities evolved to lower barriers to CA adoption by the extreme poor and how these barriers could be further reduced or removed in the promotion of CA to the extreme poor by development stakeholders who, like Concern, are promoting CA as a major component of agricultural development strategy in line with the Malabo Declaration and Agenda 2063.

The review methods used for this chapter include a desk review of Concern's baseline, mid-line and end-line evaluations conducted on our CA projects in Malawi and Zambia, project progress reports, periodic reviews of distribution mechanisms, interviews with key project stakeholders and discussions with current staff in Malawi. Monitoring data collected by Concern and by the author from the period 2010–2016 when working as the project manager for CA in both Concern country programmes were also utilized in developing these narratives, as well as data from 2017 onwards as Concern's Technical Adviser for Agriculture.

22.2 Background: Concern's Approach to Alleviating Extreme Poverty

Concern's overall approach to poverty alleviation entails targeting the segments of the rural population that rank as the poorest among those who are physically and mentally capable. This segment is targeted with activities that will address the various constraints that keep those people in conditions of extreme poverty. The contexts that shape extreme poverty vary greatly across various landscapes; therefore, a detailed contextual analysis exercise is conducted approximately every 5 years where Concern operates to identify both overarching and specific contexts. Consequent selection of interventions is then determined from both the contextual analysis, past experiences in either the same country and/or similar contextual configurations, and best practices developed internally within Concern and/or externally by other non-governmental organizations (NGOs), government partners, research institutions and so forth.

In the case of both Malawi and Zambia, the decision to utilize CA as the primary means of addressing chronic crop production deficits was strongly influenced by Concern's experience with undertaking CA in Zimbabwe between 2008 and 2010. The excellent performance of early-maturing hybrid dent maize along with open-pollinated varieties of cowpeas, and groundnuts under CA by extremely poor farmers in marginal areas such as Gokwe District, Zimbabwe, provided a working case study for what was possible in neighbouring country programmes. Additionally, there was (and continues to be) a strong institutional background in all three countries, including CIMMYT and Foundations for Farming in Zimbabwe, Total Land Care (TLC) in Malawi and the Conservation Farming Unit (CFU) in Zambia from which Concern could derive further learning, reference materials and institutional support. Funds were successfully solicited through Accenture Incorporated's 'Skills to Succeed' programme for a dedicated CA project operating in parallel in Malawi and Zambia that would commence in 2010 and end in 2013. Specific areas targeted were Dowa, Lilongwe and Nkhotakota districts in Malawi; and Kaoma, Mongu and Senanga districts in Zambia.

22.3 Contextual Configurations of Project Areas

Extremely poor rural households that engage in agriculture as their primary means of livelihood share certain characteristics that arguably span the breadth of the African continent, creating contextual configurations that forcefully shape (and often constrain) households' agriculture endeavours (Bland and Bell, 2007; Oluwatayo and Ojo, 2016; Gassner *et al.*, 2019). In Malawi and Zambia, we noted the poorest farmers shared the characteristics of having limited labour capacity, lack of access to financial resources, a depleted agricultural soil base and extension services that were characterized as weak or unresponsive to the needs of the poorest farmers. We articulate these conditions in the following sub-sections.

22.3.1 Limited Labour Capacity

Travelling by vehicle across Malawi or Zambia prior to the onset of the rains in late November, one would see early in the morning groups of people, particularly women, labouring in agricultural fields. In Malawi, this would be the making of large planting ridges using hand hoes from the remnants of the prior year's cultivation; in Zambia, this work would take the form of clearing land utilizing axes and fire. Provided the owner of the field is a smallholder, most of the people engaged in those activities are taking part in what is known in English as 'piecework' and in the Malawian vernacular as '*ganyu*'. This is a form of temporary, informal labour engagement in which the worker agrees with the hiring farmer the size of the area upon which the clearing, digging or weeding will occur, and the payment for such work (Dimowa *et al.*, 2010). Payment for work to the labourer is made with food; generally maize in either country, but often cassava roots were used in western Zambia. The number of people participating in piecework drives the payment types and amounts; fewer people looking for piecework against a high labour demand results in larger payment (food) amounts and, in some cases, cash payment. Conversely, larger numbers of people seeking piecework drives down labour rates (Whiteside, 2000).

Participating in piecework is generally viewed as a negative coping strategy, as piecework is often poorly paid, and time spent on piecework exhausts one's own capacity for productive labour on one's own farm. However, for the poorest, who lack either stored foodstuffs, or money and/or assets that could be converted to foodstuffs, engagement in piecework is a Hobson's choice: Take what little is offered, or take nothing.

22.3.2 Limited Financial Capability

Consequential to farmers engaging in piecework in either country, particularly as food stores progressively draw down or disappear prior to the onset of the rains, the poorest households reported having little or no income available. This precluded the use of improved inputs (seeds, fertilizers or pesticides) being utilized by farmers. Though affordability was a major issue (e.g. not having money to purchase fertilizers from an agrodealer) access costs also included the financial and opportunity costs of accessing those inputs from agrodealers, whose shops are often located a significant distance away and require time and/or money for transportation (Una *et al.*, 2017). When assessing a pilot voucher scheme carried out in the 2015/16 farming season, one woman in Kaoma District, Zambia, reported walking nearly 9 hours to use a voucher to collect inputs and then requiring ZMW100 (approximately US$10) to return with the inputs. Considering that ZMW100 was slightly more than the monthly distribution for households registered under the Zambian social protection schemes at the time, this cost is not insignificant. Additionally, periods of long travel are exceptionally difficult for women in terms of both opportunity costs and risk: women must determine how their young children will be looked after; they often must ask permission from their husbands to leave the immediate vicinity of the household; they are subject to sexist remarks and advances; and so forth.

Both countries featured some form of government-subsidized inputs distribution schemes, both using the acronym 'FISP', the Farm Input Subsidy Programme in Malawi and the Farmer Input Security Programme in Zambia. These schemes featured subsidized prices for both predetermined packs of seeds and fertilizers sufficient for a fixed land area. However, in both countries, distribution schemes were often delayed, with packs not arriving before the onset of the rains. In Zambia, the participation of the poorest was precluded by membership requirements and fees for farmers' cooperatives or associations, as well as the need to pay the balance of the subsidies on the packs themselves (Mason and Tembo, 2015).

The lack of finance resulted in limited hiring of labour for either clearing, tilling or weeding land. Combined with the high reliance by the poorest on piecework for their livelihood, this resulted in their clearing and tilling of land in the small allocations of time and energy they had remaining following their daily piecework. In Malawi, where land holdings are much smaller, the poorest households struggle to prepare what land they have in time for the rains, particularly with regard to the heavy labour required for making the ubiquitous planting ridges that cover the country from north to south by early December. In western Zambia, although land was abundant, the limited labour capability to clear forested or secondary growth left farmers no choice but to continually work the same area every year.

22.3.3 Compromised Soil Health

When discussing soils with farmers throughout the programme, we would often hear them describing their soils with enervating terms: 'tired', 'exhausted', 'weak', 'thin', 'worn-out', and the like. The characteristics we observed and later measured verified these descriptions: chemically, soils featured low organic matter levels, low pH, insufficient nitrogen and limited exchangeable cations. Physically, Malawi farmers tended to have massive soil structure, leading to poor moisture-holding capacity and high runoff erosion susceptibility. Conversely, soils in most of western Zambia are dominated by ancient Aeolian deposits of Kalahari sands; sand fractions in soils were at least 95%, meaning soils were excessively drained, had low inherent organic matter and were subject to high soil temperatures. In September and October 2014 the author measured soil temperatures in excess of 60°C in six sites in Mongu District.

Conventional farming practices, such as clearing and burning of surface biomass, and the repeated tillage of topsoil through ploughing or hand-hoeing, contribute to the depletion of soil health for the poorest farmers. We did not find any cases in either country where farmers were not well aware of conventional methods of improving soil health, as these would often be articulated by the farmers themselves as a comparison with better-off farmers. Where better-off farmers could utilize cattle for tillage and manure resources, poorer farmers with no or few livestock had to till the soil by hand and lacked manure to replenish soil organic matter. Better-off farmers could access fertilizers and improved seeds, leading to more *in situ* organic matter on their soils; poorer farmers used no fertilizer and sourced their seeds from grain or pulse sellers in the district capitals, meaning low yields and poor biomass production. Additionally, in areas where land is considered as communal during the dry season, wealthier farmers' livestock would intentionally or accidentally graze crop residues off the fields of the better-off and poor alike, but would deposit the majority of their manure in their owner's kraal, at which point the manure belonged to the livestock owner. Though not insidious in intent, communal grazing did end up having the insidious impact of transferring fertility resources from the fields of the poorest to the better-off households. It was, therefore, no small wonder that target populations would continuously request improved seeds, fertilizers and cattle, as these were the only levers they knew of to improve their soil health and, consequently, their crop productivity.

22.3.4 Limited Provision of Extension Services

The last critical component affecting the poorest with regard to their agricultural performance is the lack of extension support available to the poorest. Although both countries have established conventional research and extension services, these services are chronically underfunded and over-extended. At the advent of the CA programme (2010) in Zambia, there had been a long-term hiring freeze of new extension agents by the government dating back to the structural reform of the economy in the mid-1990s, meaning that many posts were left vacant as officers retired. Remaining officers had limited opportunities for new or refresher training, and had few resources for conducting field extension, notably motorcycles or the fuel and/or spares to keep them running. Baseline surveys conducted by Concern in early 2012 in western Zambia showed that although extension officers were known and valued by community members, farmers had little or no interaction with those officers.

With regards to the number and availability of extension officers, Malawi was slightly better-off than Zambia, in no small part due to Malawi having the same population as Zambia, but only one-seventh the land area. However, extension officers in Malawi still faced similar logistical challenges, and were particularly overburdened with the organization, registration and distribution of government-subsidized agriculture inputs. This often had the effect of crowding-out time for other extension activities such as demonstrations and farmer training.

22.4 Concern's Approach to Conservation Agriculture (CA) – Phase I (2010–2013)

Both countries utilized the farmer-to-farmer extension method in which lead farmers were identified by the community. The lead farmers were trained in basic CA practices and provided with basic input support packages of seeds and fertilizers to develop basic CA demonstration plots of 0.15–0.25 ha adjacent to equivalent or larger areas of conventional farming to show comparisons between practices. CA practices differed slightly between countries; in Malawi, emphasis was placed on creation of a heavy mulch layer (10–20 cm deep) through the transfer of maize stover from adjacent fields onto the demonstration plot during the dry season; farmers would then plant in regular stations through the mulch with the onset of the rains. In Zambia, more emphasis was placed on the digging of planting basins at regularly spaced intervals in order to concentrate rainfall into those basins. In both countries, farmers were trained in the timing and application of fertilizer dosages, and basic management of weeds. Lead farmers in Malawi received hybrid maize (*Zea mays*), groundnuts (*Arachis hypogaea*) and soybeans (*Glycine max*); in Zambia, hybrid maize, groundnuts and cowpeas (*Vigna unguiculata*), as there was a consensus among farmers and practitioners that soybeans were not appropriate to western Zambia's soils.

The initial response of crops to CA practices was not surprising; in both countries, yield increases from lead farmers were noted in both the 2011/12 and 2012/13 farming seasons among sampled beneficiary farmers. Although absolute yields in Central Region, Malawi, were much higher than in Western Province, Zambia, CA yields in Zambia were higher relative to conventional yields. For example, in 2013, maize yields under CA practice in Mongu District, Zambia, were 1.960 t ha^{-1}. Although not an impressive number, it was an increase of 430% against government-estimated conventional yields of 0.37 t ha^{-1}.

Results from the project were judged a success in that overall crop yields were higher. Interpreting the project as a success in terms of adoption or acceptance of CA methodology was less apparent; to take one example, despite the higher yields from mulching in Malawi, it was rare to see emulation of mulching practices in neighbouring farmers' fields. Similarly, it was uncommon for Zambian farmers to expand their CA plots beyond the prescribed 0.25 ha. A review of the project with staff and lead farmers in late 2012 implied the following shaped farmers' views and adoption of CA practice:

1. Farmers often associated the practising of CA as a requirement for getting inputs from the project, causing non-beneficiary farmers to eschew the practice in lieu of receiving inputs.

2. Farmers conflated CA practices and improved inputs: that is, to practice and get good results from CA, one had to use improved seeds and fertilizers.

3. Gathering and preserving mulch and/or retaining crop residues was difficult in both countries, as residues were subject to fires, grazing animals and/or theft for fuel in the case of Malawi.

4. Despite shifting labour requirements for land preparation earlier in the dry season, the practices of digging basins (Zambia) or mulching (Malawi) was seen as onerous for extremely poor farmers, who would otherwise engage in other livelihood activities during the dry season.

5. Zero tillage in unmulched soils created significant challenges with regards to weed pressure, particularly in fields where grass species such as *Cynodon dactylon* (couch grass) and *Cyperus rotundus* (nutsedge) were prevalent.

6. In the Zambian sites, better outcomes from CA were dependent on farmers' access to manure; however, the manure was often unavailable to the poorest.

22.5 Concern's Approach to Conservation Agriculture (CA) – Phase II (2013–2016)

The success of the first CA project was convincing enough to receive funding from Accenture again in 2013 for a continuation of the project for another three years (2013–2016), albeit at a larger scale and, in the case of Malawi, in a new district (Nsanje). However, care was taken to integrate solutions to the challenges identified in the first project.

22.5.1 Lead Farmers as Innovators

Farmer-to-farmer extension approaches were adapted to have the lead farmers' demonstration plot be more of an experimental learning plot. This was a learning process, as many of the lead farmers from the previous phase had assumed certain practices as canonical; further, there is in both countries an in-built expectation by farmers that knowledge is disseminated to farmers from extension or project staff and concurrently there was a devaluation of local knowledge.

To legitimize lead farmers' knowledge generation, government and project extension staff encouraged farmers to develop basic experimental plots. Lead farmers were encouraged to develop their own experiments with different crops, planting rates, planting dates, organic inputs, integrated pest management and the like, where the only proscription was that overall CA principles had to be observed. For instance, one lead farmer in Mongu District, Zambia, did four side-by-side plots, each 10 × 10 m, in which he planted Bambara nuts (*Vigna subterranea*), four different plant populations using traditional (stochastic) spacing; single lines with 10 cm between plants; double lines with 10 cm between plants and 10 cm between lines; and double lines with 5 cm between plants and 10 cm between lines. Another more common practice in Zambia was experiments with different organic inputs buried in the planting basins; lead farmers would trial different types of manure (goat, cow and chicken); green leaves from local trees or shrubs such as *Baphia massaiensis*, *Brachystegia spiciformis* or *Terminalia sericea*; wood ash, charcoal and so forth.

In Nsanje District, Malawi, in the floodplains of the Shire River, mulching was tested using readily accessible grass species in dry-season irrigated plots used for green maize, sweet potatoes and leafy vegetable production. In both countries, lead farmers were trained in the basics of manufacturing local botanical sprays to deter black aphids (*Aphis craccivora*) in cowpeas, stalk borers (*Papaipema nebris*) and, more recently, fall armyworms (*Spodoptera frugiperda*) in maize, utilizing both local and exotic species such as *Bobgunnia madagascariensis*, *Melia azedarach* and *Tephrosia vogelli*.

Lead farmers and extension staff regularly alternatively hosted or visited lead farmers and extension staff from other communities or districts. During these visits, the visiting group of lead farmers would utilize peer-to-peer evaluation tools to assess the hosting lead farmers' plots, and then feedback in a participatory fashion to the hosting farmers. In this way, lead farmers could learn from their hosts, but also provide feedback on their approaches. Although the experiments could not be remotely considered scientific, the basic exercise of experimentation and evaluation imparted a greater confidence in farmers' development of new practices. Additionally, it created a space for lead farmers to learn from failures in their own experiments without major risk to either their pride or their own livelihoods. For example, one farmer trialled sawdust as an organic input for maize; though technical staff could foresee the resulting poor outcome, it was evaluated correctly by other lead farmers as a valid experiment given the availability of sawdust in that location and the adjacent comparison with wood ash and green tree leaves as inputs. Consequently, that lead farmer stopped using sawdust and utilized a different input source.

22.5.2 Follower Farmer Adoption

The nature and diversity of the experiments across the spatial extent of either country made quantitative analysis difficult. Practices were therefore not assessed or compared quantitatively, but were rather made using basic observations such as visual assessments of the plants, cobs, pods, etc. These observations were conducted by both lead farmers during their exchange visits, as well as by follower farmers in their visits to the lead farmers' fields for either regular training, visits or field days. Follower farmers were encouraged to choose and utilize the practices that were most appropriate to their specific situation.

Some practices selected were ubiquitous; in the light, sandy soils of Western Province (Zambia), the practice of digging basins for crops other than maize virtually ceased, with farmers using dibble sticks to sow legumes in planting lines. Basins continued to be utilized for maize production, although the practice became tied with the application of green tree leaves in lieu of unavailable manure resources. Other practices were gendered, in that women were the primary adopters of certain practices; this was true for increasing the planting densities for groundnuts and Bambara nuts. Higher planting densities required less area needing preparation for planting, but also presented opportunities for women with access to more seed to increase yields of either crop on their limited land allocations. In both countries, women were the primary users of botanical sprays on legumes, and later, on their home gardens and irrigated vegetable plots. However, as fall armyworm infestations in maize crops increased after 2016, both male and female farmers in the Malawi project increased their utilization of botanical sprays on maize as a countermeasure.

However, some practices continued to see minimal adoption, with mulching being the most noticeable case. Although deep mulching is an effective way to mitigate against recurrent dry spells that plague rainfed maize production in both countries, adoption has up to now been ephemeral, with few farmers persisting in the practice. It was not for want of demonstration: mulching was demonstrated extensively in both countries, with variations in timing, depth and type of mulching material uniformly showing improvements in maize yields. However, follower farmers often mentioned the time and effort required to gather and systematically mulch fields during the dry season, and later, protect the mulch from fire, grazing or (in the case of Malawi) theft. Malawian farmers in particular were hard-pressed to gather adequate mulch from their own fields, which ironically, left those fields without organic matter of any sort. There were some notable exceptions to that rule; namely, farmers were more likely to mulch on their home gardens, and in Nsanje District, adoption of mulching in irrigated plots along the Shire River increased due to the immediate returns in terms of lower irrigation labour and time, as well as the readily available grass resources.

22.5.3 Negotiating the Last Mile of Seed Provision

In the first phase of the project, inputs were delivered directly to lead and follower farmers as standardized packs of inputs (i.e. seeds and fertilizers). Although Concern put significant effort into procuring and supplying the appropriate seeds and fertilizers for the respective locations, extremely poor farmers lacked agency in making decisions about which crops they wished to grow, or in what quantities. Further, the logistical and financial burden of procuring and delivering seeds over vast distances added large fiduciary and opportunity costs to the project, while distorting or suppressing local agrodealers' capabilities.

In the second phase of the CA project, Concern undertook different schemes for bringing farmers closer to the input supply. In Malawi, Concern developed a system of seed fairs and vouchers with local agrodealers. Target farmers received vouchers of fixed values that they exchanged for seed inputs at local seed fairs conducted by the agrodealers. In Zambia, the lower population density and fewer agrodealers necessitated a modified approach. Local farmers were engaged in the production of Quality Declared Seed (QDS) for open-pollinated species like cowpeas, groundnuts and Bambara nuts, which they then sold to local agrodealers. Farmers received vouchers of a fixed value that they took to the agrodealers' stores to exchange for inputs of their choice. Over subsequent years, voucher values were lowered so that farmers were weaned off external dependence for inputs. These actions fostered greater involvement of the poorest in accessing inputs, as well as providing local sources of QDS for agrodealers to exploit future sales opportunities.

22.6 Persistent Challenges in CA Scaling and Uptake

In spite of the best intentions and interventions of Concern and government stakeholders in CA promotion, there were immutable realities that continued to constrain farmers' performance of CA that negatively impacted both crop yields and their adoption of CA practices. Particularly for the poorest, poverty drives them to rely on negative coping strategies such as piecework, which does not afford sufficient energy resources or time on one's own farm to carry out the critical field preparation activities (Cole and Hoon, 2013). Although a great deal of that labour can arguably be done during the dry season when food security is higher, that work would likely displace other on- or off-farm livelihood activities that might yield more immediate returns. An additional effect of piecework and the resulting hand to mouth existence is the diminished capacity of people to plan, as well as increased stress levels. Farmers engaged in piecework during the dry season are in a state of near panic due to stress and worry resulting from the hunger and the tenuous nature of their livelihoods (Cole and Tembo, 2011). Farmers engaged in piecework, particularly women, were continuously worried about where their next meal would come from, where they could find money to pay for clinic or school fees, and the like. This stress is to the extent that it can negate the ability to conceive, plan, and/or undertake new, comprehensive agriculture methodology like CA or, at the very least, expect the returns characterized in most CA promotional literature.

A secondary challenge is the limited financial capability of the extremely poor to access improved inputs that would contribute to their agriculture production with or without the CA methodology. Part of the justification for input provision in both phases of the CA project was the fact that targeted farmers' cash reserves were insufficient or non-existent to purchase seeds, fertilizers, and/or pesticides. In theory, increases in yield would reduce purchase of external foods, leaving more money for input purchase. Although this was the case for some farmers, the majority of farmers stated that sale of produce was typically done to satisfy immediate needs such as school fees and loan repayments. Farmers also cited market structures in which small-scale, so-called 'briefcase buyers', would come to the market only during harvest periods (May–July). Although prices offered were low due to the glut of produce on the market, it was again something of a Hobson's choice: take the low price offered, or be left to your own devices to transport and sell grains on the open market later in the year. Similarly, though there were parastatal entities in both countries (the Agriculture Development and Marketing Corporation (ADMARC) in Malawi and the Food Reserve Agency (FRA) in Zambia) that offered higher-than-market, pan-territorial prices, both were perennially delayed in receiving funds to pay farmers.

22.6.1 Consumption Support and Conservation Agriculture (CA)

The CA project staff and associated government stakeholders became increasingly aware of these issues as the project progressed. After the 2013/14 rainy season, provincial baseline studies conducted in Zambia showed hunger gaps in most communities emerging a few months after the maize harvest (May), with critical food shortages among the poorest from September to February. This, unfortunately, overlapped with the crucial field preparation, planting and cultivation season. Focus group discussions with farmers revealed that time spent looking for and performing piecework and the low labour rates precluded farmers or their households from having either sufficient time or energy to work on their own fields. Consequently, despite receiving input packages and CA training, farmers were often physically incapable of carrying out the field preparation activities (mulching, digging basins, etc.) on time, nor were they able to hire labour as a substitute.

In response, Concern Zambia conducted a pilot exercise starting in October 2015 where 50 female beneficiaries were issued ZMW100 (approximately US$10) per month for 5 months. Conditions were not attached to the cash distribution, but recipients had to account for how the money was spent prior to receiving the next month's allotment. The recipients of the allotment typically spent the majority of it on food purchases for the household. This had a series of positive knock-on effects: recipients obviously reported far less hunger and time spent engaged in piecework, but also described a large expansion in available hours of labour per day. This had a number of different positive outcomes, not the least of which was an expansion of land cultivated using CA techniques. Although the sample was relatively small, it showed that a relief from the stress of food insecurity created a more enabling environment for farmers to utilize CA training on their own fields. In a similar fashion, Concern Malawi has started integrating CA trainings into its graduation model projects, which provides graduated financial support through case management to ensure sustainable departure from poverty cycles.

22.6.2 Essential Takeaways in Conservation Agriculture (CA): Remembering the Poor

Concern's work in CA has extended to integration in larger-scale programmes involving all aspects of rural livelihoods, such as hygiene, nutrition, livelihoods (both on- and off-farm) and socio-cultural empowerment both within and external to a household. We learnt that purported gains in productivity alone were not enough to spur full-scale adoption of CA, particularly amongst the poorest. Despite their clear desire to improve their own livelihoods, the poorest are often unable to adopt narrowly defined CA intervention packages. Concern has yet to come up with the perfect solution to guarantee adoption of CA among different agroecological and socio-economic contexts, but some common threads have emerged from Concern's work in Malawi and Zambia around reducing the barriers for greater utilization of CA by the poorest:

1. Integrate programmes around household income support and management (graduation model) with CA interventions to reduce households' need to engage in piecework as coping strategies that lower their initial capacity to succeed at CA.
2. Encourage lead farmers to experiment with different methods and crops within CA principles to develop both contextually appropriate, locally owned solutions that optimize use of local resources that do not have conflicting uses and are freely available for purposes of soil improvement and pest management.
3. Increase farmers' agency around seed selection by working on solutions that allow for better selection and storage of non-commercialized open-pollinated crops (e.g. Bambara nut and cowpeas), as well as developing appropriate 'last-mile' solutions for commercialized hybrid crops such as maize.

22.7 Conclusion

Ragged Dick, the fictional and titular hero of American author Horace Alger's best-selling *Bildungsroman* series in the late 19th century, was the personification of the 'rags-to-riches' narrative. A poor New York City bootblack, Dick desired to leave his shambolic life behind and 'to turn over a new life, and try to grow up [re]'spectable'. Through hard work, honesty, frugality and any number of episodes of *deus ex machina*, Ragged Dick emerges from life on the street and joins a mercantile firm, renaming himself Richard Hunter and embarking on a middle-class lifestyle (Alger *et al*, 1868).

There is a strong element of Ragged Dick permeating the promotion of CA. Successful CA farmers are celebrated, photographed, featured in posters, brochures, case studies, short films, and the like. Similar to Ragged Dick learning his '3 Rs', they learnt and practised the three principles, and lifted themselves up by pluck and the *deus ex machina* of project support. However, like Dick's less-successful comrades in the Bowery, farmers who fail to perform as well at CA with or without external support have that failure equated to deficits in character (laziness, ignorance, etc.). The message that comes across is that success and failure with CA is due entirely to farmers' internal agency or intention, neatly shorn of the structures they physically and culturally inhabit. This narrative is slowly changing, but it persists, and simplifies larger structural issues with adoption of CA practices that are less easy to tackle.

In this chapter, we have recounted Concern's experience promoting CA with the poor in rural Malawi and Western Province, Zambia, from 2010 to 2018, and how the projects adapted to the specific ecologies of contexts in which they functioned. It was a testament to both staff and farmers that, in both cases, we were able to utilize and adapt a well-known and static methodology to improve both farmers' yields and their resilience to climatic shocks. However, we recognized that even the utilization and adaptation of a comprehensive agriculture package such as CA was still topical relative to the deep, underlying contexts and intentions that shape farmer behaviours, and that additional steps have to be taken to address those specific internal behaviours and external pressures that perpetuate household poverty. This requires addressing aspects of financial capacity, gender inequality, market access and well-being that impact households prior to or in parallel with implementing a CA project.

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23 Development of Adaptive Training Materials for Conservation Agriculture Promotion in Africa

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Abstract

In order for Conservation Agriculture (CA) to reach and impact small-scale farmers in Sub-Saharan Africa (SSA), CA technologies need to be adapted to suit the diversity of agroecological zones and cultures present on the continent. Training materials for CA promotion need to be similarly customizable to help extension staff and farmers develop their own, context-appropriate solutions from among the many possible CA approaches. From 2015 through 2018, a diverse set of farmer-level training materials for CA and complementary technologies was developed and field-tested by Canadian Foodgrains Bank partners. Together with a participatory, adaptive training methodology, these materials have enhanced the effectiveness of CA promotion, and they have been made available for copyright-free download in English, French, Kiswahili, Portuguese and Amharic (http://caguide.act-africa.org/, accessed 6 August 2021). This paper describes the process of developing these materials as well as challenges and constraints to their utilization.

Keywords: Participatory learning, curriculum, master trainer, question-posing, facilitation

23.1 Introduction

Conservation Agriculture (CA) is a climate-resilient strategy which has been increasingly promoted for smallholder farmers in Africa over the past 20 years. In the last decade, CA adoption in Africa has increased gradually, though it still lags behind much of the rest of the world (Kassam *et al.*, 2015; 2019). Access to information and extension services has been shown as one determinant of CA adoption (Arslan *et al.*, 2014; Brown *et al.*, 2018). Other factors include the need to formulate and adapt CA technologies to suit the diversity of agroecological zones and cultures present on the continent (Liniger *et al.*, 2011; Brown *et al.*, 2018) and the need to combine the application of CA principles with other agronomic practices, such as integrated soil fertility management, which complement the benefits derived from CA and provide greater short-term returns (Vanlauwe *et al.*, 2014; Thierfelder *et al.*, 2018).

Training materials for CA promotion in Africa have been developed by international agencies, national extension programmes and non-governmental organizations (NGOs) (IIRR

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and ACT, 2005; Dryden, 2009; FAO, 2015; CFU, 2017). However, many of these materials are context-specific and not easily customized to the wide range of cultures and farming systems encountered in Sub-Saharan Africa (SSA). *Adaptive* training approaches are needed, which use higher cognitive learning (Nappi, 2018) to help extension staff and farmers develop their own, appropriate solutions from among the many possible CA approaches. This paper describes a diverse set of training materials for CA and complementary technologies that, together with a participatory, adaptive training methodology, has enhanced the effectiveness of CA promotion by some 35 NGOs throughout SSA (see Annex 23.1). Such approaches can contribute significantly to the Malabo Declaration Commitment of enhancing resilience to climate variability, for which only 22.4% of African countries were on track during the recent Biennial Report (DREA, 2020).

23.2 Development of Adaptive Training Materials

Canadian Foodgrains Bank (CFGB) has supported CA projects implemented by African NGOs for over 15 years (Annex 23.1). In 2015, CFGB and the African Conservation Tillage Network (ACT) organized a writeshop in which NGO partner extension staff, together with experienced CA farmers and scientists, prepared a set of core CA modules for farmer-level training (Table 23.1).

The curriculum is comprised of three elements. A *Facilitator's Guide* with a series of questions and hands-on activities is designed to guide a farmers' group through a process of discussion and discovery. One or more *A1-size colour posters* accompany each module, illustrating key CA concepts and serving to engender discussion. The posters are picture-rich with minimal text (Fig. 23.1) so that farmers can offer their own explanations and solutions. Facilitators are encouraged to replace the text with local languages, and the stock pictures with others taken locally, in order to maximize their relevance to each community. And finally, the same images are compiled in a *Farmer Booklet*, which can be printed for wider distribution, and for farmers to share what they have learned with their families and neighbours.

The question-posing approach utilized by this curriculum grows out of a great deal of evidence showing that effective learning comes when facilitators and participants join together in a genuine dialogue (Nappi, 2018). Facilitators may bring knowledge of the scientific world, but farmers best know the reality of their community and farming system. A lecture format, where a teacher talks and the students passively receive information, is rejected in favour of a dialogue in which all parties discuss the reality of their lives, and work together to identify solutions and action plans. A skilled facilitator asks open-ended, generative questions, for which there are many possible answers, rather than simply providing answers. The posters and farmer booklets help these discussions by illustrating the issue at hand, but they should also be used in a question-posing mode, allowing participants to discuss and discover what they represent rather than to have the facilitator explain what they mean.

The core modules were designed to be taught separately, with each session taking place according to the cropping cycle. In between training sessions, farmers are expected to practise and adapt what they have learned before continuing with the next module (Fig. 23.2).

Table 23.1. Core Conservation Agriculture (CA) modules for farmer training. Authors' own table.

Module	Timing of training
Situation analysis: why CA?	2 months before planting
Minimizing soil disturbance with planting basins	1–2 months before planting
Importance of soil cover	1–2 months before planting
Planting with precision	2 weeks before planting
Cover crops	2 weeks before planting
Weed management in CA	2 weeks after planting
Crop residue management	1 month before harvest

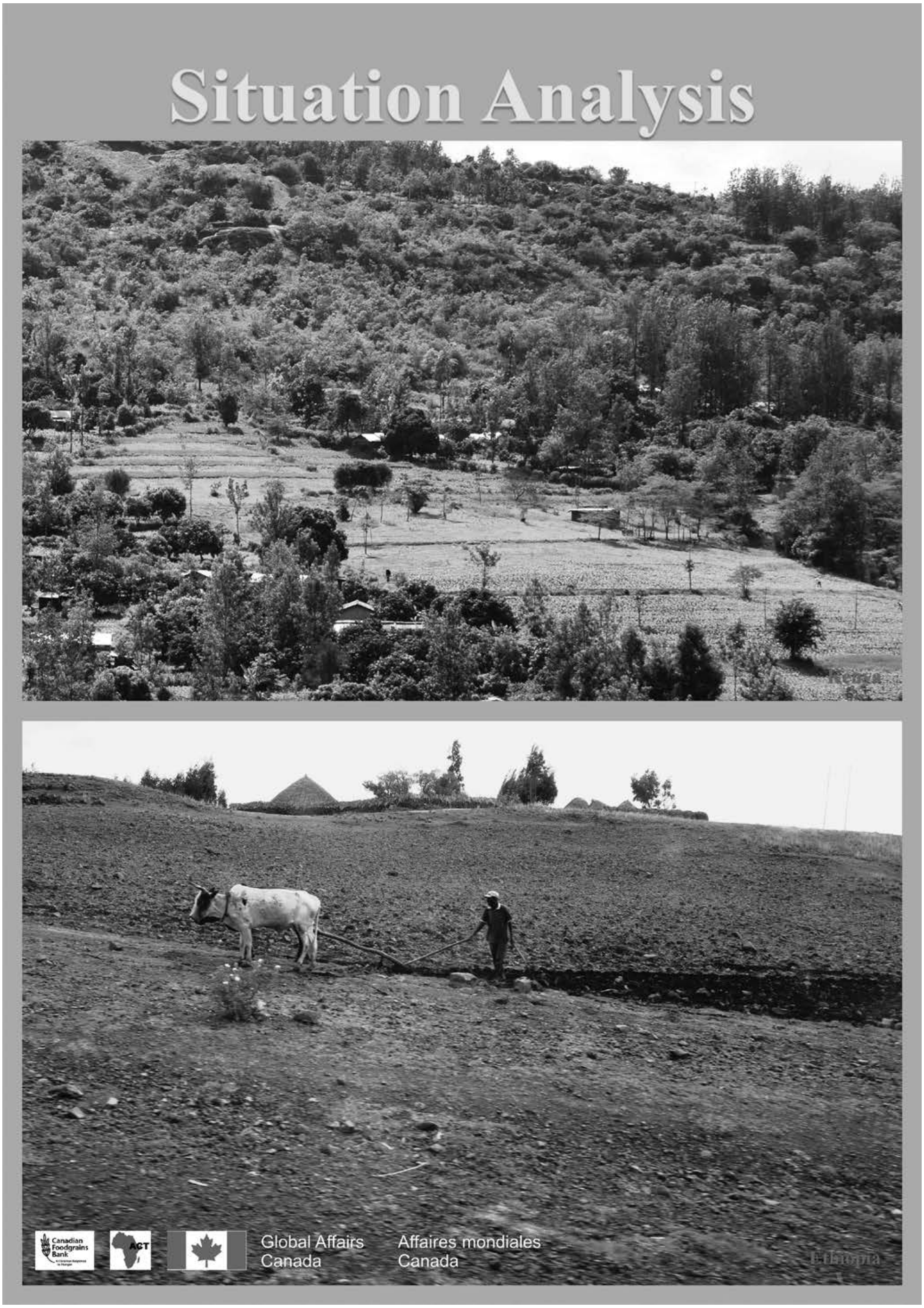

Fig. 23.1. 'Situation Analysis' poster used in the introductory Conservation Agriculture module. Participants discover the relevance of the pictures presented to the challenges they face in their own farming system with minimal guidance from text. Authors' own figure.

	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
	🌧	🌧	☀	☀	🌧	🌧	🌧	🌧	☀	☀	☀	☀
Field Operations	Plant minor crops		Field prep	Field prep	Plant main crops	Weeding	Weeding		Harvest	Harvest		Minor field prep
Training Workshops												
Situation Analysis/ Introduction to CA		X										
Minimum Tillage and plant spacing			X									
Importance of Soil Cover			X									
Planting with Precision				X								
Cover Crops				X								
Weed Management with CA					X							
Crop Residue Management								X				
Follow-up Visits			X		X	X			X			

Fig. 23.2. A typical curriculum cycle follows the seasonal calendar with time for practical application between each training session. Authors' own figure.

This timely, iterative approach was designed to address the particular learning styles of adults (Kolb, 1984; FAO, 2016).

The core training modules were field-tested by CFGB's partner organizations throughout SSA over a 2-year period, during which they were encouraged to translate the materials into local languages and adapt them to reflect appropriate CA options for their farming systems and for farmers with differing resource endowments. The training setting varied from partner to partner, but most projects used groups of 10–30 farmers facilitated by partner staff or trained lead farmers.

In 2017, a more extensive writeshop was organized with support from the Government of Canada to finalize the core materials and to draft additional modules on other CA and CA-complementary subjects (Table 23.2). A gender specialist was engaged after the 2017 writeshop to review all materials and ensure gender sensitivity, after which changes were made in both text and images.

After final editing, these materials were initially made available for download in English, French, Kiswahili, Portuguese and Amharic from the ACT website (http://caguide.act-africa.org/, accessed 6 August 2021) and more recently ECHO (ECHOcommunity.org, accessed 6 August 2021), with other languages being added as demand and resources allowed. All materials were distributed without copyright in easily editable formats (Microsoft Word© and Microsoft Publisher©), and users are encouraged to edit and adapt them to their local context after which they may be added to the website for wider distribution. Additional training modules on associated technologies are added periodically, and these plus the core CA modules are continually being improved and updated.

23.3 Results and Discussion

23.3.1 Adoption and Adaptation of Training Materials

Field testing of these materials by the above-mentioned NGO partners from 2015 through 2018 affirmed the effectiveness of an adaptive, participatory approach to farmer training. Field staff indicated that the large-size posters, customized with pictures from their local communities (Fig. 23.3), were particularly useful in CA promotion. Printed on waterproof vinyl material,

Table 23.2. Additional modules on Conservation Agriculture and complementary subjects. Authors' own table.

Modules	Notes
Preparing CA fields with ox-drawn rippers	
CA with root crops	
CA & livestock integration	Introductory module
Soil conservation & CA	
Integrated soil fertility management	Introductory module
Safe and effective grain storage	
Insect identification and monitoring	Part of an IPM series
Natural pesticides	Part of an IPM series
Using pesticides safely	Part of an IPM series
How to experiment on your farm	
Lead farmer training	

IPM, integrated pest management.

they are easy to transport and use in remote locations and very effective in generating dialogue and conveying key concepts.

Fitting the training schedule into local cropping cycles (Fig. 23.4) was effective in avoiding farmer information overload. Farmers were able to implement and adapt the practices learned in each module before undergoing another learning session. These cycles of reflection and action created a powerful praxis of learning (Freire, 1970) through which farmers were empowered to adapt the ideas with which they were presented, and develop appropriate solutions to their own farming constraints.

While these training materials were used in a variety of settings, the most effective approach proved to be holding training sessions on the farms of individual farmer group members. This helped prevent the 'demonstration farm syndrome' whereby farmers doubt the credibility of what they are shown because outside resources, which are unavailable to the average farmer, have been used to achieve the demonstrated outcomes. By hosting training sessions in rotation, on different farms, a sense of peer accountability and competition was created as participants strove to establish high-quality plots which impress their group members and allow them to host the next training session (Fig. 23.5).

23.3.2 Scaling Out

The core CA training materials were translated into more than 12 languages, though the actual number is unknown since they have now spread beyond the CFGB network. This distribution was aided by the web-posting by ACT and ECHO (see above) as well as through project-to-project dissemination. The method was used to train over 70,000 farmers (59% women) involved in CFGB-funded projects in ten countries of SSA. From 2014 to 2018, the percentage of trained farmers who began practising CA increased from 53% to 83% (CFGB, unpublished). Although the criteria used to document CA practice varied from project to project, the increase in success rate over this time period was consistent.

A key indicator of successful scale-out in these projects has been CA adoption by farmers who have *not* been trained directly by the projects (Box 23.1). So-called 'spontaneous adoption' ensues when farmers own the learning they have gone through, and the successes they have achieved on their farms, to such a degree that they are motivated to share their knowledge, and as their neighbours and family members value and seek their advice. Tracking these individuals can be challenging, but CFGB-funded projects are increasingly including this key indicator as a measure of success in their monitoring and evaluation frameworks.

In 2017, the successful implementation of CA training by NGO partners using these training materials in the Amahara, Southern Nations Nationalities and Peoples, and Benshangulgumuz Regions of Ethiopia, were showcased as part of an initiative to attract

Fig. 23.3. 'What is Conservation Agriculture?' posters customized to: (top left) Chichewa, (top right) Amharic, (lower left) Alur, (lower right) Kikuyu. Authors' own figure.

Fig. 23.4. A simple, hand-written Conservation Agriculture training calendar guides training according to the cropping cycle in Lakka Kabele, Arba Minch Woreda, Ethiopia. Authors' own figure.

Fig. 23.5. In addition to improving soil health, suppressing weeds and providing fodder for her goats, this velvet bean field planted by Martha Raciuw (second from left) serves as a one of several 'classrooms' established on the farms of members of her farmer group in Kucwiny, Uganda. Authors' own figure.

Box 23.1. Spontaneous Spread of Conservation Agriculture in Tharaka Nithi, Kenya

The National Council of Churches in Kenya (NCCK) has promoted CA, using the training materials described in this chapter, in three Wards of Tharaka Nithi County since 2015. At the end of their first project cycle, a survey of 283 farmers revealed that they had promoted the CA technologies they learned to 598 other farmers who were *not* members of their farmer groups. The actual uptake of CA practices by these 'spontaneous adopters' will be documented in future surveys. However, the enthusiastic promotion of CA by project participants is notable in its own right. The evaluators concluded 'This is an important indicator of not only success in outcome but also sustainability of the project. The greatest factor of sustainability in any project is behaviour change in the larger community' (Wangia and Nyongesa, 2018).

the attention and support of the Ethiopian government. This exposure resulted in the Minister of Agriculture (Hon. Dr Kaba Urgessa) affirming the practice of CA in Ethiopia and calling on agriculture extension services to provide CA training for farmers. A Master Trainer initiative began with support from the David and Lucile Packard Foundation in 2019, designed to train and equip district-level extension staff from the above regions, together with Oromia, and to adapt and use the training materials described herein for CA promotion.

23.3.3 Challenges and Constraints: an Evolving Response

Most of the farming communities served by CFGB projects in SSA are dominated by maize cropping systems. The CA curriculum was, accordingly, developed with CA technologies and demonstrations appropriate to maize-based production systems. This bias has led to challenges in communities where other crops, like small-grain cereals or cassava, dominate. Prior to the launching of the 2019 master trainer programme in Ethiopia, the curriculum was revised substantially by adding new modules on CA methods for production of small-grain cereals and root crops. The cover crops module was also expanded to include species appropriate to the mid-highland agroecological zones of Ethiopia. Additional training modules are still needed, particularly on critical issues such as livestock–CA integration and CA mechanization.

New practitioners of question-posing approaches to adult learning often complain that the process takes far more time than conventional methods of teaching. Indeed, helping farmers discover their own solutions through discussion and practice is far more time consuming than simply supplying them with solutions. Furthermore, many NGOs are used to staging multi-day workshops at the beginning of the cropping season, thus completing their training obligations in a one-off event.

While such approaches may, at first glance, appear more time- and cost-efficient, their relatively low adoption rates often result in a much lower return on investment in training. Indeed, rigid, directive training approaches have been identified as one cause of low adoption of CA practices among small-scale farmers in SSA (Liniger *et al*., 2011; Anderson and D'Souza, 2014; Brown *et al*., 2018). In order to accommodate the added time and staff resources which will be needed to implement a question-posing approach to farmer training, project budgets and work plans often need to be adjusted and targets for the number of farmers directly trained may need to be reduced.

During the 2017 writeshop and subsequent field testing, concern was raised that many field extensionists lack the skills to fully utilize this curriculum. The facilitation, question-posing approach was new for many individuals brought up in formal didactic educational systems. To maximize the effectiveness of these materials, therefore, training in adult education and facilitation methods was identified to be as critical as training in technical CA concepts and practices.

Furthermore, although the materials were made available in copyright-free, simple-to-edit formats, extension and NGO staff often struggled to edit and adapt them appropriately to their context. Many lacked the computer skills and needed further training and editing support in order to develop and reproduce high-quality training materials. This need was particularly felt by the staff of smaller NGOs where such support was not available within their own organization.

In response to these challenges, a more comprehensive training strategy is being formulated to assure wider and more effective use of this training approach for CA adoption and scaling. The master trainer initiative described for Ethiopian government extension staff will be extended to other countries where CFGB is actively supporting agricultural training initiatives, and to other organizations outside the CFGB network. Curricula for this training will include adult education, question-posing facilitation methods and agronomic practices appropriate to each country, as well as skills for developing and adapting training materials. Master trainers will undergo four, 1-week-long cycles of training, interspersed with practical exercises and applications in their area of work. At the end of their training, participants will be judged on their learning and application, and successful candidates will be certified to train others in the question-posing, CA training methodology. By investing in such local expertise, the successes described above should be expanded in a sustainable and far-reaching manner.

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Annex 23.1. Summary of Canadian Foodgrains Bank-funded projects with a Conservation Agriculture component and beneficiary numbers in Sub-Saharan Africa, 2014–2018.

	2013–2014		2014–2015		2015–2016		2016–2017		2017–2018	
Country	Projects	Farmers trained	Projects	Farmers trained	Projects	Farmers trained	Projects	Farmers trained	Projects	Farmers trained
Burkina Faso									2	370
Burundi			1	36	1		1	720	1	1,440
DR Congo			2	40	2	60	3	1,627	4	1,784
Ethiopia	4	689	4	1,160	8	2,087	7	11,737	7	5,642
Kenya	4	2,026	5	3,504	7	1,450	7	2,930	7	13,508
Lesotho	1	617	1	617	1	759	1	1,092	1	41
Malawi	1	84	2	362	3	492	3	3,367	2	399
Mozambique	2	950	1	12	1	22	1	1,120	1	905
Rwanda	2	1,407	2	2,173	2	1,794	2	2,673	2	3,735
South Africa	1	30	1	161	1	94	1	68		
South Sudan			2	600	1	628				
Tanzania	2	1,109	2	1,745	3	62	3	1,632	3	4,285
Uganda	1	164	1	302	1	n/a[1]	1	321	3	n/a
Zambia	1	815	2	815	1	12				
Zimbabwe	6	6,354	2	596	2	747	2	720	2	1,009
Total	25	14,245	28	12,123	34	8,207	32	28,007	35	43,118

[1] n/a = data not available.

Empty cells = zero projects or farmers.

24 Sustainable Agricultural Mechanization and Commercialization for Widespread Adoption of Conservation Agriculture Systems in Africa

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Abstract

To confront the situations of climate crisis, natural resource degradation and rising populations, farmers need access to modern sustainable agricultural technologies, especially Conservation Agriculture (CA) and sustainable agricultural mechanization (SAM). Without such access, the UN's SDGs will not be met in their entirety. The implications of mechanizing CA are discussed for both smallholder and larger-scale farmers. Constraints, issues and options are reviewed and the need for commercial, private sector, CA mechanization service provision for smallholders is identified. The Framework for Sustainable Agricultural Mechanization for Africa (SAMA) is a key pillar for achieving Aspiration 1 (a prosperous Africa based on inclusive growth and sustainable development) of the African Union's (AU) Agenda 2063; and SDG 2 (ending hunger and achieving food security). The move towards commercialization of smallholder agriculture in Africa is seen as an inevitable reality in the medium term. It is also a necessary prerequisite for the adoption of SAM, which is being actively promoted in Africa, both at the level of the AU and by national governments, research centres, non-governmental organizations (NGOs) and private-sector agricultural machinery companies. The policy dimensions of promoting SAM are discussed from the public and private-sector perspectives. A forward look identifies novel business models for sustainable mechanization services, an increasing application of information technology (IT) and the (longer term) potential for drones and robotics. The conclusion is that CA and SAM are essential ways forward to answer Africa's needs for sustainable food production while engaging young entrepreneurs in the provision of mechanization services using IT, digital tools and precision equipment.

Keywords: scaling out, mechanization, smallholder, large-scale farms, service provision, training, government policies, SAMA

24.1 Introduction

Our planet is facing an interlocking series of challenges which together combine to make the continuing prosperity of the human race rather uncertain. The three major challenges are: the burgeoning human population, natural resource degradation and accelerating climate change.

Currently (early 2021) our planet's human population stands at 7.9 billion. It is projected to

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rise to 8.5 billion by 2030, 9.7 billion by 2050 and 11.2 billion by the end of this century (UN, 2020a). The dramatic rise in the number of people to be fed presents a serious technical and economic challenge to the world's agricultural community. Currently farmers use 1.5 billion ha for crop production either as arable land or under permanent crops (FAO, 2003). It is estimated that, of the world's 570 million farmers, over 80% are smallholders with up to 2 ha of land and are concentrated in Africa, Asia and Latin America (European Commission, 2019). Estimates suggest that smallholder farms globally produce around 80% of the world's food (FAO, 2014).

The degradation of natural resources, especially soil and water, has been a direct result of the intensive farming practices employed to produce food crops. Apart from deforestation, one of the chief culprits is the over-manipulation of soils through the use of tools and implements such as the hoe and plough (both animal-drawn and tractor-mounted). Soil degradation through the destruction of structure and the creation of hardpans gives rise to reduced soil biodiversity and results in lower levels of fertility, water-holding capacity and infiltration of water into the soil profile. None of this is conducive to greater food production for a rising world population.

The Intergovernmental Panel on Climate Change has warned that climate change is resulting in heat and drought stress, affecting agricultural production, shifting climate zones, increasing migration and making food production more precarious (IPCC, 2019; Sims, 2020). It further warns that our climate chaos situation is palpably worsening as weather systems intensify and grow more lethal. Conservation Agriculture (CA) is widely considered to be the best production system to address the challenges of climate change adaptation and mitigation (Kassam *et al.*, 2017). The key constituent elements of CA are: (i) continuous no- or minimum mechanical soil disturbance through no-till (NT) or direct seeding, to maintain soil structure, carbon content, biodiversity and water-holding capacity, reducing erosion and conserving soil moisture; (ii) permanent soil biomass cover, through the retention of crop residues and the establishment of cover crops – these protect the soil from the erosive influences of rain, wind and sun; and (iii) diversified cropping, enhancing system biodiversity through the use of crop rotations and associations, in both main crops and cover crops. In CA systems, biodiversity is enhanced both above ground and in the soil profile.

A further issue of great concern in the effort to produce more food is the intolerable level of wastage all along the food production chain. FAO (2011) estimates that roughly one-third of food produced for human consumption is lost or wasted globally, which amounts to about 1.3 billion tonnes per year: 'This inevitably also means that huge amounts of the resources used in food production are used in vain, and that the greenhouse gas emissions caused by production of food that gets lost or wasted are also missions in vain'. Food loss and waste in developing countries have their roots in limitations in harvesting techniques, storage and cooling facilities in difficult climatic conditions, poor infrastructure, and inadequate packaging and marketing systems. Many smallholder farmers in developing countries are dangerously exposed to food insecurity, and so a reduction in loss and wastage would have a positive impact on their livelihoods.

The situation discussed thus far leads to the conclusion that sustainable agricultural practices, including CA, are a vital part of the armoury required to achieve the UN's Sustainable Development Goals (SDGs). The SDGs were adopted in 2015 and will frame development agendas up to 2030 (UN, 2020b). SDG1 (end poverty in all its forms everywhere) and SDG2 (end hunger, achieve food security and improved nutrition and promote sustainable agriculture) are directly impacted by the practices and are, perhaps, the most important for improving the livelihoods of the rural poor. SDG12 (ensure sustainable consumption and production patterns) underlines the importance of protecting natural resources while producing sufficient nutritious food for the world's growing population.

In order for smallholder farming to escape from the rut of drudgery, low yields and low investment, new paradigms of profitable sustainable production are required to be implemented. This means that smallholder farming needs to be considered as a business through strengthening smallholder–market linkages and taking a value-chain approach (including all aspects of production from field through processing, storage, transport and marketing to the consumer) (FAO, 2012). Another phenomenon affecting many rural economies in the developing world, but also Africa in particular, is the drift of healthy young males to urban centres in search of more rewarding payment for their efforts (Kienzle and Sims, 2015). Fifty percent of the world's global population is urban today (40% in Sub-Saharan Africa – SSA) and this is projected to rise to 70% (60% in SSA) by 2050 (Sims and Kienzle, 2015). This means that those being left behind to work on the farms are women, the elderly and children, and the consequence is that farm power becomes an increasingly severe constraint. Seventy percent of the power source for smallholder farms in SSA is supplied by manual labour and less than 10% comes from engine-powered sources. The remaining 20%–25% of farm power is supplied by draught animals (Sims and Kienzle, 2006). If the supply of human labour emanates principally from women, the elderly and children, it is clear that supply constraints will have a negative impact on farm productivity. The next generation (today's youth) needs to be attracted back to farming and the provision of more power and labour-saving devices will constitute one possible pathway for this to happen.

A move towards CA to produce more food, conserve natural resources, adapt to climate change, reduce waste and attract the next generation to farming will, as we have seen, require a dramatic change in farming systems. And this, in turn, will require a graduation to sustainable agricultural mechanization (SAM); that is, mechanization that nurtures (rather than degrades) natural resources and that is profitable for smallholder farmers to use.

The history of agricultural mechanization in Africa shows that transition from traditional manual production systems to mechanized ones has been a slow process. This is because a system of technical training, financing, procurement, service provision, repair and maintenance and spare parts supply has to be established and managed by the public and private sectors to support the transformation. For example, the sustainable provision of mechanization services, especially to smallholder farmers, is best achieved by the private sector supported by enabling public-sector policies and institutions, with supply chains for machines, parts, maintenance and fuel firmly located in the same sector in the future.

It is for this reason that in 2018, FAO and the African Union Commission (AUC) developed (with several iterations) the Framework for Sustainable Agricultural Mechanization for Africa: the SAMA Framework. It is a non-prescriptive framework that will guide the African governments in developing their own national agricultural mechanization strategies and to break down the issues to national levels. The key parts of the SAMA Framework are its ten elements of which the first five focus on commercial sustainability; elements seven and eight focus on socio-economic aspects; and elements nine and ten focus on the overarching aspects. However, element six of the SAMA Framework focuses on the need for environmental sustainability of any mechanization intervention. It is very important that this is noted as it clearly indicates CA-based mechanization options. It leads the way for upscaling smallholders' agricultural production systems in a sustainable way through mechanized CA (FAO and AUC, 2018).

National governments can play a crucial role in the promotion of SAM. They can significantly support the sector by establishing enabling environments, enhancing capacity building, supporting research and development, strengthening national and sub-regional organizations and mechanisms which facilitate adaptation and adoption of mechanization technologies and services, and creating incentives by providing public goods and services to ensure that large areas and segments of the population are not left behind as agricultural sectors become more modern, commercial and mechanized (FAO and AUC, 2018).

The purpose of this chapter is to illustrate the connections between the various stakeholders in a rural CA-based mechanization scenario. Nevertheless, with the SAMA Framework in place and recognized we – today – have the right policy framework for a continental uptake and enhancement of CA-based mechanization services providers across Africa.

24.2 Mechanization of Conservation Agriculture

24.2.1 The Significance of Mechanization Towards the Application and Adoption of Conservation Agriculture (CA)

There has been some debate about the relevance of CA to smallholder farming systems in SSA (e.g. Giller *et al*., 2009); the issues mainly revolve around competing uses for crop residues, increased labour demand for weeding and access to inputs.

Mechanization, through the provision of mechanization services, can go some way to addressing these perceived constraints. Soil cover is an essential element of CA and can be achieved in a variety of ways, chief among them is to leave crop residues on the soil after harvest. The incorporation of associated intercrops, especially perennials, in the system can also provide continuous soil cover; as can cover crops grown to continue to cover the soil after the main crop harvest. The use of crop residues for dry-season stock feed may compete with the need for soil cover, and it may be that crop residues need to be shared between the two interests. Communal cattle grazing after harvest may also be a threat and this has been resolved through consensus amongst farming stakeholders to voluntarily control the practice at community level. Mechanized harvesting with combine harvesters, especially of grain crops, can aid the even spread of crop residues with the use of spreaders located at the rear of the machine and which are able to cover the full working width of the combine.

Weed management in CA crops can be achieved in a wide variety of ways including mechanical, biological and integrated weed management strategies for the effective and sustainable management of weeds in smallholder systems (Sims *et al.*, 2018). Soil tillage (by ploughing or hand-hoeing) has traditionally been used to bury weeds. However, ploughing does not control weeds in the long term and can frequently create problems of soil compaction and plough or hoe pans which can seriously reduce the volume of soil available for crop root exploration, and impede rain water infiltration and movement within the soil profile. The elimination or dramatic reduction of tillage, under CA, requires other measures of weed control than ploughs and cultivators. Control can be achieved with herbicides. However, environmental concerns, herbicide resistance and access to appropriate agrochemicals on the part of resource-poor farmers, highlight the need for alternative weed control strategies for smallholders adopting CA. There are options that can reduce weed pressure and incorporate the idea of integrated weed management, rather than total weed elimination. These include preventive weed management (e.g. impeding the introduction of weed seeds in the field); cultural weed management (e.g. through the selection of competitive crops, crop rotations and trap crops); improved crop competitiveness (e.g. seed rate, transplanting and multi-cropping); and direct weed management including mechanical (e.g. through weed heading – removing weed flower heads with rotating knives), slashing, surface scraping, hand-rogueing and chemical elimination with appropriate herbicides. It is here that crop spraying, preferably by well-trained and qualified service providers, can come into play.

24.2.2 Issues and Options for Smallholder and Large-scale Farms in Sub-Saharan Africa

Mechanization options are available for the CA operations of direct sowing and for weed and cover crop management. All power sources can be employed including human muscle power, draught animal and engine-powered options (including two- and four-wheel tractors and combine harvesters). Detailed descriptions of the technical options available can be found in Sims *et al.* (2017) and de Araújo *et al.* (2020).

Smallholder Conservation Agriculture (CA) Farmers

Throughout SSA, smallholder farmers are the major food producers. This is in spite of the small farm sizes of around 2 ha, difficult access to quality inputs, poor infrastructure impeding market access and, rural–urban migration (especially of young, fit people). Attempts to alleviate the problem of access to farm power have usually centred on ploughs, which have no long-term place in sustainable mechanization systems that embrace CA principles.

There is a range of appropriate implements for each power source employed in smallholder CA systems. These include jab planters and animal- and tractor-powered direct seeders and planters (using narrow tines and/or discs to cut through surface vegetative cover). One popular practice in SSA is the use of rippers (narrow, inclined tines) to open rip lines for subsequent manual seeding. Ripping is also a useful practice for rehabilitating heavily compacted soil after years of abuse from ploughing.

Local manufacture of CA equipment for smallholders is increasing, especially in East and

South Africa. There is much potential for local manufacturing in the future as the needs of sustainable mechanization are perceived and catered for.

Weed management cannot employ conventional, soil disturbing, machinery and so must depend on hand-pulling, surface scraping with sharp hand-hoes or slashing with machete. Cover crops can be managed by crimping with knife rollers. Chemical weed management with herbicides is most commonly achieved with the knapsack sprayer, but boom sprayers are available for animal traction and tractor power. Biological weed management (always the preferred option) is best achieved by increasing the competition between crops and weeds in various ways, for example: increasing the seed rate and reducing inter-plant distances; through a range of multi-cropping systems; practising crop rotations; and mulching.

Large-scale Conservation Agriculture (CA) Farmers

Africa as a whole is only recently implementing environmentally friendly farming systems in the large-scale sector, led by South Africa. Specialized equipment is needed for scaling up CA, with particular needs for seeding through surface mulch and the management of weeds, cover crops and crop residues. The adoption of CA technologies has meant that Africa's large-scale farms, which constitute 10% of agricultural land and contribute 10% of food production, are increasingly becoming environmentally friendly and climate smart.

Mechanized CA systems can contribute to the rehabilitation of degraded soils; improve rainfall infiltration and retention; greatly improve the timeliness of farming operations; increase annual cropping intensities from 1 to 1.5 or 2; and make large cost savings from reduced investment in machinery, reduced maintenance and fuel consumption. As an example, one farm in Kenya has, by converting to direct drilling CA farming, replaced its break-even point for wheat from 2.5 t/ha to 1.3 t/ha and has increased yields from 3 t/ha to 4.4 t/ha (ACT, 2016).

African manufacturers have responded to the challenges of providing CA machinery for large-scale farmers and there is a growing industry, especially of direct seeders (e.g. Ndume, Kenya and Piket, South Africa). Precision agriculture with global positioning system (GPS) guidance and aligned track widths for all machines (combines, grain tanks, sprayers and seeders) is now being adopted. An area for future expansion is in the greater integration of mechanization of crop production and agroprocessing. Integration of production with processing chains is common with sugarcane, but minimally developed for other commodities. However, there are useful initiatives, for instance in the production and processing of vegetable oils and the production of livestock feeds from home-grown raw materials.

24.2.3 Commercialization of Conservation Agriculture (CA) Service Provision

One of the main obstacles to more widespread adoption of CA among Africa's smallholder farms is the lack of available and affordable CA machinery. To date there have been insufficient policy initiatives in Africa to actively promote the development of the CA machinery industry. Improved access to farm power (especially motorized) and appropriate mechanization options will play a crucial role in enabling smallholders to transition to sustainable agricultural practices.

Smallholder farmers are generally resource-poor and have problems in investing in expensive CA machinery which require high initial investment and may have lengthy payback periods. One way out of this difficulty is to create a cadre of well-trained, well-equipped and knowledgeable CA service providers in the private sector (FAO and CIMMYT, 2018). The establishment of such a cadre of entrepreneurs will usually benefit from a programme of specific training on the technical aspects of CA machinery operation and maintenance, and on the business skills needed to run a commercially viable CA service provision enterprise (Sims and Heney, 2017). The technical skills required will include equipment selection, calibration of seeders and sprayers, field operation, maintenance and repair. Business skills will include market research and feasibility studies, business planning, calculation of operational costs, partial budgets, break-even points and cash flows.

With this set of skills, and equipped with the appropriate array of power sources and CA equipment, entrepreneurs will be able to offer services at sustainable and affordable rates and enable smallholder farmers to raise their productivity in an environmentally sensitive way.

24.3 Sustainable Agricultural Mechanization: a New Perspective on Mechanization

Mechanization covers all levels of farming and processing technologies, from simple and basic hand tools to more sophisticated and autonomous equipment. It eases and reduces hard labour, relieves labour shortages, improves productivity and timeliness of agricultural operations, improves the efficient use of natural resources, enhances market access and contributes to mitigating climate related hazards. Sustainable mechanization considers technological, economic, social, environmental and cultural aspects when contributing to the sustainable development of the food and agricultural sector (FAO, 2016b).

Innovative and accessible agricultural mechanization technologies can fundamentally transform the way of farming. As we have seen, most farm power is still provided by manual labour in SSA, mostly from women, the elderly and children. This is despite the fact that the agricultural sector generates up to 50% of gross domestic product (GDP), contributing more than 80% of the trade in value and more than 50% of raw materials to industries.

The COVID-19 pandemic has shown that, specifically with regard to agricultural productivity, SAM technologies are even more important. The uptake of SAM could be achieved by supporting countries to adopt mechanization as an indispensable pillar for reducing hunger, attaining economic growth, ensuring gender equity, creating new jobs and introducing innovative business models (including micro-finance programmes and support to farmer cooperatives) for the provision of sustainable mechanization services that could attract and benefit youth.

In SSA, farm power for agricultural activities for resource-poor smallholder farmers is highly manual and intensive, barely profitable and often environmentally unsustainable. It is essential to make equipment, services and technologies accessible to all. Furthermore, for mechanization to contribute significantly to agricultural transformation in SSA, public–private partnerships could be key and a clear definition of each partner's roles is necessary. It is important to have in place an underlying enabling environment (agreed standards, rules and regulations) to improve access to high-quality yet affordable farm tools and equipment. This is needed to address the major constraints to the development of adequate and accessible agricultural mechanization for value-chain actors, especially the smallholder farmers (men and women equally) and youth.

Sustainable agricultural mechanization in Africa (FAO, 2020a) is one of the key pillars for attaining Aspiration 1 of the AU's Agenda 2063 (a prosperous Africa based on inclusive growth and sustainable development) as well as the SDGs already discussed. It is also important for the reduction of food loss and waste (SDG 12). Moreover, doubling agricultural productivity and eliminating hunger and malnutrition in Africa by 2025 will only be possible if mechanization is accorded the utmost importance. This includes improving access to, and use of, mechanization services, appropriate land preparation considering healthy soils as a key asset for farmers, and timely and precise field operations, such as planting and fertilizer application. Other applications are the use of protected cultivation systems including hydroponics, and the efficient management of water resources including irrigation, modern harvest and post-harvest technologies that assure quality harvest with reduced losses as well as effective transportation and on-farm storage. This can ultimately lead to enhanced market access.

Considering the above, SAM therefore must be applied along the entire agricultural value chain, be private sector-driven, environmentally sustainable and competitive, climate smart and economically viable and affordable, especially to smallholders. In addition, mechanization must both target primary agricultural products and support the development of higher-value products, while being gender inclusive and targeting youth. The labour being freed from the upstream side of the value chain could be used to create new jobs on the downstream side, thus leading to enhanced income and livelihoods.

Mechanization is most successful as a private sector-driven business with government support, particularly during the initial stages, and in the provision of an ongoing enabling environment for both farmers and service providers. Lessons learned from the past must help to ensure that future mechanization efforts are led by the private sector while the government (public sector) plays its part in creating a conducive environment for inclusive mechanization along the value chain.

24.4 Commercialization of Agriculture to Enhance Conservation Agriculture (CA) and Sustainable Agricultural Mechanization (SAM) Adoption

For a long time, agriculture has been considered a way of life rather than a business enterprise in many African countries, but the growing population and changing demands have brought about opportunities for growth and challenges to the African agricultural sector which has now begun to be influenced by commercial considerations. Certain specialized crops have begun to be grown, not for consumption in the village, but for sale in national and even in international markets. The transition from subsistence to commercial agriculture represents a key ingredient for the economic development of low-income countries.

Commercialization of agriculture means different things to different people, but largely some stakeholders have in mind an increase in production above subsistence level and resulting sales of marketable surpluses. Others stress the management of markets, including the capacity to access regional and foreign markets. Still others point out the greater role of modern technology in production, the integration of farmers with agricultural processors or the emergence of strong farmer and agribusiness organizations. There are several factors that encourage and facilitate commercialization of agriculture in the African continent which include the rapid growth of economies in developed countries, the introduction of new technologies, market expansion, market liberalization, urbanization, rapid increase in demand for food, decreasing population of farmers, liberalized and open economic policies, bilateral and multilateral economic agreements, developed infrastructure facilities in farming areas and government agricultural policies (Bandara, 2010).

The commercialization of agriculture stimulates the relationship between agriculture and other sectors of the economy. It augments the farmers' welfare by improving their income, wealth, health, status and the wellbeing of their household members. It enhances trade and efficiency, leading to economic growth and welfare improvement at the national level. This is further expected to initiate a virtuous cycle which raises household income, thus improving consumption, food security and nutritional outcomes inside rural households.

24.4.1 Opportunities and Constraints to Practising Commercialization of Agriculture

Commercialization of agriculture has varying effects on the economy, society and environment. The effects may be either positive or negative depending on certain conditions. It leads to more diversification of farmers' production and livelihoods, more market linkages and more opportunities in employment and income sources. With the increasing commercialization of agriculture, a greater area has been brought under cultivation and, further, a greater percentage of the cultivated area has been brought under irrigation. It has stimulated economic growth and advancement, life expectancy and health improvement but, on the other hand, it has exacerbated environmental degradation in the form of pollution of water and air and impoverished soil health as sustainable production practices have not always been adhered to (Jaleta *et al*., 2009).

Higher labour costs increase reliance on herbicides for weed control, primarily for the staple crops (Jaleta *et al*., 2009). The use of insecticides and fungicides could also rise, especially for high-value fruit and vegetable crops. Increased use of agricultural chemicals could lead to higher environmental and human health risks.

There are many factors that facilitate or hinder commercialization in agriculture. Chirwa and Matita (2011) suggest that, at the household level, commercialization is mainly affected by agro-climatic conditions and risks; access to markets and infrastructure; community and household resource and asset endowments; input and factor markets; laws and institutions;

and cultural and social factors affecting consumption preferences, production and market opportunities and constraints. The main exogenous forces that drive commercialization include population and demographic change, urbanization, availability of new technologies, infrastructure and market creation, and macroeconomic and trade policies. These factors affect commercialization by altering the conditions of commodity supply and demand, output and input prices, transaction costs and risks that farmers, traders and others in the agricultural production and marketing system have to cope with (Jaleta *et al.*, 2009; Chirwa and Matita, 2011).

24.4.2 How Commercialization of Agriculture Contributes to Conservation Agriculture (CA) and SAM Adoption

As agriculture in Africa becomes increasingly commercialized, the need to intensify production in a sustainable manner, value addition and food systems development all become integrally important. While recognizing the urgent requirement for increased agricultural productivity, there is also the concurrent need to restore and nurture the planet's natural resource base. Thus, commercialization of agriculture provides a perfect opportunity to promote sustainable intensification technologies such as CA and the application of sustainable agricultural mechanization practices in agri-food systems. In this case, if Africa is to intensify and mechanize its agriculture, it must do so with care and in line with the principles of sustainable production intensification based on environmentally friendly CA mechanization with the aim of achieving resilience in the face of a changing climate (FAO, 2016c).

Commercialization is normally necessitated by contract urban or export markets. These demand high product quality and large volumes of products at designated times. Mechanization becomes of immediate need to achieve timeliness and the volumes required. Furthermore, these demands are simultaneously met by the 'Green Revolution' approaches of increased usage of non-renewable resources, particularly inorganic fertilizers, pesticides and irrigation water. The associated resource depletion and toxicity effects on the environment call for sustainable and regenerative agriculture methods such as CA.

The level of agricultural mechanization possible is determined by the profitability of the farming system which, in turn, is influenced by the domestic and international markets for farm products. Attention needs to be placed on increasing the profitability of mechanized operations by encouraging commercial agriculture. The establishment of viable agribusiness enterprises, mechanization services, agri-processors, transport services and similar activities along the agri-food chain, as demanded by the commercialization process, contributes significantly to the increase of sustainable agricultural mechanization technologies in rural areas. This generates employment and income opportunities and, thereby, enhances the demand for farm produce. Mechanization plays a key role in enabling the growth of commercial agri-food systems by improving the efficiency of post-harvest handling, processing and marketing operations.

African agriculture cannot be sustainably mechanized if development efforts are focused on the profitability of the mechanization service alone. The efforts must be focused on the entire value chain, while ensuring that information flows freely across all the value-chain actors, enhancing stakeholders' capacity to respond logically to market signals and to seek to increase profitability through increased productivity.

While it is important to make farming profitable, the high use of external inputs by smallholder farmers could easily make them more vulnerable and dependent, due to inequities and exploitative marketing systems. With regenerative CA, farmers can reduce production costs with retained or increased yields. This does not leave them more vulnerable than they are at the moment and enables them to produce a surplus for the market and so become increasingly commercial.

24.5 Promotion of Sustainable Agricultural Mechanization in Africa

The SAMA Framework (FAO and AUC, 2018) has been discussed in our Introduction and more detail is given in Section 24.6. FAO and its partners (International Maize and Wheat Improvement Centre (CIMMYT), African Conservation Tillage Network (ACT), Nairobi, Kenya, Conservation Tillage Research Centre (CTRC) in China and others) have made efforts and invested in capacity-building programmes designed to help train actual and potential farm mechanization service providers, in order to increase access to sustainable farm power and to raise the productivity of smallholder farmers. These efforts focus on two crucial aspects: the provision of farm mechanization services as a viable business opportunity for entrepreneurs; and the essential criterion of raising productivity in an environmentally sensitive and responsible way (i.e. one that includes CA). FAO and CIMMYT's practical guidance on the essential business development and management skills required to successfully run a mechanization service provision business is discussed in Section 24.2.3.

There are also other international and national organizations such as the Alliance for Green Revolution in Africa (AGRA), Kenya, and the Centre for No-Till Agriculture (CNTA), Ghana, which contribute to the creation of an ecosystem supportive of mechanization and sustainable intensification. With the advent and spread of information and communication technologies (ICT), several private-sector players in different countries are innovatively developing new solutions that support smallholder farmer access to mechanization services as well as bringing greater efficiency in the distribution of agricultural machinery. Several 'Uber-type' approaches and business models for the rapid spread of agricultural mechanization services are under development. Uber-type models can work across nations and the continent; some of them (e.g. Hello Tractor and TroTro tractor) are discussed in Section 24.7.

Several other private-sector players such as AGCO Corporation, European Agricultural Machinery Association (CEMA), Agrievolution, John Deere and CNH Industrial are operating in some SSA countries in the supply of farm machinery and mechanization services. Their roles encompass importation, manufacturing, distribution and end-user technical support. CEMA, for example, is an association representing the European agricultural machinery industry and is promoting the wider use of sustainable agricultural mechanization in developing countries. Mechanization can only be regarded as sustainable when local financial institutions are actively involved in lending to farmers and entrepreneurs for the acquisition of agricultural machinery and implements. Therefore, there is an urgent need in most of the African countries to develop mechanisms to increase the flow of financial resources for agricultural mechanization investments from commercial banks and other financial institutions, as emerging small- and medium-scale commercial farmers and entrepreneurs require access to loans (FAO and AUC, 2018).

The focus of any government should be on the creation of enabling environments supportive of private-sector players and public–private partnerships (PPPs) and engagements. It should design and formulate policies and strategies for implementing SAM in consideration of the three critical pillars of sustainability of any interventions – commercial, environmental and socio-economic. Fully private sector-owned businesses require public support with regard to the policy environment.

In general, besides building up sustainable mechanization supply chains and support systems, it is the capacity-building element that has to be the focus for supporting actions of any actors in the sector. Within rural areas of Africa, educated farm machinery operators are rarely available; there are very few training schemes for sustainable mechanization service providers and machinery operators. This is a key entry point where policies, investments and any interventions from any actor need to start from, by providing knowledge and skills building to enable widespread mechanized CA to prosper. Any attempt or strategy to promote SAM in Africa needs to take into consideration the interaction among the many actors within the sector and how they relate to each other and the farmers (Fig. 24.1). The focus should be on enhancing research and innovation; standards and testing; manufacture and trade in agricultural machinery and implements; technology transfer and extension; and capacity building in all fields (FAO and AUC, 2018).

Strengthening the national, sub-regional and regional institutional infrastructure and networks, governance and coordination in supporting the development of sustainable agricultural mechanization is a significant need and is imperative. This may involve the establishment of governance

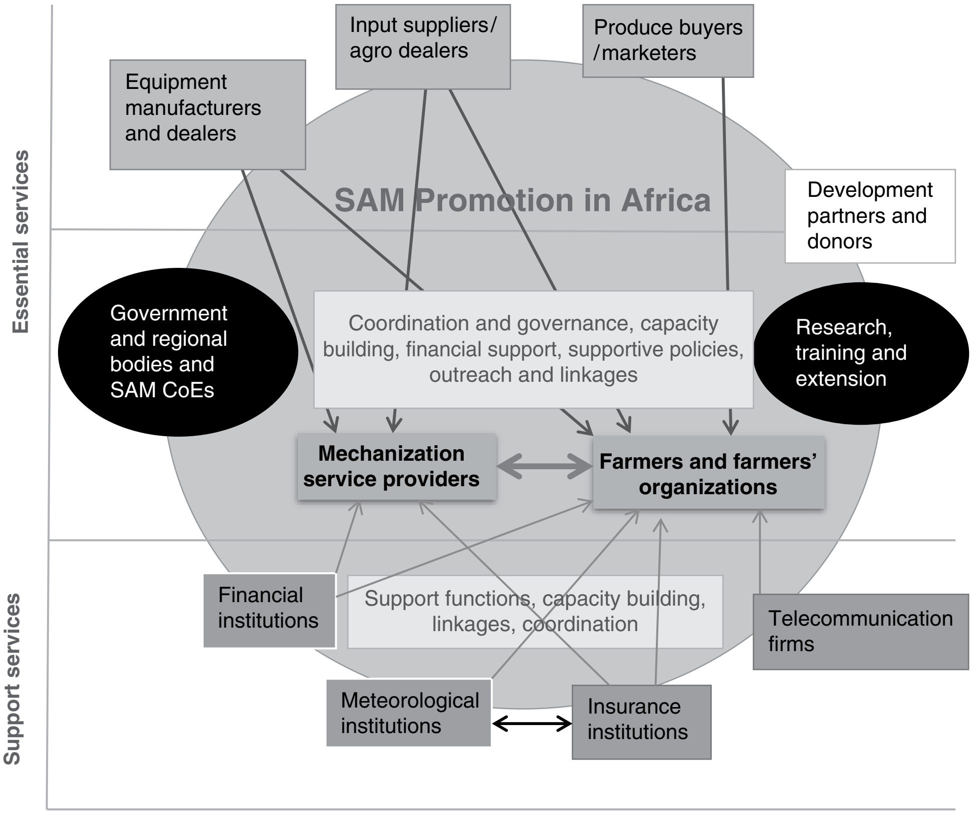

Fig. 24.1. The interlinked relations of various categories of actors in Sustainable Agricultural Mechanization for Africa. Authors' own figure.

and coordination mechanisms at the national, sub-regional and regional levels to manage the interrelations of the various stakeholders in the sector with diverse roles. These include:

- Management and coordination: This will involve engaging the structures that include the AUC, regional economic communities and national platforms to mainstream SAM into national, regional and continental policies and plans. This structure has an important role in political convening, mobilization, policy making and accountability to the stakeholders. It is also responsible for overall resource mobilization and fundraising.
- Governance and coordination: SAMA implementation at the national, regional and continental levels is overseen by the steering committees (namely National Steering Committee (NSC), Regional Steering Committee (RSC) and Continental Steering Committee (CSC), respectively). This dimension is responsible for approving workplans and budgets and constantly monitoring the implementation of SAMA at their respective levels. This structure is also responsible for resource mobilization and fundraising, particularly at country level.
- Support functions: The support functions in the implementation of the SAMA projects include monitoring, reporting, learning and evaluations and are provided by the executing agencies (EA) and secretariats.

24.5.1 Mechanization Supply Chain Business Models, Support Services and Associated Businesses

The agricultural mechanization supply chain has a number of actors that encompass importation, manufacturing, distribution and end-users. Key stakeholders involved include importers/dealers, manufacturers, distributors, mechanization service providers, farmers, local mechanics and financial institutions. The importation sector for agricultural machinery and implements in Africa is dominated by a multitude of small-scale private-sector actors who manage the mechanization supply chains and distribution franchises. Owing to their small size, the services they provide to farmers tend to be expensive. Therefore, any mechanization supply chain and mechanization business model approach must focus on addressing the specific constraints that affect the sector's stakeholder relations. These could include the relationship between the farmer – the customer – and the dealer/importer; the farmer and the service provider; and the farmer and the manufacturer and supplier of spare parts. In the context of smallholder agriculture, business models must deliver essential services to farmers to enable them to adopt and utilize SAM technologies. There is a growing body of experience showing that 'win–win' outcomes are possible through commercially viable business models which involve farmers and businesses (Vorley *et al.*, 2008). Strong dealer (service provider)–farmer relationships are the foundation on which commercially viable business models can be developed to provide mechanization services that meet farmers' requirements in terms of quality, price and support services.

A key issue is how to assist manufacturers to establish supply chains and dealer franchise networks and to cater for areas where profit margins may initially be small or non-existent. Supply chains must be established not only for power sources, but also for implements and post-harvest equipment, especially in countries where the current demand for machinery and implements is low. Creation of regulatory frameworks by governments will be critical to facilitate the operation and management of mechanization supply chains and franchises through the coordination of chambers of commerce and business associations, which may also operate across national boundaries and offer services at the sub-regional level. This will also help to avoid creating distortions in the agricultural equipment market through the introduction of large quantities of equipment free of charge. Efforts are needed to support access to economical resources for entrepreneurs, established artisans and technicians specialized in the repair and maintenance of agricultural equipment, in order to facilitate the development and upgrading of their business. This will involve the development of financial mechanisms to facilitate the procurement of machinery and equipment or mechanization services by smallholders. Tailored and sustainable subsidies should be considered, especially where they can catalyse the initial procurement of mechanization inputs, with the provision that viable and sustainable farming enterprises ultimately emerge. Nevertheless, the main investment effort must be made by the agricultural private sector, including small- and medium-scale farmers, who constitute the largest group (FAO and AUC, 2018).

24.6 Policy Dimensions

The AUC and FAO view agricultural mechanization in Africa as an urgent matter (FAO, 2018) and an indispensable pillar for attaining the Zero Hunger vision by 2025, as stated in the Malabo Declaration of 2014 (AUC and NEPAD, 2014), Goal 2 of the SDGs and the Prosperous Africa We Want, as indicated in Agenda 2063 (AUC, 2015).

As previously discussed, in 2018, FAO and the African Union launched the SAM Framework document which offers a detailed look at the history of agricultural machinery in Africa, and points the way towards addressing challenges and creating new opportunities to assure the successful adoption of sustainable mechanization. The framework notes that successful national mechanization strategies will address key sustainability issues including gender, youth, environmental protection and the overarching principle that farming must be profitable. It also emphasizes that these strategies should cover the entire agri-food value chain, including harvesting, handling, processing and food safety aspects, with an eye to reducing food losses, boosting rural employment and bolstering the links between farmers and consumers.

FAO and the AU's strategy (FAO and AUC, 2018; Trendov *et al.*, 2019) acknowledges that '*there is great potential for innovation in African agriculture*' – notably with the proliferation of mobile technologies and access to information and services – and that a significant effort in capacity development will have to be made to rise to related challenges.

The ten elements of SAMA are:

1. Boosting farm power through appropriate technologies and innovative business models.
2. Promoting innovative finance mechanisms for agricultural mechanization.
3. Building sustainable systems for manufacture and distribution of mechanization inputs.
4. Sustainable mechanization across agri-food value chains.
5. Innovative systems for sustainable technology development and transfer.
6. Transformation of soil tillage and crop husbandry practices.
7. Achievement of socio-economic sustainability, considering:
  ○ the role of small-scale farmers and their organizations
  ○ the role of women
  ○ the role of youth.
8. Human resources development and capacity building for SAMA.
9. The need for a long-term vision: policy and strategy issues.
10. Creating sustainable institutions for regional cooperation and networking.

24.6.1 Promoting National Buy-in of the AUC SAMA Philosophy

Policy support is critical to mechanization, particularly with regard to ‘sustainability’ issues. Policies must support the sustainable agricultural mechanization process; for example, a change in tillage practices may require additional investments in agricultural machinery and equipment. Likewise, to satisfy demand for agricultural machinery and implements, interventions may be necessary in industrial licensing and trade policies. Local and regional manufacture of implements could require a change in fiscal policies (e.g. subsidies and credit lines), and decisions will have to be made whether to impose or waive duty on imported equipment.

Policy formulation necessitates close coordination within governments, involving the ministries of agriculture, trade and industry, finance and planning, environment and energy.

At the sub-regional and regional levels, there must be close coordination and collaboration between countries. With the liberalization of trade policies for goods and services, entrepreneurs can offer cross-border mechanization services (e.g. land preparation, crop husbandry and paddy harvesting) in different countries and in different seasons according to peak demand; the national market in most countries is currently quite small. Regional cooperation is critical for the establishment of sustainable systems offering such services. International development agencies, such as FAO and UNIDO, have a leading role in promoting the sharing of experiences among member countries on successful in-country policies and strategies. It is important that they keep an open mind and recognize their part in past failed strategies. They must objectively guide the advancement of new enabling policies and regulations to facilitate cross-border trade of mechanization inputs and services as well as support systems. This must take place within an Africa-wide framework and in the context of South–South collaboration. The RECs could play a leading role in facilitating the development of agricultural mechanization in Africa (FAO and AUC, 2018).

It will be important to create an enabling environment for the private sector to finance mechanization investments and this will require the enactment of appropriate laws for banking, contracts and leasing regulations.

With regard to the role of international research centres in R&D for SAM, CIMMYT is quite outstanding among the CGIAR Centers for having taken on board long-term action research programmes in eastern and southern Africa to field test the practicability and adoptability of two-wheel-tractor-based (2WT) CA systems. They also support local manufacturers in adopting imported direct seeders, and test prototypes and bring them to scale as deemed appropriate. While it remains an open question whether or not the 2WT systems will make a breakthrough in SSA, it can at least be verified that local adaptability was tested with some local success stories in Ethiopia, Zambia and Zimbabwe to name a few (ACIAR, 2020).

24.6.2 The Role of the Public and Private Sectors

At the global level, the private sector has played an important role in various fields, including:

1. Research and development (R&D).
2. Technology transfer (agricultural machinery and implements) in developing countries.
3. Manufacture and distribution of agricultural machinery, implements and equipment to farmers.

Some private-sector entities are branches of multinational corporations; others are local companies mainly established in the past 10–20 years. Coordinating and regulating the activities of all these public and private entities is an issue of concern for most countries in the developing world, at both the national and regional levels. In order for SAMA to be successful, Africa must explore the possibility of establishing some regional capacity for coordination to reduce duplication of efforts and increase efficiency (FAO, 2008; FAO, 2015).

In the majority of African countries, the strongest in-country capacity resides in the universities, specifically in the agricultural engineering departments, which are responsible for undergraduate and postgraduate training and research and for training human resources in three critical areas:

1. Agricultural engineering and mechanization.
2. Irrigation and water resources engineering.
3. Post-harvest process engineering.

The engineering and agricultural departments, together with the departments of agribusiness and farm management, are crucial for effective action within a country, provided they are properly enabled. Centres for research in agricultural mechanization and rural technologies (in countries where they exist) would constitute an important country node for any regional network for SAMA. The primary role of a regional mechanism for SAMA should be to facilitate the coordination of efforts of national centres to work together in a structured regional network to achieve economies of scale and scope.

It is vital to consider R&D, especially in the context of the roles of the private and public sectors. The hardware aspects of mechanization inputs and services are offered efficiently almost exclusively by the private sector. Linkages between public and private in R&D need to be strengthened to ensure that the many prototypes emerging from large public-sector R&D establishments actually move beyond the laboratory/workshop. These prototypes must be licensed and transferred for development in the private sector, where manufacturers have a comparative advantage in producing and transferring technologies, to farmers through their distribution, marketing and financing franchises for agricultural machinery and implements. Moreover, the extension of agricultural mechanization technologies is achieved through a combination of public- and private-sector organizations with the private sector more involved in the hardware aspects and the public sector dominating the software side (e.g. raising awareness and training).

Private-sector enterprises dominate the importation, distribution and servicing of agricultural mechanization inputs, while the public sector is traditionally involved in the extension of know-how, such as cultivation and crop husbandry practices, and soil and water conservation methods. Unless new approaches are adopted, this division is likely to continue.

24.6.3 Capacity Development for Mechanization

Increased adoption of agricultural mechanization is stimulating jobs and entrepreneurial opportunities in Africa where youth and women increasingly face job insecurity.

There is a market for farm mechanization services that can make a big difference for a smallholder farm and help it transition from subsistence farming to a more market-oriented farming enterprise. Apart from hire services, mechanization creates additional opportunities for new business with repair and maintenance of equipment, sales and dealership of related businesses including transport and agro-processing along the value chain.

Today, more than ever, the application of digital technology to agriculture is streamlining efficiency and productivity. But, in Africa, many people do not have access to agricultural tools and equipment to improve their yields and reduce heavy labour. These tools, digital and non-digital, need to be available to farmers.

24.7 Business Models for Sustainable Mechanization Services

The intention is to bridge the gap that exists between smallholder farmers moving towards market-oriented farming and the mechanization opportunities that are on offer or at least in the vicinity of smallholder communities. Smallholders cannot often afford agricultural equipment, and the type of equipment that is on offer in the market place is often not suitable for smaller holdings or fields. Service providers, in the form of mechanization hire services, can and should fill this gap. By providing access to the right equipment and services, smallholder farmers can adopt sustainable practices, reduce or eliminate drudgery and transform their lives and those of their families.

Inappropriate equipment often exists because there is a gap between what the farmer needs and what is available and produced by agricultural machinery suppliers. A dialogue is needed between farmers and service providers as well as development agencies as to what type of equipment (size, quality, impact) should be made available. It is important to acknowledge that not all farmers' needs will be fully met by suppliers. Besides the size, it is also crucial to reflect on the desirability of promoting equipment that is in line with sustainable crop production and resource use efficiency. Hence, equipment that has heavy impact on the soil (resulting in erosion and compaction) should not be promoted (and could even be penalized).

There is a need for capacity building and training for new start-up hire services; there is also a need for increased investment in financing modalities for machinery investments. Greater private-sector development of mechanization options should be encouraged, not only in terms of hire services, but also of dealerships, spare parts provision and repair and maintenance enterprises (FAO, 2016a). Current models to finance mechanization (such as leasing, agricultural development bank loans and cooperative ownership) have shown some potential but they need to be carefully considered on a case-by-case basis within local socio-economic contexts. For example, there is a niche for more flexible finance schemes for women and youth attracted to setting up mechanization service provision businesses.

In the development of business models, both the private and public sectors need to partner (in PPPs); all stakeholders have a role to play in these PPP schemes. The public sector will often be best placed to develop national and regional policies and design financial support schemes for those rural areas where the smallholding mechanization needs are the greatest. The public sector can create an enabling environment for the partnership to flourish, while the private sector invests in equipment to provide mechanization services and farmer support arrangements such as producer associations and cooperatives. The array of stakeholders in the mechanization sub-sector is wide. Appropriate and affordable equipment needs to be developed and sold. Distribution and dealer networks and innovative manufacturers are essential in addition to the actual service providers and farmers.

FAO can help farmers and other entrepreneurs to identify appropriate business models to set up hire service businesses (offering animal- and/or motor-powered mechanized services) through capacity building, related training materials and enabling private-sector involvement and development (FAO, 2016a). The essence of a hire service's business model is how it organizes to do business – how a hire service provides value through its services, acquires customers, serves customer needs, sources its equipment, finances such equipment and how it makes a profit. The business model approach takes into consideration the networks and relationships a hire service has in place to earn money.

A business model will reveal which networks a hire service accesses to connect to customers and which transactions it enables, how these are governed and the costs that are incurred. Identification of the current business models of a hire service will enable it to be appraised, assessed and diagnosed, and indicate how the hire services may be better organized and market its services. Furthermore, it can reveal its strategies and plans, how it may innovate and how entrepreneurial it may be.

The aim of taking a business model approach for the development of hire services is to facilitate improvements in the business and operational processes of the hire service. The business model approach involves identifying and analysing the existing business model or models, a diagnosis of the current situation, the facilitation of design, implementation of new or modified business models and the monitoring of such business models (FAO, 2020b).

Business models mark out how providers operate, interact with their clients, cover costs and make a profit (FAO, 2021). For many decades most agricultural equipment hire services were provided by the public sector as they were considered to be public goods services aimed at increasing food production. Unfortunately, all the experiences were doomed to failure as the programmes were economically unsustainable. FAO (2021) identified the different types of mechanized service provision as five models:

1. The mechanized farmer as an informal service provider: this widespread model typifies those smallholder farmers who have invested in farm equipment to meet their own needs and then provide the service to their family, friends and neighbours. In this way, the enterprise, which is generally fairly informal, will spread the fixed costs of the equipment acquired and so reduce the cost per unit of work.

2. The farmers' group as a service provider: this model can be typified by the UN-CUMAs (Union Nationale des Coopératives d'Utilisation De Matériel Agricole) in Benin. A CUMA is a collective investment, managed by farmers in independent groups in the same territory (Cooperatives Europe, 2020). In Benin there are 115 CUMAs serving 1250 farmers with 57 tractors and associated equipment. The CUMA process is participatory, not passive, and CUMAs promote strong relationships within themselves and they react positively with other unions and cooperatives in the national and international institutional environment.

3. The formal private agricultural enterprise: these are enterprises usually run by entrepreneurial managers. Their goal is to generate a profit from the service and they can cover all equipment hire activities along the agricultural value chain. They may also be characterized by a diversification of activities, typically the supply of other agricultural inputs such as spare parts, seeds and fertilizer.

4. The formal private enterprise belonging to the agricultural mechanization supply chain and service provider: this is a modification of model 3 and includes enterprises whose main activity could be manufacturing, repairing and selling agricultural equipment. Hire service provision typically does not represent the main activity compared to the others.

5. The enterprise as an intermediary: in this model, the company may not have its own farm equipment, but rather plays the role of intermediary between the owners of the farm equipment and the producers, using a digital platform to connect producers to the owners of the agricultural equipment. Examples of this model are given in Section 24.8.1.

24.8.1 Examples of Novel Forms of Service Provision

In the future it should be possible for smallholder farmers to call upon a mechanization hire service provider for certain tasks – this may be possible through an online call system. There are a number of such schemes operating in Africa such as TroTro tractors in Ghana and Zimbabwe, Hello Tractor in Nigeria and Kenya, and Tinga in Kenya; others are being developed.

Tinga

A bank trust in Kenya has come up with an innovative solution dubbed Tinga, which helps farmers book their preferred tractor service(s) at the click of a button and track it right to their farm. The concept seeks to connect farmers in search of mechanization to tractor service suppliers (Oundo, 2017). Tinga is a short message service- (SMS) and mobile-based application that enables farmers to access a host of services, including NT planting. The application allows farmers to create an account and to indicate their preferred service, location and the size of land to be worked on. When the request is received and processed, the tractor is dispatched from the nearest Tinga hub to work on the farmer's farm within the allocated time frame.

Hello Tractor

Hello Tractor is a technological start-up in Nigeria that has a platform linking smallholder farmers to tractor owners. The model involves the use of a booking platform to request mechanization services and a GPS tracking device to monitor the location of equipment. The booking platform comprises a mobile app and a booking agent who aggregates demand from farmers in a location and, when sufficiently large, makes the bookings (FAO, 2020c; Hello tractor, 2020). As an add-on, the same GPS tracker that is mounted on the tractor can also transmit engine performance data and can send alerts for servicing and repair, which helps the tractor supplier to optimize tractor performance.

TroTro

TroTro in Ghana describes itself as a team of Africans using the internet of things (IoT) and technology to change the lives of smallholder farmers through the provision of platforms that make agricultural mechanization services available, accessible and affordable to enhance productivity, improve efficiency and reduce post-harvest loss (TroTro, 2020). It connects farmers and tractor operators and also allows tractor owners to monitor movement and the work progress of their machinery. Farmers are able to request, schedule and prepay for mechanization services, and the operators benefit from increased demand for their services. Recently this start-up has, at its own risk, established similar tractor hire service businesses in Zimbabwe and Kenya. It is liaising with ACT on a continental network for this business model.

Online tracking of tractor service providers also offers the clear advantage that the tractor owners (which could be a bank) have the possibility to easily follow the tractor's movements, as well as for the tractor supplier/dealer to monitor performance and possible servicing requirements online. These options are clearly providing new fields of opportunities for smallholder farmers and service providers to get connected and to close the existing gap separating user demand from service providers.

24.8.2 Increasing Application of ICT

As can be seen in the description of novel forms of service provision, ICT has great potential for the future development of agriculture in Africa, and will play an especially important role in smallholder mechanization. In the last few years there has been an increase in the use of ICT tools made possible by the mushrooming of mobile phone services in many African countries. These allow farmers to monitor and improve agricultural practices and access information on inputs, markets and services (FAO, 2020c).

Currently there is a need for a platform for comprehensive information on existing demand, especially for machinery suppliers who need such information to tailor their offer. The European Agricultural Machinery Industry Association (CEMA) has made a proposal to promote sustainable agricultural mechanization in Africa (CEMA, 2019) and, to be effective, they need to know which technologies are most appropriate in each context, and what the demand is likely to be. What will be required is an ICT-level site to manage information and link to other ICTs serving the farming community (SMS, WhatsApp, YouTube, databases, etc.) (FAO, 2020c).

There is a similar need in the nascent mechanization service provision market that is emerging in several African countries as reported by FAO (2020c). They suggest that tractor owners incur high information costs and difficulty in locating and aggregating demand over small and scattered farms. At the same time smallholders face high transaction costs due, in part, to those arising from a lack of information (or information distortion) on the availability of service providers, equipment and access channels. These information costs can be a barrier to adoption and result in poor linkages between farmers and service providers.

24.8.3 Potential for Drones and Robotics

Taking a look far into the future, there will be opportunities for smallholder farmers in SSA to make use of precision agriculture technologies such as drones and robotics.

Drones can be used as a precision agriculture technology to monitor crop and soil health and needs (such as fertilizer, herbicide or pesticide application). They are one of the key tools for creating detailed maps in conjunction with other data sources such as a GPS to allow farmers to better plan their cropping strategy according to the potential of each sector. Sylvester (2018) observes that the use of drones is extending at a rapid pace in crop production, early warning systems, disaster risk reduction, forestry and fisheries, as well as in wildlife conservation. In crop production, drones can map spatial variability in the field, not only for soil and crop scans, but also for irrigation scheduling, yield estimation (through normalized difference vegetation index – NDVI – maps) and weather analysis. He *et al*. (2017) provide a review of research on plant protection unmanned aerial vehicles that gives a good account of the current status and potential of precision application of pesticides with highly specialized drones. This is a good response to the ever-increasing pressure from the general public to reduce pesticide use, which has been the driver for developers to achieve greater efficiency through spot application and highly effective formulas. The same drones may also apply liquid fertilizer at equally efficient rates.

FAO (2020d), in a review of the future of agricultural robotics, suggests that, as agriculture evolves with science and technology, it is a matter of time until the IoT reaches the farmscapes of the world. Technical improvement of innovative technologies should optimize production efficiency, optimize quality, minimize environmental impact and minimize production risks.

Agricultural robotics can combine a series of information management roles such as crop monitoring, information processing with specific software and artificial intelligence (AI) and provision of intervention options and activation via automated equipment. It can also specialize in one or more of the stages of the process. Management of robotics systems will require high levels of IT skills which are far from common in any farming system today. Currently agricultural robots (agrobots) have been developed for specific agricultural tasks such as cultivation, transplanting, weeding, precision spraying, precision fertilizer application, spot application (as opposed to blanket application) of inputs and selective harvesting, all under human supervision but without direct human labour. Agrobots developed include those for mechanical weed control using a solar-powered vehicle; motorized vehicles for soil preparation, sowing and weeding; and in-row weeding of row and orchard crops with targeted herbicide sprays or lasers.

24.8 Conclusions

Mechanization of smallholder agriculture is of crucial importance in Africa for a number of reasons including alleviation of drudgery; increasing labour productivity; improving the timeliness of farming operations; expanding the area under cultivation; and facilitating the adoption of productivity enhancing innovations.

For CA to be scaled out it needs to be mechanized and this involves the application of more farm power and the employment of specialist CA machinery, especially for direct seeding and the management of residues, weeds and cover crops. CA and its associated mechanization confer resilience to smallholder farming systems in the sense that there is better toleration of environmental and economic stresses and shocks. This results in improved and more stable yields and profits, reduced use of inputs and better returns on investment. Mechanizing CA also means that innovative technologies can be introduced into smallholder farming systems, including precision agriculture and a greater incorporation of information technology (IT). CA, along with other innovations such as controlled environment agriculture, also has the potential to improve rural livelihoods and stem rural–urban migration by creating new business opportunities in the agricultural sector.

There are constraints to the adoption of CA mechanization on smallholder farms in SSA due to the resource-poor condition of many smallholder farmers. The first step is to identify the constraints in a particular region and then to develop a strategic plan in response to them. CA farmers need to be skilled in agronomy, machinery application and running a business, and this may not always be the case. Counselling from extension sources is a viable option when the quality of the service is high enough; other options include the formation of CA farmer mutual support groups and cooperatives.

Public-sector mechanization services have historically been rather less than successful. And so one way to provide smallholder farmers with CA mechanization technology is through private-sector mechanization service providers. These include machinery manufacturers and suppliers, maintenance and repair services, extension support, access to finance, and technical and business skills training. Skilled service providers, operating in an enabling environment, are the key to sustained CA out-scaling.

Local manufacture of CA equipment should be encouraged and supported to ensure that equipment is best suited to local conditions and that local skills in overcoming technical problems are incubated and honed. The capacities of relevant government departments need to be strengthened so that they play their vital roles in creating a level playing field that is not disadvantageous to local manufacture, and foster an enabling environment for facilitating acquisition of CA equipment by farmers and service providers. Mechanization creates a new and different set of jobs in the mechanization supply chain and along the value chain.

It is recommended that African governments, the private sector, civil organizations and development partners substantially increase their strategic involvement and investment in advancing smallholder sustainable agricultural mechanization to deliver on the targets set out by the African Union's Agenda 2063 (AUC, 2015) and the Malabo Declaration (AUC & NEPAD, 2014).

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25 Centres of Excellence in Conservation Agriculture: Developing African Institutions for Sustainable Agricultural Development

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Abstract

Conservation Agriculture (CA) is an important component in addressing food insecurity, biodiversity degradation and water scarcity challenges. Its adoption in Africa has lagged behind other continents. One major area of need to enable the acceleration of the adoption of CA in Africa relates to building the necessary cross-sectoral institutional and human capacity across the education–research–extension–enterprise axis along the value chain. This study was conducted in order to contribute to the discussions about the need to create sustainable institutions: specifically, Conservation Agriculture Centres of Excellence (CA-CoEs) in Africa. The CA-CoEs model includes a stakeholder team, a shared facility or an entity that provides leadership, best practices, research, support and/or training in CA, with linkages to service providers along the value chain. This literature-based research involved systematic identification, collection, analysis and documentation of data to identify and address the unique roles these CA-CoEs play in the promotion and adoption of CA and their level of performance. It employed a CA quality assurance self-assessment tool to measure the performance of the CA-CoEs against predetermined performance descriptors. Although the CA-CoEs are facilitating and catalysing adoption of CA, their capacity in providing the CA-related programmes, training and research is not optimal. CA-CoE quality assurance of services can be helpful in identification and design of measures for addressing the challenges faced. To be impactful, CA-CoEs need well-coordinated, participatory and demand-driven CA-based agricultural practices, information services and knowledge for farmers and other stakeholders such as non-governmental organizations (NGOs), CA service providers and CA equipment manufacturers.

Keywords: Adoption, linkages, outreach, research, quality assurance

25.1 Introduction

Agriculture is an important economic sector for most African countries and is a significant part of overall livelihood and employment. Agriculture contributes 15% of total GDP for Africa although there is large variation among countries. It is 3% in Botswana and South Africa but 50% in Chad (OECD/FAO, 2016). Agriculture employs more than half of the total labour force

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(IMF, 2012) and, within the rural population, provides a livelihood for multitudes of small-scale producers. Using individual, disaggregated, plot-level labour input data from nationally representative household surveys across six countries in Sub-Sahara Africa (SSA), Palacios-Lopez *et al.* (2015) estimates the average female labour share in crop production at 40%. It is slightly above 50% in Malawi, Tanzania and Uganda, and substantially lower in Nigeria (37%), Ethiopia (29%) and Niger (24%). Smallholder farms constitute approximately 80% of all farms in SSA and employ about 175 million people directly (AGRA, 2014). In many countries women comprise at least half of the labour force (FAO, IFAD and WFP, 2015). The development economics literature in Africa shows that increases in agricultural productivity reduces poverty by raising farm and off-farm incomes, improving human health and nutrition, lowering food prices and broadening wage employment opportunities (Schneider *et al.*, 2011).

The important role of the agricultural sector in contributing to food security and poverty reduction is reflected in its prioritization in Africa's development agenda. The Comprehensive Africa Agriculture Development Programme (CAADP) is Africa's policy framework for agricultural transformation, wealth creation, food security and nutrition, economic development and prosperity for all. Specifically, CAADP aims to stimulate and facilitate increased agricultural performance through improvements in policy and institutional environments, access to improved technologies and information, and increased investment financing. Africa's agriculture is dominated by a variety of staple food crops and traditional cash crops. The sector is also characterized by a high percentage of smallholder farmers (80%) cultivating low-yield staple food crops on small plots with a minimal use of inputs. These farms depend on rainwater, thus subjecting production to the vagaries of the weather (Shiferaw *et al.*, 2014).

25.2 Conservation Agriculture (CA) and its Benefits

Conservation Agriculture (CA) is a farming system that promotes continuous minimum soil disturbance, maintenance of a permanent soil cover and diversification of plant species (FAO, 2020). It enhances biodiversity and natural biological processes above and below the ground surface, which contribute to increased water and nutrient use efficiency and to improved and sustained crop production. According to Kassam *et al.* (2018), in 2015/16, CA had spread across all continents and in most agroecologies, covering an area of more than 180 M ha of annual cropland. Some 50% of the CA area is located in the developing regions. Since 2008/09, the spread of CA cropland systems has been at an annual rate of 10.5 M ha, bringing productivity, economic, environmental and social benefits to farmers and their communities and to society in general. CA is, therefore, a form of sustainable agriculture as it focuses on promoting the economy through increased productivity while protecting the environment. Although CA initially began to spread and scale up in North and South America and then in Australia, in the last 20 years CA has been spreading across Asia, Africa and Central America, where millions of smallholder farmers are able to adopt CA systems and benefit from greater productivity, income and food security.

The adoption of CA in Africa is on the increase. According to Chapter 4, CA was practised on 2.7 M ha in Africa in 2019, an increase of 207% compared with the CA area in 2013/14 (0.99 M ha), and 560% compared with the CA area in 2008/09 (0.49 M ha). There are several factors that need to change if the rate of uptake of CA in Africa is to be accelerated. These include, for example, an insufficient enabling policy environment to boost sustainable land management and scaling of success stories of projects and community's efforts; weak capacities at institutional, community and various stakeholder levels; insufficient partnerships and investments in CA; mindset, lack of awareness and improper knowledge; and capital constraints.

Numerous policy statements concerning science, technology, innovation and development have emphasized the creation of CA Centres of Excellence (CA-CoEs) in developing countries as a key goal in sharing best practices and addressing scaling up of technologies. In pursuing this goal, for example, the African Union (AU) emphasizes the importance of building centres of excellence and investments in education, technical competences and training, and in science, technology, research and innovation (African Union Commission, 2014). The CoEs are seen as a means to enhance science and technology capacity in developing countries, and hence to promote productive linkages between science, technology, policy and development (Leach and Waldman, 2009) and the eventual attainment of Agenda 2063.

The CA-CoEs approach will also contribute to operationalization of Vision 25×25 of the First Africa Congress on Conservation Agriculture (1ACCA) Lusaka Declaration target of reaching 25 million farm households with CA systems and practices by 2025. This was further modified and adopted by the AU heads of state in the 2014 Malabo Declaration to have 25 million farm families adopt climate smart agriculture by 2025.

25.3 Centres of Excellence in Sustainable Agricultural Development in Africa

A CA-CoE may be described as an organizational environment that strives for and succeeds in developing high standards of conduct in a field of research, innovation or learning and therefore possesses the ability to absorb, generate and share/exchange new knowledge (Hellström, 2011). In today's world, a CoE applies to any organization committed to continuous creation, use and showcasing of its technological, service and business-oriented capabilities to stakeholders in a competitive environment to acceptable international standards (Hewlett Packard, 2009). Centres of excellence also serve as a platform for public policy consultation (Aksnes *et al.*, 2012).

The Commission for Africa in 2005 recommended the establishment of a network of centres of excellence within Africa to help the continent catch up and keep up with the fast-moving pace of technology-led economic growth (Commission for Africa, 2005). In pursuing the goal of creation of centres of excellence in science, technology, innovation and development, the AU, for example, emphasizes the importance of building CoEs and investments in education, technical competences and training, and in science, technology, research and innovation (AU, 2014). The CoEs are seen as a means to enhance science and technology capacity in developing countries through the dynamic linkages between science, technology, policy and development (Leach and Waldman, 2009).

The African Conservation Tillage Network (ACT) initiated recognition of CA-CoEs in various parts of Africa (ACT, 2017a). The CA-CoEs are public research and/or training institutions dedicated to the goals, education, facilitation and persuasion for the widespread adaptation and adoption of CA at the national level (ACT, 2018). They can, however, be private institutions. Through collaboration and strategic partnerships, ACT has a strategic vision to establish 25 CA-CoEs in Africa by 2025, accomplished through a phased approach. ACT has found that CA-CoEs are important vehicles to facilitate capacity building on CA technologies for farmers, farmer groups, farmer organizations and non-governmental organizations (NGOs); facilitate information sharing/exchange among stakeholders in CA; generate, validate, disseminate and transfer the appropriate and scientific CA information and knowledge; and develop knowledge-sharing platforms for stakeholders.

25.4 Methodology

Over the past decade ACT has been working with a number of institutions in promoting the adoption of CA in Africa. This study was conducted to address two important questions: (i) the roles CA-CoEs can uniquely play in promotion of adoption of CA in Africa; and (ii) the level of performance of CA-CoEs as determined by ACT's quality assurance framework. The purpose of this study is to contribute to promoting the expansion of CA-CoEs in Africa that operates on acceptable standards for catalysing CA farming systems. The study covered three cases from Burkina Faso (University of Nazi Boni), Tanzania (TARI Uyole) and Zimbabwe (Gwebi College). These CA-CoEs implemented CA projects in partnership with ACT.

A desk study and literature review was used to respond to the question about what roles CA-CoEs can uniquely play in promotion of adoption of CA in Africa. The desk research involved systematic identification, collection, analysis and documentation of data to assist the study to identify and address the key research questions. Analysis of the data collected from the desk study and literature review employed the content analysis technique.

The CA quality assurance self-assessment tool, developed by ACT, was used to analyse the level of performance of CA system for the CoE in training, research or programme delivery. Several tools for similar applications have been developed to support quality assurance monitoring in the fields of education, research or practices (AVETAE, 2011). A four-point scale grading system was to assess the quality of the CA-CoEs:

1. Excellent (4 points): Meets all indicator performance requirements with innovation.
2. Good (3 Points): Meets all indicator performance requirements.
3. Satisfactory (2 Points): Meets some indicator performance requirements.
4. Unsatisfactory (1 Point): Performance does not meet indicator performance requirements.

25.5 The Role of Conservation Agriculture (CA) Centres of Excellence in Promoting its Adoption

25.5.1 Knowledge Management and Communication

Analysis of the work conducted by the CA-CoEs in Tanzania, Burkina Faso and Zimbabwe confirms that knowledge management and communication is a key function which CA-CoEs can play. Knowledge management is important because extension systems in many African countries are ineffective (Mutimba, 2014). It was revealed that the absence of extension platforms makes extension workers operate as individuals, each struggling in the best way to make a difference. There were no ways of harnessing the experiences the individuals are going through for purposes of learning and sharing without the existence of processes for learning which can, alternatively, be provided through CA-CoEs. It is clear that extension is no longer an isolated activity and it operates within a larger knowledge system that includes research, education and support systems (Agbamu, 2000). Findings suggest also that CA-CoEs are facilitating access to information and affordable CA equipment including supporting commercial entrepreneurial CA service provision. Availability of information about CA services is crucial to influence the choices individuals make in choosing adoption of agricultural technologies (Sims *et al.*, 2011). Access to affordable CA hand tools and animal-drawn direct seeders capable of planting on the stubble (unploughed land), for example, is crucial to reduce the arduousness of labour inherent with hand-hoe ploughing – and entice youth back to farming.

Other experiences support the view that CA-CoEs are knowledge-sharing organizations. Knowledge-sharing organizations have the potential to continuously improve service delivery, both their own and that of peer organizations in their areas of work. Becoming a knowledge-sharing organization requires leadership that encourages the needed changes in culture, provides supportive governance structures and financing, and encourages external partnerships, all to develop the disciplined practice of knowledge capture, learning, sharing and listening to the voices of stakeholders and end-users (Soulejman, 2016).

25.5.2 Establishment and/or Supporting Conservation Agriculture (CA) Communities of Practice

Findings show that within the last decade ACT supported formation of three communities of practice (CoPs): CA equipment manufacturers, suppliers and service providers; farmers and farmer organizations; and academia and researchers through projects supported by the EU (ACT, 2015a) and the Norwegian Agency for Development Cooperation (NORAD) (ACT, 2015b). Review of the existing documents, however, established that the CoPs have not been active. It may be that the formation was probably not based on strong conviction of the stakeholders or there exist other platforms that could do the functions even more effectively. The lack of a financing mechanism for the CoP is likely to have hampered the smooth operationalization and sustainability of the ACT-initiated CoPs.

There are still suggestions that CoPs are important infrastructure that CA-CoEs can innovatively support in promoting learning and sharing. CoPs are groups of people who share a common pursuit, activity or concern (Oreszczyn, 2010). According to Wenger *et al*. (2002), each CoP is a unique combination of three fundamental elements: a domain of knowledge, which defines a set of issues (creates common ground and a sense of common identity); a community of people who care about this domain (creates the social structure for learning, fostering interactions and relationships based on mutual trust and respect); and the shared practice that they are developing to be effective in their domain (denotes a set of socially defined ways of doing things in a specific domain: a set of common approaches and shared standards that create a basis for action, communication, problem solving, performance and accountability). The lack of combination of the three fundamental elements for CoP suggests why the ACT-initiated CoPs are facing challenges of operational and financial sustainability.

25.5.3 Partnership Development

The review of the progress reports suggests that the CA-CoEs are important in the development of partnerships. The partnership in the EU-funded, ACT-implemented agroecology-based aggradation–conservation agriculture (ABACO) project comprised: (i) University of Zimbabwe representing the Soil Fertility Consortium for Southern Africa; (ii) Centre International de Recherche Développement Sur L'elevage en Zone Subhumide (CIRDES) based in Burkina Faso; (iii) National Centre of Research Applied to Rural Development (FOFIFA) of Madagascar; (iv) Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD) of France; (v) Wageningen University, The Netherlands; (vi) Natural Resource Institute, Greenwich University, UK; (vii) Yellow Window of Belgium; and (viii) the Brazilian Agricultural Research Corporation (EMBRAPA). Other key partners that were pooled into the programme included the local and central government authorities, NGOs and community-based organizations (CBOs) where the ABACO project was implemented. The advantage of such partnerships was in sharing technical expertise in research, training and practice. It has been cited that forming partnerships is often a strategy for broadening an organization's sustainability while pulling together the expertise needed to fully address its mission and goals (Gray and Stites, 2013). CA-CoEs partnerships can achieve a higher level of quality and have a greater impact at a relatively lower cost than they could alone. It should be noted, however, that not all partnerships are successful; it is critical to identify partners who will actually help with the centre's success. Obstructive partners can weaken or bring down a project.

25.5.4 Policy Analysis and Advocacy

The study found that CA-CoEs were engaged in policy research that is necessary in the differing socio-ecological environments to enable identification of the right policy incentives to target beneficiaries and address differentiated needs. For example, in the ABACO project CA-CoEs were involved in policy research which was necessary in the differing socio-ecological environments to enable identification of the right policy incentives to target beneficiaries and address differentiated needs. This research tried to answer as to how to create conducive policy environments and incentives for CA adoption. A good number of publications, reports and other communication materials were generated during the ABACO project that were used as advocacy materials for policy change. From a national policy and investment perspective, a key question governments face is where and how to invest scarce financial resources to boost agricultural productivity (NEPAD, 2007). CA-CoEs are important in coming out with the answers to address the government policy issues and subsequent implementation of CA programmes in Africa.

25.5.5 Conservation Agriculture (CA) Education and Training

Training of key stakeholders through CA-CoEs is critical in promotion and adoption of CA. The visit of the 20 members of the Parliamentary Portfolio Committee on Lands, Agriculture, Mechanization and Irrigation Development to Gwebi Agricultural College witnessed that training provided to farmers, extension personnel and all other stakeholders is a necessary input in promotion of adoption of CA in Africa. The principal of the college noted to the members of parliament that 'The College has managed to carry out successful farming and training partnerships with organizations such as Food and Agriculture Organization (FAO), African Conservation Tillage Network (ACT), Windmill (Pvt) Ltd and Seed Potato Coop, among others. Over 2000 farmers in Guruve and Zvimba constituencies of Mashonaland West province received training in CA. The college was appointed as a CoE for CA by ACT. Gwebi College are proud hosts of the Chinese Agricultural Demonstration Centre. The Centre's farm machinery, irrigation facilities and laboratory equipment are accessible to students for training purposes (Gwebi, 2017). The role of Gwebi College in training cannot be underestimated, particularly when a large number of farmers are reached through the CA trainings'.

Through the smallholder CA promotion (SCAP) project in western and Central Africa, the University of Nazi Boni (formerly University of Bobo Dioulasso) in Burkina Faso trained 19 students (1 PhD, 11 MSc and 7 BSc) in CA or related fields such as cropping systems, knowledge management and innovator networks (ACT *et al.*, 2012). These graduates are engaged in research, training or practice of CA in Burkina Faso.

In recent decades a number of factors have reduced significantly the critical quality mass of human capacity in African agriculture (NEPAD and CAADP, 2015). Africa has also, over the years, invested disproportionately little in agricultural training and research: facilities and content of programmes in relevant institutions have deteriorated over time and are not keeping pace with technology developments. Consequently, knowledge generation, acquisition and sharing in and across Africa are sub-optimal (NEPAD and CAADP, 2015). These trends present a major challenge to the realization of agricultural transformation in the continent. The weak capacity, low knowledge base and absence of systems and culture of formal knowledge accumulation and sharing represent major impediments to ensuring high and sustained agricultural production and productivity (IFPRI, 2016). Serious constraints to quality education and training include weaknesses in policies that guide agricultural extension and training. Other constraints are related to reforming curricula, teaching methods and technologies; building capacity and stakeholder partnerships for technical education and training; and developing effective in-service and life-long learning capacity among public workers who interact frequently in the agricultural innovation systems.

It is observed that CA-CoEs should be engaged in addressing the factors that inhibit their performance in provision of education that contributes to enhancing the human resources capacity. CA-CoEs, however, which are agricultural education and training institutions, should be linked to extension and research services and to rural communities themselves. It is important to perform training needs identification (including rural labour market studies) which is often lacking, in order that the results are fed into curriculum design processes. To address emerging issues (e.g. sustainability, gender, farmer participation in research and extension, changing career patterns) the CA-CoEs should focus on adjusting their curricula accordingly. CA-CoEs should embrace participation by key stakeholders (including researchers and extension workers, farmers, agribusinesses) in curriculum reviews and the evaluation of training. Training and education CA-CoEs are encouraged to develop or engage in networks and outreach programmes that can enhance the quality of their training programmes.

25.5.6 Engagement by Private Sector and Conservation Agriculture (CA) Service Providers

Review of the CA projects undertaken by CA-CoEs, for example the ABACO project, showed that a major constraint to adoption of CA is linked to inadequate linkage of farmers to CA service providers for production inputs, output markets and financing. Small-scale farmers largely do not own CA tools, equipment, draught animals and machinery for different farm operations such as land preparation, planting, spraying, threshing, shelling and transportation. The few farmers who have the CA equipment lack the necessary support services (spare parts and veterinary services, for example) and the businesses for the same are not well developed. Availability of CA services is crucial to influence the choices individuals make in using their natural resources. Physical access by each farmer to affordable CA based mechanization services through entrepreneurial mechanized service provision helps reduce the arduousness of labour inherent in hand-hoe ploughing, and at the same time entice youth into farming and employment. It can, therefore, be concluded that CA-CoEs lack experience in considering business models that attract demand-driven business or private sector engagement in promotion of CA. Several advantages emanate from the CA-CoEs engaging with the business and private sector, including private sector linkage with farmers and producers in ensuring the provision of market and business-related services for CA, and improving the rural retail network for supply of inputs and services.

With regard to access to financial services, ABACO and many similar projects did not invest in supporting farmers in accessing these key services. It is generally accepted that in Africa access to financial resources is poor. For example, the Microfinance Handbook of 2013 showed that Tanzania still has low access to financial services (for example credit, deposit avenues, insurance, money transfers and pensions) within the Sub-Saharan region. Only 12% of the population in Tanzania have access to financial services from commercial banks. The share of GDP at 2011 market prices for agricultural sector activities stands at 25.5% (URT, 2011), but its financing in the form of loans accounts is for only 1% (Simbakalia, 2012). Access to financial services including credit by smallholders can promote the uptake of CA and also lead to thriving local economies. Agricultural production is typically a risky business; therefore, crop insurance can lessen the risk of farmers' exposure to external shocks (Meinzen-Dick *et al.*, 2004). A system approach in crop insurance is needed, incorporating a public–private partnership between the government, the farmers and the insurance industry. CA-CoEs are an appropriate vehicle to engage in supporting farmers to access financial services through research, training or outreach services.

25.6 Quality Assessment of the Conservation Agriculture (CA) Centres of Excellence

Using the self-assessment tool, which is part of the CA quality assurance framework (ACT, 2017b) assisting in monitoring the performance of African education, research and implementing organizations on their CA systems, the results suggest that the sampled CA-CoEs only had satisfactory performance (level 2), denoting that they are achieving some of the requirements of the indicators' performance descriptors in the used reference standards. This section discusses briefly the descriptor indicators for the sampled CA-CoEs. The key indicators considered in this study included vision, mission and objectives of the CoE, quality assurance system, CA learning and research delivery, staff management and development, budget and funding sources, facilities and environment, learners and research user support and public relations and marketing.

25.6.1 Vision, Mission Statements and Objectives

All of the CA-CoEs in this study were created by law in their respective countries and their vision and mission statements broadly support agricultural technologies such as CA. For example, the University of Nazi Boni was created by government decree with the mission to provide education to students in all fields of science and technology; conduct basic and applied research activities; to raise the technical, scientific and cultural level of production actors through continuous training; to contribute to the economic, social and cultural development of the country by proposing innovative solutions; and to valorize skills in all sectors of the country. The Tanzania Agricultural Research Institute Uyole's mission is to provide demand-driven agricultural technologies, information services and knowledge to farmers and other stakeholders for increased agricultural productivity, profitability, competitiveness and sustainable use of natural resources in the Southern Highlands Zone. Gwebi Agricultural College's vision is to be the flagship agricultural college in Zimbabwe with the mission to produce professionally and technically sound agricultural graduates capable of farming commercially and delivering agricultural services in agro-businesses, research and extension. Although it was confirmed from the review of the existing documents that the vision and mission statements for these organizations do not explicitly mention CA, they recognize that agricultural technologies and innovations are part of the key

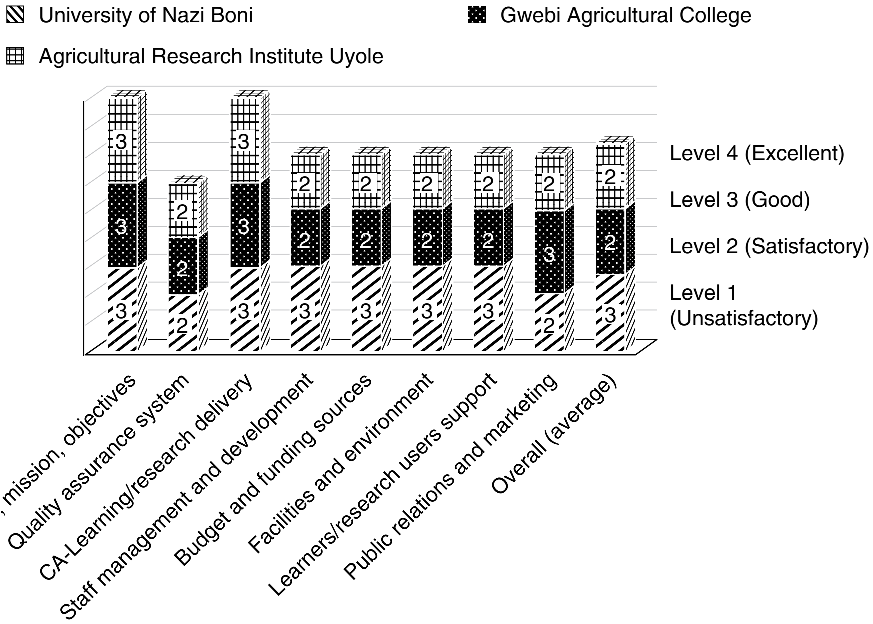

Fig. 25.1. Level of performance of the case CA-CoEs.

outputs. In addition, these organizations are focusing their efforts on contributing to achieving their government's vision on the application of agricultural technologies in addressing poverty, food security and climate change effects. However, in order to become more focused on CA, the CA-CoEs should deliberately develop programmes and strategies for promotion of CA to contribute to Africa's ambition of using climate smart agriculture technologies in addressing some of the challenges that face Africa.

25.6.2 Quality Assurance Systems

Review of the existing information for the CA-CoEs revealed lack of sufficient information to demonstrate how the quality assurance systems are working and therefore the inability to trace the reasons for the same. Qualified staff or lack of funds may be the reason for the weak implementation of the quality assurance system, as is supported by Hayward (2006). Effective quality assurance systems could be demonstrated through indicators such as existence and operation of the quality assurance committee and quality assurance information sharing system. The study findings suggest that the CA-CoEs are at their very initial stages of development and no self-assessments or training on quality assurance on CA farming systems have been undertaken.

25.6.3 Conservation Agriculture (CA) Demonstration, Adoption and Research Delivery

There was sufficient evidence that the CA-CoEs promoted CA demonstration and delivered on research. Experiences in Tanzania, Burkina Faso and Zimbabwe for the three case centres indicate that knowledge management and communication were fundamental interventions in ensuring farmers have access to needed information to help them adopt CA. The CA-CoEs promoted sustainable land management technologies and practices such as direct seeding, soil cover crops, residue retention, mulching, crop rotations, intercropping and agroforestry. In addition to the CA practices, good agronomic practices including timely planting, use of improved seeds and judicial use of inorganic fertilizers were communicated by CA-CoEs through a variety of approaches including model farmers, lead farmers, service providers, farmer field schools, learning centres, co-innovation platforms, farmers' field days, exhibitions, training and workshops, student placement, study tours, exchange visits, promotional materials and online platforms (websites) and social media.

Through participatory surveys, knowledge and information needs of the various stakeholder groups were assessed and appropriate user-friendly materials developed and distributed by the CA-CoEs. Mapping of available facilities in target areas such as radio and TV in promoting CA were studied and used to reach the communities. Knowledge-sharing products in various forms (fact sheets, technical bulletins, training materials and radio broadcasts) were disseminated to learning alliances of farmers, agro-service providers and members of regional networks. The final report of the ABACO project indicates that more than 8000 farmers were reached in the five project countries, which are Burkina Faso, Kenya, Madagascar, Tanzania and Zimbabwe, using a variety of approaches. High level influential public figures such as ministers, members of parliament and religious leaders were involved in the public awareness. About 23 participants drawn from directors of departments from the Ministries of Agriculture of Ethiopia, South Sudan, Kenya, Uganda and Tanzania and others from NGOs, universities, research and development institutions, and district executive directors participated in a study tour to Zambia through the NORAD-funded CA for Climate Change project. Workshops were organized to synthesize and promote CA knowledge and information to targeted stakeholders of farmers, service providers, academics and policy makers segregated by gender.

The results from the CA-CoEs case studies indicate that, at least during the implementation of CA projects, the main research focus areas were on a number of thematic areas including water productivity and climatic risks, soil rehabilitation and integrated soil fertility management, agroecological functions and environmental services and livelihoods, and gender and policy analysis. The focus on water productivity and climatic risks resulted from the fact that semi-arid areas of Africa are characterized by erratic rainfall and seriously affected by climate change, therefore need to design and test complementary technologies to enhance water use efficiency or productivity. Soil rehabilitation and integrated soil fertility management represented the core of the biophysically oriented research with emphasis on soil fertility management and combating land degradation, as has been conducted in most CA research projects in Africa. Africa is characterized by livestock keeping in many semi-arid areas, which in turn affects soil management. It was revealed in this study that the question of cover crop–livestock integration issues that contributes to integrated soil management aspects was at the core of the research.

25.6.4 Staff Management and Development

Review of documents showed that TARI Uyole has researchers with BSc or BA, MSc or MA and PhD qualifications in different fields relevant to the sciences and arts of agricultural development. Ideally, the institute requires a ratio of 16:32:16 BSc/BA: MSc/MA: PhD scientists with a target number of 64 compared to the current 17:28:2 of the 47 scientists in place (TARI Uyole, 2012). The scientists are supported by other staff, with diploma and certificate levels of education in fields of agricultural sciences. Efforts are under way to achieve the target and ratio through training and recruitment of young scientists in relevant fields for manning the activities at the institute. The majority are in crop production, followed by natural resources management, socio-economic sciences (agricultural economics and sociology), extension and information technology. Furthermore, there are supporting staff working in administration, farm operations and finance units at the institute. Review of available documents suggests a shortage of human resource and capacity for effective implementation of research for development by the institute. Currently, government has made efforts to recruit and train young scientists at Masters and PhD levels. This is meant to address the emerging challenges in agricultural research and development including skills, knowledge, experience and exposure to novel methods, equipment and approaches (e.g. biotechnology, tissue culture, value chain, rapid spectral soil analytical methods and multi-stakeholder processes). Africa has invested disproportionately little in agricultural training, which means there is less knowledge generation and knowledge sharing throughout Africa, thus hampering agriculture technology development and adoption (WB, 2014). Leadership skills are essential for success of the CA-CoEs.

25.6.5 Budget and Funding

The study results revealed that two of the three CA-CoEs are impeded with inadequate budget and funding sources, post-training and research user follow-up and support, and insufficient awareness creation and marketing of the work they do. A number of factors contribute to this, including lack of a resource's mobilization plan, poor government funding to the institutions and changing donor preferences in financing development projects. The review of the existing documents confirmed that income-generation plans did not exist in many of the organizations studied. Literature supports that most of the countries focused on did not have innovation funding agencies and, where such institutions exist, they tend to be weak because they lack adequate funds (Mugabe, 2011). Instruments such as venture capital are not developed in most of the countries. This means CA-CoEs do not have access to financial capital to establish businesses and to develop and disseminate technologies. This results in an important conclusion: that countries and CA-CoEs should explore various options and advocate for the establishment of agencies that are dedicated to developing funding instruments and business tools for innovation. Such institutions should have legal authority and autonomy to work directly with the private sector and invest public resources (Mugabe, 2011). The CA-CoEs should also try to explore and access global finance opportunities to obtain funding for implementation of their programmes. For example, in 2017, the World Bank announced funding for 19 'African Centres of Excellence' to the tune of US$150 million, and these funds were intended to serve seven countries in West and Central Africa, and to be used to assist in the transformation of scientific and technological education across the continent (World Bank, 2014).

Further results indicate that public relations or marketing of the CA-CoEs to the public and stakeholders is not above average, but satisfactory. Both CA-CoEs were found to have websites that provide information about their organizations. There was evidence from the project documents that one of the CA-CoEs had a number of outreach public relations or marketing interventions, even if limited, such as field days, community meetings, and dissemination of printed materials for sharing information about CA. To achieve business excellence there is a need to continuously improve CA-CoEs' business through continuous improvement of the quality of operations. The market aspect of improving the quality of operations is related to satisfaction of consumer needs, suitability of use, market positioning and the achievement of competitive advantage. Public relations is the function that manages the communication between an organization and its public to build and enhance healthy relationships to the benefit of all parties involved, and is seen as an important ingredient for an effective organization (Stroh, 2007). That is, in view of the stakeholders of the organization, relationships influence the success or failure of an organization (Harrison, 2003). Based on the literature, CA-CoEs are, therefore, dependent on how well they build their public relations with the stakeholders or recipients of their programmes. Carrying out CA research or training or project implementation can only be successful if there are good public relations. Good public relations and marketing can enhance visibility and attention to the CA-CoEs' field of research or training but also improves their ability to attract funding and support from other sources that had previously not been available. The digital and social media tools using the emerging tools of information and communication technologies (ICTs) offer tremendous opportunities towards building public relations and interactions with stakeholders.

25.6.6 Facilities and Environment

Availability of facilities and conducive environments are key performance descriptors for CA-CoEs. Findings, for example, showed that TARI Uyole and its outreach sub-stations have a total area of 3714 ha of land for research, training and technology verification applications and multiplications at large scale (TARI Uyole, 2012). There are eight outreach sub-stations with a huge agroecological zone variation of 900–2300 m above sea level (m.a.s.l.) (Table 25.1).

Table 25.1. Sub-stations of TARI Uyole and their location.

S/N.	Sub-stations	Region	District	Altitude (m.a.s.l.)
1	Mbimba	Mbeya	Mbozi	1600
2	Mitalula	Mbeya	Rungwe	1052
3	Ismani	Iringa	Iringa Rural	1370
4	Seatondale	Iringa	Iringa Urban	1700
5	Igeri	Njombe	Njombe	2300
6	Suluti	Ruvuma	Namtumbo	900
7	Ndengo	Ruvuma	Mbinga	1650
8	Milundikwa	Rukwa	Nkasi	1800

m.a.s.l., metres above sea level.

These facilities provide a good space for undertaking outreach activities in CA. Previous visits made by one of the authors to the centre's headquarters indicated that most of the residential and office buildings, feeder roads, water systems and electricity supply systems are very old, and require major renovations. These housing and social services situations make work conditions difficult and reduce workers' efficiency, and directly impacts on the work performance and the institute at large. Modern and fast equipment and techniques for laboratory diagnostics are lacking, particularly, in the soil and plant tissues analysis, plant pathology, entomology and food science and technology laboratories. The centre received resources mainly from the government for supporting physical resources such as laboratories, office buildings, transport, and other services infrastructure and financial support for research and station up-keep funds. The study conducted by Blom and Meyers supports the importance of learning environment and physical resources as key determinants for quality within training institutions (Blom and Meyers, 2003).

Gwebi Agricultural College has some land which is allocated for offices, on-station trials and a production farm. The College has been working in partnership with a number of organizations such as FAO and Zimplow, which also partly contribute to the assets. Debont Co. Ltd operates a farm in the vicinity, providing opportunities for students learning about mechanized CA.

25.6.7 Post-training and Research Support Follow-up

Regarding post-training and research support follow-up, two of the CA-CoEs had a satisfactory rating and one had a good level rating. Following up the farmers or beneficiaries of the project provides an opportunity for the CA-CoE to improve on its operations which can translate into improvement of the quality of service or activities to beneficiaries.

Borrowing from the impact-based training evaluation model (Kirkpatrick Partners, 2010), which offers some promising innovations in promoting the training participants' capacity to improve their level of contribution of institutional productivity, it is emphasized that CA-CoEs conduct monitoring of the services they provide to their farmers.

The framework 'New World Kirkpatrick Four Levels' (Fig. 25.2) refers to the four levels of evaluation that have to be employed for post research and training follow-ups (Kirkpatrick and Kirkpatrick, 2010).

25.7 Conclusions and Future Prospects

A major constraint to the adoption to CA is the weak linkage between farmers and CA service providers, output markets and financial institutions. The CA-CoEs are still at early stages of their development, with two demonstrating only satisfactory performance. It clear that CA-CoEs face a number of challenges, particularly the inadequacy of funds to operate and implement their CA-related programmes, training and research support, marketing of their work, and improving facilities for learning and research. CA-CoEs need to conduct monitoring of the services they provide for their clients in order establish the outcomes of their efforts. Lack of qualified staff or of funds are the reasons for weak implementation of quality assurance programmes.

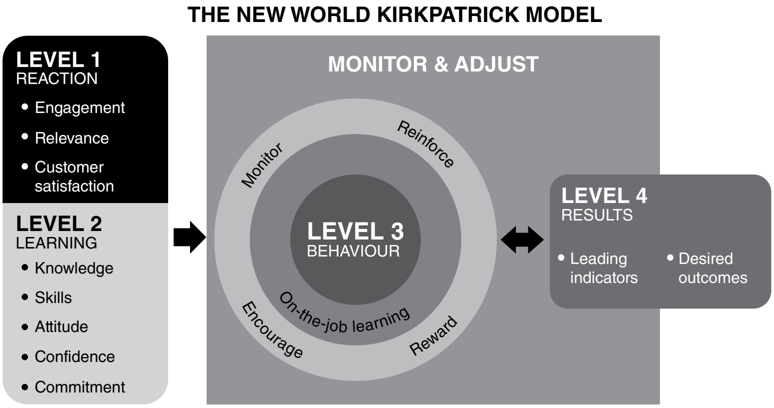

Fig. 25.2. The four levels of training evaluation work. From Kirkpatrick Partners (2010).

Promotion of CA can only be impactful if it is innovatively implemented, beyond the business-as-usual scenario. This can be through provision of coordinated demand-driven CA-based agricultural practices, information services and knowledge to farmers and other stakeholders such as NGOs, service providers, equipment manufacturers, researchers and academia.

As a pan-African organization and through its strategic plan, ACT should continue working with partners, particularly with the CA-CoEs as a model, to accelerate adoption rates of CA in African countries through global knowledge partnerships. The opportunities are huge. As a contribution to future agricultural development in Africa, ACT should take an active role in the implementation of the Lusaka Declaration on CA from 1ACCA, as well as the implementation of the Stakeholder Statement from 2ACCA. This will, among other things, provide the support to establishing learning mechanisms that will accelerate the adoption of CA in the continent, thereby contributing to poverty reduction, food security, and resilience to climate change effects in line with the Malabo Declaration and Agenda 2063.

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26 On-farm Experimentation for Scaling-out Conservation Agriculture Using an Innovation Systems Approach in the North West Province, South Africa

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Abstract

A project under the Farmer Innovation Programme (FIP) that aimed to adapt Conservation Agriculture (CA) among grain farmers in South Africa was implemented in a commercial farming area of the North West Province. The following on-farm, collaborative-managed trials produced key findings concerning: (i) plant population densities (high versus low) under CA; (ii) conventional crop systems versus CA crop systems; (iii) the testing and screening of cover crops; (iv) green fallow systems for soil restoration; and (v) livestock integration. Key results from these trials were that the yield of maize was significantly higher under high-density no-till (NT) systems compared to the normal NT systems. The yield of maize in local conventional systems was lower than the yield in NT systems tested on three farmer-managed trials. The screening trial assisted in testing and learning the suitability and the different attributes of a range of cover crops in that area. Cover crop mixtures used as a green fallow system with livestock showed that CA can facilitate the successful restoration of degraded soil.

Keywords: on-farm trials, soil health, crop rotations, cover crops, livestock integration

26.1 Introduction

In virtually all South African arable land, crop production systems based on intensive and continuous soil tillage have, over many decades, led to the loss of about 46% of South African soil organic carbon (SOC) (Swanepoel *et al.*, 2016). This triggered a downwards spiral of soil degradation leading to a reduction of vital soil biological activity and destruction of soil structure, severe levels of soil erosion and a considerable decrease in soil health. South Africa's soils have, over the past 60 years, been over-exploited to the point where about 70% of the country's food-producing lands are critically and severely degraded. According to Le Roux *et al.* (2008), the average soil loss under annual grain crops in South Africa is 13 tonnes ha^{-1}yr^{-1}, which is much higher than the natural soil formation rate. This adds to the growing problems with profitability and financial risk in the grain industry, supporting the need for the paradigms of agriculture production and management to change.

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There is general agreement among key role players in South Africa, such as government, research institutions and producer's organizations (such as Grain SA), that this negative situation can be changed through the adoption and adaptation of Conservation Agriculture (CA) in various unique farming situations. CA is seen as an ideal system for sustainable and climate smart agricultural intensification in South Africa, through which farmers can attain higher levels of productivity and profitability (i.e. 'green prosperity') while improving soil health and the environment (Swanepoel *et al.*, 2016; Smith *et al.*, 2017).

For the widescale adoption and adaptation of CA, a change in paradigm is required by farmers, researchers, extension officers, agricultural businesses and policy makers. To create this new paradigm an approach embracing and empowering all the involved actors within the value chain is needed. Fortunately, this 'paradigm change', or transformation process, has in fact already been 'happening' on farms and by farmers for decades, here in South Africa and across the world. Innovative farmers have been adopting and adapting CA principles in various conditions and driving the creation of networks of actors who are interested and passionate in creating sustainable rural livelihoods. These so-called on-farm, farmer-centred innovation systems (ISs) brought the understanding that innovation emerges from the interaction of multiple actors or stakeholders; that is, researchers, advisory service providers, non-governmental organizations (NGOs), farmers' organizations and private sector actors (Röling and Wagemakers, 1998; Hall *et al.*, 2006; Waters-Bayer *et al.*, 2009). This chapter presents 6 years (2013–2018) of experiences and results from research using a farmer-centred IS approach developing and adapting CA among commercial grain farmers in the Ottosdal area in the North West Province of South Africa. The programme was funded by The Maize Trust of South Africa with material contributions from participating farmers and several agribusinesses.

26.2 Methods and Materials

26.2.1 Background

Grain SA started an initiative in 2013 called the Farmer Innovation Programme (FIP) to research, develop and adapt CA among commercial and smallholder grain farmers in South Africa. This programme followed a farmer-centred IS process that used local social structures or farmer groups as platforms to launch various projects (Smith and Visser, 2014). Various activities were implemented and facilitated that allowed participants to act, observe, reflect, plan and learn, creating a culture of sharing and learning that enabled farmers and their networks to be innovative and interactive in managing and adapting their farms in a sustainable manner. This type of IS model strongly relies on interactive, in-field discovery learning, using on-farm, farmer-led experimentation as one of the main tools.

During this period four projects were implemented in partnership with commercial farmer groups in key grain production regions in South Africa, namely the Ottosdal No-till Club (Ottosdal, North West Province), the Ascent study group (Vrede) and the Riemland study group (Reitz), the latter two groups were both in the north-eastern Free State Province. Project teams were created that included local farmers and researchers who were made responsible for specific work package topics, namely soil, agronomy and cover crops. Agricultural businesses such as cooperatives, input suppliers and machinery dealers were also involved rendering specific inputs and services, for example seed, agro-chemicals and implements. CA treatments or practices were jointly identified by each of the project teams and a series of trials was designed and established on various farms.

26.2.2 On-farm Experimentation

In the IS approach, on-farm experimentation is a necessity and an inherent, intuitive part of a farmers' innovativeness and resilience. As nature, economy, politics and social factors change and evolve, farmers are required to continuously and effectively adapt. For this reason, experimentation by farmers is often an integrated component of a sophisticated risk management strategy; it happens spontaneously, rather than as the result of some exceptional stroke of genius (Hansson, 2019).

On-farm experimentation methodology (trials) has three goals that supports the vision of this project.

- To generate data on which to assess technology performance under realistic farmer conditions.
- To complement the agronomic trial data with farmers' assessments and observations of the adoption potential of technologies. This information helps to understand how the technologies fit into farmers' broader farming and livelihood strategies.
- To encourage farmers to actively participate in the trials to stimulate farmer experimentation with, and adoption/adaptation of, new technologies and practices.

The objectives of on-farm trials are to improve experiential learning and understanding and adaptation of technologies to local farmers and conditions, increase awareness among farming communities and facilitate farmer-to-farmer extension. Selener (1998) classified trials conducted on farms according to the level of control and management exercised by farmers and researchers (Table 26.1). Table 26.2 shows the application, assumptions and intended outcomes of on-farm experimentation in the Ottosdal CA project.

26.3. On-farm Collaborative-managed Trials Implemented in Ottosdal

The Ottosdal study area is located between 25.9°S and 27.1°S at an elevation from 1250 m to 1600 m. The landscape is rolling with most slopes < 1% gradient on land used for crop

Table 26.1. Classification of on-farm trials (adapted from Selener, 1998).

Collaborative-managed (CM)	Farmer-managed (FM)
Farmers and researchers work together on problem definition, design, management and implementation of trials as well as evaluation. Ideally, a collaborative relationship means balanced participation in and control over the research process in order to achieve the objectives of both farmers and scientists. Some of the trials implemented under the CA policy will be established in this fashion, although the purpose of these trials is not to achieve local farmer-level adaptation.	Farmers are the main actors and decision makers in these trials, continuously experimenting, developing and adapting complicating technology in their own complex realities. Many farmers will become aware of CA options and start doing their own CA experiments in this fashion. Awareness generally happens through different media (publications, social media, etc.), at field days, or farmer group meetings or visits.
Researcher-managed (RM) (non-participatory)	Researcher-managed (consultative) (RMC)
RM trials are done on farmers' fields to develop technology for farmers or to test and validate research findings obtained at the research station. Farmers do not participate actively in this process, which leads to very little ownership and adoption.	Farmers are consulted at the beginning of the research process to assist researchers in interpreting farmers' circumstances, problems or needs. This leads to experimental designs for trials which often will not include farmer participation at the initial (i.e. planning and design) stages of on-farm testing. Technology is developed for farmers based on the researchers' understanding of their farming systems, which leads to very little ownership and adoption.

HIGHER LEVELS OF OWNERSHIP AND ADAPTATION →

HIGHER LEVEL OF PARTICIPATION, LEARNING AND UNDERSTANDING BY FARMERS →

Table 26.2. Application, assumptions and intended outcomes of on-farm experimentation in the Ottosdal Conservation Agriculture project (adapted from Smith, 2006).

Application	Assumptions	Intended Outcomes
FM and CM trials on local farmers fields	Experimentation where farmers actively participate will: Improve the collection and use of monitoring and evaluation (M&E) information Lead to a better understanding of CA principles and natural resources Provide an experiential learning environment for farmers Facilitate the adaptation of technologies among local farmers Allow a platform for field days, 'Look and Learn' visits and conferences, which increase the awareness among local farmers	Improved experiential learning Improved modification and adaptation by local farmers Increased awareness among farming communities Effective farmer-to-farmer extension and training Development of locally adapted CA systems

FM, farmer-managed; CM, collaborative-managed.

production. Deep, freely drained sandy to sandy loam soils, are predominant in this area with a low water-holding capacity and low organic matter content. The natural vegetation is mainly grassland with some savannah, but around 70% of this area is cultivated.

The climate is semi-arid (aridity index = 0.37), with mean annual summer precipitation from 500 mm to 620 mm (Schulze, 1997). Dry spells often occur during December, January and February, which can seriously affect crops, as it usually coincides with the flowering and grain-filling growth stages. A large proportion of rainfall events occur in the afternoon as thunderstorms with a high intensity cause runoff.

In the Ottosdal project, on-farm experimentation, especially collaborative-managed trials (CMTs), were used as key tool to involve and assist farmers to adapt CA in the region. Most of the CMTs consisted of a single replicate of treatments. The objectives of these trials were identified by the participating farmers. Fields with homogeneous soil were selected for these trials and, as commercial equipment was used, plots assigned to treatments consisted of strips across a field, usually exceeding 0.5 ha each. Experience has shown that results from large plots such as these have a higher credibility than small plots. The following CMTs and treatments were implemented in the Ottosdal study area of the North West Province:

1. Crop rotation systems under CA.
2. Tines versus coulter fitted on no-till (NT) planters.
3. Plant population densities (high versus low) under CA.
4. Maize cultivar evaluation under high plant population density CA cropping systems.
5. Conventional crop systems versus CA crop systems.
6. The testing and screening of cover crops.
7. Green fallow soil restoration trial.
8. Livestock integration trial.

For the purposes of this chapter, the following trials are presented that produced the most significant results during this period in the Ottosdal project.

26.3.1 Comparison Between Low Plant Density in Wide Rows (Local) and High Density in Narrow Rows (Argentinian) Configurations

Owing to the availability of commercial equipment, row spacing used for maize in CA systems are 0.76 and 0.91 m. The norm used for CA which was developed under conventional soil tillage for maize plant population densities is ≤ 24,000 ha^{-1} for the area. These guidelines are in sharp contrast with the configuration system used in Argentina where the row spacing is 0.52 m and the plant population density 40,000 ha^{-1}. The aim was to compare the yield of maize as affected by the Argentinian system (high density and narrow rows) and local system (low density and wide rows).

From 2014/15 to 2016/17, 19 trials were done on several farms, each representing one replicate, using an Argentinian Pierobon planter with row widths of 0.52 m representing the Argentinian system, while the planter of the farmer was used to plant according to his usual low densities and row spacings of either 0.76 or 0.91 m. The two configuration systems were planted in strips and separately harvested. All inputs, such as fertilizer and cultivars, were similar for both treatments.

26.3.2 Comparison of Conventional and Conservation Agriculture (CA) Cropping Systems

Due to a local lack of scientifically based results the need exists to collect results on the success of CA systems in comparison with conventionally produced maize in field trials. It was reasoned that such a comparison will confirm and demonstrate the improved productivity and sustainability of maize production under CA over that of maize production under tilled soil.

A demonstration trial with three production systems as treatments was done over three seasons on Doornspruit Farm. For the first two seasons, the treatments were not replicated while two replicates were added in the final season. The treatments consisted of: (i) NT maize in 0.52-m spaced rows at 40,000 plants ha^{-1} (CA1); (ii) NT maize in 0.91-m spaced rows at 24,200 plants ha^{-1} (CA2); and (iii) maize in rip-on-row 40 cm deep tillage, 2 × 2.3 m + 1 × 1.5-m spaced rows at 18,000–22,000 plants ha^{-1} (CT) which is the conventional system practised on the farm. Plots consisted of strips 30–35 m wide and 200 m in length across an area of land. All crop residues were left on the surface in the CA systems while about 90% of them were incorporated in the CT system. Crop rotation was not applied.

26.3.3 Testing and Screening Cover Crops

The initiation of a cover crop (CC) screening trial at Ottosdal took place at a stakeholder meeting of farmers and researchers in 2013. The decision to plant the screening trial stems from the fact that farmers were engaged in NT activities, but were unaware of the possible benefits of cover crops. The discussions revealed that farmers lack information on different CCs and their performance in this semi-arid agroecological zone of South Africa. The trial was proposed and designed as a tool for farmers and researchers to evaluate and demonstrate the suitability of a range of CCs and mixtures for their contribution to soil health, biomass production and residue cover. General knowledge generation on planting, caring for and terminating the different crops was envisaged.

The aim of the screening trial was to familiarize farmers with alternative CCs and to screen them for their adaptability to local conditions as well as to get an indication of their effect on the yield of currently important grain crops. Due to the size of the trial (13 possible cover crops), it was un-replicated; however, the trial was conducted over 4 years with specific plots assigned to specific crop rotations. The trial had a criss-cross, strip-plot layout with 17 treatments (7 winter annuals and 10 summer annuals) and was executed over four seasons, i.e. 2015–2018. The design was such that every 2nd year the strips were planted in the same locality or plot. Strips with the winter and summer annuals as main plots with the different crops (subplots) were randomly assigned within the main plots. Species were planted as monoculture and in rotation with all other treatments (see Table 26.3 for the trial lay out). All the local cash crops were included as treatments, which were maize, soybean, sunflower and grain sorghum.

Planting was done with a commercial six-row NT planter, resulting in strips with 12 rows for every crop and 50 cm inter-row spacing. Plant density depended on the species; for example maize was planted at 40,000 plants ha^{-1} while cowpea was planted at 150,000 plants, which were seen as high-density cropping systems. Inputs such as herbicides and fertilizer were applied according to practices commonly used by the farmer.

Table 26.3. Treatments in screening trial. Authors' own table.

Common name	Scientific name	Seed rate kg ha^{-1} and plants ha^{-1}
Winter annual cover crops planted in mid-February after rain event		
Black oats	*Avena strigosa*	70
Oats	*A. sativa*	70
Rye	*Secale cereale*	70
Radish	*Raphanus sativus*	5-6
Triticale	*Triticale*	70
Grazing vetches	*Vicia dasycarpa*	25
Mixture	*Vicia dasycarpa* + *A. strigosa* + *R. sativus*	40
Summer annuals cover crops planted in Nov – Dec after rain		
Dolichos	*Lablab purpureus*	25
Maize	*Zea mays*	40,000 plants ha^{-1}
Cowpea	*Vigna unguiculata*	25
Velvet bean	*Mucuna pruriens*	25
Sunflower	*Helianthus annuus*	50,000 plants ha^{-1}
Sorghum	*Sorghum bicolor*	12
Pearl millet	*Pennisetum glaucum*	20
Soybean	*Glycine max*	300,000 plants ha^{-1}
Mixture	*Sorghum bicolor* + *L. purpureus* + *Crotalaria juncea*	40
Sunn hemp	*Crotalaria juncea*	50

The following measurements were made on the trial: wet biomass of all crops harvested in a late vegetative, actively growing stage each year to determine the dry matter (DM); plant available water (PAW) measured under the different treatments; the yields for the different cash crop treatments on the different rotations; Haney soil health tests (SHT) and the phospholipid fatty acid (PLFA) analyses to study the effects of selected treatments (i.e. the different functional CC groups) on a range of soil health parameters. Although residue cover and infiltration rates for the different treatments were also measured, they are not included in this chapter.

26.3.4 Green Fallow Soil Restoration Trial

This trial was initiated in 2016 to investigate a soil restoration process with a green fallow on a degraded maize field through the establishment of a ten species CC mix, as part of a CA rotation system. The hypothesis was that high crop diversity, in this case summer and winter CC multi-species mixtures, will enhance and speed up the biological (ecosystem) processes in the soil to quickly restore the productive capacity of the soil. A huge problem in this semi-arid region is to accumulate enough crop residues on the soil surface, especially in the transitional phase from conventional to CA.

Two adjacent 10-ha fields were planted with a multi-species cover crop mixture and cash crops, respectively, during alternative years from 2016. Similarly, to the screening trial, the size of the trial made replications unfeasible, whereby the farmer would lose a large proportion of the farm's productive land. No fertilizers were used because of the availability of residual fertilizers left from the previous crop that was not harvested due to a poor stand and performance.

The following functional plant groups were used to create the mixtures:

- warm season (summer) grasses (maize, millet, sorghum);
- warm season broad leaves (soybeans, cowpea, lablab, sunflowers);
- cool-season (winter) grasses (cereal rye, wheat, triticale); and
- cool-season broad leaves (vetch, radish and turnips).

The summer annual CC mixture used in this trial included functional groups such as legumes, cash crops and grasses, as well as a brassica in the form of radish. The winter mixture included the same functional groups. The summer mixture included mainly annual grasses that are not easily decomposed (such as millet and fodder sorghum), while the winter CC mixture had temperate crops that decomposed fairly quickly (Table 26.4).

Measurements included biomass production and cash crop yields. Soil samples were taken on an annual basis at the trial site; both CC plots and cash crop plantings were monitored.

26.3.5 Livestock Integration Trial

The economic viable integration of CC plus livestock in a crop–livestock rotation system was investigated. The hypothesis was that livestock management systems that use the principles and practices of short duration or high utilization (density) grazing, also called mob grazing, are necessary to profitably integrate CCs, and simultaneously achieve a range of environmental outcomes such as the restoration of the soil food web and eventually soil organic matter (SOM) content and soil health levels (Montgomery, 2017). The main purpose of the grazing practice was to increase the growth and production of livestock, to increase the competition among livestock, to improve the efficient conversion of solar energy by plants, to improve the interception and retention of precipitation in the soil and to optimize the cycling of nutrients while promoting high ecosystem biodiversity. The theory is that above-ground chewing, tearing and trampling actions by grazers creates wounds in the plants that must heal. In order to heal, plants need micronutrients and microbial metabolites and to achieve this cooperation they pump a steady supply of carbon-rich exudates (products of photosynthesis) from their roots to feed soil microbes and in exchange these microbes supply nutrients to the plants back through the roots. This cooperation stimulates regrowth and production in the cover crops planted, but also facilitates the improvement of soil health (Montgomery, 2017).

Electric fencing equipment was used to divide the field into grazing areas of 3 ha each. These areas were grazed for a period of 3 days before the livestock was moved to a new area. An inclusion area was also identified where animals could stay in case of extended rainy events, to prevent soil compaction. A perennial warm season grass pasture of Smuts finger (*Digitaria eriantha*) close to the cover crop was identified as suitable for this purpose. Water was supplied at a central point with a corridor on the side of the field trial giving livestock access to the water. Livestock weight gain, available biomass and economic parameters were measured to evaluate the performance of the treatments.

26.4 Results and Discussion

The application of on-farm collaborative-managed trials (CMTs) in the Ottosdal study was an important tool for the wider awareness

Table 26.4. Summer and winter CC mixtures used in the green fallow trial, Ottosdal. Authors' own table.

Cover crops in summer mixture	Seed rate kg ha^{-1}	Cover crops in winter mixture	Seed rate kg ha^{-1}
Fodder sorghum (*Sorghum bicolor*)	10	Cereal rye (*Secale cereale*)	10
Cowpeas (*Vigna unguiculata*)	10	Black oats (*Avena strigosa*)	15
Pearl millet (*Pennisetum glaucum*)	4	Grazing vetch (*Vicia dasycarpa*)	15
Dolichos (*Lablab purpureus*)	3	Tillage radish (*Raphanus sativus*)	1
Sunn hemp (*Crotalaria juncea*)	2		
Maize (*Zea mays*)	2		
Sunflower (*Helianthus annuus*)	2		
Soy bean (*Glycine max*)	2		
Tillage radish (*Raphanus sativus*)	1		
Total seeding rate: 37 kg ha^{-1}		Total seeding rate: 41 kg ha^{-1}	
Total seed costs: ZAR600 ha^{-1}		Total seed cost: ZAR800 ha^{-1}	

and adaptation of CA by farmers in the region. CMTs were essential for strengthening the understanding and skills-base of farmers, especially experimentation skills, to better and quicker refine and adapt specific, new CA practices in their local conditions. The following results were achieved from each of the CMTs during this period.

26.4.1 Comparison Between Low Plant Density in Wide Rows (Local) and High Density in Narrow Rows (Argentinian) Configurations

The analysis of variance showed that the yield of maize was significantly affected by the row width plant population systems ($p = 0.02$). The mean yield of the Argentinian system was 0.55 t ha^{-1} higher than the yield of the wider row width and lower plant populations. However, in three instances, the opposite was true, where the yield of the local system was between 0.38 and 1 t ha^{-1} higher than the yield of the Argentinian system. Results are shown in Fig. 26.1.

26.4.2 Comparison Between Conventional and Conservation Agriculture (CA) Cropping Systems

Although a sound statistical analysis was not possible, the results were remarkable. The yield of maize in the rip-on-row with a 2.3-m row spacing system (CT) was between 0.80 and 2.18 t ha^{-1} lower than the mean yield of the two NT systems (CA1 and CA2) from 2015/16 to 2017/18 (Table 26.5). The yield differences are most likely due to differences in the water infiltration capacity among the cropping systems in this water-limited environment. It took almost three times longer for 25 mm of water to infiltrate into the soil of the CT than into the soil of the two CA systems. This caused differences in runoff and soil erosion which can be seen in Fig. 26.2.

26.4.3 Testing and Screening Cover Crops

Biomass production was highest from C_4 grass species (Table 26.6). These annual grasses

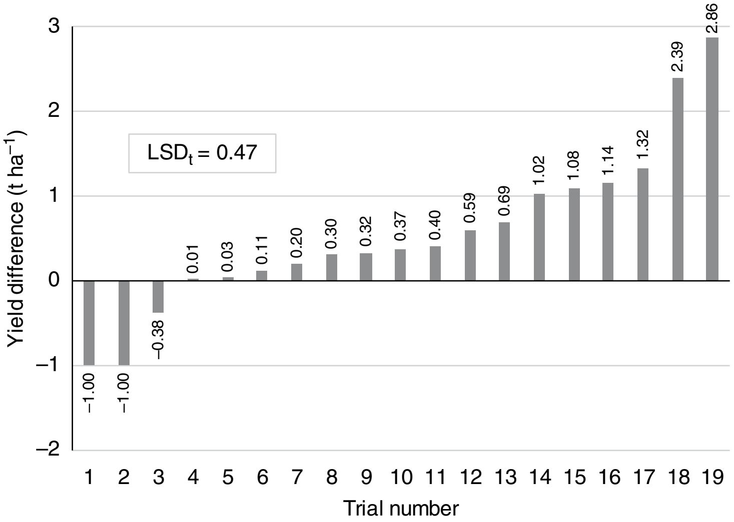

Fig. 26.1. The yield difference of maize in Argentinian (row width 0.52 m and population 40,000 plant ha^{-1}) and local system (row widths 0.76–0.91 m and plant population ≤ 24,000 ha^{-1}. Positive values represent cases where the yield of the Argentinian system was higher than that of the local system while negative values represent the opposite. Authors' own figure.

(sorghum, maize and millet) produced up to an average of 13.7 t ha^{-1} over the 4-year period, which emphasized their superior ability to convert sun, nutrient and water resources into biomass in a semi-arid environment. Summer annual legumes such as cowpea, lablab, velvet bean and sunn hemp also produced well; they form a symbiosis with rhizobium bacteria to convert atmospheric nitrogen (N_2) to soil nitrogen. The summer and winter mixture produced well, but was outperformed by the highest-producing summer and winter annual treatments. From the winter functional groups, the radish dominated in terms of DM production. Winter annuals need rain after establishment and produced less biomass when rain received during autumn was less than optimal.

Table 26.5. The yield of maize (t ha^{-1}) as affected by cropping system on the farm Doornspruit from 2015/16 to 2017/18. Authors' own table.

Season	Cropping systems		
	CA1	CA2	CT
2015/16	4.68	3.39	2.47
2016/17	6.22	6.35	4.11
2017/18	3.77	3.83	3.04
Mean	4.89	4.52	3.21

Winter CCs affected cash crop yields negatively, probably due to the high soil water use before the new summer growing season. However, they have other benefits, such as the provision of a green pasture in winter (compared to the normal practice of bare or black fallow), that could assist with animal integration and production and may increase SOC and improve biodiversity.

Most C_4 plants are grasses native to the tropics and warm semi-arid zones with high light intensity and high temperature. Under these conditions, C_4 plants exhibit higher photosynthetic and growth rates. In terms of residue cover, these crops also exhibit the ability to break down slowly due to a high C:N ratio, producing a residue cover at the soil surface for longer. In this region, cash crops such as sunflower and soybean cannot cover the soil sufficiently as required for CA. Brassicas such as radish, and legumes such as grazing vetch

Fig. 26.2. Evidence of runoff and erosion on a conventionally tilled plot (right) with a lower water infiltration capacity compared to a no-till plot (left) with a higher water infiltration capacity and with little signs of runoff and erosion. Authors' own figure.

Table 26.6. Average dry matter (DM) from the 2015–2018 seasons. Authors' own table.

Treatments	Average DM yields (t ha^{-1})
Avena sativa	3.93
Avena strigosa	4.99
Secale cereale	4.10
Triticale spp.	4.44
Mixture, winter (*Raphanus sativus, Avena strigosa, Vicia dasycarpa*)	8.10
Raphanus sativus	9.36
Vicia dasycarpa	3.12
Crotalaria juncea	5.18
Glycine max	7.14
Lablab purpureus	5.81
Mucuna pruriens	6.06
Vigna unguiculata	4.46
Mixture, summer (*Lablab purpureus, Sorghum bicolor, Crotalaria juncea*)	7.49
Helianthus annuus	9.80
Pennisetum glaucum	11.42
Sorghum bicolor	9.93
Zea mays	13.70

Table 26.7. Plant available water (PAW) measured after selected treatments, Ottosdal 2014. Authors' own table**.**

Crops 2014	PAW 2015 (mm)
Crotalaria juncea	22.0
Mixture summer (*Lablab purpureus*, *Sorghum bicolor*, *Crotalaria juncea*)	26.4
Glycine max	19.3
Pennisetum glaucum	7.8
Sorghum bicolor	5.2
Helianthus annuus	22.4
Mucuna pruriens	51.6
Vigna unguiculata	18.4
Zea mays	38.3
Lablab purpureus	17.6
Vicia dasycarpa	0.4
Mixture winter (*Raphanus sativus, Avena strigosa*, *Vicia dasycarpa*)	0.04
Triticale spp.	0.04
Raphanus sativus	0.3
Secale cereale	0.0
Avena sativa	0.0
Avena strigosa	0.6

had the same problem, especially in less than optimal rainy conditions.

PAW was measured before the planting season by a local co-operative (North Western Corporation) in the different treatments in 2015 and it became clear that cool-season (winter) CC treatments were using most of the available moisture in the soil profile due to seasonality of rain (summer rainfall) (Table 26.7). The practice of planting winter CCs has since been abandoned by the farmers in Ottosdal owing to the negative effect it might have on the yield of the following cash crop.

Soil analytical results showed that rotations between lablab and millet (a summer annual legume and a summer annual grass) outperformed other treatments by increasing the SOM (Table 26.8). For cash crops, the summer CC mixture (lablab, sunn hemp and fodder sorghum) rotated with sunflower outperformed all other treatments in terms of SOM build-up.

Cash crop yields were influenced by the different treatments (Table 26.9). The cash crop yields presented here are the average of the 3-year trial. Table 26.9 shows it was clear that maize (with a high nitrogen demand) did well after rotation with summer legume CCs such as cowpea, soybean, velvet bean, sunn hemp and lablab. Only the maize on sunflower and sorghum treatments were lower than the long-term average of 5 t ha^{-1} for maize. For the cool-season annuals, only triticale and vetch resulted in an average maize yield of 5 t ha^{-1} and higher. Treatments of oats, black oats, rye, radish and the winter mixture resulted in lower maize yields than the long-term average.

Sunflower and grain sorghum did well after cool-season crops such as oats and black oats, while for the summer annual treatments the overall yield was good except for the sunflower monoculture. Soybean in all treatments was disappointing in terms of yield production.

26.4.4 Green Fallow Soil Restoration Trial

Due to the variation in rainfall between the seasons, the DM produced from the summer CC mixture varied between 11.8 and 16.8 t ha^{-1} (Table 26.10). In the 2017 season the biomass

Table 26.8. SOM (%) on selected screening trial treatments for 2015 and 2018. Authors' own table.

Treatments	SOM (%) in 2015	SOM (%) in 2018
Helianthus annuus on summer mix	1.1	2.0
Pennisetum glaucum on *Zea mays*	0.9	1.9
Glycine max on *Zea mays*	1.3	1.6
Helianthus annuus on Zea mays	1.1	1.6
Lablab purpureus on *Zea mays*	1.5	1.7
Lablab purpureus on *Avena strigosa*	1.7	1.5
Lablab purpureus on winter mix	1.0	1.4
Lablab purpureus on *Crotalaria juncea*	0.9	1.7
Pennisetum glaucum on winter mix	1.5	1.8
Sorghum bicolor on *Pennisetum glaucum*	1.0	2.0
Lablab purpureus on *Pennisetum glaucum*	1.2	2.4
Pennisetum glaucum on *Lablab purpureus*	1.0	1.5
Zea mays monoculture	1.0	1.6
Veld (natural pasture)	1.4	1.2

Table 26.9. Average cash crop yields (2015–2017) after different cover crop treatments. Authors' own table.

Crops	*Glycine max*	*Helianthus annuus*	*Sorghum bicolor*	*Zea mays*
Crotalaria juncea	1.33	2.02	2.53	5.26
Glycine max	1.19	2.04	2.46	5.88
Mucuna pruriens	1.45	2.21	2.39	5.40
Lablab purpureus	1.29	1.96	2.67	5.05
Vigna unguiculata	1.41	2.16	2.93	5.98
Mixture summer	1.46	2.16	2.86	5.61
Helianthus annuus	1.04	1.80	1.75	4.93
Pennisetum glaucum	1.46	2.20	3.06	5.25
Sorghum bicolor	1.35	2.64	2.33	4.95
Zea mays	1.29	2.17	2.39	5.48
Avena sativa	1.03	2.22	3.17	4.90
Avena strigosa	1.19	2.15	2.70	3.94
Triticale	0.58	1.92	2.02	5.02
Secale cereale	1.17	1.76	1.68	4.46
Vicia dasycarpa	1.03	1.94	2.11	5.19
Raphanus sativus	1.03	1.81	2.05	4.14
Mixture winter	1.52	1.99	2.10	4.91

Table 26.10. Annual rainfall and production from two separate fields on the green fallow trial. Authors' own table.

Years/Annual rainfall	Field A (t ha^{-1})			Field B (t ha^{-1})		
2016	Summer CC			Commercial no-till maize field		
412 mm	11.8 (DM t ha^{-1})					
2017	Soybeans	Sunflower	Maize	Summer CC		
608 mm	1.7 (t ha^{-1})	1.6 (t ha^{-1})	8.8 (t ha^{-1})	16.8 (DM t ha^{-1})		
2018	Summer CC			Soybeans	Sunflower	Maize
398 mm	13.1 (DM t ha^{-1})			1.2 (t ha^{-1})	1.5 (t ha^{-1})	3.9 (t ha^{-1})
2019	Soybeans	Sunflower	Maize	Summer CC		
550 mm	0.5 (t ha^{-1})	1.0 (t ha^{-1})	3.0 (t ha^{-1})	13.6 (DM t ha^{-1})		

production of the CC mixture was 16.8 t ha^{-1} DM and a 100% soil cover was achieved after receiving 608 mm of rain.

In 2017 the maize yield after the summer CC was 8.8 t ha^{-1} which, according to the participating farmer, was the highest yield ever for maize on that particular field.

In 2019, maize, sunflower and soybean were successfully planted into the cover using a NT planter with disc openers, instead of tines. Rainfall during the growing season was a mere 280 mm, compared to the average of 500 mm. After pollination a rain event of 250 mm did occur in April and might have assisted in kernel filling.

When comparing the maize yield and gross margins from this trial to all the other different practices on the same farm during 2019, maize after the green fallow treatment produced the second highest yield with 3.0 t ha^{-1} (Table 26.11).

Maize yields were the highest after the livestock integration practice (4.7 t ha^{-1}), with maize after soybean and cowpeas third and fourth. Maize yields were the lowest after monoculture maize and sorghum. In terms of soil health, the green fallow treatment increased the Haney SHT index score from 2.9 in 2016 to 11.7 in 2019, which represents an improvement in soil health.

Table 26.11. Maize yields after different rotation treatments in the Ottosdal area, 2019 season. Authors' own table.

Previous crop	Maize yield 2019 (t ha^{-1})	Gross margin (ZAR/ha)
Vigna unguiculata	2.7	6850
Sorghum bicolor (fodder type)	2.3	5800
Sorghum bicolor (grain type)	2.0	4875
Zea mays	1.6	4025
Glycine max	2.6	6475
Helianthus annuus	2.5	6275
Livestock integration	4.7	11,750
Green fallow	3.0	7500

26.4.5 Livestock Integration Trial

The Haney SHT results revealed that after employing only NT under cash crops (maize and sunflower) for 6 years, soils still had a low SOM content of 1.0%–1.2%. The PLFA results under these treatments (Table 26.12) showed a poor total microbial biomass and the absence of soil microbial predators such as protozoa and nematodes. This illustrates that NT with simple rotations cannot reverse the effects of decades of tillage and high levels of agrochemical use, such as insecticides and inorganic fertilizer. However, using CC and livestock did have a clear effect on soil health. Key indicators such as the total microbial biomass, the predator to prey relationships and the fungi to bacteria ratio increased sharply.

Livestock grazed half of the crop biomass available in the treatment thus allowing the diverse sward to regrow. There were 100 cows with calves grazing 3 ha over a 3-day period. The livestock added a considerable amount of manure, estimated at 800 kg ha^{-1}, which contains more humic substances than plant residue on its own. Dung beetles and saprophytic fungi fed on this nutrient-rich matter and helped to recycle elements into the soil.

By utilizing CC for grazing in this manner, the CC clearly stimulated soil ecosystem functions and services. The mulch left on the surface decayed, releasing plant-accessible nutrients back to the soil to be used by subsequent crops. Much lower amounts of agrochemicals (e.g. 2 l ha^{-1} Roundup® before planting) were applied, which allowed the soil to improve, with microorganisms

Table 26.12. Some key soil biological parameters from the phospholipid fatty acid (PLFA) analyses done before (2017) and after (2018) cover crops and grazing were implemented. Authors' own table.

Parameters	PLFA results (2017)	PLFA results (2018)
Total microbial population (ng/g)	552 (poor)	4730 (beyond excellent)
Fungi : bacteria	0.2207 (average)	0.36 (beyond excellent)
Gram (+) : Gram (–)	2.97 (slightly gram (+) dominated)	1.25 (balanced bacterial community)
Predator:prey	0.0 (all prey)	0.0037 (good)

breaking down unwanted chemical substances much more easily.

The most nutritional leaves and seed heads were consumed by animals whereas most of the more fibrous stems were trampled into the soil. This created a mulching effect that covered the soil surface completely. Meat production was 215 kg ha^{-1} with a feed conversion ratio of 10.7:1. A total of 11.4 tons of meat was produced on 55 ha in 69 days. Table 26.13 gives a breakdown of the biomass that was produced by the cover crop. Between days 55 and 69, livestock grazed on regrowth and was sold at an auction.

Weight increase of 100 kg per cow and 64 kg per calf was achieved over a grazing period of 69 grazing days, realizing a gross income of ZAR4308 per cow/calf combination and a net margin of ZAR6128 ha^{-1} (US$486 ha^{-1}).

The farmers also had some Haney SHT analyses done, which revealed high values of organically bonded N, P and K nutrients with higher SOM levels (Table 26.14).

The Haney SHT index increased from 7.4 to 12.5 from pure NT treatments (maize and sunflower rotation) to the treatment with cover crops and livestock integration (where scores above 7 are considered good). Retaining 9 t ha^{-1} crop residues on the soil surface had a positive impact on the soil water balance by increasing the residential time of rain at the soil surface, but posed potential problems of planting maize into a thick mulch (Fig. 26.3). A disc NT planter was used, instead of tines, and resulted (as reported by the farmer) in a lower fuel use and a higher planting speed.

26.5 Conclusions

Following a farmer-centred IS approach, it guided and supported the project team to implement a number of proven tools assisting with the research, development and adaptation of CA systems within a commercial farming context of the Ottosdal area. On-farm experimentation and specific, collaboratively managed trials were used extensively and successfully to investigate specific research questions raised by the local farmers.

The yield of maize was significantly higher under high-density (i.e. narrower row width and higher plant population) NT systems (i.e. the so-called Argentinean system) compared to the normal NT systems in the Ottosdal area. The yield of maize in local conventional systems was lower than the yield in NT systems tested on three farmer-managed trials in the Ottosdal area.

A screening trial played a significant role to test and learn the suitability and the different attributes of a range of CC in that area, such as their ability to fix nitrogen, the role of a fibrous root system, bio-fumigation abilities, mulching ability and the general growth habits of the crops and mixtures. The trial also served as an excellent demonstration and awareness tool at annual field visits and conferences.

Using a CC mixture as a green fallow system showed that CA can facilitate the successful recovery of some critical soil ecosystem functions and the restoration of degraded soils in a fairly short period. This process requires a quality implementation and adaptation of CA practices such as crop diversity and – more specifically – multi-species CC systems and the integration of animals. It also requires an emphasis on soil health and a long-term vision of soil restoration, especially under dry and sandy soil conditions.

Table 26.13. Biomass (dry matter, DM) breakdown of integration trial at Humanskraal, 2018. Authors' own table.

	Biomass (t ha^{-1})
Available DM before grazing	13.1
Animal intake (3% DM of body mass)	2.0
DM left after grazing	9.3
Unaccounted DM	1.8

Table 26.14. Some Haney soil health test (SHT) results with and without cover crops + livestock. Authors' own table.

	No cover crops	Cover crops + livestock
Available nutrients (kg ha^{-1})	N = 42.8 P = 52 K = 303	N = 75 P = 118 K = 410
SOM (%)	1.01	1.51
Soil respiration (Solvita®)(CO_2 - C, ppm C)	45.9	94.1
Soil health index score	7.4	12.5

Fig. 26.3. Crop residues after a 3-day grazing period. Authors' own figure.

The benefits of a green fallow, multi-species CC system in soil restoration were multiple: fixing nitrogen, scavenging leftover nitrogen in the soil, biomass produced above ground, benefits of deep-root systems, diversity of plant roots that created an underground habitat for diverse soil microbial communities and a healthy soil food web, weed control and attraction of beneficial insects. Exponential synergy was created, with an increasing number of species resulting in an acceleration of biological time and function in nutrient cycling.

The benefit of CC diversity in mixtures manifested very clearly in a drought situation. While monocultures struggled, six to eight species mixtures flourished in dry periods. Using mixtures that included both warm and cool-season plants, and both grasses and broadleaf plants, was ideal. Having two or three representative species from each group would be ideal, but there is a practical side to consider. Seed availability, cost, seeding methods, ability to terminate the plants and other factors determined how many species were used. Some studies suggest that six to eight species from three of the groups would suffice.

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27 Conservation Agriculture for Climate Smart Agriculture in Smallholder Farming Systems in Kenya

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Abstract

Climate change is any significant change in climatic conditions. Such changes may negatively affect productivity of the rain-fed agriculture practised by over 75% of the smallholder Kenyan farmers. The effect leads to failure to sustainably provide adequate food and revenue to famers. It is on this basis that an almost 8-year field study was conducted to evaluate and scale climate resilient agricultural technological options associated with Conservation Agriculture (CA) systems and practices (no-till; maintenance of permanent soil cover; and crop diversification – rotations and associations), complemented with good agricultural strategies. The activities involved were targeted to sustainably increase productivity of maize–legumes farming systems while reducing environmental risks. The results showed improved soil properties (physical, chemical and health) and consequently increased crop yields and human nutrition by over 30%. Such benefits were attributed to cost savings arising from NT and reduced labour requirement for weed control. This was further based on enhanced crop soil moisture and nutrients availability and use efficiency leading to over 25% yield increase advantage. Apart from the field trials, the study used the Agricultural Production Simulator (APSIM) computer model to simulate CA scenario with the aim of providing potential quick answers to adopting CA practices for farm system productivity. The results were inclusively shared, leading to over 21% increase in the number of farmers adopting the CA practices within and beyond the project sites. The study's overall recommendation affirmed the need to integrate the CA practices into Kenyan farming systems for sustainable agricultural livelihoods and economic opportunities.

Keywords: Sustainable intensification, soil health, bulk density, acid soils, water use efficiency, weed control

27.1 Introduction

Climate change is a significant change in climatic conditions such as temperatures, precipitation and wind patterns at a given location over time, and is a global impediment to sustainable agricultural development (UNFCCC, 2007). Kenyan agriculture is predominantly rain-fed and manned by over 75% smallholder farmers (World Bank, 2018). In the face of the growing diverse needs of the human population, sustainable intensification needs to be embraced by individuals/institutions and projects whose operationalization objectives are anchored on crop productivity and environmental protection. In particular, farmers ought to benefit from

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a sustainable intensification framework through adoption of climate smart agricultural (CSA) procedures so as to transform agricultural systems for greater efficiency while ensuring sustainable food security in the changing climatic situation options (UNDP, 2016). The CSA approaches make use of conservation agriculture (CA) principles to address sustainability of increasing agricultural productivity through adaptation and mitigation of climate change (Wall *et al*., 2013). As narrated by Dixon *et al*. (2019), there is a need to sustainably produce food while protecting the environment. This is possible through validation and adoption of strategies that mainstream CA procedures within the existing and future agricultural programmes and activities.

27.2 Conservation Agriculture (CA)

According to Wall *et al*. (2013), CA is a farming system that sustainably conserves and makes more efficient use of the locally available resources. The underlying principles of CA are minimum soil disturbance, permanent soil surface cover and crop diversification (rotations and intercrops). The benefits of CA accrue in both the short and long term (Giller *et al*., 2011). The immediate benefits include soil moisture conservation, soil organic matter capitalization and nutrient recycling for increased crop yields (Vanlauwe *et al*., 2014). Successful application of CA principles, therefore requires, a change in production systems and use of additional sustainable intensification practice that embraces appropriate varieties, seeds, fertilizers and weed-control strategies (FAO, 2018).

27.2.1 Conservation Agriculture (CA)–Sustainable Intensification (SI)

CA-sustainable intensification (CASI) uses CA principles combined with optimal use of complementary agro-inputs and agronomic practices (Dixon *et al*., 2019). The process prevents land degradation, contributes to higher and more stable yields, and reduces production costs while enhancing the resilience of smallholder farming systems to climate change (Thierfelder *et al*., 2018) and see Fig. 27.1.

CASI procedures were employed in the project Sustainable Intensification of Maize–Legume Cropping Systems for Food Security in Eastern and Southern Africa (SIMLESA). The project was conducted for 9 years (2010–2018) with sites in Ethiopia, Kenya, Malawi, Mozambique and Tanzania, and also with spillover effects in Rwanda and Uganda (ASARECA, 2019). The main objective of the project was to sustainably increase food security and income to smallholder farmers in eastern and southern Africa. On the basis of CASI procedures, the project

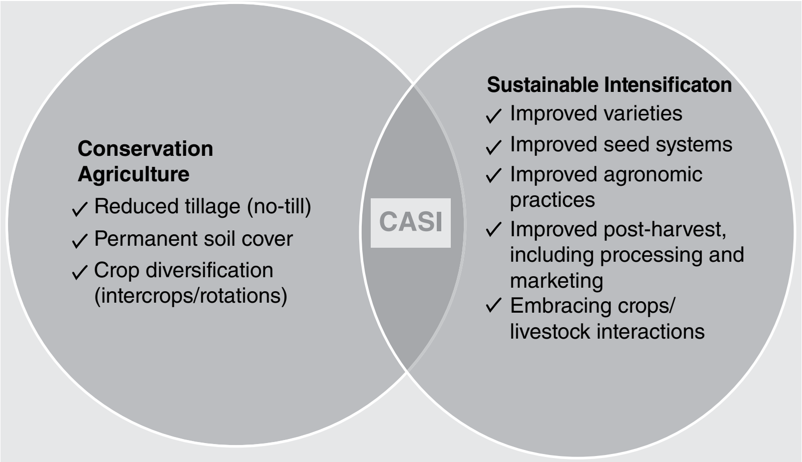

Fig. 27.1. Conservation Agriculture-based sustainable intensification (From Dixon *et al*., 2019).

tested and scaled different maize (*Zea mays*) and legume species/varieties and their associated production practices. In Kenya, the project worked with plant breeders and seed companies to obtain high-yielding and pre-released maize and legume varieties. The project's implementation framework focused on gender mainstreaming. This led to an increase in the number of men and women participating in the activities, and therefore owning the processes and benefits therein (Nkonge *et al*., 2019). Additionally, wider adoption of CASI technologies and practices was possible through engaging government and private institutions in scaling the SIMLESA project's endorsed knowledge (ASARECA, 2019). Due to the need to sustainably produce food while protecting the environment, the project recommended strategies to mainstream CASI procedures within and beyond the initial target sites (Dixon *et al*., 2018).

27.2.2 Improving Soil Productivity With CASI Practices

Soil bulk density reduction

Soil bulk density (BD) is an indicator of the degree of soil compaction (Hakansson and Lipiec, 2000). The BD affects infiltration, rooting depth, available water holding capacity, soil porosity and aeration. The parameter is calculated as a ratio of dry weight of the soil to its volume, and expressed in kg m^{-3}. High BD can be ameliorated through the avoidance of soil compaction and the addition of organic matter in the soil. To confirm this, the SIMLESA project investigated the effect of adapting conventional tillage (CT) and CA practices on soil porosity in humic Nitisols of eastern Kenya. The site had been continuously tilled with heavy farm machinery for over 50 years. Additionally, the farmland had continuously been cropped with maize with no residue retention on the soil surface. The soil initial characterization defined the site soil texture as clay–loam because of its richness in clay (60%), sand (20%) and silt (20%), and it had a BD of 1.3 kg m^{-3} within a depth of 0–30 cm.

The experiments tested: (i) different tillage methods (Conventional tillage (CT), no-till (NT) and furrows–ridges); (ii) two rates of crop residue retention (0 and 3 t ha^{-1}); and (iii) three cropping systems (sole maize, sole bean and maize/bean intercrop). After 4 years of experimentation, the BD did not change under CT, but reduced to 0.9 kg m^{-3} with furrows–ridges and 1.1 kg m^{-3} in NT (Micheni, 2015). Reduction of the BD under furrows–ridges and NT was manifested with residue retention, potentially due to soil moisture conservation, soil organic matter build-up and enhanced soil porosity. The study concluded that adherence to CA is one of the CSA approaches to increase soil productivity for soil microbes and crop root development benefits.

Soil health

Soil health is the capacity of a soil pool to function as a vital living ecosystem to sustainably support plants, animals and human reproduction and activities, while maintaining the soil nutrients, water and air quality (Bunemann *et al*., 2018). Improving SOM using CA practices is the key to the maintenance of healthy farmland for farmers advocating for CSA (Wayne *et al*., 2017). Under CA farming systems, the soil-retained plant material decomposes, improving SOM and soil microbes (Njeru *et al*., 2012). Soil fauna play important roles in soil aggregation, carbon sequestration, nutrient and water use efficiencies (Paul *et al*., 2015). It is with this background that a study was conducted in eastern Kenya to investigate the effect of bacteria, fungi and nematode populations in maize–bean cropping systems as influenced by the CA and CT regimes. This was a four-season study involving two CA practices (NT and furrows–ridges) and CT, two crop residue management methods (removal or retention) and three cropping systems (sole maize, sole bean and maize/bean intercrop).

The study observed increased fungi colony-forming units (CFU) and nematode populations in the CA-based treatments. Interaction in maize–bean cropping systems and CA resulted in higher fungi CFU and nematode population counts (Table 27.1). Significantly higher macrofauna richness was observed under maize/bean intercrop compared to sole bean or sole maize. The study also found higher macrofauna taxonomic richness and abundance of mesofauna in the CA-based treatments than under CT without residues on the soil surface. This led to the conclusion that retaining crop residues on the farmland,

Table 27.1. Effect of tillage methods, cropping systems and residue retention on bacteria, fungi and nematode populations in humic Nitisols of eastern Kenya.

Main factor	Treatment	Bacteria (CFU × 10^6)	Fungi (CFU × 10^6)	Nematode count (g^{-1} soil)
Tillage method	Conventional tillage	261.44^{a}	23.50^{b}	139.47^{ab}
	CA-no-till	248.28^{a}	33.25^{ab}	90.43^{b}
	CA-furrows–ridges	242.03^{a}	50.44^{a}	150.89^{a}
Cropping system	Maize–bean intercrop	254.44^{a}	39.36^{a}	170.56^{a}
	Sole maize	253.75^{a}	36.89^{a}	128.42^{ab}
	Sole bean	243.56^{a}	30.94^{a}	81.57^{b}
Residue	Retained	253.44^{a}	35.35^{a}	155.57^{a}
	Removed	247.72^{a}	36.11^{a}	98.43^{b}

Means with the same letter in the same column are not significantly different ($p \leq 0.05$). CA, Conservation Agriculture; CFU, colony-forming unit. From Micheni, 2015.

coupled with single crop or multiple cropping, are appropriate CSA approaches to improving soil productivity for soil fauna reproduction and activities, thus healthy soils, as described by Ayuke *et al.* (2019).

Management of acid soils

Acidic soils are developed from parent materials of acid origin (Kisinyo *et al.*, 2014). Such soils have a pH of less than 5.6 resulting from high numbers of aluminium ions (above 2 cmol Al^{3+} kg^{-1}) and are low in available phosphorus (≤ 5 mg P kg^{-1} soil) (Kisinyo *et al.*, 2014). Such soils cover about 13% (7.5 million ha) of Kenyan agricultural land (Kanyanjua *et al.*, 2002). This problem is aggravated by continuous cropping, application of acidifying fertilizers and removal of SOM through biomass and grain harvest (Kanyanjua *et al.*, 2002). Soil acidity in Kenyan farms is partially responsible for low (less than 1.5 t ha^{-1}) maize crop yields compared to a potential yield of above 5.0 t ha^{-1} (Obura *et al.*, 2010). Opala *et al.* (2014) notes adoption of CA practices and application of appropriate inorganic and organic fertilizers, water harvesting and liming greatly amending the soil pH. The latter was achieved by applying agricultural lime containing calcium or magnesium compounds. The liming material increases Ca^{2+} and Mg^{2+} ions and reduces aluminium (Al^{3+}), hydrogen (H^+), manganese (Mn^{4+}) and iron (Fe^{3+}) ions in the soil solution (Kisinyo *et al.*, 2014). In the SIMLESA project (Micheni, 2015), a study was conducted to investigate the effect of liming acid soils on the status of soil properties. The study's main activities included site characterization and calibration of the soil lime requirement that may be needed to raise the pH from 4.8 to 5.6 under CA farming practices. The first activity was to incubate lime samples for 7 days in the laboratory, followed by calibrating the amount of lime required for the soil at the experimental site. The result gave 4.7 t lime ha^{-1} as the most appropriate option. The activity was followed by field liming trials where adequate lime material was weighed and uniformly spread and incorporated into a depth of 0–15 cm dry soil. The trials were based on NT practice where approximately 75% of the crop residues were retained on the soil surface. The plots were planted with maize and assessments made on the effect of liming on soil properties.

Results indicated reduction in soil Al^{3+} and H^+ ions and increases in Ca^{2+}, Mg^{2+} and Na^+ ions under CA–NT for maize production where the pH increased from 4.8 to 5.1 (Table 27.2). As described by Kisinyo *et al.* (2014), liming material contains basic cations and basic anions capable of neutralizing H^+ from exchange sites to form $H_2O + CO_2$. The observed changes may have resulted from the liming material neutralizing excess H^+ and Al^{3+} ions that were consequently replaced by Ca^{2+} or Mg^{2+} ions on the soil exchange sites. The exchangeable phosphorus ions concentration increased from 4.0 to 14.3 mg kg^{-1}. This was potentially attributable to enhanced phosphorus availability and due to the effect of liming. This could also have happened due to availability of residual *ex situ* P applied to the test crop. The study concluded that apart from implementing CA tillage practices, the low pH soils are made more productive through liming using appropriate liming materials.

Table 27.2. Effect of liming on soil properties after four maize–bean cropping seasons in an eastern Kenya site (from Micheni, 2015).

Soil property	Before liming	After liming	Effective change
pH (1:3 soil:water)	4.76	5.08	+ 0.32
Exchangeable acidity (cmol kg^{-1})	3.89	3.00	– 0.89
Exchangeable hydrogen (cmol kg^{-1})	0.50	0.44	– 0.06
Exchangeable aluminium (cmol kg^{-1})	1.12	1.11	– 0.01
Exchangeable calcium (cmol kg^{-1})	2.03	2.12	+ 0.09
Exchangeable potassium (cmol kg^{-1})	78.01	78.00	– 0.01
Exchangeable magnesium (cmol kg^{-1})	3.83	3.88	+ 0.05
Exchangeable sodium (cmol kg^{-1})	0.17	0.22	+ 0.05
Exchangeable iron (mg kg^{-1})	24.40	24.9	+ 0.50
Exchangeable phosphorus (mg kg^{-1})	4.00	14.27	+ 10.27

27.2.3 Effect on CASI in Semi-arid Cropping

Climate change and its variability is emerging as a major challenge to global food production. Adaptation of the agricultural cropping systems to climate change using CSA is one of the key measures to improve agricultural system productivity (Akinnagbe and Irohibe, 2014). Climate smart agriculture embraces tillage practices such as NT, tied-ridges and zai pits. NT with direct seeding is a cropping system with a maximum 25% of soil disturbance, only placing seed and fertilizer in the upper soil layers. Over 75% of residues are retained on the soil surface. Zai pits are small and circular, measuring 30 cm wide, 20 cm deep and spaced at 60 cm apart. They combine water harvesting and conservation for crop use, particularly during dry spells (Danjuma and Mohammed, 2015). According to Eden *et al.* (2017), CSA has the ability to alleviate soil moisture problems and to increase crop yields in drought-prone areas. On this basis, a 4-year field study (2016–2019) investigated the effect of CSA practices on yields of green gram *(Vigna radiata var.* N26*)* in semi-arid areas of Embu and Tharaka-Nithi Counties, eastern Kenya. The trials were laid out in a randomized complete block design. Crop residues were retained on zai pits and NT, but removed from the CT methods. This resulted in higher average grain yields from zai pits. This was attributed to the presence of residues on the soil surface that conserved extra moisture for crop use during dry spells. Although residues were present, NT did not show appreciable yield benefits as compared to yields obtained from CT. This was possibly due to the use of undecomposed residues and to the reliance on short- rather than long-duration of CA application benefits. Indeed, as reported by Wall *et al.* (2013), positive effects of residues are realized in the long term (≥ 10 seasons) rather than in short periods. The study recommended further testing for scaling different CASI approaches in varying soil types, crop species and farming systems in semi-arid environments.

27.2.4 CASI on Maize–Legume-based Cropping Systems

As part of the SIMLESA activities (Nkonge *et al.*, 2019), studies were conducted in four sites in humid areas of eastern Kenya to evaluate the benefits of CA and CT practices on crop yields, water use efficiency (WUE) and economic benefits. Three treatments (CT with residue removed, NT with residue retention, and furrows–ridges with residue retention) were tested under a maize–bean intercropping system. Maize (*var.* DK 8031) and beans (*var.* Mwende) were the test crops and grown as an intercrop. The maize crop was provided at sowing with 60 kg N and 60 P_2O_5 ha^{-1}, while the beans were supplied with 20 kg N and 20 P_2O_5 ha^{-1} from 23:23:0 fertilizer materials. Data sets collected included rainfall, crop biophysical performance and economic variables.

Crop yields

Results from the trials over four consecutive seasons found that the CA treatments significantly improved maize and bean yields as compared to the yields harvested from the CT plots. However, the NT did not yield significantly more than CT in the first season of experimentation. This was attributed to the lack of crop residue cover at the start of the experiment. There were appreciable yield advantages observed during the second season. Residue benefits during the first season could have been achieved through *ex situ* harvesting and using plant materials from outside the farm.

Labour productivity

Labour requirements for ploughing/harrowing and weeding remained significantly high (US$88 ha^{-1} season^{-1}) for CT as compared to US$24 ha^{-1} season^{-1} for CA practices, whose labour requirements had considerably declined. Preparation of furrows–ridges attracted more person-days ha^{-1} (US$50 ha^{-1} season^{-1}) at the initial stage of experimentation. However, with minimal repairs and maintenance of the furrows and ridges in subsequent seasons, this declined to USD$13 ha^{-1} season^{-1}. The fewer labour requirements under CA practices implied that more labour may be released for off-farm income-generating activities. Thus, the exhibited combined high yields and reduced labour costs meant that shifting from CT to CA practices would be a major step in making farming a productive enterprise in Kenya (Micheni *et al*., 2015).

Crop water use efficiency

In the early seasons of the experiment, the CT farming methods recorded higher WUE compared with CASI practices that provided higher WUE and yield advantage ranging 25%–34% after four cropping seasons. For example, the furrows–ridges treatment gave higher WUE values of 6.8 kg mm^{-1} compared with 5.5 kg mm^{-1} under CT during the fourth season of experimentation. The results corroborated well with an earlier study (Micheni, 2015) that indicated higher soil water and crop yield benefits from raised beds coupled with residue retention in CA intensification systems. The higher WUE values were attributed to the effects of water harvesting and residue retention on furrows–ridges than on the other tillage practices that were characterized by flat surfaces or under CT farming practices.

Weed control

Weed competition with the crops for growth resources is singled out as one of the challenges faced by smallholder farmers (Mashingaidze *et al*., 2012). Over 80% of Kenyan farmers control weeds conventionally using hand hoes and end up spending more on such operations (Muoni *et al*., 2013). According to Thierfelder and Wall (2012), conventional weeding practices often lead to poor soil porosity and nutrient loss through erosion. Use of herbicides is therefore encouraged for weeding to alleviate weed challenges. On this basis, field trials were conducted for four seasons in eastern Kenya within the SIMLESA project (see Section 27.2.1, this chapter) to evaluate the effect of conventional and herbicide weed control methods in maize cropping systems. The treatments were the unweeded control, the conventional weeding method and three rates of glyphosate-based herbicide sprays. The results reported 0%, 75% and 85% weed suppression under the unweeded, conventional weeding and NT CA practice, respectively (Table 27.3). The herbicides effectively controlled both grasses and broad-leaved weeds, increased maize yields and net benefits as compared to either unweeded or conventionally weeded treatments. The increased net benefits in NT resulted from reduced labour costs on land preparation and weeding operations. In addition, the herbicides did not cause phytotoxicity on the target maize crop. The study therefore recommended use of herbicide products as a worthwhile climate smart strategy for easing off labour bottlenecks experienced by maize farmers in Kenya.

Computer model simulations

Variable rainfall patterns, nutrients and moisture stress, pests and diseases and unimproved genotypes are some of the challenges faced by smallholder farmers in Sub-Saharan Africa (SSA) (Bouma and Jones, 2001). The ability to overcome these challenges depends largely on

Table 27.3. Effect of glyphosate-based herbicide weed control on maize yields in eastern Kenya.

Weed control method	Herbicide rate (l ha^{-1})	Maize yield (t ha^{-1}) Biomass	Maize yield (t ha^{-1}) Grain
Roundup® WeatherMAX	3.0	9.20^{a}	4.30^{ab}
Roundup® WeatherMAX	2.5	9.52^{a}	4.02^{ab}
Roundup® WeatherMAX	1.5	8.50^{ab}	4.51^{a}
Roundup® Turbo	2.5	8.60^{ab}	4.42^{ab}
Unweeded control	Not applicable	1.00^{c}	0.11^{c}
Conventional method	Not applicable	7.01^{b}	3.61^{b}
Mean	–	7.31	3.52
LSD (0.05)	–	1.901	0.911
CV (%)	–	16.30	22.51

Means in the same column with the same letter are not significantly different ($p \leq 0.05$). CV, coefficient of variation; LSD, least significant difference. From Micheni, 2015.

the existing cost-effective capacity to support farm-level decision making (Cox *et al.*, 2010). The complex interaction of soil, climatic, biophysical and socio-economic factors may be eased by using computer simulations (Meinke *et al.*, 2001). Indeed, computer models are reported to aid researchers in generating sustainable information for diverse farming systems through answering fundamental questions on rainfall variability and cropping systems (Keating *et al.*, 2003). The models are capable of providing accurate predictions on critical climate change adaptation and mitigation cases within the CA integration systems (Yang *et al.*, 2018). Because of their capability to simulate ecological and socio-biophysical processes to better define climate change-related risk reduction factors, agricultural production systems simulator (APSIM) is an example of such models (Dias *et al.*, 2019).

APPLICATION OF APSIM COMPUTER MODEL. The APSIM modelling framework has functional modules, which include a range of crops/cultivars, soil processes and farm management aspects (APSRU, 2008). The model has a system control module that allows the user to specify the intended cultivar, field management and the type of soil input(s) in the model engine system that controls communication between independent modules and the user (McCown *et al.*, 1996). APSIM outputs can significantly reduce production losses caused by rainfall variability or the effect of climate change. For example, APSIM prediction for Australia's wheat industry for the year 2070 through crop simulation showed benefits worth US$50 million a year from changing varieties and planting dates (Yunasa *et al.*, 2004). While there has been extensive testing and use of models elsewhere in the world, not much effort is reported in Kenyan farming systems. It is on this basis that the SIMLESA project (see Section 27.2.1, this chapter) invested in building capacity for APSIM model application in maize–legume cropping systems in eastern and western Kenya.

The model was, therefore, applied in a field study conducted in eastern Kenya where soil, crop variety/cultivar, field operations and climate data sets were used to run the model in relation to the real field situations. The model setting had the initial soil water (ISW) content set at the lower limit (LL) or equivalent to zero plant available water (PAW = 0 mm) and initial available nitrogen (mineral-N) at 10 kg N ha^{-1} (7 kg nitrate-NO_3^- and 3 kg ammonia-NH_4^+ ha^{-1}). The soil water-holding capacity (PAWC) was set at 50 mm and run-off curve value at 70 to reflect higher moisture capture in the model engine. The soil water evaporation coefficients were set at 3 mm and 6 mm day^{-1} for the first and second stages of evaporation, respectively. The model was made to provide simulations for the four seasons (2011–2013) when, in reality, the two crops were grown and simulated on the basis of sole maize, sole bean and maize–bean intercrops. To make comparisons between the field observations and the model simulations, the approach assumed that the residual soil moisture and nutrient balances were simulated with potential cumulative effects on crop growth in the subsequent seasons.

Results showed comparable outputs for measured and APSIM-predicted maize grain yields (Fig. 27.2). This was apparent under sole maize under CT practice across the four seasons of experimentation. However, the model underpredicted maize yields when intercropped with bean in both CT and CA (no-till) treatments. This was observed in only one of the four seasons in

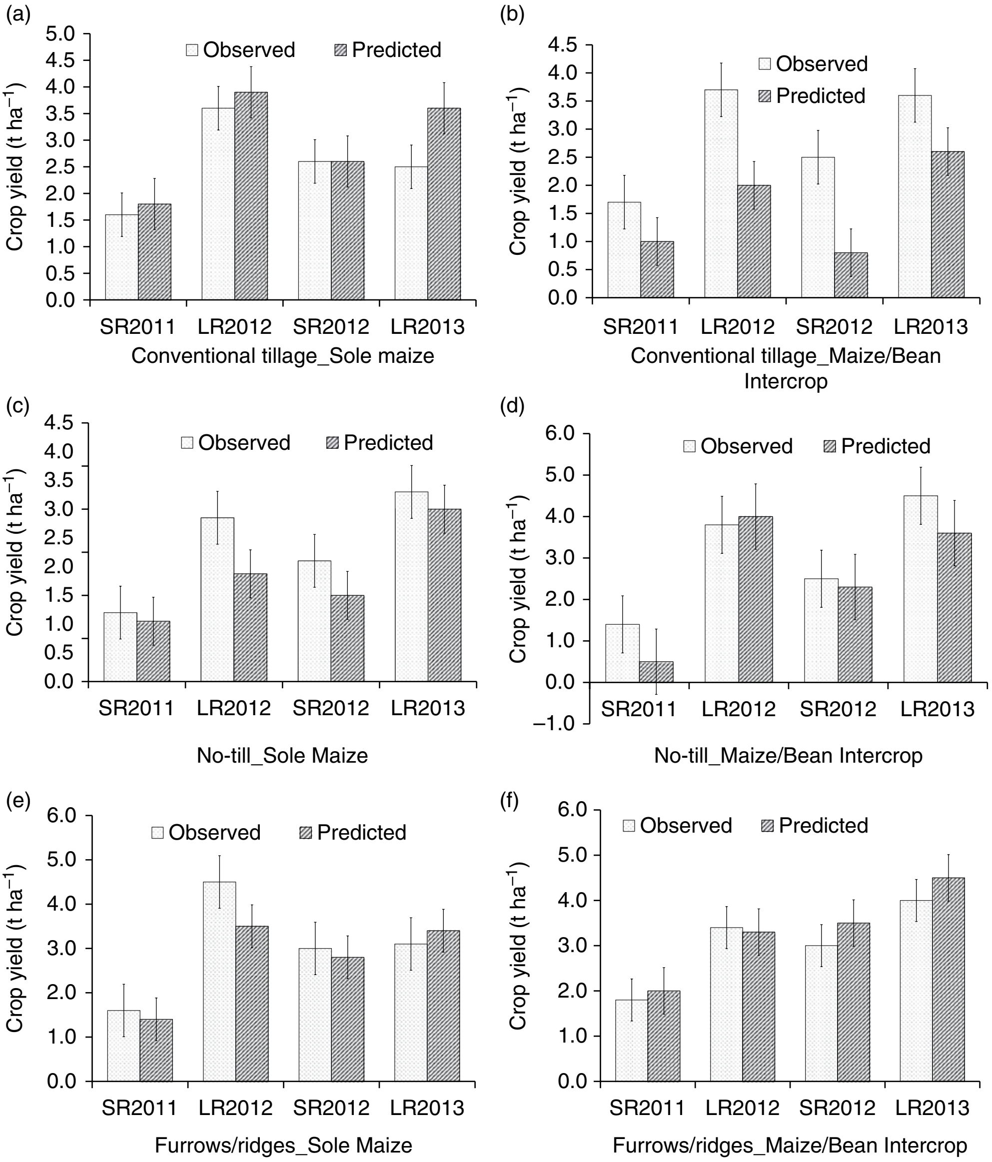

Fig. 27.2. Observed and agricultural production simulator computer model- (APSIM) simulated grain yield of maize grown as sole crop or intercropped with beans under conventional tillage (a and b), no-till (c and d) and furrows–ridges (e and f) tillage methods at the Kenya Agricultural and Livestock Research Organization in Embu, Kenya during 2011, 2012 and 2013 short rains (SR) and long rains (LR).

the case of the furrows–ridges. The yield underprediction may have been caused by one of two factors: (i) due to expected N-immobilization resulting from application of undecomposed residues (Grahmann *et al*., 2013), when most of the soil mineral nitrogen (NO_3^- and NH_4^+) may have been utilized by soil microbes to break down/mineralize the residues; or (ii) intercropping with bean where the model perceived the bean crop to out-compete maize for growth resources. In the real field situations, maize grain yields were not significantly affected by the bean crop in the intercropping arrangements. Similarly, a high degree of accuracy was witnessed from APSIM model simulations and field observations for crop productivity under the CA intensification systems in western Kenya (Achieng *et al*., 2011). The observations led to a conclusion that computer models are appropriate tools for predicting crop yield performance under CT and CA crop intensification systems.

27.2.5 Scaling CASI in the SIMLESA Project

At the beginning of the SIMLESA-Kenya project (see Section 27.2.1, this chapter), studies were conducted in specific sites to characterize production systems for maize–legume input and output value chains. The project used different approaches to validate and expose CASI practices to farmers within and beyond the project sites. The approaches included hosting participatory on-farm mega-demonstration plots, field days and farmers' tours, and managing farmer groups and agricultural innovation platforms that also doubled as co-project implementers. The CASI community-endorsed options were further scaled through linking farmers' platforms to seed companies, agro-dealers, input/output marketers, credits, financial institutions and media houses, among other service providers. In all cases, the effort focused on key stakeholders' capacity building on appropriate farm enterprise selection, diversification and integration of the various technologies towards transformed and cost-effective CASI-based outputs. As a result, greater linkages and formation or strengthening of the existing innovation platforms were realized. Adherence to technological options that reduce labour costs were the key drivers for increased farmer participation in CASI practices in Kenya (Nkonge *et al*., 2019). The project witnessed increased adoption of combinations of CASI practices and crop diversification. For example, the area allocated for maize–legume diversification increased up to 21% during the period 2010–2018 of the project life. The percentage increase grew gradually since the project was initiated. Of the three CA principles and associated CASI practices, farmers did not adopt everything at once, but sequentially. For example, farmers adopted NT at early stages, and residue retention principles at other times of the project implementation period. Apart from the cost-benefits (labour saving) considerations, the CASI practice taken by farmers depended on the gender and the various CASI combinations available at farm level. The study recommended continued and long-term efforts in investments in demonstrations and institutionalizing CASI practices through diversification of adoption pathway strategies at both county and national government levels for sustained adoption.

27.3 Conclusions

Kenyan farmers are facing growing stress from climate change. This calls for enhanced implementation of diversified agricultural systems towards building sustainable resilience into agricultural systems. The challenges to increasing adoption of diversified agricultural management strategies are mainly biophysical and require enhancement, and adoption of diversified agricultural systems to maximize production and profits per unit resource (farmland, time and labour/inputs). With this in mind, the SIMLESA project conducted farmer-oriented, participatory and exploratory field trials with the aim of testing and scaling maize and legume species/varieties using CASI practices for improved food and income security and resilience to climate change at farm level. By utilizing CASI procedures, the project was able to identify and enhance activities and procedures capable of increasing soil and crop productivity in the Kenyan farming systems. The project reported higher benefits to the farmer and to the environment from adherence to the three CA principles (permanent soil organic cover, minimum mechanical soil disturbance and species diversification) coupled with the right inputs and good agronomic practices. The most important driver for acceptance of CASI practices by farmers is a saving on labour for land preparation and weed control. The study noted that the crop/farm system computer model simulations can help farmers define strategies for maintaining optimal farm production and profits. Effectively integrating CASI practices into Kenyan farming systems will, therefore, lay a firm foundation for sustainable agricultural development, improved livelihoods and economic opportunities.

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28 Conservation Agriculture for Smallholder Farmers in Rainfed and Irrigated Systems in the Eastern Indo-Gangetic Plain: Lessons Learned

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Abstract

Conservation Agriculture (CA), which delivers multiple benefits for crop cultivation, is becoming increasingly popular worldwide. However, CA is not a single, ready-made or simple technology that can be adopted everywhere without necessary farm-level refinement. The CA practitioners may need to incorporate changes in practices and each needs a few years of experience to fully learn how to optimize the technology on a particular crop on each farm. Implementation of CA is challenging in resource-limited, intensively cropped and rice-based smallholder farms. This chapter is a reflection on lessons learned during the last two decades of research, farmers' adoption and service providers' (LSP) feedback on CA practice in rainfed and irrigated systems where farmers grow three crops per year including at least one transplanted rice crop. We review smallholder farmers and LSP affordable and preferred CA planters, and the performance of CA in crop establishment and management, weed management, role and involvement of farmers' groups, farm level benefits, rice and upland crops. Case studies are also presented on the benefits of CA practice including resources optimization, long-term trends of crop yield and profit margin, soil organic carbon sequestration and greenhouse gas (GHG) implications. These lessons may be useful for new practitioners, extensionists, researchers, teachers, students and policy planners to implement CA in smallholder regions considering food security, soil health and livelihoods and their contribution to mitigation of global warming.

Keywords: greenhouse gas, long-term experiments, non-puddled rice, VMP, smallholders farm mechanization

28.1 Introduction

Conservation Agriculture (CA) is a knowledge- and management-intensive shift in the way crop production is managed. It requires engagement with land, crops and ecosystem management, as well as the willingness of the practitioners to learn and innovate continuously. The shift of cropping practices from multiple tillage and crop stubble removal operations to minimum soil disturbance, crop stubble retention and diversified cropping is likely to alter the nutrient forms and their availability in soils. The shift also has a bearing on crop responses to fertilizer applications

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and weed dynamics and requires, among others, adjustments of agronomic practices and water management.

Recent (2015/16) estimates put the area of CA globally at 180 million ha of cropland (Kassam *et al.*, 2019). About 70% of the world CA area is located in five countries: Argentina, Australia, Brazil, Canada and the USA, predominantly on large mechanized farms but also on smaller farms. In South America, adoption of CA covers 60% of cropland. In some regions, such as Western Australia (WA), adoption of CA is more than 90% (Rochecouste and Crabtree, 2014). It is increasingly occurring on small farms in Africa and Asia but also in Latin America and Europe, where institutional support is available. In 2015/16, nearly 9% of the global CA area was in Asia, mainly in Kazakhstan, India, Pakistan, China and Iran. In Bangladesh, CA cropland area in 2015/16 was about 1500 ha.

Application of CA has multiple benefits for crop production. These benefits include savings in labour, time, irrigation water and diesel fuel, and in wear and tear of farm implements. The relative value of these benefits varies among farms (e.g. farm type and size and farm power sources), crop species, soil types and agro-climatic zones. For a cash-poor farmer, the reduced cost of crop production could be the major benefit, while for a farmer with adequate farm labour provisions, the labour savings may not be influential on the decision to adopt CA. Reducing the drudgery of farm labour, particularly for the younger generation of farmers, is another incentive for mechanized planting (Baudron *et al.*, 2015). Controlling excessive soil erosion and utilizing the stored soil moisture to establish crops on time were the main drivers to adopt CA in Australia (Thomas *et al.*, 2007). By contrast, in Brazil, government incentives to farmers to reduce sediment loading of water reservoirs accelerated the adoption of CA. As reported by Llewellyn *et al.* (2012), the minimum soil disturbance planting in a single-pass operation, weed control effectiveness and yield benefit for relatively early planting in dry zone areas are the main drivers to adopt CA in WA. Every year Indian farmers burnt about 92 million tonnes of crop residues that led to serious air pollution (Bhuvaneshwari *et al.*, 2019). To reduce residue burning, the Government of India announced subsidies of 50%–70% to farmers for purchasing seed drills that have the capacity to handle planting in minimal soil disturbance conditions with high levels of retained crop residues. This initiative can be attractive to farmers as it minimizes residue burning and increases residue retention in cropland; there is also minimal soil disturbance when planting the next crop, and this ultimately enhances the adoption of CA. In some countries in Africa, governments impose taxes for non-CA planters, whereas farmers are getting up to 90% price support for CA planters. Such types of initiatives could foster the adoption of CA.

Water savings are a key benefit for CA, particularly in rainfed cropping of semi-arid and arid environments. To date, only limited research has been done on the irrigation water savings under CA in the Eastern Gangetic Plain (EGP). This chapter focuses on the development of CA for smallholders in the EGP over the last two decades and on lessons learnt from research, farmers' adoption and service providers' views on CA practice.

28.2 Substantial Time Needed During Learning Period

Every new practitioner of CA should be prepared to allocate time for learning, since CA is a complex set of innovations. In the case of CA for smallholders in the EGP, there are many changes to incorporate and each needs a few years of experience to fully learn how to optimize the technology on a particular crop on each farm. It is more complex than adoption of a new crop variety, where essentially every task in the crop production process remains the same or similar. In contrast, the CA practitioners have to give consideration to optimum soil moisture for seed sowing and basal fertilizer application in rows in a single pass operation by a planter, not by broadcasting these inputs all over the field. The CA practitioner needs to learn more on minimum soil disturbance planting systems using new types of seeders in fields, along with crop residue retention. Weed management practices, therefore, have to be changed, to control weeds before seed sowing. The major barriers to CA adoption are lack of knowledge, pre-judgement about its success, absence of appropriate policy and non-availability of appropriate and farmer-affordable planters (Friedrich and Kassam, 2009; Jat *et al.*, 2014).

The CA concept is based on three principles (as defined by FAO): (i) continuous no- or minimum mechanical soil disturbance with no-till seeding and weeding; (ii) permanent biomass soil cover with stubble, crop biomass or cover crops; and (iii) diversification of crops in rotation and associations involving annual and perennial crops. There is now plenty of evidence in the EGP that adoption of CA practice improves soil health, decreases crop cultivation costs and increases crop profitability (Bell *et al.*, 2019). Nevertheless, CA is not a ready-made singular technology that can be applied directly everywhere. It will need further adapting and fine-tuning research for local situations. The outcomes of CA research and practices could vary depending on soils, climatic conditions, land types, cropping systems and intensities, agronomic management and practices. The three basic elements, along with complementary crop and production management practices, are essential to implement good-quality CA.

The CA practitioner should possess a learning attitude and mind set when optimizing CA for their own farm conditions. In the EGP, it is not only the farmers who need to acquire knowledge about CA practice, it is also the service providers (SPs) who own 2-wheel tractors (2WT) and planters, and are contracted by individual farmers to plant crops on a fee-for-service basis. Currently, these SPs provide their 2WT services for full conventional tillage (CT) operations and other mechanized services (e.g. transportation, irrigation and threshing). Hence, they need to acquire new skills to provide cost-effective CA planting and other services for farmers (e.g. weed control).

Elsewhere in the world, the development of CA has been facilitated by learning alliances involving a network of farmers, machinery suppliers and manufacturers, agribusiness service providers, researchers and agricultural extension agents from public and private sectors (Pieri *et al.*, 2002). These alliances are farmer-led partnerships that thrive on farmer-to-farmer learning. As individual farmers learn how to solve a particular problem, they quickly share that learning through the alliance, often in a practical setting on farms. For more recalcitrant problems, researchers are invited to identify the underlying cause(s) and suggest options that farmers could test and adapt. An example of a farmer-led organization is the West Australian No-Till Farmers Association (WANTFA) which is one of the first of these groups to form in Australia. As a group, they conduct adaptive on-farm research on aspects of CA and carry out strategic R&D within the organization or in partnerships with research providers. They organize regular demonstrations and field days and produce newsletters. Their annual meetings generally feature a keynote international speaker. They organize study tours overseas for members of the organization to widen their knowledge about CA practices for application in Western Australia (WA) and identify new machinery that could be purchased or adapted. In recent years, WANTFA has been involved in controlled field-traffic research and has established long-term field trials that test ideas of the role of residue quantity and quality and furrow opener types (tines versus discs) for seed and fertilizer dispensing on crop performance, water balance and soil properties. While farmer-led groups in Asia and Africa may not have the resources for international travel or exchanges, sharing of ideas from other places is useful to enhance innovation and problem solving. In similar efforts, Bangladesh is supporting the development of the Conservation Agriculture Service Providers Association (CASPA) as a farmer-led network of 178 groups across the country to foster CA; however, it is still in its initial stage of expansion. These groups are developing business ventures to generate funds for the group to pursue their learning goals. Some of the groups are developing collective-action models of working to achieve economies of scale for fertilizer management; mechanization of planting, transplanting and harvesting; and the procurement of machinery for herbicide application, threshing and combine-harvesting operations.

28.3 Conservation Agriculture (CA) is a Continuous Evolution and Improvement Process

28.3.1 Designing No or Minimum Mechanical Soil Disturbance Planters for Conservation Agriculture (CA)

With the increasing shortage of labour in the EGP, mechanized seeding with minimum soil disturbance into standing crop residues is critical for the adoption of CA. A growing range of planters is available for selection (Johansen *et al.*, 2012). There are a number of criteria and challenges that should be addressed by potential planter designers to satisfy the varying demands of the end users. These include: low purchase price; sufficient earning capacity for SP; and flexible set up in the field with capability to be modified quickly for different seed and fertilizer rates, row spacing, seed size and planting depth. Planter durability and reliability in operation, light weight and minimal vibrations are desirable features (Haque *et al.*, 2016a). While 4-wheel tractor (4WT)-based seeders are readily available, they are often too large to manoeuvre in small fields and too expensive for smallholder farmers in the EGP. The rapid adoption and spread of the 2WT for primary tillage that has occurred in many Asian and African countries (Fig. 28.1; Haque *et al.*, 2017) is an opportunity for the spread of new seeders that are suitable for smallholders (Johansen *et al.*, 2012). In addition, a range of hand-held manual planters such as the Li Seeder, Hand/Jab Planter and Star Wheel Planter is available. These hand-held planters are cheap (US$3–100), but have low capacity (25–50 m^{-2} h^{-1}), and mostly suit widely spaced crops such as maize (*Zea mays*) (Araujo *et al.*, 2020).

Since 2004 Bangladesh has led the development of 2WT-based CA planters including a Zero Tillage Planter (Haque *et al.*, 2004), the BARI Strip Drill (Roy *et al.*, 2009), the Versatile Multi-crop Planter (VMP) (Haque *et al.*, 2017) and the Versatile Strip Seed Drill (VSSD) (Haque *et al.*, 2016a). The effective field planting capacity of these 2WT-based planters ranges from 0.07 to 0.11 ha h^{-1} and the ex-factory prices range from US$600–1500. Only a few of the 2WT-driven planters like the VMP have sufficient flexibility or versatility to sow a diverse range of crop species from small-seeded sesame (*Sesamum indicum*) to large-seeded chickpea (*Cicer arietinum*), in either continuous seed dropping mode for crops like wheat (*Triticum aestivum*) or spaced seeding for crops like rice (*Oryza sativa*) and maize in the diversified cropping systems of the EGP plus the ability to deliver seed and fertilizers separately into the soil behind the tines while varying the rates of seed and fertilizers. Seeding depth and row spacing can also be adjusted in VMP while planting by zero tillage, strip planting (SP), single pass shallow tillage, shallow beds and CT[1] modes.

28.3.2 Lands and Soils Suitable for Conservation Agriculture (CA) Practice

Loamy soil textures with 22%–34% soil water content and 20–30-cm high anchored standing residue with low weed burdens on flat fields are

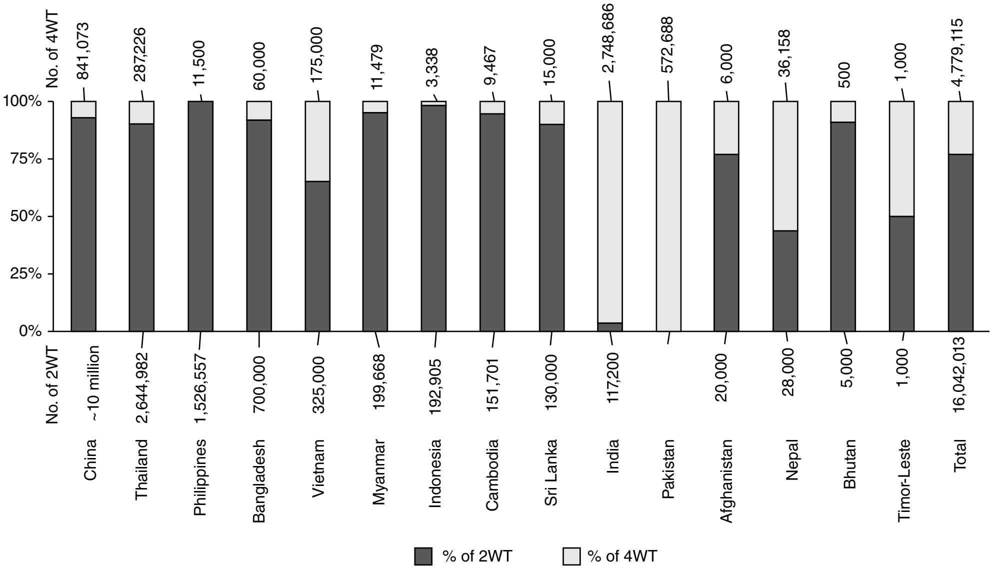

Fig. 28.1. 4-wheel tractor (4WT) and 2-wheel tractor (2WT) numbers in selected Asian countries (Araujo *et al.*, 2020).

the most suitable land to practice CA. In the small farms of the EGP, however, CA has to be an adaptable and reliable technology for a range of soil types; soil water regimes; and stubble types – height and density, weed density and land slope. Poor performance of seeding equipment may result in crop failure and loss of confidence by farmers in the CA approach. Well-levelled land enhances the performance of small farm equipment, and also subsequent irrigation and crop management. Uneven land surfaces can result in poor depth control for seed and fertilizer placement due to the narrow wheelbase and small diameter wheels of the 2WT and seeders. Use of planters with zero tillage tine openers is effective if land is weed free, soil has light texture (sandy) and for low volumes of weathered residue. Double disc-type furrow openers (which may require a heavier tractor and increase the planter cost) may be a good option if the fields have higher amounts of fresh and loose residues. The strip planters operated by 2WT, apart from their low cost and light weight (Haque *et al.*, 2017), perform well in alluvial soils with 2–3 t ha^{-1} of comparatively fresh residue. There are many advantages in the use of rotary-tillage strip planters, but the only demerit of the rotary type seed drill is that it cannot be operated in gravel- and stone-rich soils, which are indeed less common in the EGP. Their experience of using rotary tillage operations to prepare wet soils for rice establishment means that the low-skilled operators in Bangladesh tend to plant with seeders in excessively wet soil, which can lead to excessive smearing of soil around the seeds that hampers subsequent root elongation and crop yield (Paul *et al.*, 2020; Vance *et al.*, 2020). When post-sowing irrigation is planned and facilities are available, seeding in drier than optimal soil moisture could be beneficial, provided the crops are sown at the optimum planting date.

28.3.3 Weed Management

Pre-planting weed control

In the intensive cropping systems (2–3 crops per year) of the EGP, farmers' fields may be relatively weed-free immediately after harvesting of the previous crop. Repeated tillage (3–4 operations in a single field) and ponding of water in the rice fields are common practices to kill pre-planting weeds. By switching to minimum soil disturbance, farmers lose the benefits of tillage as one of the tools for initial weed control. However, recent surveys indicate that, in conventional rice cropping, more than 85% of farmers have now started using herbicides for weed control in Bangladesh (Haque and Bell, 2017). A range of tools are needed for weed control prior to establishment of crops in CA systems. Establishment of the next crop, if done quickly after harvesting the previous crop, increases crop competition to suppress weeds. No-till (NT) SP provides some mechanical control of weeds within the strip. Retained crop residue suppresses weeds (Hossain *et al.*, 2015). Knockdown herbicides such as glyphosate has been found to be effective in pre-planting weed control. However, much training of farmers is needed to ensure appropriate dose and time of herbicide application, calibration of sprayers, selection of appropriate sprayers and nozzles, safety issues of herbicide uses, etc. Farmers and service providers who are hired to plant crops using CA are initially not aware of the need for vigorous pre-planting weed control, especially in the case of heavily weed-infested plots, for establishing crops using minimum soil disturbance. Heavy weed infestation remains a barrier to effective direct seeding of monsoon season rice by zero tillage. Non-puddled transplanting of rice seedlings after strip tillage has been developed, so that standing water can be retained in CA fields to suppress early weeds in wetland rice. In summary, integrated pre-plant weed control in CA systems of the EGP relies on increased stubble retention, diverse crop rotations, reducing turn-around-time between crops and application of knockdown herbicide.

Post-planting weed control

Greater weed density challenges may be faced during the initial years after switching to CA practice. To control weeds successfully, farmers' attention is required throughout the season. Many weed species are able to flourish when the intense tillage operations of conventional full tillage are stopped. However, over time, the weed seed-bank declines by 30% in CA systems and the prevalence of weeds commonly declines, but perennial weeds may become more prevalent (Hossain, 2019). The integrated weed management

(IWM) approach is the best option to control weeds. The goals of the IWM system should be to reduce the movement of weed seeds and propagating units into the soil and reduce the impact of weeds on crops to an economically acceptable level. The IWM system emphasizes the management of weeds rather than eradication, employing two major approaches: (i) preventive methods; and (ii) pre-and post-crop planting control strategies.

PREVENTIVE METHODS. Sanitation is an important component of prevention methods, which are easier and less costly than controlling the invasive and alien weeds from crop fields. Use of clean seeds (free from weed seeds), clean agricultural implements, protecting the land from weed seed flow (through irrigation and rain water flow, wind, etc.), managing weeds on bunds or levees and roadsides, minimum soil disturbance and planned livestock grazing are prevention methods for noxious weed establishment in crop fields. Any safe action that helps to reduce the deposition of weed seeds on soils will undoubtedly result in less weed interference and better crop growth. Crop rotation, minimum soil disturbance, crop canopy cover (by adjusting seed rate and row spacing), crop stubble cover and natural mulches, practising use of a stale seedbed, reducing turnaround time between crops, intercropping, physical weed control and herbicidal weed control, etc., are recognized as weed management strategies in IWM; however, their relative importance in CA practices in the EGP have yet to be understood. The annual rotation of wetland rice with upland crops in the EGP may prevent some weed species from becoming unmanageable (Locke and Bryson, 1997). Retention of 50% stubble to cover the soil can reduce the weed pressure by 25%–40% in monsoon season rainfed rice (Aman) and in winter season irrigated (Boro) rice, wheat, mustard and mungbean (*Vigna radiata*) (Haque *et al*., 2018).

POST-PLANTING WEED CONTROL. Controlling weeds by herbicide has become popular in Bangladesh because it requires less labour to achieve timely and effective weed control. However, injudicious and continuous use of a single herbicide over a long time may result in herbicide-resistant biotypes, shifting weed flora, residual effects for succeeding crops and, finally, it can cause human health and environmental hazards. Selection of appropriate herbicide types, and appropriate time and dose of application are critical (Buhler, 1995; Chauhan *et al*., 2006). Zahan *et al*. (2018) reported that herbicides with a range of modes of action are able to suppress weeds in wetland rice and wheat. The capacity to rotate the use of herbicides with different modes of action is an important strategy for slowing the development of herbicide-resistant weeds. In the diverse cropping patterns used by farmers in the EGP, the use of herbicides with varied modes of action may result in plant-back phytotoxicity if residues of the herbicides persist from one crop to the next. Zahan *et al*. (2020a) found no evidence of plant-back injury from *Pyrazosulfuron-ethyl* to wheat planted after rice. However, research is needed to extend these studies to a wider range of herbicides, soil types, soil moisture contents and crop species. Moreover, there needs to be systematic screening of current and soon-to-be-released cultivars of the main crop species to the currently used herbicides with different doses and modes of action. Zahan *et al*. (2020b) found that eight currently recommended wheat cultivars in Bangladesh are tolerant to the label rate of pendimethalin, but some are susceptible to doses that are two or three times higher. In smallholder farms, some level of manual weed control is still a useful approach if it is economically viable.

28.4 Performance of Conservation Agriculture (CA) in Rice Cultivation

Conventionally, rice establishment depends on tillage and puddling of wetland soil for transplanting of seedlings. Continuation of puddling of soils is one of the major impediments to adopting CA in rice-based cropping systems (Alam *et al*., 2020).

28.4.1 Rice Cultivation in Non-puddled Soils

Haque *et al*. (2016b) reported a novel technique to establish the rice crop in strip-based, non-puddled soils. In general, the rice seedling establishment methodology in non-puddled systems is the same as for rice seedlings transplanted in puddled soil, except for a different land preparation. In non-puddled systems, strips 5–7 cm deep and 4–6 cm wide were made by VMP in a single-pass operation, then irrigation water (in the case of winter season irrigated rice) was applied to inundate the field for 18–24 h before transplanting rice seedlings into the softened soil in the strips. The follow-up study by Haque and Bell (2019) reported that a non-puddled condition did not hinder rice cultivation, but produced similar or greater grain yield, reduced the cost of cultivation and increased profit for both monsoon season rainfed and winter season irrigated rice relative to conventional puddled rice.[2]

28.4.2 Strip Planting Direct Seeded Rice

Direct seeded rice is becoming popular in Asian countries due to labour shortage (Pandey *et al.*, 2002). Elsewhere, direct seeded rice is being practised either in well-tilled land or puddled and saturated fields. Neither of those systems complies with the CA practices as the soils are heavily disturbed through tillage or puddling operations. However, direct seeded late Boro and Aus rice can be established in SP systems or with zero tillage. The crop cultural management of direct seeded rice remains the same as for strip-planted direct seeded rice apart from row placement of basal fertilizers and the use of the sprouted rice seeds for sowing. According to Haque *et al.* (2018), with strip-planted direct seeded rice, the irrigation water requirement could be reduced by up to 60% and, together with reduced labour and other costs, profitability significantly increased relative to puddled rice without yield penalty.

28.5 Performance of Conservation Agriculture (CA) in Upland Crop Cultivation

Use of 2WT-based planters to establish various crops other than rice resulted in up to 50%–85% fuel and 30%–50% labour saving over CT along with manual seed and fertilizer broadcasting. The plant populations for strip-planted lentil, chickpea, mungbean, maize, wheat and jute (*Corchorus olitorius*) were greater or as good as conventionally planted crops (Bell *et al.*, 2017). The yields of various upland non-rice crop in strip-planted fields were generally greater or as good as conventionally planted crops (Johansen *et al.*, 2012; Salahin *et al.*, 2014; Vance *et al.*, 2014; Bell *et al.*, 2017; Haque *et al.*, 2017). However, there is still a requirement for more research on optimum seed rate, row spacing, seeding depth and cultivars for CA production of dryland crops.

28.6 Long-Term Benefit of Conservation Agriculture (CA) in Intensive Rice-based Systems

While CA practices for smallholders in the EGP are now developed for crops other than rice, the CA practice in transplanted rice-based systems remains a challenge. The application of CA practices in smallholder cropping reduces crop production cost, maintains grain yield and increases profit from 48% to 460% relative to CT (Miah *et al.*, 2017). Although CA has considerable potential, only a small percentage of smallholder farmers practise CA in the EGP. The nutrient forms and availability in soils and fertilizer response, weed dynamics, etc., are likely to alter when changing the cropping practices from conventional multiple tillage operations and crop residue removal or burial to minimum soil disturbance, crop residue retention and diversified crop rotations in CA. Thus, systematic long-term research is needed on the performance of CA in rainfed and irrigated conditions, particularly in rice-based cropping systems. Two case studies of long-term experiments conducted on farmers' fields and another one on a research station are presented below.

Long-term experiments have been conducted since 2010 on farmers' fields in Durgapur (24°28′ N, 88°46′ E) and Godagari (24°31′ N, 88°22′ E) upazilas (sub-districts) of Rajshahi district, and another long-term experiment has been conducted since 2012 at Bangladesh Agricultural University (BAU) farm, Sadar upazila, Mymensingh, Bangladesh. Two soil disturbance practices were tested: CA practice with SP including non-puddled transplanted (NPT) rice (Haque *et al.*, 2016b) and CT. All experiments had two levels of residue retention: (i) low = 20 cm height of anchored and standing residue comprising about 2.5 t of biomass ha^{-1}, equivalent to farmers' current residue retention practice; and (ii) high = 40 cm height of anchored and standing residue that weighed about 4 t of biomass ha^{-1} of rice and wheat residues. Each year three crops were grown and followed different cropping sequences (Table 28.1). The VMP (Fig. 28.2) (Haque *et al*., 2017) was used for establishing all upland crops such as lentil (*Lens culinaris*), mustard (*Brassica juncea*), chickpea, Aus rice (as direct seeded), jute and mungbean in a single-pass operation for SP to implement CA, and 3–4 tillage operations by 2WT followed by hand-broadcast seeding and fertilizing done for CT. In the case of irrigated (Boro) and rainfed (Aman) rice, NPT was practised in CA; and for CT, conventional puddled transplanting of rice seedlings was followed.

28.6.1 Long-term Trends of Crop Yield and Profit Margin

The yields of CA rice crops in the rotation compared to CT system were similar to those in CT rice in the first 3 years of experimentation (2010/13) at both Durgapur and Godagari sites (Islam, 2016). In the Durgapur site, the seed yield of mungbean was 62% higher in 2011/12 and the lentil was 22% higher ($p < 0.05$) in 2012/13, respectively. The mustard seed yield was 18% lower during 2013/14 in the case of CA (Fig. 28.3, A1). However, in case of CA and CT, statistically similar grain yields were recorded for the Godagari site in all 16 crops (Fig. 28.3, A2). The rice equivalent yield for 12 crops (Fig. 28.4), gross return and gross margin (Fig. 28.5) were statistically higher ($p < 0.05$) for CA than for CT at the Mymensingh site. On-going monitoring of disease incidence in CA plots, particularly with high residue management, has not yet shown any notable increases in the level of infection.

28.6.2 Irrigation Water Saving

The long-term experiment of CA with aman rice–wheat–mungbean crop rotation saved 11%–33% of the irrigation water for the wheat season compared to CT. In addition to significant water saving, there was more efficient irrigation water use and higher water productivity. Water productivity of wheat was higher in SP compared to CT in all 3 years. For example, in 2015, water productivity of wheat was 2.06 and 1.25 g grain l^{-1} of water for SP and CT, respectively (Mahmud *et al*., 2017).

28.6.3 Soil Organic Carbon Sequestration

In comparison with CT, considerably higher soil organic carbon (SOC) was measured in CA soils at 0–10 cm depth after 3–4 years of cropping. Practising CA for upland crops and NPT for rice crop accumulated an extra 4.2 and 3.8 t CO_2eq ha^{-1} in Durgapur and Godagari experiments, respectively, after 4–5 years (Alam *et al*., 2016). The long-term effects on minimum soil disturbance and residue retention were also assessed on a long-term CA experiment at BAU farm, Sadar, Mymensingh. The effect of CT and CA and nitrogen (N) fertilization on SOC concentration of the surface and sub-surface soils was assessed only after the harvest of the 8th crop (wheat). A significant ($p < 0.01$) increase in SOC concentration was observed in the 0–5 cm soil layer between CT (1.58%) and CA (1.83%) when SOC was averaged over the residue management and N fertilizer treatments. The SOC concentration at 0–5 cm soil depth was not altered by residue retention nor by N fertilization or their interactions with crop establishment systems. However, at 5–15 cm soil depth, the SOC content was not significantly influenced by any of the above treatments (crop establishment, level of residue retention or N fertilization) and their interactions.

28.6.4 Greenhouse Gas Implication

The practice of CA reduced life cycle greenhouse gas emissions (GHG) relative to CT by about 30% in irrigated rice (Alam *et al*., 2016). For wetland monsoon rice, a 16% reduction in GHG emissions was estimated using the life cycle analysis for the CA practice (non-puddled transplanting and increased residue retention) compared to the CT practice. Moreover, if the whole cropping cycle of two rice crops and mustard were considered, there was a 32% decrease in net CO_2-e emissions (Alam *et al.*, 2019a). Hence, cultivation

Fig. 28.2. Versatile Multi-crop Planter (VMP) planting in large field and transportation mode (top) and operation mode in smaller plot (bottom) (photos courtesy of Md. Enamul Haque).

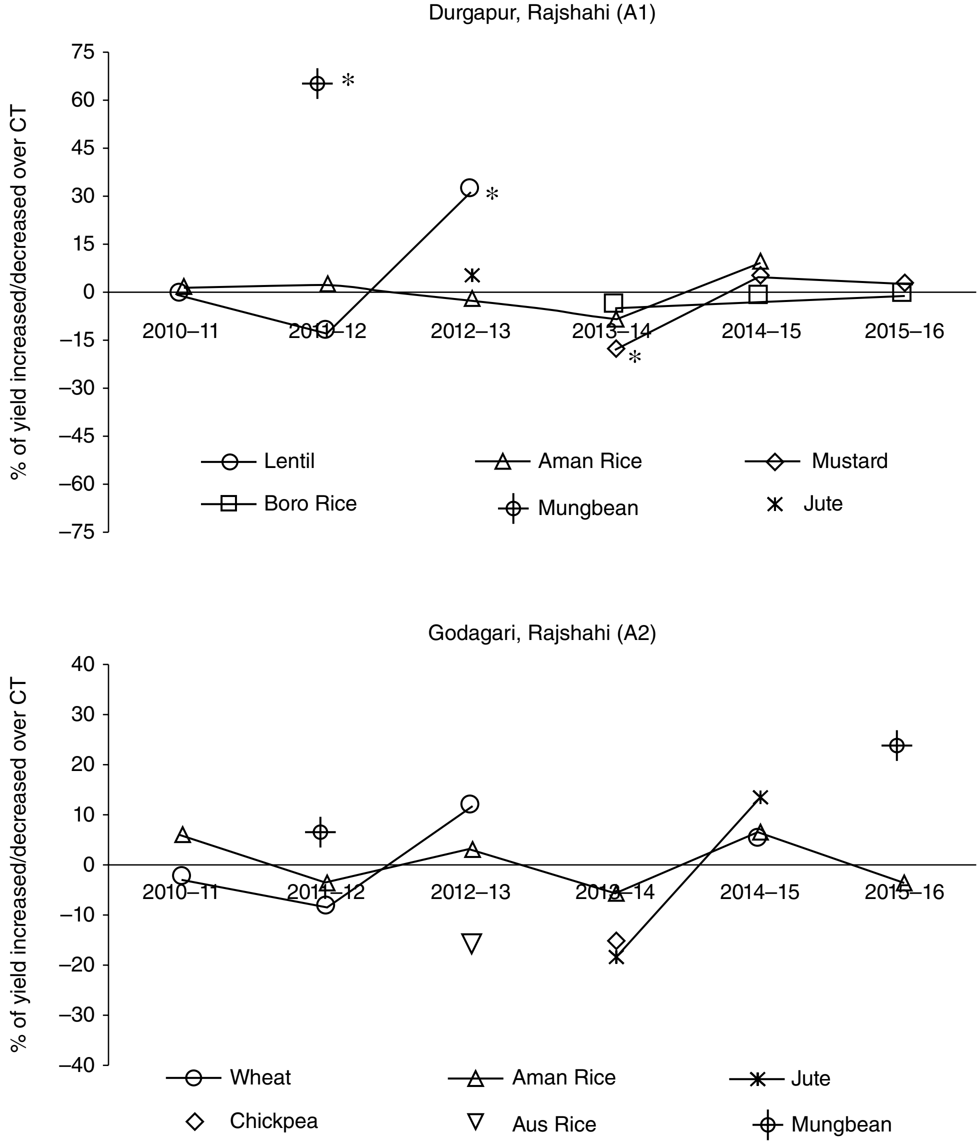

Fig. 28.3. Long-term effect of Conservation Agriculture (CA) on grain/fibre/seed yield in Durgapur (A1) and Godagari (A2) sites, Rajshahi, Bangladesh, from 2010/11 to 2015/16. Authors' own figure. *denotes statistical difference between conventional tillage (CT) and CA.

of rice under CA systems offers significant GHG saving in the 100-year time horizon relative to CT, mostly due to lower emissions of methane (Alam *et al.*, 2016; 2019b) and due to the sequestration of SOC, which increased by about 65% (Alam *et al.*, 2019a, b).

28.6.5 Farm-level Benefit of Conservation Agriculture (CA) Adoption

Compared to 2WT-based CT, the average benefits from farm mechanization and CA adoption that were estimated from a study of 135 farmers

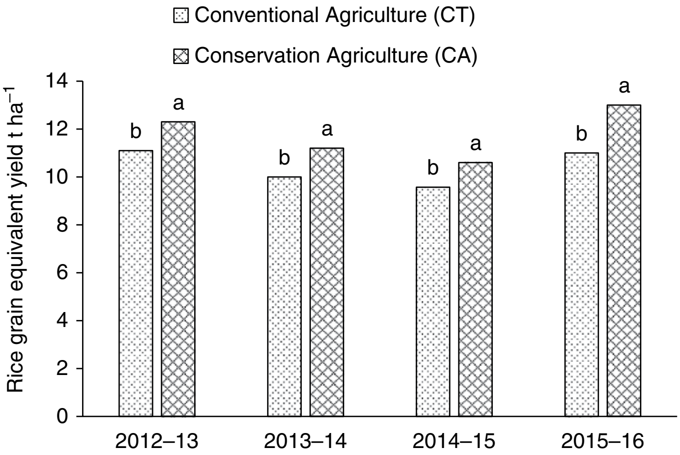

Fig. 28.4. Long-term effect of Conservation Agriculture (CA) on rice equivalent grain yield in Mymensingh, Bangladesh. Authors' own figure. Different letters above the bars denote statistical difference between CA and conventional tillage (CT).

in northwestern Bangladesh are: 34% labour saving, 31% less seed required, 6% fertilizers saving, 32% pesticide cost saving leading to up to 10% lower production cost for lentil, mustard, maize and wheat (Miah *et al.*, 2017). There was a yield increase of 28% for lentil, 19% for mustard and 6% for wheat for farmers who adopted CA planting using the VMP. There was an increase in profit by 47% for lentil, 55% for maize, 46% for mustard and 76% for wheat due to adoption of CA planting using VMP (Miah *et al.*, 2017).

In Durgapur Upazila, where a concerted effort was made to promote the VMP and extension of CA over a 5-year period, the adoption of CA in the 2016/17 Rabi (winter) season was 4.5% of the total crop area. In three blocks, CA planting reached 10%–16% of all Rabi season crops. Hence there is evidence of early adoption by farmers where there were programmes to build farmer awareness, practical skills and confidence in the technology and the availability of the planters and local SP (planting service contractors with VMP) to offer planting services to farmers on a custom hire basis (Haque *et al.*, 2018).

28.7 Relevance to Conservation Agriculture (CA) for Africa in the Context of the Malabo Declaration

The Malabo Declaration and approved Agenda 2063 signed by African Union heads of state and governments makes significant policy commitments regarding farm mechanization in Africa. The Declaration aims to double agricultural productivity by providing emphasis on: (i) sustainable smallholders' agriculture; (ii) provision of appropriate knowledge, information and skills to users; and (iii) suitable, reliable and affordable mechanization and energy supplies. The adoption of CA is in the early stage in African countries. The large-scale farmers of South Africa, Zambia and Zimbabwe are practising CA, but there is a need for appropriate machinery and CA technology for smallholder farmers across 17 African countries. The lessons learned in South Asia from CA practice, research and technologies as described in this chapter could be useful to African contexts but need further local-level refinement.

28.8 Conclusions

More than two decades' experience and research evidence in machinery development; fuel/labour/water cost savings; system-based irrigated and rainfed crop establishment and agronomy; soil health improvement; and decrease in GHG has been acquired. We now have sufficient confidence to recommend more widespread outscaling of CA across different agroecosystems in the EGP with the engagement of smallholder farmers, researchers, extension agents and private sector partners.

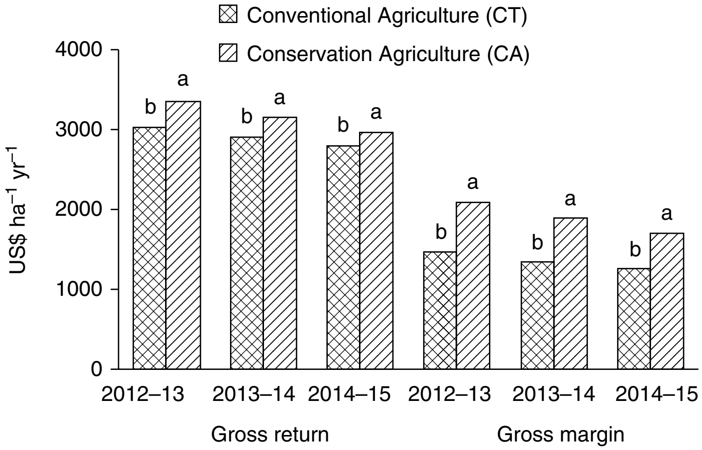

Fig. 28.5. Gross return and gross margin of long-term Conservation Agriculture (CA) practice and conventional tillage (CT), Mymensingh, Bangladesh. Different letters above the bars denote statistical difference between CA and CT.

Table 28.1. Year-wise cropping sequences in long-term experimental sites. Authors' own table.

		Crop sequences in each cropping year		
Location	Year	Crop 1	Crop 2	Crop 3
Durgapur, Rajshahi	2010/11	Lentil	Mungbean	Aman rice
	2011/12	Lentil	Mungbean	Aman rice
	2012/13	Lentil	Jute	Aman rice
	2013/14	Mustard	Boro rice	Aman rice
	2014/15	Lentil	Boro rice	Aman rice
	2015/16	Mustard	Boro rice	Aman rice
Godagari, Rajshahi	2010/11	Wheat	Mungbean	Aman rice
	2011/12	Wheat	Mungbean	Aman rice
	2012/13	Wheat	Aus rice	Aman rice
	2013/14	Chickpea	Jute	Aman rice
	2014/15	Wheat	Jute	Aman rice
	2015/16	Wheat	Mungbean	Aman rice
Sadar, Mymensingh	2011/12			Aman rice
	2012/13	Wheat	Mungbean	Aman rice
	2013/14	Wheat	Mungbean	Aman rice
	2014/15	Wheat	Mungbean	Aman rice
	2015/16	Wheat	Mungbean	Aman rice

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Notes

[1] In this chapter, conventional tillage (CT) refers to 3–4 rotary tillage passes by 2WT followed by 1–2 land levelling passes by a ladder attached to the 2WT for upland crop land preparation. Seed and fertilizers are broadcast manually.

[2] In this chapter, conventional puddling refers the process of land preparation prior to rice seedling transplanting of Aman rice and Boro rice. The land preparation for puddled rice by 2WT comprises two dry tillage passes followed by ponding of water in the field (either from rain or irrigation water) for 3–7 days and again 2–3 wet tillage passes done along with 1–2 land levelling operations using a ladder pulled by a 2WT.

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29 Evaluation of the Technical Capacity of Artisans to Fabricate the Animal-powered Direct Seeder Super-Eco in Sénégal

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Abstract

This study focused on the ability of local Senegalese artisans to fabricate the animal-powered no-till (NT) direct seeder Super-Eco to reduce the expensive import of seeders. Technical specifications and design of the animal-powered direct seeder Super-Eco were first given to 90 heads of artisanal workshops in three regions of the Southern Peanut Basin for them to reproduce the machine. Detailed information on their workshop equipment was collected in advance. A principal component analysis (PCA) was then used to classify artisan workshops. The results showed that Class 3 was very well equipped and was able to fabricate the direct seeder. It was followed by Class 2 which was fairly well equipped, but was only able to develop 90% of the seeder parts. Because of a low level of equipment, the third class of artisans was only capable of fabricating very few pieces of the seeder. Artisans from Class 3 were able to fully construct the animal-powered direct seeder. However, it was noted that the other classes of artisans were able to reproduce some parts of the animal-powered direct seeder Super-Eco but they could not make the seeder box with its nested seed metering device due to their low level of equipment. They instead buy it from the Sahelian Industrial Company of Mechanics, Agricultural Materials and Representations or from traders. The need to evaluate the performance of the seeders developed by local artisans is also noted.

Keywords: direct seeding, tools, machinery, workshop, typology

29.1 Introduction

Animal-powered direct seeding tools in African countries such as Kenya, Morocco and Mali are mostly imported from Brazil, France, Bangladesh, India, the USA and China (Terre de Touraine, 2014). The machines are usually expensive because of import tax and transportation costs. In some cases, machines are not suitable for local field conditions, which can result in poor

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field performance in small-scale farming systems in Africa (Vadon *et al.*, 2011). In other cases, adaptation tests for the French Farmers and International Development (AFDI) prototype seeder and the Fitarelli seeder have been conducted in some countries, like Mali (Fert and Afdi Touraine, 2014), Burkina Faso (Ashburner, 2004; Bozza and Kourouma, 2004) and Morocco (Fert and Afdi Touraine, 2014). For the AFDI prototype, the results were not successful since the seeder required a flat soil surface without crop residues (Sissoko and Autfray, 2007), even though adaptations have been made to make it lighter and easier to reproduce by local artisans (Thomas, 2006). For the Fitarelli no-till (NT) seeder, it was necessary to conduct seeding tests using seeds and the recommended fertilizer doses that farmers were mostly using under local conditions (Vadon *et al.*, 2011).

Modifications of the Fitarelli seeder (such as adding a drawbar and wide rear wheels) have already been made by some farmers. Some spare parts (seed hopper and plastic seed discs) were imported from Brazil and reproduced by Kéné Workshop in Mali. Also, an attempt was made to fabricate a seeder by local artisans from Nankorola (Mali), to evaluate the possibility of reproducing it using only local materials (Sissoko and Autfray, 2007). Based on the National Center for Agricultural Machinery of Rural Engineering, Water and Forests (CEMAGREF) and the National Research Institute in Science and Technology for the Environment and Agriculture (IRSTEA) principles, Afdi Touraine (with the support of two artisans from France) designed a NT seeder which was able to sow directly into a mulch or crop stubble (Terre de Touraine, 2014). Prototypes of a motorized AFDI seeder have been operating in Morocco, Tunisia and southern Mali (Terre de Touraine, 2014). The Afdi Touraine seeder, with two options of intercropping (for maize–sunflower and cereals), required a low draught force which could easily be provided by a 40–80 hp tractor.

Mali, financed by the French Development Agency (AFD) (Terre de Touraine, 2014), identified that the Fitarelli seeder (even if still working) had not fully met farmers' expectations in terms of ease of use and time saving (Vadon *et al.*, 2011). According to Diakhaté (2009), the success of innovations in the Sénégal context is dependent on many local and external factors like physical, socio-economical, environmental, climatic and human ones. In all cases, there is no suitable seeder yet available which is simple and efficient for direct sowing under permanent cover crops. This was the reason why the Afdi Touraine team went looking for an adapted machine for sowing, with the help of farmers in Mali (Thomas, 2006). Suggestions for adaptation to local conditions had been made (Sissoko and Autfray, 2007) for simpler and cheaper seeders and without a fertilizer applicator, which makes the machine heavier. The local seeder was modified to sow cotton, millet and sorghum, based on the Fitarelli seeder modified by attaching a metal wheel at the front side for chopping the vegetation, a furrow opener at the rear to open the soil (at an adjustable depth) to form a furrow where seeds are deposited, a seed hopper in the middle and increased diameter wheels to raise ground clearance.

Like their counterparts in Mali, Senegalese artisans were able to fully repair and maintain the animal-powered equipment (Havard, 1987a; Gaye, 1991; Pirot *et al.*, 2004). They made a variety of animal-powered tools (such as ploughs, weeders, cultivators and carts), but most of them had difficulties building the animal-powered Super-Eco seeder entirely (Fall, 1985; Sow, 1995; Diop, 2011). This latter is a single row animal-powered seeder weighing 37 kg. Its hopper has a capacity of 5 kg and it can be fitted with different discs for sowing legumes and cereal crops. It is very suitable for Senegalese farmers. There are two models of the Super-Eco seeder made by artisans in the Sénégal market. For the first, the distribution system consists of a pinion with 8 teeth and a seed plate of 24 holes which is very similar to the industrial Super-Eco seeder. The second model is designed with a distribution system of two bevel gears (one with 16 teeth and another with 10 teeth). The materials are mostly collected from vehicle wrecks or obtained from mechanics' workshops or scrap dealers.

Mechanization is an important part of agricultural development as reflected in the Malabo Declaration and Agenda 2063. Recently, the African Union (AU) launched a pan-African initiative on sustainable mechanization along the value chain, based on sustainable production systems such as Conservation Agriculture (CA) that rely on NT direct seeding for crop establishment. Thus, the expansion of the ability to locally fabricate NT direct seeders in Africa is an important part of improving the productivity of agriculture in the future. The objective of this research, therefore, was to characterize the different types of artisans in the Southern Peanut Basin, based on their ability to fabricate the animal-powered Super-Eco direct seeder.

29.2 Materials and Methods

29.2.1 Context

The study was conducted in the southern region of the Peanut Basin in the centre of Sénégal as this is the main area where agricultural operations are conducted with draught animals, land degradation is significant (Havard, 1993) and artisan workshops are well developed (Sow, 1995). The area has a Sudano–northern Guinea savannah climate with an annual rainfall of 600–800 mm recorded between June and October. It corresponds to the former province of Sine-Saloum (Fall and Lô, 2009) which is now divided into the three administrative provinces of Fatick, Kaffrine and Kaolack (Prêcheur, 2012).

In the southern region of the Peanut Basin, many authors, such as Havard (1987b), Gaye (1991), Sow (1995), Kaffrine Centre for Artisans (CMK) (2007) and Sarr (2013b) have carried out characterization studies of artisans' sociodemographic characteristics, conditions and means of work, conditions of supply of raw materials, types and frequencies of repairs, level of training and types of agricultural machinery manufactured.

According to Sarr (2013b), 28% of artisans of the Peanut Basin were members of an association or economic interest group (GIE) and 24% were members of the chamber of trades. This grouping allowed them to be more visible, be able to share their experiences in business and have direct links with the authorities, enabling them to defend their interests (CMK, 2007).

The artisans of the Southern Peanut Basin are assisted by development institutions involved in the 'metal' sector such as the Regional Development Agency (ARD), the chamber of trades, Rural Entrepreneurship Promotion Project II (PROMER II), Promotion of the Artisanal Microenterprise in Central and Southern Sénégal (PROMACESS) and the CMK. Those usually included technical, logistical and financial support. For instance, PROMER II provided start-up capital to help apprentices acquire the tools and equipment they need to start their businesses, and offered a revolving matching fund where customers could get loans to buy tools and equipment, which were to be reimbursed over a given period of time (Boateng, 2012).

29.2.2 Characteristics of the Adapted Animal-powered Direct Seeder Super-Eco

The design of the first prototype of the animal-powered direct seeder Super-Eco was based on a participatory study with artisans of the South Peanut Basin according to the methodology of 'experimentation-modification' (Havard, 1998). This phase of exchange with the artisans enabled the definition of required adaptations in the Super-Eco seeder to a NT seeder. To this end, a model of the Super-Eco seeder mounted with a front cutter disc for cutting through permanent mulch cover for direct seeding was presented to the artisans (Fig. 29.1).

Compared to the factory-produced Super-Eco seeder, the following adaptations were made to the modified direct seeder (Diakhaté, 2018): (i) the frame was strengthened by replacing the 8 mm × 30 mm flat iron bar with 10 mm × 30 mm; (ii) the seed soil covering wheel made of cast iron was replaced by one made of aluminium; (iii) the diameter of the metal drive wheels was increased from 400 to 500 mm; (iv) the furrow opener with a width of 47 mm was replaced with a narrower one with a width of 40 mm; (v) the vertical knife of 30 mm × 12 mm flat iron bar with a length of 110 mm was replaced by a cutter disc made of steel 2 mm thick and with a diameter of 280 mm; and (vi) the number of seed holes on the seed disc was increased to adjust to the recommended seeding densities.

29.2.3 Collection of Data

In each province (Kaolack, Fatick, Kaffrine) the Regional Director for Rural Development (DRDR) and the director of the chamber of commerce were consulted for further information and on data of artisans manufacturing animal equipment.

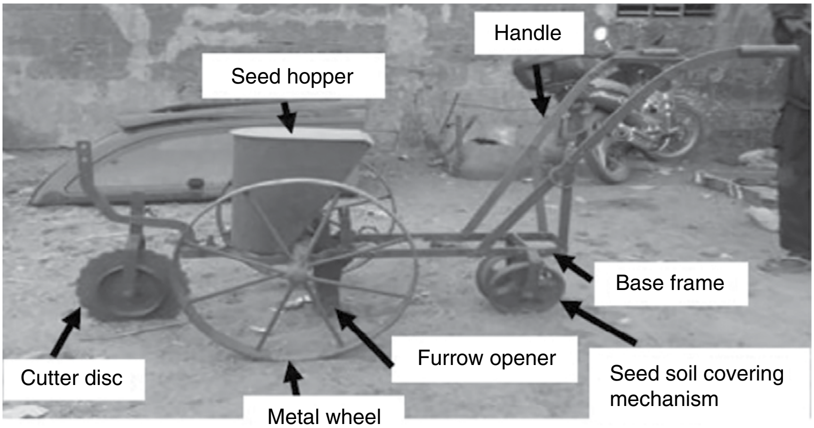

Fig. 29.1. Adaptation of the Super-Eco seeder by fitting a front-mounted cutter disc. Authors' own photo.

The list of artisans received from the chamber of commerce included different categories: jewellers, electricians, mechanics, watchmakers, blacksmiths, hairdressers and wood sculptors. The list of artisans selected for our study were those repairing and manufacturing animal-drawn agro-equipment. To carry out the field surveys, all workshops of artisans presented in our area of interest were visited in each province (Table 29.1).

A two-stage stratified sampling (province and workshop) design was adopted using a proportion based on the total number of artisan workshops per province. According to Dagnelie (1998) a stratified sampling is recommended when the initial population is very heterogeneous. Hence, all components will be well represented in the sample and can provide a significant improvement of accuracy compared with random sampling, without any changes in the total number of observations to be made (Nyirahabimana, 2011). In this study, an overall sample of 90 workshops or artisans was used. Subsamples within a province were weighted with its number of artisans (Table 29.1).

Table 29.1. The number of artisans surveyed in the three regions of the South Peanut Basin. Authors' own table.

Province	Number of artisans	Percent (%)	Number of sampled artisans
Kaolack	58	39	35
Kaffrine	50	33	30
Fatick	42	28	25
Total	150	100	90

To collect data, a questionnaire was used including demographic parameters of the workshop owner or supervisor (age, sex, level of education); workshop characteristics (type of equipment, quantity of equipment, acquisition mode for the workshop); workshop operation (number of workers, condition of equipment, types of equipment manufactured); and numbers of equipment sold annually and the average price of each item.

This questionnaire was administered to selected artisans in their workshops or at their homes between June and July 2015. The minimum number of tools required to design an animal-powered direct seeder was obtained from the most experienced artisans with high sales of the animal-powered direct seeder. The equipment required to fabricate the Super-Eco seeder machine consisted of electric arc welders (PSA), grinders (M), hacksaws (SMM), drills (PC), anvils (ET), forge (SF) and bench vices (E).

This study aimed at establishing different types of artisans in the Southern Peanut Basin based on the minimum equipment required to manufacture the animal-powered direct seeder Super-Eco using a multivariate statistical analysis. This is a quantitative and independent approach of classifying artisans into groups and running correlation tests on selected variables, as applied by Adjiri *et al.* (2019).

29.2.4 Data Analysis

The typology of artisan workshop was used as an analytical tool to capture the diversity of a population based on the variables or criteria selected. Two methods of multivariate analysis were used: principal component analysis (PCA) and hierarchical cluster analysis (HCA), and the analyses were made with XLSTAT software.

29.3 Results

29.3.1 Choice of Quantitative Variables Relevant to the Typology of Artisans

Artisans specialized in manufacturing agricultural equipment, and with the minimum number of tools for fabricating the animal-powered direct seeder Super-Eco, were selected from the correlation matrix of the seven quantitative variables (Table 29.2). The explanatory variables were divided into three classes, according to the seven criteria selected. These groups of artisans differed, based on the availability of sophisticated manufacturing equipment in their workshops.

Seven variables showed positive correlations, meaning that each variable is partially explained by the others, but in reality the operating levels were different from one workshop to another as their means were not similar. Therefore, all seven quantitative variables were used and retained in the PCA (Table 29.2). It was observed that correlations with low values were related to the number of forges (SF) and to the number of vices (E) (r = 0.11) (Table 29.2).

29.3.2 Socio-demographic Characteristics of the Artisans Within the Peanut Basin

In the Southern Peanut Basin the age of the artisans ranged between 30 years (9% of the sample) to over 60 years (8% of the sample). The age group 30–60 years represented 83% of the surveyed artisans. They have a strong practical experience as in general they have inherited their businesses from their parents at an early age. They have an education level hardly going beyond primary school. Despite their low level of schooling, they were able to manage all the administration activities in their workshops (management of customer orders, providing quotations and invoices, management of equipment, supplies and stocks of raw materials). Nearly all artisans participated in other businesses related either to agriculture (86%), livestock (3%), trade (8%) or other activities (scrap dealer, earthmoving machine operator and trainer in the metal construction business).

Eighteen percent of workshop artisan managers received training from the state, non-governmental organizations (NGOs) or projects, and their own parents on the production of animal-traction agricultural equipment such as seeders, hoes and carts (for horses and donkeys) and rippers.

29.3.3 Characteristics of the Artisans Capable of Manufacturing the Animal-powered Super-Eco Direct Seeder

The eigenvectors and eigenvalues of a covariance (or correlation) matrix represent the ‘core’

Table 29.2. Matrix of correlation between the variables. Authors’ own table.

Variables	PSA	M	SMM	PC	ET	SF	E
PSA	1						
M	0.562	1					
SMM	0.338	0.276	1				
PC	0.381	0.414	0.403	1			
ET	0.422	0.309	0.313	0.395	1		
SF	0.295	0.255	0.162	0.155	0.382	1	
E	0.476	0.493	0.366	0.442	0.309	0.110	1

PSA, number of electric arc welders; M, number of grinders; SMM, number of hacksaws; PC, number of drills; ET, number of anvils; SF, number of forges; E, number of bench vices.

of a PCA: the eigenvectors (principal components) determine the directions of the new feature space and the eigenvalues determine their magnitude. In our study, axis 1 represents the large tools allowing the manufacture of the NT seeder and axis 2 represents the small tools. The first two axes explain 59.3% of the variability (Fig. 29.2). Axis 1 (45% of the variability) shows that some workshops are well equipped and fully able to fabricate the NT seeder. Axis 2 (15% of variability) shows equipment constraints of some workshops in terms of grinders, hacksaws and drills, resulting in problems in seeder fabrication.

We analysed the distribution of the different artisan workshops surveyed in the Southern Peanut Basin on axes 1 and 2 from the PCA. This revealed the distribution of the tools needed for the fabrication of the animal-powered direct seeder in the different classes, which are explained by the correlation circle (Fig. 29.3). The analysis in Table 29.3 shows roughly three distinct classes of workshop in terms of the availability of the minimum equipment needed to manufacture the animal-powered direct seeder, with Class 3 being better equipped with sophisticated equipment compared to the other two classes.

The data collected from the respondents were submitted to descriptive statistics analysis tools by calculating averages and standard deviations.

Class 1 is the least well equipped compared to the others. It is also characterized by having almost no drills and forges. Given the importance of these two tools in the fabrication of the animal-powered direct seeder, Class 1 will hardly be able to achieve manufacture of the seeder. The drill makes it possible to make holes for the bolts, and the forge makes it possible to work the steel and shape the various seeder components. Class 1 cannot build the entire Super-Eco seeder but members of this group are more specialized in building the spare parts for this machine. They can build 72% of the frame, 81% of the wheels and 80% of the seed hopper. They cannot make the Super-Eco seeder due to the lack of appropriate equipment.

Class 2 is characterized by an adequate number of drills and number of forges needed for the manufacture of the seeder. Class 2 is the intermediate class, and can build 89% of the frame, 100% of the wheels and 100% of the seed hopper. Like Class 1, this class is also handicapped by the lack of appropriate equipment needed to make the complete seeder because neither of these classes can build the seed box containing the seed metering device mechanism. Instead of building, they buy this part of the Super-Eco seeder from the Sahelian Industrial Company of Mechanics, Agricultural Materials and Representations (SISMAR) and from retailers.

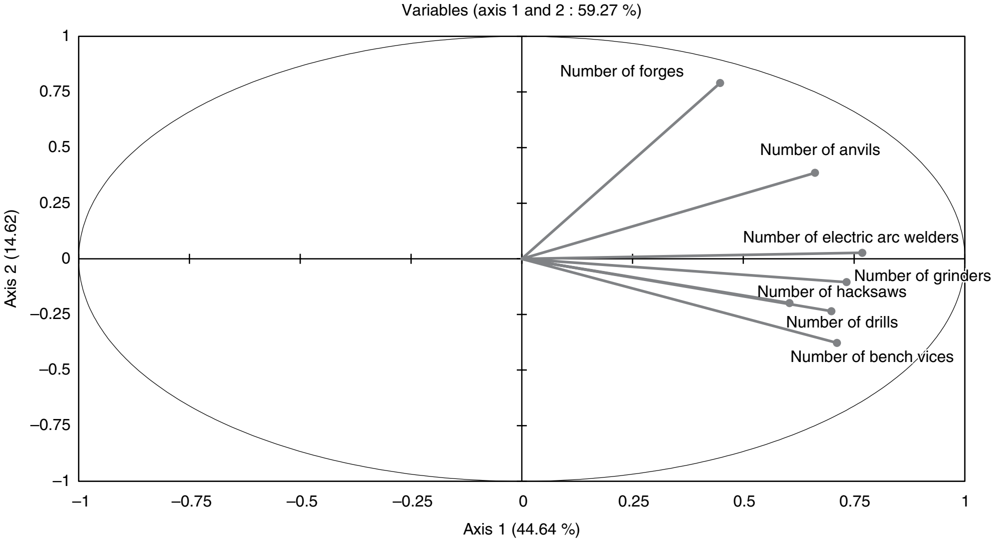

Fig. 29.2. Projection variables of principal component analysis in the factorial plane Axis 1–Axis 2. Authors' own figure.

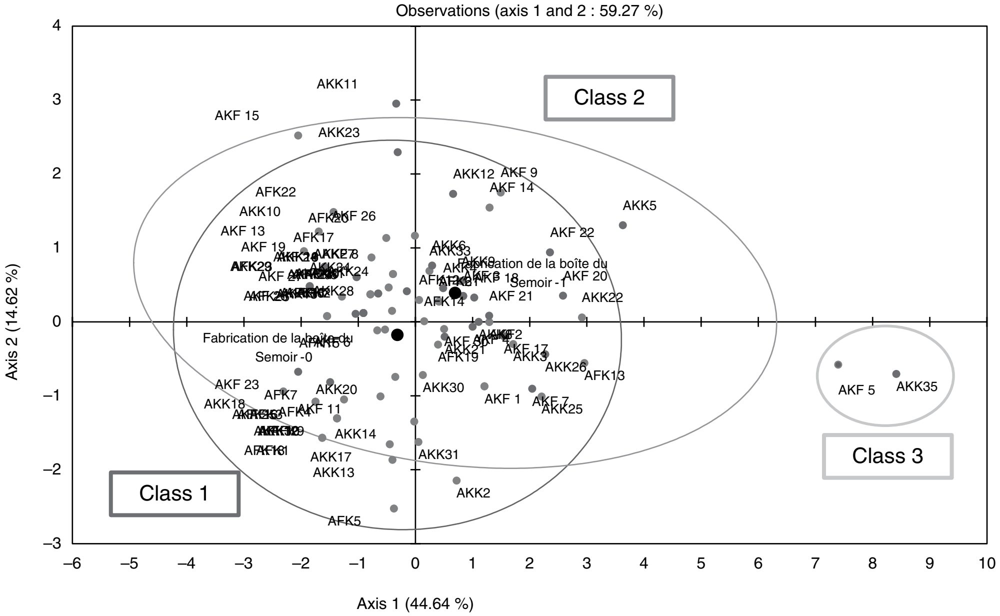

Fig. 29.3. Correlation circle of the factorial design Axes 1–2, showing the classification of manufacturers specialized in fabrication of agricultural equipment. Authors' own figure.

Table 29.3. Mean characteristics of tools used in each artisanal workshop class in the Southern Peanut Basin. Authors' own table.

Tools used	Class 1	Class 2	Class 3
Number (total 90)	69	19	2
Electric arc welders	1.33 ± 0.61	2.21 ± 0.71	4.5 ± 2.12
Grinders	1.06 ± 0.54	1.74 ± 0.65	3.5 ± 2.12
Hacksaws	1.20 ± 0.5	1.37 ± 0.5	3.0 ± 1.41
Drills	0.59 ± 0.63	1.74 ± 1.1	4.5 ± 2.12
Anvils	1.67 ± 1.08	3.37 ± 1.61	5.0 ± 1.41
Forges	0.78 ± 0.59	1.00 ± 0.00	2.0 ± 0.00
Bench vices	1.04 ± 0.47	1.42 ± 0.51	3.5 ± 0.71

Class 3 is the best-equipped group, with all the tools required for fabrication of the complete seeder. This class produces the highest quantity of the Super-Eco seeder per year compared with the other classes and has no difficulty in fully producing the complete seeder. The correlation circle of the factorial plan Ax1–Ax2 (Fig. 29.3) shows that axis 1, with 44.64 % variance, is determined in its positive part by Class 3 and some portion of the Class 2 and Class 1 workshops which have the minimum of tools to build agricultural equipment. It is determined in its negative part by the rest of Class 2 and Class 1, comprising artisans who lack tools. The axis 2 with 14.62% variance is expressed in its positive part by one portion of Class 1 and Class 2 and in its negative part by the other portion of Class 1, Class 2 and Class 3.

29.4 Discussion

29.4.1 Role of Artisans in Fabrication, Repair and Maintenance

The importance of the fleet of animal-powered agricultural equipment distributed by the various state programmes (Diop, 2011) has encouraged the development of artisans for the maintenance and repair of agricultural equipment. This has made it possible to keep most agricultural equipment in service for more than 20 years (Gaye, 1991).

With the bankruptcy of the Senegalese Industrial Company of Agricultural Equipment (SISCOMA) in 1980, a structure strongly dependent on the Agricultural Program (PA), and the cessation of sales of their agricultural equipment (Bordet *et al.*, 1988), the new SISMAR was created in 1982 for manufacturing (Havard, 1987b). As a result, the repairs continued to be managed by artisans.

Blacksmith craftsmanship has developed strongly for the maintenance and upkeep of animal-powered agricultural equipment, and also for the manufacture of certain equipment. Today, artisans cover most of the demand for ploughs, hoes and carts, as well as for spare parts (Havard *et al.*, 2009). Artisans are heavily involved in the maintenance of equipment at different scales: village, market and city of regional importance, especially for the manufacture of spare parts and peanut lifters (50% of the models identified in the Peanut Basin), there is approximately one artisan per 750 machines in the region of Kaolack (Havard and Mbengue, 1989). The same tendency was noted in North Cameroon, where artisans produce 50% of the ploughs and almost all of the wearing parts. (Kemtsop, 1999; Oumarou, 2006). In fact, imports of agricultural equipment and their spare parts are expensive for governments. Therefore, it is imperative that the manufacturing of these spare parts be done by local artisans who are well trained. This will ensure the sustainability of agricultural mechanization.

29.4.2 Ability of Artisans to Design and Fabricate the Animal-powered Super-Eco Direct Seeder

The results showed that, in contrast to Class 1 and 2 artisans, Class 3 had the ability to manufacture the different parts of the Super-Eco seeder, including the seed box-metering device, which was a challenge to most artisans in the past. The good performance of these artisans can be explained by the donation of equipment and training received from the institutions promoting metal working, such as PROMER phase I and II (Boateng, 2012). These results are very similar to those of Fall and Ndiamé (1988), which showed three contrasting types of artisans in Southern Casamance, where 59% of artisans made manual tools. Of these, 35% made manual tools and spare parts for animal-traction equipment and only 6% of the artisans were able to fabricate additional animal-traction equipment.

It should be noted that, today, the Super-Eco seeders made by local artisans (Fig. 29.4) have not been tested by researchers to validate their technical and agronomic performance. During this survey, some farmers claimed that, when using the locally fabricated Super-Eco seeder, the sowing rate is reduced compared to the industrial Super-Eco seeder.

29.4.3 Smallholder Farmer Interest in the Animal-powered Super-Eco Direct Seeder

Various sources of energy ranging from human and animal to motor are used for sowing in the permanent cover-crop system of crop production. Among these energy sources, the tractor-mounted NT seeder is one of the most prevalent in countries where CA is relatively widely adopted, such as the USA, Brazil, Australia and South Africa. The tractor-mounted NT seeder provides various benefits to farmers as a result of the speed of execution of the work and high sowing precision, but acquisition and maintenance costs are very high. Hence the intervention of the state to subsidize them or provide some financial support for their purchase is important in developing countries. However, it is clear that the introduction of these large machines in developing countries where CA is not yet widely practised can have consequences for its adoption. That is why it is better to start in countries where CA is not yet fully developed with human and animal power, as the majority of farms in Sénégal are already using animal traction and the Super-Eco seeder machine (Sarr, 2013a). Indeed, the animal-powered Super-Eco direct seeder has been strongly adopted by farmers for more than half a century (Bordet *et al.*, 1988) and it is now well mastered by some artisans. For this reason, a project for implementing the direct-seeded permanent

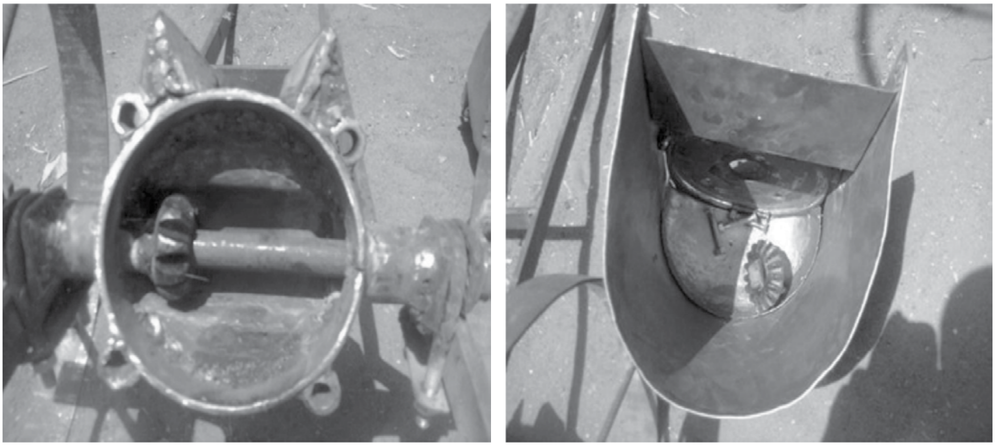

Fig. 29.4. Bevel gears of 10 (left) and 16 (right) teeth salvaged from car gearboxes and used as part of the seed metering system in artisanal seeders. Authors' own photo.

mulch cover cropping system can have a good possibility of success in countries where CA is not yet widely adopted by farmers.

The current policies of the government of Sénégal in the modernization of agriculture, where agricultural equipment is subsidized by up to 70% of the sale price (Ministry of Agriculture and Rural Equipment (MAER), 2015), are very encouraging for new farmers specializing in CA who will be able to benefit from its advantages. This will facilitate the establishment and adoption of CA in Sénégal.

Experiences in the development of CA from Kenya, Pakistan, Brazil and all others have highlighted the interest of farmers in these countries in savings in labour and inputs, and in improved soil fertility compared to conventional farming (Sims and Kienzle, 2009).

29.5 Conclusion

Multivariate statistical analysis resulted in a typology of craftsmen. Three classes were identified and contrasted according to their ability to fabricate the Super-Eco seeder. The first class included the most well-equipped artisans capable of manufacturing the seeder, owners of the workshops had access to electrical power, electric arc welders and grinders. The second class included well-equipped artisans, who can fabricate most of the seeder parts, except the seed distribution system which is made elsewhere. The third class included less well-equipped artisans, most of whom do not have access to electricity, and do not have the equipment to manufacture most of the seeder parts, even though they were able to carry out certain repairs, and to manufacture some parts (furrow opener, seed soil covering wheels, etc.).

Most of the constraints and challenges encountered by artisans in the 1980s were still valid in this study and included: expensive raw materials; low level of education and literacy of workshop artisan managers, making it difficult to properly run accounting operations and administration of workshops; and low access to funding for operational activities and investments, etc.

This study shows that there has been little change in the past 30 years in the sector of artisanal maintenance and manufacturing of animal-traction equipment. Support for the development of this artisanal sector by the state (incentives, training, advisory support, etc.) and by the private sector (financing, supply of raw materials, marketing, etc.) is still critical. For the Malabo Declaration and Agenda 2063 to become a reality continent-wide, CA-based sustainable agricultural mechanization – especially involving locally fabricated equipment such as the NT Super-Eco seeder – is an absolute necessity.

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30 The Future: Towards Agenda 2063

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30.1 The Second Africa Congress on Conservation Agriculture (CA)

The Second Africa Congress was an attempt by Conservation Agriculture (CA) stakeholders or the community of practice to come together to support the implementation of the Malabo Declaration and Agenda 2063 at all levels and in all sectors. The subject of the book is critically important at this time in the process of transformation of agriculture in Africa, when current climate extremes and greater variability are severely impacting agricultural production around the world. For Africa, agriculture – and its important role in rural and urban development – is a sector of abundant opportunity, as has been envisaged by the Malabo Declaration and Agenda 2063. For the foreseeable future, agriculture in Africa has a major contribution to make in terms of food security, and also in terms of economic, social and environmental development. The changing climate in Africa already calls for the adoption of the best alternative agricultural production strategy that can deliver both productivity and ecosystem services sustainably. As this book shows, CA has amply shown itself to be a relevant and worthy core component of climate smart agriculture in Africa. The area under CA in Africa has more than trebled since 2008/09, and some 25 countries are promoting it institutionally across the public, private and civil sectors.

As the book shows, much new expertise and experience in CA has been gained, especially during the last decade. Research, training, farmer innovation and the increasing agricultural investments in institution building mean that CA now holds greater promise of serving as a sustainable pillar in the implementation of Agenda 2063. The Second Africa Congress on Conservation Agriculture and the work presented in the chapters of this book provide ample evidence that CA is already contributing to the implementation of Agenda 2063. In his speech during the official opening of the Congress, the Director General of the Department of Agriculture, Forestry and Fisheries (DAFF), Mr Mzamo Michael Mlengana, called for a greater contribution by CA and the multi-stakeholder CA community of practice towards Agenda 2063 (see Section 30.2).

Conservation Agriculture in Africa (S. Mkomwa and A. Kassam eds)
DOI: 10.1079/9781789245745.0030

30.2 Speech by the Director General of the Department of Agriculture, Forestry and Fisheries (DAFF), Mr Mzamo Michael Mlengana, at the Official Opening of the Second Africa Congress on Conservation Agriculture (CA)

agriculture,
forestry & fisheries
Department:
Agriculture, Forestry and Fisheries
REPUBLIC OF SOUTH AFRICA

LANDCARE
SOUTH AFRICA

Honourable Ministers,
Members of Parliament,
Senior Government Officials,
Members of Diplomatic Corps,
Sponsors,
The Chairman of the Congress Organizing Committee,
Distinguished Guests
Ladies and Gentlemen

It is my great pleasure to join you today at the Second Africa Congress on Conservation Agriculture (2ACCA) and welcome to this wonderful country with its diverse culture and agro-ecological landscape.

The Second Africa Congress on Conservation Agriculture is a very important occasion for Africa where we can endeavour to scale up the adoption of climate-smart agriculture technologies to benefit not thousands but millions of farmers in the continent, by taking a fresh look on how to realize sustainable agriculture, in the context of the African Unions' Malabo Declaration.

I want to thank all the institutions, multilateral organisations, donors, exhibitors that have provided visionary leadership and tireless efforts in making this conference a reality. I want to thank all the delegates for setting aside their time to attend this event.

Ladies and Gentlemen

The Second Africa Congress on Conservation Agriculture is a follow up to the First Africa Congress on Conservation Agriculture (1ACCA), held in Lusaka, Zambia in March 2014, under the theme "*Conservation Agriculture: Building Entrepreneurship and Resilient Farming Systems*". The 1ACCA reaffirmed that the restoration of soil health and intensification of agriculture through Conservation Agriculture could become the cornerstone in transforming the way farming is done in Africa, representing a major contribution to achieving NEPAD-CAADP's goal of 6% growth of the agriculture sector.

During that congress, ten resolutions were made which centred towards realization of the Lusaka/ Malabo Vision 25x25, under the broad themes of (i) policy, political commitment and leadership; (ii) private sector engagement; and (iii) training, extension, research and innovation, and knowledge support. Governments, development partners, private sector, farmers, education and training institutions, research institutions, regional economic communities and non-governmental organizations are among the stakeholders called upon to support and facilitate the implementation of the resolutions in order to enhance the adoption and scaling-up of Conservation Agriculture across Africa.

The 2ACCA is therefore a perfect opportunity for us all to reflect and evaluate how far and even report back on the progress of the 1ACCA resolutions.

Excellencies, Ladies and Gentlemen.

South Africa has the largest area, 483,000 hectares, under Conservation Agriculture in the continent, which is contributing immensely to food security. The intensive crop production of cereals, pulses and oilseeds in the large-scale commercial farming in South Africa is also associated with pastures and other fodder crops for intensive livestock production. It will be ideal to emulate this sustainable system even to our smallholder farmers, who are majority in our farming system. Indeed, this is a unique model for the continent to emulate; given that livestock are perceived as threat to adoption of Conservation Agriculture instead of being an asset.

There is no doubt, appropriate mechanization and commercialization has a very significant role to play in the modern and sustainable agriculture. The Government of South Africa is progressing well in providing a conducive environment by developing the Conservation Agriculture Policy to accelerate upscaling by our smallholder farmers.

Excellencies
Ladies and Gentlemen.

The Second Africa Congress on Conservation Agriculture has set in motion the catalytic process for policy dialogue in Conservation Agriculture and Climate Smart Agriculture within national government systems.

Furthermore, the Africa Congress on Conservation Agriculture is an agenda under the Africa Conservation Tillage Network, to facilitate continued engagement with investors, to highlight the business opportunities in smallholder and medium scale farming to innovate on how to seize the opportunity. The targeted and organised 25 million farm-households gives no small magnitude in terms of business volumes for inputs, implements, financing, crop insurance, manufacturing and distribution, skills development, information, etc.

My Department, has already demonstrated the commitment, and we are open to work with NGOs, and development partners in furthering the infrastructural setup and non-business services. Our training, LandCare programme, research and extension institutions are continually developing innovative products and services that will contribute to improving the farmers technical, economic and social needs. This is in appreciation that today's products will be obsolete in the future and therefore the need to develop new CA products to add on the existing or even replace the current.

I assure you that the Government of South Africa will continue to create an enabling environment to promote sustainability and growth of all sectors through the provision and development of policy and legal frameworks to ensure that we provide competitive services to our clients. My pledge is to continue supporting you and giving you all the guidance you may require. The local organising team will take the delegates to thriving Conservation Agriculture farms during the last day of the congress. I hope you will learn and build on the knowledge of Conservation Agriculture and enjoy the sights of our beautiful country.

Lastly, let me acknowledge:

The African Conservation Tillage Network, The Government of the Republic of South Africa, the African Union Commission, the NEPAD Agency, the Regional Economic Communities, International NGOs, the Norwegian Agency for Development Cooperation (NORAD), the European Union (EU), the Food and Agriculture Organization of the United Nations (FAO) and various bilateral and multilateral partners for the immense contributions.

As usual, we all know there are people who are providing support. My brief is that the African Conservation Tillage Network was supported by a team of 30 persons' International Steering Committee which is chaired by NEPAD and with the vice chair as the Kenya Agricultural and Livestock Research Organization (KALRO). I commend the 2ACCA Secretariat for the persistent desire to transform smallholder farming in Africa by realizing the Lusaka Declaration of the First Africa Congress on Conservation Agriculture (1ACCA), and the African Union Heads of State Malabo Declaration and particularly Vision 25 x 25 – which aims at having 25 million smallholder households practicing climate smart agriculture by 2025. The Scientific and Technical Committee, led by the International Conservation Agriculture Advisory Panel for Africa (ICAAP-Africa) Chairperson, the National Organising Committee led by DAFF, and the Review Committee for Papers and Posters led by ACT are all commended for the job well done.

Ladies and Gentleman,

With all these welcome remarks, I therefore wish you fruitful deliberations.

THANK YOU.

30.3 Action Statement from Stakeholders

The Second Africa Congress ended with an Action Statement from Stakeholders (Section 30.3.1). This defines the mandate and scope of the Third Africa Congress on Conservation Agriculture which is expected to be held in a few years.

30.3.1 Action Statement from Stakeholders of the Second Africa Congress on Conservation Agriculture (CA)

Background

1. The African Conservation Tillage Network (ACT), in collaboration with the Government of the Republic of South Africa, African Union Commission, the NEPAD Agency, Regional Economic Communities, International NGOs, Norwegian Agency for Development Cooperation (NORAD), European Union (EU), Food and Agriculture Organisation of the United Nations (FAO) and various bilateral and multilateral partners, organised and hosted the Second Africa Congress on Conservation Agriculture (2ACCA) in Johannesburg, South Africa from 9th to 12th October 2018. The Congress was attended by 501 delegates, from 52 countries globally. African countries were represented by 37 countries, of which 4 were from North Africa, 9 from Eastern and Central Africa, 11 from Southern Africa and 9 from Western Africa. The categories of the delegates were government 19%, farmers and farmer organisations 12%, Research institutions and academia 29%, Non-Governmental organisations 24%, Private sector 11%, and Development Partners 5%.

2. The theme of the Congress was "Making Climate Smart Agriculture Real in Africa with Conservation Agriculture: Supporting the Malabo Declaration and Agenda 2063". The main purpose of the Congress was to foster sharing, learning and building of public, private and civil sector support for the Africa-wide adoption of Conservation Agriculture systems as a basis for Climate Smart Agriculture in the implementation of the Agenda 2063. At the conclusion of the Congress, delegates identified the key take home messages for sharing at respective spheres of influence. These are meant to reach all Conservation Agriculture stakeholders, players and Interest groups including the African Union and its agencies, Regional Economic Communities in Africa, National Governments, Policy Makers, Farmers and Farmer Organisations, Private sector, Development Partners (both bilateral and multilateral), Research Institutions and the academia, Non-Governmental Organisations, and the Media.

Introduction

1. We, the Conservation Agriculture (CA) stakeholders who attended the Second Africa Congress on Conservation Agriculture (2ACCA), which met in Johannesburg, South Africa from 9th to 12th October 2018:

2. Note that discussions and agreed actions at this Congress, were directly building on the OUTCOMES of the First Africa Congress on Conservation Agriculture (1ACCA) in March 2014, Lusaka, Zambia (https://tinyurl.com/ydg3rkwc). This underlines the point that this is not an event, but a process.

3. Acknowledge that the Congress is inspired by continental development aspirations and development goals as outlined in the African Union's Agenda 2063 and specifically the Malabo declaration on Agriculture Transformation (2014); this is the momentum we are riding on.

4. Underline that CA is not the ultimate goal, but a critical MEANS, hence it is about: CA in the context of economic growth and inclusive development (food, water, incomes, etc.) and CA in the context of global efforts and agreements, including the Paris Climate Agreement, Land and water as well as the Biodiversity Conventions and their related country obligated targets.

5. Recognise that National and Local ownership in the efforts to advancing practicing of CA is an imperative. This is why mainstream CA buy-in into national implementation instruments, including National Development Plans related policies and budget is critical. At Sector level, the instruments include the Agriculture Investment Plans and the Nationally Determined Contributions (NDCs) and this provides an avenue to align to local implementation structures.

6. Underline that "knowledge" is one of the most important resources Africa has in advancing and accelerated uptake and spread of CA in both small and large scale farming entities.

7. Recognise that CA is critical in achieving sustainable development and therefore would play a critical role in the efforts to bring agriculture to the fore in the pursuit for wealth creation, creation of job and entrepreneurship opportunities for many of the continent's populations including those in rural areas and sustainable food systems. Appreciates that CA has an immense contribution in halting land degradation, mitigating the negative effects of climate change, improving biodiversity and mitigating vulnerability of people in the light of climate change.

Statement of Actions

1. In continued resolve to foster and bring to scale the practicing of CA, thereby making tangible contributions towards the attainment of Africa's development goals as in Agenda 2063, in general and, specifically, the Malabo Declaration on Agriculture Transformation, including the 25 x 25 target, We, the Congress Participants:

2. Appeal to Governments and other public institutions, organisations and partner institutions, civil society players as well as private sector, at all levels, to intensify locally adapted actions aimed at fostering the enabling environment and empowering human capital in scaling up the practicing of CA

3. In this regard, the following is highlighted:

a) Continued commitment by public, private, farmers and farmer organisations, Civil Society and development partners to embrace and build on the gains and lessons from implementation of the OUTCOMES of the first Africa Congress on CA

b) Stakeholders including the public, civil society and private sectors and development partner institutions (e.g. African Development Bank, FAO, IFAD, World Bank, EU and bilateral and multilateral donors) urged to institute appropriate policies and public-private engagements foster harmonisation and coherence in funding instruments and mechanisms to expand accessible financing available for CA – including CA research, mechanisation as well as acquisition of inputs

c) Ensuring heightened efforts to expand access to education and skills development in CA related competencies and knowledge

d) Through appropriate training, nurturing and access to information and data, facilitate and support strengthening of sustained capacity at all levels to identify and address risks especially those faced by farmers and rural communities in their efforts to expand CA practice

e) Advocate for policies and investment options and mechanisms which give affirmative attention to smallholder farmers and entrepreneurs, especially women and youth, across various national and regional agricultural value chains

f) Within the context of strengthening and increasing accessible CA related knowledge and information, urge ACT to even further catalyse expansion and widespread functioning of CA Community of Practice and regional and national level CA forums with intense vertical and horizontal, within and across sectors, communities and nations networking, sharing of experiences and co-creation of knowledge and building knowledge-based social capital

4. Reaffirm that the Africa Congress on Conservation Agriculture is an important event with essential value in providing platform for sharing, networking and linking up for potential collaborations. Therefore, urge ACT to continue in mobilising all concerned stakeholders and championing the hosting of the Congress.

The Participants to the 2nd ACCA
Johannesburg, South Africa
12th October 2018

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CABI – who we are and what we do

This book is published by **CABI**, an international not-for-profit organisation that improves people's lives worldwide by providing information and applying scientific expertise to solve problems in agriculture and the environment.

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The profits from CABI's publishing activities enable us to work with farming communities around the world, supporting them as they battle with poor soil, invasive species and pests and diseases, to improve their livelihoods and help provide food for an ever growing population.

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Conservation Agriculture in Africa

Climate Smart Agricultural Development

Edited by **Saidi Mkomwa** and **Amir Kassam**

Tillage agriculture has led to widespread soil and ecosystem degradation globally, and more particularly in the developing regions. This is especially so in Africa where traditional agricultural practices have become unsustainable due to severe exploitation of natural resources with negative impacts on the environment and food system. In addition, agricultural land use in Africa today faces major challenges including increased costs, climate change and a need to transform to more sustainable production intensification systems.

Conservation Agriculture has emerged as a major alternative sustainable climate smart agriculture approach in Africa and has spread to many African countries in the past decade as more development and research, including in sustainable mechanization, has enabled its extension and uptake. It is key to transforming Africa's agriculture and food system given its ability to restore soil health, biodiversity and productivity of millions of smallholder as well as larger-scale farms.

This landmark volume is based on the material presented at the Second Africa Congress on Conservation Agriculture which was held in Johannesburg, South Africa, 9–12 October 2018. The main theme of the Congress was 'Making Climate Smart Agriculture Real in Africa with Conservation Agriculture: Supporting the Malabo Declaration and Agenda 2063'. The Congress was aligned to mobilize stakeholders in all agriculture sectors to provide greater technical, institutional, development and investment support, impetus and direction to the vision and agenda for transforming African agriculture as set out by the Malabo Declaration and Agenda 2063.

This book is aimed at all agricultural stakeholders in the public, private and civil sectors in Africa engaged in supporting the transformation of conventional tillage agriculture to Conservation Agriculture. The book will be of interest to: researchers, academics, students, development stakeholders, public and private sector investors and policy makers as well as institutional libraries across the world.

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