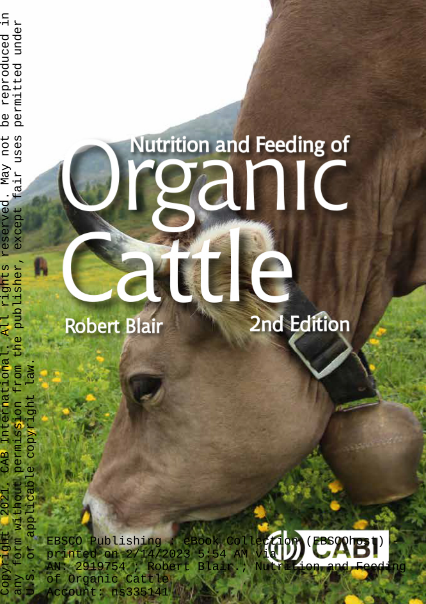
Nutrition and Feeding of
Organic
Cattle
Robert Blair
2nd Edition
CABI

Nutrition and Feeding of Organic Cattle, 2nd Edition

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2nd Edition

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The information presented in this book is for advisory use only. Readers who formulate diets based on the information presented should verify the nutrient contents of the feedstuffs to be used prior to the diet being formulated and fed to cattle.

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Foreword

It is with great pleasure that I write this foreword to Professor Robert Blair's *Nutrition and Feeding of Organic Cattle* (2nd Edition). I first met Professor Blair during my undergraduate degree about 30 years ago when he arrived at The University of British Columbia to take up the Head position of what was then the Department of Animal Science. He was then, and is continuing to be, an advocate for incorporating the latest available science into the field of farm animal nutrition. I clearly remember sitting in his classroom where he encouraged us to think about animal nutrition as an evolving science and that we should never be satisfied with the status quo.

My own education started out in the field of animal nutrition beginning with my undergraduate degree completed in Professor Blair's department. After completing a Master's degree and then a PhD in ruminant nutrition I worked in the animal feed industry for 7 years before returning to UBC to focus on animal welfare. It is through both lenses – animal nutrition and welfare – that I encourage readers to take the time to read Professor Blair's most recent textbook on the nutrition and feeding of organic cattle. As the public increasingly questions where our food comes from, we see a growing number of citizens turning to organic products. For example, sales of organic goods, including food animal products, doubled in the European Union (EU) between 2012 and 2016. This increase has resulted in a corresponding increase in animals designated as organic; for instance, the number of dairy cows in the EU rose from approximately 100,000 in 2000 to just under a million in 2015, now representing about 4% of the European herd. We see similar trends in North America: according to the latest (2017/2019) data from the US Census of Agriculture the total number of beef cows was 31,722,039 of which 39,412 were certified organic. Although small in comparison with European figures, both organic milk and organic beef production in the US increased by about 20% between 2016 and 2019.

Increases in the number of beef and dairy cattle designated organic has resulted in more interest and arguably need in how best to feed them. Professor Blair's book is a wide-ranging collection of the available peer-reviewed literature that provides a platform for those interested in feeding organic cattle to see where the latest research sits in this important area of science but also where the gaps in knowledge remain. Equally important to the consumer is the latest evidence regarding the health of organic cattle products, a topic that Professor Blair integrates into the narrative.

Those who take the time to sit and read this interesting and well researched book will not be disappointed. Indeed, I strongly encourage all individuals working in the animal feed industry who are faced with the daily challenge of formulating rations for organic dairy and beef cattle, students interested in organic cattle farming and researchers who are interested in pursuing future studies in this area to read this comprehensive review of the latest science on feeding organic dairy and beef cattle.

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Some data have been reproduced from the books *Nutrition and Feeding of Organic Pigs* and *Nutrition and Feeding of Organic Poultry*, with the permission of the publisher.

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Introduction and Background

This book completes a trilogy of books dealing with the nutrition and feeding of farm animals that are produced organically; *Nutrition and Feeding of Organic Pigs* (Blair, 2007, 2009 (Chinese version), 2018a), *Nutrition and Feeding of Organic Poultry* (Blair, 2008, 2018b) and *Nutrition and Feeding of Organic Cattle* (Blair, 2012). This update on *Nutrition and Feeding of Organic Cattle* deals with both dairy and beef cattle and, like the previous books in the series, presents information on how to feed these animals so that the milk and meat produced meet organic standards.

The available data confirm that there is an increasing market for organic products, if they can be delivered at a price acceptable to the consumer. As a result organic animal production has increased in many countries. This development is a response to an increased consumer demand for food that is perceived to be fresh, wholesome and flavoursome, free of hormones, antibiotics and harmful chemicals and produced in a way that is sustainable environmentally and preferably locally, and without the use of genetically modified (GM) crops.

Organic farming can be defined as an approach to agriculture in which the aim is to create integrated, humane, environmentally and economically sustainable agricultural production systems. Thus maximum reliance is placed on locally or farm-derived renewable resources. In many European countries, organic agriculture is known as ecological agriculture, reflecting this emphasis on ecosystem management. The term for organic production and products differs within the European Union (EU). In English the term is organic; but in Danish, Swedish and Spanish it is ecological; in German ecological or biological; and in French, Italian, Dutch and Portuguese it is biological. In Australia the term used is organic, biodynamic or ecological.

The organic standards relating to feeding of animals share a commonality internationally and continue to be refined to deal with practical issues, such as a recurring shortage of organic feedstuffs. As a result some exceptions to the regulations are permitted in some countries. For instance, the Australian Standard is similar to European standards in relation to permitted feed ingredients; feed supplements of agricultural origin having to be of certified organic or of biodynamic origin. A derogation allows that, if this requirement cannot be met, the approved certifying organization may allow the use of product that does not comply with the Standard provided that it is free from prohibited substances or contaminants and it constitutes no more than 5% of the animal's diet on an annual basis. Permitted feed supplements of non-agricultural origin in Australia include minerals, vitamins or provitamins only if from natural sources. Treatment of animals for trace mineral and vitamin deficiencies is subject to the same provision of natural origin. Animal nutritionists will regard with some scepticism the requirement that 'The use

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of trace elements must be on the basis of a demonstrated deficiency' since this could lead to animal suffering. The US regulations exemplify a different approach to the use of trace minerals and vitamins. The standards in that country contain a National List, which includes feed ingredients. It allows all non-synthetic (natural) materials unless specifically prohibited and prohibits all synthetic materials unless specifically allowed. A difference between US and EU regulations affecting feedstuffs is that no derogations are sanctioned under the US National Organic Program. Trace minerals and vitamins that are approved for feed supplementation by the Food and Drug Administration can be used for enrichment or fortification of organic feed. These examples illustrate the point that organic farmers need to be very familiar with the details of the standards applicable to their region.

In many ways organic farming appears to be a turning back of the clock, but it should be practised using modern knowledge. Ration balancing programmes have been used for many years in conventional cattle production to allow feedstuffs to be used efficiently and this book advocates their use in organic production, including the use of computers to formulate diets and feeding programmes tailored to the type of cattle and the particular environment in question.

Application of the appropriate technical knowledge will allow the organic industry to thrive and produce the type of product sought by the public, at a competitive price. In addition, application of this knowledge will weaken the accusation that organic cattle farming contributes more to greenhouse gas production than conventional cattle farming.

This book provides an important source of peer-reviewed references on the organic feeding of cattle, drawn from the international scientific literature. The organic industry needs to have access to a compilation of unbiased, documented references such as this, and not available elsewhere.

One interesting aspect of the available scientific literature – as pointed out by Manuelian *et al.* (2020) – is that countries which started the organic farming movement still account for most of the published papers. These authors made that conclusion after reviewing selected documents from 44 countries worldwide. Germany was the country with the most scientific papers published on organic livestock farming (56 documents), followed by France (31) and Denmark (30). This was a reflection of the fact that countries with a long tradition in organic farming (German-speaking countries, English-speaking countries and France) are still the predominant countries in organic livestock research. The most cited countries of authorship, within the 320 selected documents, were Germany (751 citations), the United Kingdom (728 citations) and Denmark (596 citations). Manuelian *et al.* (2020) commented also on the fact that the number of citations of the publications appeared to be related to the language in which the documents were written (supporting the hypothesis that the language of the documents influences their chance to be cited). The choice of journal for publication was another factor, since most of the peer-reviewed journals in question were published in English.

Support for the better application of technical information was provided by Sundrum (2010). His review of the organic meat industry concluded that, although defined by specific and basic guidelines, organic livestock production is characterized by largely heterogeneous farming conditions that allow for huge differences in the availability of nutrient resources, the implementation of feeding regimes and the use of genotypes, etc. All of these have an effect on meat production. Correspondingly, there is substantial variation in the quality of organic meat entering the marketplace. The quality of organic beef is inconsistent and often falls short of expectation. In addition, it is often similar in quality to conventionally produced meat. He concluded that, in some cases, the organic guidelines play only a minor role with respect to meat quality.

This publication sets out guidance on nutrition and feeding practices that relate to the standards for certification of organic cattle. Although aspects of the various topics addressed in the book have been presented at conferences and in trade and scientific publications, no comprehensive text has yet been published. Details on permitted feed ingredients, with an emphasis on those grown or available locally, and on suitable dietary formulations are included in the book. The book will be of interest to the advisory personnel that service the organic milk and beef industries and also researchers, university and college teachers, students, veterinarians, regulatory agencies, feed manufacturers and feed supply companies. Organic producers with some technical knowledge of animal nutrition will also benefit from the information provided.

The book addresses the topic in several chapters, as follows.

- Chapter 1 **Introduction and Background** sets out a description and background to the topic.
- Chapter 2 **Aims and Principles of Organic Cattle Production** outlines the international standards relating to organic production of milk and beef and the roles of international organic agencies.
- Chapter 3 **Elements of Cattle Nutrition** provides a description of the fundamentals of the digestive processes in ruminant animals, required nutrients, deficiency signs and factors affecting feed intake.
- Chapter 4 **Ingredients for Organic Diets** is a large chapter that provides a nutrient profile and feeding value of a complete range of feeds for ruminant feeding, including forage plants, silages, grains, protein and micronutrient supplements. In addition, it provides information on the effects of feedstuffs on milk and beef production, quality and safety.
- Chapter 5 **Breeds for Organic Production** provides data relating to the choice of the right breeds for specific environments and on effects of breed type on productivity. Dual-purpose breeds are in general recommended for organic production systems.
- Chapter 6 **Integrating Feeding Programmes into Organic Production Systems** deals with the effects of feeding programmes on productivity, health and welfare of organic cattle and on the quality and safety of organic milk and beef.
- Chapter 7 **Conclusions and Recommendations for the Future** summarizes the aspects covered in the book and recommends approaches that should be taken to fill gaps in existing knowledge, consumer aspects and research needs.

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2

Aims and Principles of Organic Cattle Production

According to the Codex Alimentarius Commission (1999) and the Joint FAO/WHO Food Standards Programme, organic agriculture is:

> a holistic production management system which promotes and enhances agroecosystem health, including biodiversity, biological cycles, and soil biological activity. It emphasizes the use of management practices in preference to the use of off-farm inputs as opposed to using synthetic materials. The primary goal is to optimize the health and productivity of interdependent communities of soil life, plants, animals and people … the systems are based on specific and precise standards of production which aim at achieving optimal agroecosystems which are socially, ecologically and economically sustainable.

Thus organic cattle production differs from conventional production, and in many ways is close to the agriculture of Asia. It aims to fully integrate animal and crop production and develop a symbiotic relationship of recyclable and renewable resources within the farm system. Livestock production then becomes one component of a wider, more inclusive organic production system.

Organic cattle producers must take into consideration several factors other than the production of livestock. These factors include the use of organic feedstuffs (including limited use of feed additives); use of pasture-based systems; and minimizing environmental impact. Organic cattle production also requires certification and verification of the production system. This requires that the organic producer must maintain records sufficient to preserve the identity of all organically managed animals, all inputs and all edible and non-edible organic livestock products produced. The result is that organic food has a very strong brand image in the eyes of consumers and thus should command a higher price in the marketplace than conventionally produced food.

The whole organic process involves four stages:

1. Application of organic principles (standards and regulations).
2. Adherence to local organic regulations.
3. Certification by local organic regulators.
4. Verification by local certifying agencies.

Restrictions on the use of ingredients in organic diets include:

- No genetically modified (GM) grain or grain by-products.
- No antibiotics, hormones or drugs. Enzymes are prohibited as feed ingredients used to increase feed conversion efficiency (they may be used under derogation where necessary for the health and welfare of the animal).
- No animal by-products, except that milk products are permitted.
- No grain by-products unless produced from certified organic crops.
- No chemically extracted feeds (such as solvent-extracted soybean meal).
- No pure amino acids, either synthetic or from fermentation sources.

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Organic Standards

The standards of organic farming are based on the principles of enhancement and utilization of the natural biological cycles in soils, crops and livestock. According to these regulations organic livestock production must maintain or improve the natural resources of the farm system, including soil and water quality. Producers must keep livestock and manage animal waste in such a way that supports instinctive, natural living conditions of the animal, yet does not contribute to contamination of soil or water with excessive nutrients, heavy metals or pathogenic organisms, and optimizes nutrient recycling. Livestock living conditions must accommodate the health and natural behaviour of the animal, providing access to shade, shelter, exercise areas, fresh air and direct sunlight suitable to the animal's stage of production or environmental conditions, while complying with the other organic production regulations. The organic standards require that any livestock or edible livestock product to be sold as organic must be maintained under continuous organic management from birth to market. Feed, including pasture and forage, must be produced organically and health care treatments must fall within the range of accepted organic practices. Animal health and performance are optimized by careful attention to the basic principles of husbandry, such as selection of appropriate breeds and strains, appropriate management practices and nutrition and avoidance of overstocking.

Stress should be minimized at all times. Rather than being aimed at maximizing animal performance, dietary policy should be aimed at minimizing metabolic and physiological disorders, hence the requirement for a high content of forage in the diet. Grazing management should be designed to minimize pasture contamination with parasitic larvae. Housing conditions should be such that disease risk is minimized.

Nearly all synthetic animal drugs used to control parasites, prevent disease, promote growth or act as feed additives in amounts above those needed for adequate growth and health are prohibited in organic production. Dietary supplements containing animal by-products such as meat meal are also prohibited. No hormones can be used. When preventive practices and approved veterinary biologicals are inadequate to prevent sickness, the producer must administer conventional medications. However, cattle that are treated with prohibited materials must be clearly identified and they (or their milk or meat) cannot be sold as organic.

International standards

The aim of organic standards is to ensure that animals produced and sold as organic are raised and marketed according to defined principles. Standards and state regulations in conjunction with accreditation and certification are therefore very important as guarantees for the consumer.

Currently, there is no universal standard for organic food production worldwide. As a result many countries have now established national standards for the production and feeding of organic animals. They have been derived from those developed originally in Europe by the Standards Committee of IFOAM (International Federation of Organic Agriculture Movements) and the guidelines for organically produced food developed within the framework of the Codex Alimentarius, a programme created in 1963 by the UN Food and Agriculture Organization (FAO) and the World Health Organization (WHO) to develop food standards, guidelines and codes of practice under the Joint FAO/WHO Food Standards Programme. Within the Codex, the Organic Guidelines include Organic Livestock production.

IFOAM Basic Standards were issued in 1998 and updated most recently in 2014. IFOAM works closely with certifying bodies around the world to ensure that they operate to the same standards. The main purpose of the Codex is to protect the health of consumers and ensure fair trade practices in the food trade, and also to promote coordination of all food standards work undertaken by international governmental and non-governmental organizations. The Codex is a worldwide guideline for states and other agencies to develop their own standards and regulations, but it does not certify products directly.

The Codex Alimentarius Commission (CAC) is an international standards-setting body for food and food products jointly run by the UN FAO and the WHO. As such, it is recognized as a standardizing body by the World Trade Organization's (WTO) Agreement on the Application of Sanitary and Phytosanitary Measures. WTO member governments are required by the Agreement to base their standards on international standards, including those of the Codex Alimentarius (available at: www.codexalimentarius.net/web/index_en.jsp, accessed 1 December 2020).

The standards set out in the Codex and by IFOAM are quite general, outlining principles and criteria that have to be fulfilled. They are less detailed than the regulations developed specifically for regions such as Europe.

The sections of the Codex regulations relevant to the coverage of this book include the following.

Nutrition

13. Livestock systems should provide the optimum level of 100% of the diet from feedstuffs (including 'in conversion' feedstuffs) produced to the requirements of these Guidelines.
14. For an implementation period to be set by the competent authority, livestock products will maintain their organic status provided feed, consisting of at least 85% for ruminants and 80% for non-ruminants and calculated on a dry matter basis, is from organic sources produced in compliance with these Guidelines.
15. Notwithstanding the above, where an operator can demonstrate to the satisfaction of the official or officially recognized inspection/certification body that feedstuffs satisfying the requirement outlined in paragraph 13 above are not available, as a result of, for example, unforeseen severe natural or manmade events or extreme climatic weather conditions, the inspection/certification body may allow a restricted percentage of feedstuffs not produced according to these guidelines to be fed for a limited time, provided it does not contain genetically engineered/modified organisms or products thereof. The competent authority shall set both the maximum percentage of non-organic feed allowed and any conditions relating to this derogation.
16. Specific livestock rations should take into account:

- the need of young mammals for natural, preferably maternal, milk;
- that a substantial proportion of dry matter in the daily rations of herbivores needs to consist of roughage, fresh or dried fodder, or silage;
- that 'polygastric' [*ruminant, R. Blair*] animals should be not fed silage exclusively.

18. If substances are used as feedstuffs, nutritional elements, feed additives or processing aids in the preparation of feedstuffs, the competent authority shall establish a positive list/s of substances in compliance with the following criteria:

General criteria

a) substances are permitted according to national legislation on animal feeding;
b) substances are necessary/essential to maintain animal health, animal welfare and vitality; and
c) such substances:

- contribute to an appropriate diet fulfilling the physiological and behavioural needs of the species concerned;
- do not contain genetically engineered/modified organisms and products thereof; and
- are primarily of plant, mineral or animal origin.

Specific criteria for feedstuffs and nutritional elements

a) Feedstuffs of plant origin from non-organic sources can only be used, under the conditions of paragraphs 14 and 15, if they are produced or prepared without the use of chemical solvents or chemical treatment;
b) feedstuffs of mineral origin, trace elements, vitamins, or provitamins can only be used if they are of natural origin. In case of shortage of these substances, or in exceptional circumstances, chemically well-defined analogic substances may be used;
c) feedstuffs of animal origin, with the exception of milk and milk products, fish, other marine animals and products derived therefrom should generally not be used or, as provided by national legislation. In any case, the feeding of mammalian material to ruminants is not permitted with the exception of milk and milk products;

d) synthetic nitrogen or non-protein nitrogen compounds shall not be used;
e) probiotics, enzymes and microorganisms are allowed;
f) antibiotics, coccidiostats, medicinal substances, growth promoters or any other substance intended to stimulate growth or production shall not be used in animal feeding.
19. Silage additives and processing aids may not be derived from genetically engineered/modified organisms or products thereof, and may comprise only:

sea salt; coarse rock salt; yeasts; enzymes; whey; sugar or sugar products such as molasses; honey; lactic, acetic, formic and propionic bacteria, or their natural acid product when the weather conditions do not allow for adequate fermentation, and with the approval of the competent authority.

Specific Criteria for Additives and Processing Aids state that:

a) binders, anti-caking agents, emulsifiers, stabilizers, thickeners, surfactants, coagulants: only natural sources are allowed;
b) antioxidants: only natural sources are allowed;
c) preservatives: only natural acids are allowed;
d) colouring agents (including pigments), flavours and appetite stimulants: only natural sources are allowed;
e) probiotics, enzymes and microorganisms are allowed.

Organic Legislation

Although there is as yet no international accepted regulation on organic standards, the WTO and the global trading community are increasingly relying on the Codex, IFOAM and the International Organization of Standardization (ISO) to provide the basis for international organic production standards, as well as certification and accreditation of production systems. The ISO, which was established in 1947, is a worldwide federation of national standards for nearly 130 countries. The most important guide for organic certification is ISO Guide 65:1996, General Requirements for Bodies Operating Product Certification Systems, which establishes basic operating principles for certification bodies. The IFOAM Basic Standards and Criteria are registered with the ISO as international standards.

It is likely that exporting countries introducing organic legislation will target the requirements of the three large markets, i.e. the EU, the USA and Japan. Harmonization will promote world trade in organic produce. Discussions in a number of forums, including FAO, IFOAM and UNCTAD (the United Nations Conference on Trade and Development), have indicated that the plethora of certification requirements and regulations are considered to be a major obstacle for a continuous and rapid development of the organic sector, especially for producers in developing countries. In 2001, IFOAM, FAO and UNCTAD decided to join forces to search for solutions to this problem. Together they organized the Conference on International Harmonization and Equivalence in Organic Agriculture, in Nuremberg, Germany, in 2002. One of the key recommendations of the Conference was that a multi-stakeholder Task Force, including representatives of governments, FAO, UNCTAD and IFOAM, should be established in order to elaborate practical proposals and solutions. In response, the International Task Force on Harmonization and Equivalence in Organic Agriculture (ITF) was established in 2003. Its agreed aim was to act as an open-ended platform for dialogue between private and public institutions involved in trade and regulatory activities in the organic agriculture sector. Following its activities, the Task Force at its final meeting in 2008 reported on a guide for judging equivalence between organic standards for organic production and processing; and on a set of performance requirements for organic certification.

The Task Force documented the world situation in 2003 (UNCTAD, 2004), listing 37 countries with fully implemented regulations for organic agriculture and processing. The most recent statistics indicate that 181 countries now have organic activities, of which 93 have organic regulations (Willer and Lernoud, 2019).

The following is a brief description of the legislation in the main regions of organic dairy and beef production. Also included are countries that are important importers of organic beef or milk.

Regional legislation

Europe

This region was the first to introduce rules and regulations relating to organic food production and it is now the most important in terms of the size and growth of the organic livestock sector. Under the regulations, each Member State in the European Union is required to establish a National Competent Authority to ensure adherence to the legislation. The various European governments have taken quite different approaches to how organic livestock production should be regulated and this difference persists to the present. In addition, within each European country the different certifying bodies adopted different positions. The end result is a wide variety of standards on organic livestock across Europe. However, every certifying body in Europe must adhere to standards that at a minimum meet the EU organic legislation (a legal requirement).

Legislation to govern the production and marketing of food as organic within the EU was introduced in 1991 (European Commission, 1991: EU Regulation 2092/91). This regulation defined organic farming, set out the minimum standards of production and defined how certification procedures must operate. Regulation 2092/91 was supplemented by various amendments, and in 1999 by a further Regulation (European Commission, 1999: No. 1804/1999) covering livestock production. An important feature of the new regulations was a list of approved feedstuffs (detailed in Chapter 4). In addition to organic production and processing within the EU, the Regulation also covered certification of produce imported from outside the EU.

Regulation EC 1804/1999 allowed the range of products for livestock production to be extended and it harmonized the rules of production, labelling and inspection. It reiterated the principle that livestock must be fed on grass, fodder and feedstuffs produced in accordance with the rules of organic farming. The regulation set out a detailed listing of approved feedstuffs. However, it recognized that under the prevailing circumstances, organic producers might experience difficulty in obtaining sufficient quantities of feedstuffs for organically reared livestock. Accordingly, a modification to the regulation allowed for authorization to be granted provisionally for the use of limited quantities of conventional (non-organically produced) feedstuffs where necessary. For cattle this modification was allowed only up to 2007.

In addition, an important provision of these regulations was to permit the use of trace minerals and vitamins as feed additives to avoid deficiency situations. The approved products were of natural origin or synthetic in the same form as natural products. Other products listed in Annex II, Part D, sections 1.3 (enzymes), 1.4 (microorganisms) and 1.6 (binders, anti-caking agents and coagulants) were also approved for feed use. Roughage, fresh or dried fodder, or silage was required to be included in the daily ration but the proportion was unspecified in EC 1804/1999.

EU regulation 2092/91 was revised in 2007 and a new organic regulation (EC No. 834/2007) was introduced for implementation on 1 January 2009 (European Commission, 2007). The new regulation did not change the list of authorized substances for organic farming. This revision followed from a review intended to define more explicitly the objectives, principles and rules applicable to organic production, in order to contribute to transparency and consumer confidence as well as to a harmonized perception of the concept of organic production. It recognized that livestock production was fundamental to the organization of agricultural production on organic holdings in that it provided the necessary organic matter and nutrients for cultivated land and accordingly contributed towards soil improvement and the development of sustainable agriculture. A provision of the legislation was that at least 50% of the feed should come from the farm unit itself or from other organic farms primarily in the same region.

Specific principles applicable to the processing of organic feed were also set out, in addition to the overall principles set out in Article 4. They specified that the production of organic feed was to be from organic feed materials, except where a feed material was not available on the market in organic form. They also placed a restriction on the use of feed additives and processing aids to a minimum extent and only in case of essential technological or zootechnical needs or for particular nutritional purposes. In addition, they specified that organic livestock had to be born and raised on organic holdings.

In regard to feed, the principles stated that feed for livestock should primarily be obtained from the holding where the animals were kept or from other organic holdings in the same region, and that livestock should be fed on organic feed that met the animal's nutritional requirements at the various stages of its development. With the exception of bees, livestock were to have permanent access to pasture or roughage. Non-organic feed materials from plant origin, feed materials from animal and mineral origin, feed additives, certain products used in animal nutrition and processing aids could be used only if they had been authorized for use in organic production under Article 16. Growth promoters and synthetic amino acids could not be used, and suckling mammals were to be fed on natural, preferably maternal, milk. It was recognized that certain feed additives and processing aids were necessary to maintain animal health, animal welfare and vitality and contribute to an appropriate diet fulfilling the physiological and behavioural needs of the species concerned or to produce or preserve such feed. In principle, feed of mineral origin, trace elements, vitamins or provitamins should be of natural origin. However, in the event that such substances were unavailable, chemically well-defined analogical substances could be authorized for use in organic production. Only products composed of substances listed in Annex I or Annex II were authorized as feedstuffs, feed materials, compound feeds, feed additives or other substances used in animal nutrition. No genetically modified organisms and/or any product derived from such organisms could be used, with the exception of veterinary medicinal products.

The revised regulations specified that feed was intended to ensure quality production rather than maximizing production, while meeting the nutritional requirements of the livestock at various stages of their development. Fattening practices were authorized in so far as they were reversible at any stage of the rearing process. Force-feeding was forbidden.

The feeding of young mammals had to be based on natural milk, preferably maternal milk. All mammals had to be fed on natural milk for a minimum period, depending on the species concerned, which was 3 months for bovines.

Rearing systems for herbivores were to be based on maximum use of pasturage according to the availability of pastures in the different periods of the year. The revised regulations specified that at least 60% of the dry matter in the daily ration was to consist of roughage, fresh or dried fodder, or silage. However, the inspection authority or body could permit a reduction to 50% for dairy cows for a maximum period of 3 months in early lactation.

By way of derogation from paragraph 8.3.1, the final fattening phase of cattle (and pigs and sheep) for meat production could take place indoors, provided that this indoor period did not exceed one-fifth of their lifetime and in any case for a maximum period of 3 months.

In 2018 the Council adopted new EU rules on organic production and the labelling of organic products, to encourage the sustainable development of organic production in the EU (Regulation (EU) 2018/ of the European Parliament and of the Council of 30 May 2018 on organic production and labelling of organic products and repealing Council Regulation (EC) No. 834/2007). The new rules were also aimed at guaranteeing fair competition for farmers and operators, preventing fraud and unfair practices and improving consumer confidence in organic products. Effective from 1 January 2021 some of the relevant changes are as follows.

- Production rules will be simplified and further harmonized through the phasing out of a number of exceptions and derogations.
- The control system will be strengthened due to tighter precautionary measures and robust risk-based checks along the entire supply chain.
- Producers in third countries will have to comply with the same set of rules of those producing in the EU.

A consolidated document (EU 02008R0889 EN 07.01.2020 017.001) was published by the EU Commission in 2020. It listed all relevant documents describing the rules for the implementation of Council Regulation (EC) No. 834/2007 on organic production and labelling of organic products with regard to organic production, labelling and control (European Commission, 2020).

North America

USA. The National Organic Program (NOP) was introduced in the USA in 2002 (NOP, 2002).

This is a federal law that requires all organic food products to meet the same standards and be certified under the same certification process. The law requires 'that organically raised livestock receive access to the outdoors and have the ability to engage in physical activity appropriate to their needs'. It also requires that cattle raised for meat production must be under fully organic management beginning no later than the third trimester of gestation. Livestock used as breeding stock may be obtained from a non-organic operation. They must be managed organically, and while they may be used to produce organic offspring, the breeding animals themselves may not be sold as organic slaughter stock. Dairy animals must be maintained under organic management for a minimum of 1 year prior to their milk or milk products being sold, represented or used as organic.

A major difference between the US and European standards is that the organic standards in the USA have been harmonized under the NOP. States, non-profit organizations, for-profit certification groups and others are prohibited from developing alternative organic standards. All organic food products must be certified under the National Organic Standards (NOS). Organic producers must be certified by NOP-accredited certification agencies. All organic producers and handlers must implement an Organic Production and Handling System Plan that describes the practices and procedures that the operation utilizes to comply with the organic practice standards. Both state agencies and private organizations may be NOP accredited. The NOS establishes the National List, which includes feed ingredients. It allows all non-synthetic (natural) materials unless specifically prohibited and prohibits all synthetic materials unless specifically allowed. A difference between US and EU regulations affecting feedstuffs is that no derogations are sanctioned under the NOP.

Under the NOP, 'livestock shall graze pasture during the months of the year when pasture can provide edible forage. The Organic System Plan shall have the goal of providing grazed feed greater than 30% dry matter intake on a daily basis during the growing season but not less than 120 days.'

Section 205.237 refers to livestock feed, stipulating that:

a. The producer of an organic livestock operation must provide livestock with a total feed ration composed of agricultural products, including pasture and forage, that are organically produced and, if applicable, organically handled: Except, that, nonsynthetic substances and synthetic substances allowed under 205.603 may be used as feed additives and supplements.

b. The producer of an organic operation must not:

1. Use animal drugs, including hormones, to promote growth;
2. Provide feed supplements or additives in amounts above those needed for adequate nutrition and health maintenance for the species at its specific stage of life;
3. Feed plastic pellets or roughage;
4. Feed formulas containing urea or manure;
5. Feed mammalian or poultry slaughter by-products to mammals or poultry; or
6. Use feed, feed additives, and feed supplements in violation of the Federal Food, Drug, and Cosmetic Act. As feed supplements – Milk supplements without antibiotics, as emergency use only, no non-milk products or products from BST treated animals.

Section 205.603 covers synthetic substances allowed for use in organic livestock production. In accordance with restrictions specified in this section the following synthetic substances may be used in organic livestock production:

2. Trace minerals, used for enrichment or fortification when FDA approved.

3. Vitamins, used for enrichment or fortification when FDA approved.

Under a 2018 amendment certain injectable vitamins, minerals and electrolytes can be used, when administered or ordered by a licensed veterinarian.

CANADA. The Canadian Organic Products Regulations came into force on 30 June 2009, in response to requests by organic groups to develop a regulatory system for organic products to address consumer protection and domestic and international market access issues. Previously, several provinces had their own regulations. The national regulations were introduced by the Government of Canada after submission to the World Trade Organization (WTO) and after a 75-day comment period by industry. Thus the situation is similar to that in the USA and unlike that of Europe. The regulations cover food and drink intended for human consumption, feed intended for livestock (including agricultural crops used for this purpose), and also the cultivation of plants.

A Canada and USA Equivalency Agreement came into effect in 2009, recognizing a common approach to organic agricultural production. The official agencies involved are the United States Department of Agriculture (USDA) and the Canadian Food Inspection Agency (CFIA).

Feed for organic animals must meet the Canadian Organic Standard and be certified. As in the NOP, no complete list of permitted feed ingredients is currently available. Crops grown for organic feed and pasture managed for organic animals to graze must meet certified organic production standards. The components of organic feed must be organically produced and handled. This latter rule may be difficult to implement. The Canadian General Standards Board (2006) published an Organic Production Systems Permitted Substances List, which contained a brief listing of feeds, feed additives and feed supplements approved for livestock production. One provision in the List requires that 'vitamins shall not be derived from organisms from genetic engineering'. The difficulty with that provision is that most or all of the vitamins used for feed supplementation in most countries are from GM sources.

MEXICO. Mexico's Organic Products Law and regulations for organic production were implemented in April 2017. These regulations require all organic products sold in Mexico to be certified under the Mexican organic standards or to a standard that has been deemed equivalent under an organic equivalency arrangement. The USDA, CFIA and the Mexican National Service for Animal and Plant Health, Food Safety and Quality (SENASICA) are currently working on an organic equivalency agreement.

South America

IFOAM has established a regional initiative for Latin America and the Caribbean – El Grupo de America Latina y el Caribe (GALCI) – coordinated from an office in Argentina. Currently, GALCI represents 59 organizations from countries throughout Latin America and the Caribbean, including producers' associations, processors, traders and certification agencies. The purpose and objectives of GALCI include the development of organic agriculture throughout Latin America and the Caribbean.

ARGENTINA. In 1992, Argentina was the first country in the Americas to establish standards for the certification of organic products equivalent to those of the EU and validated by IFOAM. Argentinian organic products are admissible in the EU and the USA. Organic livestock and poultry production in Argentina is governed by the National Service of Agricultural Food Health and Quality (SENASA – Servicio Nacional de Sanidad y Calidad Agroalimentaria), a government agency under the Ministry of Agriculture through Resolution No. 1286/93 and also by the EU Resolution No. 45011. In 1999, the National Law on Organic Production (No. 25127) came into force with the approval of the Senate. This law prohibits marketing of organic products which have not been certified by a SENASA-approved certifying agency. Each organic certification agency must be registered with SENASA.

BRAZIL. In 1999, the Ministry of Agriculture, Livestock and Food Supply (MAPA) published the Normative Instruction #7 (NI7) based on Codex principles. It established national standards for the production and handling of organically produced products, including a list of substances approved for and prohibited from use in organic production. The NI7 defines organic standards for production, manufacturing, classification, distribution, packaging, labelling, importation, quality control and certification, of products of both animal and plant origin. The policy also establishes rules for companies wishing to be accredited as certifying agencies, which enforce the NI7 and certify production and operations under the direction of the Orgao Colegiado Nacional (National Council for Organic Production).

CHILE. Chilean national standards came into effect in 1999 under the supervision of SAG (Servicio Agrícola y Ganadero), which is the counterpart of the PPQ (Plant Protection and Quarantine) branch of the USDA. The standards are based on IFOAM standards.

Australasia

AUSTRALIA. Organic production in Australia has been protected by legislation since 1992. This country is now the greatest producer of organic foods. The organic legislation covers crop production, animal husbandry, food processing, packaging, storage, transport and labelling. The Australian National Standard for Organic and Biodynamic (an agricultural system that introduces specific additional requirements to an organic system) Produce was first implemented in 1992 as the Australian Export Standard for products labelled organic or biodynamic. It was later amended in 2005 (edition 3.1; AQIS, 2005) and in 2007 (edition 3.3; AQIS, 2007); and more recently in 2016 (edition 3.7; OISCC, 2016). The Standard is issued by the Organic Industry Export Consultative Committee of the Australian Quarantine and Inspection Service (AQIS). The Standard provides a nationally agreed framework for the organic industry covering production, processing, transportation, labelling and importation. Certifying organizations which have been accredited by the Australian competent authority apply the Standard as a minimum requirement to all products produced by operators certified under the inspection system. This Standard therefore forms the basis of equivalence agreements between approved certifying organizations and importing country requirements. Individual certifying organizations may stipulate additional requirements to those detailed in the Standard.

The Standard appears to be similar to European standards in relation to permitted feed ingredients, feed supplements of agricultural origin having to be of certified organic or biodynamic origin. However, a derogation allows that, if this requirement cannot be met, the approved certifying organization may allow the use of product that does not comply with the Standard provided that it is free from prohibited substances or contaminants and it constitutes no more than 5% of the animal diet on an annual basis. Permitted feed supplements of non-agricultural origin include minerals, vitamins or provitamins only if from natural sources. Treatment of animals for trace mineral and vitamin deficiencies is subject to the same provision of natural origin. Animal nutritionists will regard with some scepticism the requirement that 'The use of trace elements must be on the basis of a demonstrated deficiency', since this could lead to animal suffering. Amino acid isolates (pure amino acids) are not permitted in organic diets.

These national standards are used to determine equivalence of imported and domestically produced organic products, and are those applied for accreditation. Certification bodies wishing to become accredited to these standards must apply to the Australian Quarantine and Inspection Service, the competent authority consenting to such accreditations. Seven Australian certification bodies had obtained government accreditation by the end of the year 2000. Of these seven certification bodies, five can export to the EU as provided for under Article 11 of EU Regulation 2092/91; however, all seven can export to non-European countries such as Canada, Japan, Switzerland and the USA. Only one national certification body, the National Association for Sustainable Agriculture, is accredited by IFOAM. At present there are no foreign certification bodies working within Australia, and no local certification bodies work in association with international certification bodies.

The legislation does not mandate that every farm labelling or selling organic produce must be certified; it is only implemented for the export of products derived from agriculture and labelled as organic. Thus the Australian organic regulations may be stronger in their application to export standards than to the standards for domestic products. The Australian Consumers' Association called for the Federal Government to issue new guidelines to prevent incorrect labelling and possible consumer fraud (Lawrence, 2006). In response, Australian Standard AS 6000 Organic and Biodynamic Products stipulates the minimum requirements for products placed on the market with labelling that states or implies they have been produced under organic or biodynamic systems. Miscellaneous Publication MP 100 Procedures for Certification of Organic and Biodynamic Products provides detailed information on the certification procedures for organic and biodynamic products. AS 6000 and MP 100 are intended to be used together, with the Miscellaneous Publication to be used as a reference document for those involved within the scope of certification procedures for organic and biodynamic products. The MP therefore forms the basis for demonstrating equally reliable organic and biodynamic product certifications to meet domestic and importing country requirements. The MP also enables operators producing organic and/or biodynamic products to interpret the certification process.

NEW ZEALAND. Revised regulations on organic farming were issued by the New Zealand Food Safety Authority, Ministry of Agriculture and Forestry, in 2011 (NZFSA, 2011: MAF Standard OP3, Appendix Two: NZFSA Technical Rules for Organic Production, Technical Rules Version 7.1). The regulations had previously been issued initially based on the relevant EU Regulation with an amendment to incorporate the US National Organic Standard requirements. The regulations set out the minimum requirements for organic production, and operators are allowed to adopt higher standards. The regulations show similarities to European and North American standards, as could be predicted from their origin, and appear to be designed to allow export of organic product to European, Japanese and US markets.

One interesting section of the revised regulations is a clarification of the term GM.

3.1.8 Genetically modified organism (GMO) means, unless expressly provided otherwise by regulations, any organism in which any of the genes or other genetic material:
(a) Have been modified by *in vitro* techniques; or
(b) are inherited or otherwise derived, through any number of replications, from any genes or other genetic material which has been modified by *in vitro* techniques.
1. Organisms not to be regarded as genetically modified:

a. Organisms that result solely from selection or natural regeneration, hand pollination, or other managed, controlled pollination;

b. Organisms that are regenerated from organs, tissues, or cell culture, including those produced through selection and propagation of somaclonal variants, embryo rescue, and cell fusion (including protoplast fusion or chemical or radiation treatments that cause changes in chromosome number or cause chromosome rearrangements);

c. Organisms that result solely from artificial insemination, super ovulation, embryo transfer, or embryo splitting;

d. Organisms modified solely by: (i) The movement of nucleic acids using physiological processes, including conjugation, transduction and transformation; and (ii) Plasmid loss or spontaneous deletion;

e. Organisms resulting from spontaneous deletions, rearrangements, and amplifications within a single genome, including its extra chromosomal elements.

2. Despite anything in subclause (1)(d), if nucleic acid molecules produced using *in vitro* manipulation are transferred using any of the techniques referred to in subparagraph (i) or subparagraph (ii) of subclause (1)(d), the resulting organism is a genetically modified organism (Hazardous Substances and New Organisms Act, 1996).

Stocking rates are specified in the regulations, and also space requirements, mainly in relation to manure-spreading on land.
Regulations on feed include the following.

6.4 Feed
6.4.1 Details under this heading are set out so that operators using feeds know what the requirements are on operators in an EU situation. More normal New Zealand pastoral grazing avoids most of the requirements. Only feed materials authorized for use in terms of New Zealand legislation may be used.
6.4.2 Feed is intended to ensure quality production rather than maximizing production, while meeting the nutritional requirements of the animals at various stages of their development. Fattening practices are authorized in so far as they are reversible at any stage of the rearing process. Force-feeding is not permitted.
6.4.3 Animals must be fed on organically produced feeds.
6.4.4 Furthermore, animals must be reared in accordance with these Rules, using feed from the unit or, when this is not possible, using feed from other units or enterprises complying with these Rules. For herbivores, at least 50% of the feed shall come from the organic unit itself, except when the animals are under transhumance (high-country grazing).
6.4.5 During transhumance, animals may graze on non-organic land while they are being moved on foot from one grazing area to another. This grazing shall not exceed 10% of the total feed ration per year, calculated as a percentage of the dry matter of feed stuffs from agricultural origin.

Animal Products

6.4.6 Up to 30% of the feed formula of rations on average may comprise in-conversion feeds. When the in-conversion feeds come from the organic unit, this percentage can be increased to 60%.
6.4.7 The feeding of young mammals must be based on natural milk, preferably maternal milk. All mammals must be fed on natural milk for a minimum period, depending on the species concerned:

- 3 months for bovines (including *Bubalus* and bison species).

TPAs (Third Party Agencies) may consider reduced periods where the rearing systems use supplementary feed in the form of fresh and dry grass as well as milk, in order to produce well reared, hardy livestock.

6.4.8 Where relevant, NZFSA, in consultation with the TPA, may designate areas or regions where movement of animals to high-country grazing areas is practicable, without prejudice to the provisions on the feeding of animals in this Section 6.
6.4.9 Rearing systems for herbivores are to be based on maximum use of grazing according to the availability of pastures in the different periods of the year. At least 60% of the dry matter in daily rations of herbivores is to consist of roughage, fresh or dried fodder, or silage. Nevertheless, the TPA can permit a reduction to 50% for animals in dairy production for a maximum period of 3 months in early lactation.
6.4.10 The TPA may, with NZFSA approval, authorize a limited proportion of conventional feed of agricultural origin where organic feed is not available on the market, and it is necessary to ensure access to feed. Such exceptions shall be kept to a minimum, and should be limited in time.

The maximum percentage of conventional feed authorized for both herbivores and non-herbivores in the daily ration is 25% calculated as a percentage of the dry matter.

6.4.11 When forage production is lost NZFSA can authorize the use of conventional feeds for a limited period and in relation to a specific area. This exception may be used as a result of adverse climatic conditions or other exceptional conditions.

6.4.13 Only products listed in Tables 3.4.5 and 3.6.1, respectively, can be used as additives and processing aids in silage.
6.4.14 Conventional feed materials of agricultural origin can be used for animal feeding only if listed in Table 3.1, subject to the quantitative restrictions imposed in this Section 6, and only if they are produced or prepared without the use of chemical solvents.
6.4.15 Feed materials from animal origin (whether conventional or organically produced) can only be used if listed in Table 3.2, and subject to the quantitative restrictions imposed in this Section 6.
6.4.16 In order to satisfy the nutritional requirements of animals, only products listed in Table 3.3, Table 3.4.1 and Table 3.4.2 can be used for animal feeding.
6.4.17 Only products listed in Table 3.4.3, Table 3.4.4, Table 3.4.5, Table 3.4.6, Table 3.4.7, Table 3.5 and Table 3.6 can be used in animal feeding for the purposes indicated in respect to the above-mentioned categories. Antibiotics, coccidiostatics, medicinal substances, growth promoters or any other substance intended to stimulate growth or production shall not be used in organic animal feeding.
6.4.18 Feeds, feed materials, compound feeds, feed additives, processing aids for feeds and certain products used in animal nutrition must not have been produced with the use of genetically modified organisms or products derived from GMOs.

One very useful feature of the regulations is the inclusion of a detailed list of permitted feed ingredients (see Chapter 4). More countries should follow the New Zealand example. The minerals and trace elements used in animal feeding have to be of natural origin or, failing that, synthetic in the same form as natural products. Synthetic vitamins identical to natural vitamins are allowed.

6.8.8 Subject to the provisions in 6.5.4, all mammals must have access to grazing or an open-air exercise area or an open-air run which may be partially covered, and they must be able to use those areas whenever the physiological condition of the animals, the weather conditions and the state of the ground permit, unless there are requirements relating to specific animal health

problems that prevent this. Herbivores must have access to grazing whenever conditions allow.
6.8.9 In cases where herbivores have access to pasture for grazing and where the winter-housing system gives freedom of movement to the animals, the obligation to provide open-air exercise areas or open-air runs during the winter months may be waived.
6.8.10 Notwithstanding the last sentence of 6.8.8, bulls over 1 year old must have access to grazing or an open-air exercise area or an open-air run.
6.8.11 The final fattening phase of adult bovines for meat production may take place indoors, provided that this indoors period does not exceed one fifth of their lifetime, and in any case for a maximum period of 3 months.

Asia

CHINA. The Organic Food Development Center (OFDC) of China is part of its State Environmental Protection Administration. Established in 1994, it has implemented the largest organic certification programme in China. Its standards are based on the IFOAM norms (http://www.ofdc.org.cn accessed 10 April 2020).

This has since been superseded by publication of an official 'National Standard of the People's Republic of China' (GB/T 19630.1–19630.4-2005), which came into effect in 2005. The Standard resembles in part the IFOAM standards but contains some unique features.
8.2 Introduction of Animals and Poultry
8.2.4 All introduced animals must not be contaminated by products of genetic-engineering products, including breeding products, pharmaceuticals, metabolism regulating agents and biological agents, feeds or additives.
8.3 Feeds
8.3.1 Animals must be raised with organic feed and forage which has been approved by the national organic agency (OFDC) or by an OFDC-certified agency. Of the organic feed and forage, at least 50% must originate from the individual farm or an adjacent farm.
8.3.4 The certification committee allows the farm to purchase regular (conventional) feed and forage during a shortage of organic feed. Daily maximum intake of conventional feed intake cannot exceed 25% of the total daily feed intake on a dry matter basis. Exemptions due to severe weather and disasters are permitted. Detailed feed records must be kept and the conventional feed must be OFDC-approved.
8.3.6 The number of animals cannot exceed the stocking capacity of the farm.
8.4 Feed Additives
8.4.1 Products listed in Appendix D are allowed to be used as additives.
8.4.2 Natural mineral or trace mineral ores such as magnesium oxide and green sand are allowed. When natural mineral or trace mineral sources cannot be provided, synthesized mineral products can be used if they are approved by OFDC.
8.4.3 Supplemental vitamins shall originate from germinated grains, fish liver oil, or brewing yeast. When natural vitamin sources cannot be provided, synthesized vitamin products can be used if they are approved by OFDC.
8.4.4 Chemicals approved by OFDC in Appendix D are allowed to be used as additives.
8.4.5 Prohibited ingredients include synthesized trace elements and pure amino acids.
8.5 Complete Feed
8.5.1.1 All the major ingredients in the complete feed must be approved by OFDC or an agency certified by OFDC. The ingredients plus additive minerals and vitamins cannot be less than 95% of the complete feed.
8.5.1.2 Additive minerals and vitamins can be derived from natural or synthesized products, but the complete feed cannot contain prohibited additives or preservatives.
8.5.2 The complete feed must meet the requirements of animals (or poultry) for nutrients and feeding goals.
8.6 Feeding Conditions
8.6.3 All animals must be raised outdoors during at least part of the year.
8.6.4 It is prohibited to feed animals in such a way that they do not have access to soil, or that their natural behaviour or activity is limited or inhibited.
8.6.5 The animals cannot be fed individually, except adult males or sick animals.

JAPAN. The Japanese Agricultural Standards (JAS) (MAFF, 2001) for organic agricultural production are based on the Codex guidelines for organic agriculture. Initially they related to plant products only but were supplemented with livestock standards in 2006 (MAFF, 2006). The

2006 standards defined the criteria relating to the production methods for organic livestock products, including approved feed categories. The list of approved feeds includes organic feeds and feed produced 'in-house' for organic livestock: natural substances or substances derived from natural substances; and, interestingly, silkworm-pupa powders (other than those irradiated or produced by recombinant DNA technology).

Revised labelling standards were introduced in 2008.

Since April 2001, the Japanese standards have required that organic products sold in Japan conform to the JAS organic labelling standard. NOP standards meet the JAS guidelines, allowing the importation of US organic products. Under new regulations, organic certification bodies are required to be registered (accredited) with MAFF and are now called Registered Certification Organizations (RCOs).

Countries whose Organic Rules and Standards are approved as being equivalent with the Organic JAS System in relation to specified agricultural and forestry products, organic agricultural products and organic agricultural processed foods include Ireland, the USA, Argentina, Italy, the UK, Australia, Austria, the Netherlands, Greece, Switzerland, Sweden, Spain, Denmark, Germany, New Zealand, Finland, France, Belgium, Portugal and Luxembourg. However, the equivalence agreements do not yet apply to organic livestock products, organic livestock processed foods, organic agricultural and livestock processed foods and organic livestock feeds.

REPUBLIC OF KOREA (SOUTH KOREA). Organic agriculture in Korea is generally defined as agricultural production without the use of synthetically produced chemicals (GAIN Report, 2005). The mandatory certification of environmentally friendly agriculture products was introduced in 2001 (UNESCAP, 2002), in accordance with Codex standards. Regulations for fresh organic produce and grains were implemented by the Ministry of Agriculture and Forestry (MAF) in 2005 and regulations affecting livestock were implemented by the Korean Food and Drug Administration (KFDA) (GAIN Report, 2005). The Korean national certification programme is regulated by two different agencies. Certification, labelling and standards for fresh produce and grains are regulated by the Ministry of Agriculture (National Agricultural Products Quality Management Service (NAQS)), and the equivalent procedures for processed organic products are handled by the Korean Food and Drug Administration (KFDA).

Other countries

In most developing countries, there are no markets for certified organic products. In some countries, however, organic urban markets are developing. Expanding demand for organic foods in developed countries is expected to benefit developing country exports by providing new market opportunities and price incentives, especially for tropical and out-of-season produce. Developing country exporters, however, will need to meet the production and certification requirements in developed countries and develop consumer preferences for imported produce.

Impact

These international guidelines, regulations and standards have a strong impact on national standards. It seems clear that convergence or harmonization of these regulations will occur as the market for organic products grows and countries seek to export to others. One requirement not included in any of the standards is a requirement for periodic testing of organic products to ensure authenticity. While research on identifying a possible test to ensure the authenticity of organic feeds and foods would be welcomed by some sectors of the organic industries, to date no such test has been derived.

A comparison of the above standards shows that many of the aims and requirements are similar. These requirements are likely to have the following impact on the cattle producer, if the producer wishes to comply with the letter and spirit of the regulations.

- Organic feedstuffs have to be used. Restrictions include no GM grain or grain by-products; no grain by-products unless produced from certified organic crops; no antibiotics, hormones or drugs; no animal slaughter by-products; no chemically extracted feeds (such as solvent-extracted soybean meal); and no pure amino acids. Feedstuffs should be produced on the farm or at least in the region. This requirement has particular relevance to regions such as Northern Europe, which does not have the climate that allows self-sufficiency in protein needs. A seasonal production pattern may be a necessary outcome of this requirement in some regions.

- The stock should be indigenous or acclimatized to the farm or region. Thus traditional, unimproved breeds and strains are preferred over genetically improved hybrids, raising questions over the appropriate nutrient requirements of such stock.
- The size of the herd is generally limited by the amount of land for manure application.
- Stock should produce well in outdoor conditions, therefore it has to be hardy and healthy. In addition, cold conditions can be expected to increase nutritional needs.
- Health of the stock may be compromised because of the restrictions on treatments for disease outbreaks, or the animals may have to be removed from organic status. Also a strict adherence to a policy of no synthetic feed supplements may lead to instances of vitamin and trace mineral deficiencies. Reliance on forage and sunlight to provide all of the required vitamins and minerals is not supported by scientific evidence.

An important point that should be noted is that the organic regulations do not take precedence over existing food laws. For example, in North America organic milk – like conventional milk – must comply with all legal requirements, including pasteurization and fortification with vitamin D. White flour has to comply with similar fortification requirements.

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3

Elements of Cattle Nutrition

Like all animals, cattle require five components in their diet as a source of nutrients. These are energy, protein, minerals, vitamins and water. A nutrient shortage or imbalance in relation to other nutrients may adversely affect growth and production.

Digestion and Absorption of Nutrients

A summary outline of digestion and absorption in cattle follows. This provides a basic understanding of how the feed is digested and the nutrients are absorbed. Readers interested in a more detailed explanation of this topic should consult a recent text on cattle nutrition or digestive physiology.

Cattle, being ruminants, differ from other farm animals such as pigs in that they ruminate or 'chew the cud'. They have the ability to regurgitate ingested feed boluses from the stomach area back into the mouth for further chewing and grinding. Chewing the cud helps reduce feed particle size and mixes saliva into the feed to assist in swallowing. In comparison with pigs they have no upper canine teeth or incisors, and have long, thick and rough tongues that are designed to optimize the prehension of forage. In addition, cattle possess a stomach compartment called a rumen, a fermentation organ populated by microorganisms that attack and break down the relatively indigestible feed components.

Digestion is the preparation of ingesta for absorption, i.e. reduction of feed particles in size and solubility by mechanical and chemical means. Chemical breakdown is achieved by enzymes secreted in digestive juices and by gut microflora.

As in other farm animals, the alimentary system of cattle is composed of a mouth, tongue, teeth, oesophagus, stomach, a small and large intestine, ancillary organs and a rectum (Fig. 3.1). However, the stomach section is more complicated, comprising a reticulum, rumen, omasum and abomasum (true stomach). This modification of the digestive system is an adaptation to a diet high in fibrous feedstuffs such as forage. The modification allows for the intake, microbial digestion and regurgitation of large quantities of forage prior to digestion by the animal. Chewing and regurgitation reduce the particle size of the ingested material, which is then exposed to further breakdown by microbes in the rumen. In this way cattle achieve a high level of predigestion before the ingested feed enters the true stomach, with around 60–75% of ingested material being broken down before the ingested material (ingesta) enters the true stomach.

Mouth

The feed bolus is ingested and chewed in the mouth, then passed to the oesophagus. This section of

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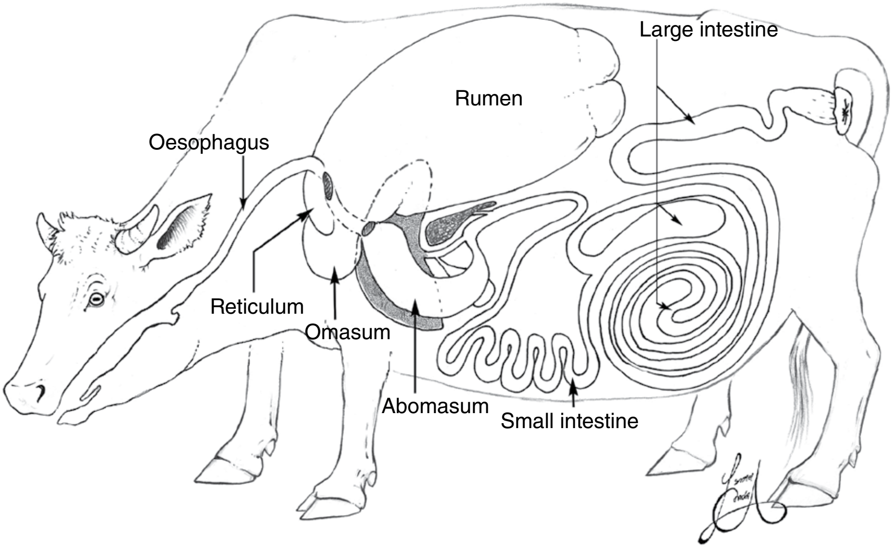

Fig. 3.1. Diagram of the alimentary system of cattle.

the gastrointestinal tract is able to move ingesta in both directions. Salivary glands in the mouth of the adult animal secrete saliva at the rate of about 45 l/day, with a pH of about 8.2. Saliva helps the transfer of ingested material from the mouth via the oesophagus to the next part of the digestive system, the reticulum. Saliva also helps to reduce the acidity in the rumen.

Reticulo-rumen

The reticulum and rumen are often considered together since the two compartments are separated by a low partition. The reticulo-rumen comprises 80% of the capacity of the stomach region.

The reticulum (tripe) is a flask-shaped compartment with a ‘honeycomb’ appearance on its inner surface. It moves ingesta into the rumen and the omasum. The reticulum also allows the regurgitation of ingesta during rumination and acts as a collection compartment for foreign objects. The contents of the reticulum and rumen intermix freely. The rumen is a large fermentation chamber (in adult cattle about 125 l) in which a large population of microorganisms (mainly bacteria and protozoa) attacks and breaks down the relatively indigestible feed particles by secreting enzymes necessary for cellulose degradation. In addition, these organisms synthesize nutrients such as B-complex vitamins and essential amino acids which become available to the animal when the microorganisms die and are digested.

The rumen together with the omasum absorbs the by-products of microbial fermentation. These are volatile fatty acids (VFAs), mainly acetic, propionic and butyric acids, which collectively provide most of the animal’s energy needs. Venous blood from the reticulo-rumen and the abomasum carries these absorbed nutrients into the portal vein and hence to the liver. The proportion of VFAs varies with diet, although the major product is always acetic acid. A high proportion of this fatty acid is important for milk fat synthesis. With a diet high in fibre, the molar ratio of acetic to propionic to butyric acids is about 70:20:10.

The rumen is not functional at birth and only becomes functional once the calf begins to eat fibrous feed. It is fully functional once the calf is about 3 months of age.

Omasum

After fermentation in the reticulum and rumen the ingesta pass to the omasum, which acts as a filter to separate liquid and fine feed particles from the larger particles that are not allowed to enter the abomasum. The omasum, or ‘manyplies’, contains numerous laminae (leaves of tissue) that help grind ingesta. These folds assist in the removal of fluid from the ingesta on their way to the abomasum.

The omasum may be the site for absorption of water, minerals and nitrogen.

Abomasum

This compartment corresponds to the stomach of non-ruminant animals such as pigs and is the true stomach, with a glandular lining. In the newborn calf, it makes up about 80% of the total stomach volume, while in the mature cow it amounts to only about 10%.

The abomasum secretes the gastric juices which aid in digestion. The pH of the abomasal contents is normally in the range of 2.0 to 2.5, owing to secretion of hydrochloric acid (HCl). This low pH facilitates initial breakdown of protein. The gastric juices contain several enzymes, principally pepsin, which act to break down protein to smaller units (peptides). Pepsin can function only in an acid medium ($pH < 3.5$), acidity being provided by the HCl. The acidic conditions allow minerals ingested with the feed, such as calcium salts, to dissolve and in addition they inactivate pathogenic organisms as well as killing off the microorganisms produced in the rumen. Mucus is released by the stomach to protect the stomach wall from acid damage. A small amount of lipase present in gastric juice initiates the digestion of fat in the abomasum. In nursing calves, the gastric juice also includes the enzyme rennin, which breaks down the protein in milk.

Stomach of the newborn calf

Calves at birth are not functional ruminants. At this stage the rumen is very small and undeveloped. As a result, digestion in the young calf is more like that of the pig.

Newborn calves for a short time after birth (up to 36 h) possess the ability to absorb large molecules via an oesophageal groove. This is important in that it allows newborn calves to receive immunoglobulin from colostrum (first milk from a nursing cow), which provides some immunity against diseases in the environment until active immunity is functional.

During the suckling process, impulses from the brain send messages to the oesophageal groove, causing the sides of the groove to curve upwards and form a tube. It allows a direct flow of milk into the abomasum and secretion of the enzyme rennin from the wall of the abomasum, causing the milk to coagulate or curdle. This slows the passage of milk through the abomasum, allowing ample time for the milk to be digested. As the calf gets older and starts to take in solid feed, the rumen begins to develop. This development is aided by the production of VFAs. By the end of the 4th week, the calf should be able to utilize some grain and high-quality hay.

Small intestine

The small intestine is the location where final digestion of the ingesta occurs and absorption takes place.

The first part of this intestinal section is known as the duodenum. Here, glands produce an alkaline secretion which acts as a lubricant and also protects the duodenal wall against HCl entering from the abomasum. The pancreas (which is attached to the small intestine) secretes fluid containing bicarbonate and several enzymes (amylase, trypsin, chymotrypsin and lipase) that act on carbohydrates, proteins and fats. The duodenal wall also secretes enzymes which continue the breakdown process. A main difference between ruminant animals and non-ruminant animals (such as pigs and chickens) is that much of the dietary carbohydrate in ruminants is broken down to VFAs rather than glucose.

Bile synthesized by the liver passes into the duodenum via the bile duct. It contains bile salts which provide an alkaline pH in the small intestine and help to emulsify dietary fat to enhance its digestion and absorption.

As a result of these activities the ingested carbohydrates, protein and fats are broken down into small molecules. Muscles in the wall of the intestine regularly contract and relax, mixing the intestinal contents and moving them towards the large intestine.

Jejunum and ileum

Absorption also takes place in the second section of the small intestine, known as the jejunum, and in the third section, known as the ileum. Digestion and absorption are complete by the time the ingesta have reached the terminal end of the ileum. This area is therefore of interest to researchers studying nutrient bioavailability (relative absorption of a nutrient from the diet) since a comparison of dietary and ileal concentrations of a nutrient provides information on its removal from the gut during digestion and absorption.

Minerals and vitamins are not changed by enzymatic action. They dissolve in various digestive fluids and water and are then absorbed. Once the nutrients enter the bloodstream or lymph, they are transported to various parts of the body for vital body functions. Nutrients are used to maintain essential functions such as breathing, circulation of blood and muscle movement, replacement of worn-out cells (maintenance), growth, reproduction and secretion of milk (production).

The remaining ingesta, consisting of undigested feed components, intestinal fluids and cellular material from the abraded wall of the intestine, then pass to the next section of the intestine, the large intestine.

Large intestine

The large intestine (lower gut) consists of two parts: a sac-like structure called the caecum and the last section, called the colon. The colon is attached to the rectum. The caecum is small, with a capacity of about 1.5–2 l. Here the intestinal contents move slowly and no enzymes are added. Some microbial breakdown of fibre and undigested material may occur, but absorption is limited.

Remaining nutrients, dissolved in water, are absorbed in the lower part of the colon (about 9 l capacity). The nutritional significance of certain water-soluble vitamins and proteins synthesized in the large intestine is doubtful because of limited absorption in this part of the gut. The large intestine absorbs much of the water from the intestinal contents into the body, leaving the undigested material which is formed into the faeces and later expelled through the anus.

The entire process of digestion takes about 24–36 h.

Digestion of Carbohydrates

Plant tissues contain about 75% complex carbohydrates such as cellulose and provide the main source of energy for both the rumen microbes and the host animal. About 30–50% of the cellulose and hemicellulose (fibre) is digested in the rumen by the microbial population. At least 60% of the starch is degraded, depending on the amount fed and how fast the ingesta move through the rumen. Most sugars are 100% digested within the rumen.

During microbial digestion an appreciable amount of gas (mainly carbon dioxide and methane) is produced, representing about 6–7% of the feed energy of the ruminant. Under normal conditions, distension from gas formation in the rumen causes the cow to belch and eliminate the gas. Bloat can occur if the gas is not released.

As outlined above, the main end products of carbohydrate digestion are VFAs that are absorbed into the bloodstream through the rumen wall and represent 66–75% of the energy derived from the feed. When large amounts of forage are fed, the formation of acetic acid predominates (60–70% of total) with lower amounts of propionic (15–20%) and butyric (5–15%) acids. When grain feeding is increased or when finely ground forages are fed, the proportion of acetic acid may decrease to 40% and the proportion of propionic acid may increase to 40%.

One of the by-products of fermentation of carbohydrates to VFAs is hydrogen, which is converted to methane gas for release from the rumen. It has been shown that as the pattern of ruminal fermentation alters from acetate to mainly propionate, both hydrogen and methane production are reduced. This relationship between methane production and the ratio of the various VFAs has been well documented (Hungate, 1966). It explains why the feeding of fibrous diets results in more methane than less fibrous diets. The fibrous diets promote a higher proportion of acetate, resulting in more hydrogen and more methane. The situation was shown dramatically in a comparison of a dairy farm in Wisconsin with one in New Zealand (Johnson *et al.*, 2002). Production of methane from belching was higher in the New Zealand farm, while carbon dioxide production was higher in the Wisconsin farm. This aspect is becoming of increasing importance in relation to greenhouse gas production from agriculture. Methane is considered to have 21 times the global warming potential of carbon dioxide. Organic milk production inherently increases methane emission because of the feeding system used unless the forage is of good quality (De Boer, 2003).

Carbohydrates such as sugars and starches that escape digestion in the rumen are digested in the abomasum and the end products absorbed through the wall of the small intestine.

Although fibre is the most indigestible portion of the diet, it is necessary for the correct functioning of the ruminant gut. The amount and type of fibre in the diet can affect rumen function significantly, influencing the amount of rumination, saliva production, rumen pH and milk fat content. The optimal amount that should be included in the diet depends on several factors, including body condition, level of production, type of fibre fed and physical characteristics of the fibre. This topic will be covered in Chapter 6. In general, dairy cows producing large amounts of milk are fed diets with less fibre, while those producing less milk or which are growing or are dry are fed diets with more fibre from forage sources.

Digestion of Proteins

Dietary protein, like dietary carbohydrate, is fermented by rumen microbes. The main products are ammonia, organic (carbon-containing) acids, amino acids and other products. Approximately 40–75% of the protein in feed is broken down in the rumen. The extent of breakdown depends on many factors, including solubility of the protein, resistance to breakdown and rate of feed passage through the rumen. Many rumen microorganisms require ammonia for growth and synthesis of microbial protein. Rumen microbes convert the ammonia and organic acids into amino acids that are synthesized to microbial protein.

Ammonia is most efficiently incorporated into bacterial protein when the diet is rich in soluble carbohydrates, particularly starch. Ammonia in excess of that used by the microbes is absorbed through the rumen wall into the blood, carried to the liver and converted to urea, which is mainly excreted in the urine. Some urea is returned to the rumen via the saliva.

Feed protein that escapes breakdown in the rumen (sometimes called bypass protein) and microbial protein pass from the rumen to the abomasum, where they are digested and absorbed into the bloodstream through the wall of the small intestine.

The fact that some of the protein passing to the abomasum is microbial protein and some is from bypass protein (protein undegraded in the rumen) makes measurements of protein digestibility difficult in ruminant animals.

Digestion of Fats

Most of the digestion and absorption of fats occurs in the small intestine. Rumen microorganisms convert unsaturated fatty acids to saturated acids through the addition of hydrogen molecules. Thus, more saturated fat is absorbed by cows than by non-ruminant animals such as pigs. Feeding large quantities of unsaturated fatty acids depresses fibre digestion, lowers rumen pH and can depress the growth of rumen microbes.

Since the various feed components are digested by different classes of microbes, allowance has to be made for new populations of microflora to establish in the rumen whenever changes are made to the diet. A change in diet should, therefore, be made gradually, otherwise a digestive disorder may occur. It may take up to 6 weeks for the rumen microorganisms to adapt to a change in diet.

Digestibility

Only a fraction of each nutrient taken into the digestive system is absorbed. This fraction can be measured as the digestibility coefficient. It is determined through animal digestibility experiments. Researchers measure both the amount of nutrient present in the feed and the amount of nutrient present in the faeces, or more exactly in the ileum. The difference between the two, commonly expressed as a percentage or in relation to 1 (1 indicating complete digestion), is the amount of the nutrient digested by the animal. Each feedstuff has its own unique set of digestibility coefficients for all nutrients present. The digestibility of a feedstuff or a complete feed can also be measured. Digestibility measured in this way is known as apparent digestibility, since the faeces and ileal digesta contain substances originating in the fluids and mucin secreted by the gut and associated organs, as well as cellular material abraded from the gut wall as the digesta pass. Correction for these endogenous losses allows true digestibility to be measured. Generally, the digestibility values listed in feed tables refer to apparent digestibility unless stated otherwise.

Some feed ingredients contain components that interfere with digestion. This aspect is dealt with in Chapter 4.

Vitamin Synthesis

During the first weeks of life, calves are essentially non-ruminant animals and have dietary requirements similar to those of pigs and poultry. Initially, therefore, they must obtain all the required nutrients from milk or milk replacer. They require high-quality, easily digested feeds to supply needed energy, essential amino acids, essential minerals and vitamins. After about 5–6 weeks of age, forage and grain consumption increases and microorganisms in the rumen become increasingly active in synthesizing essential amino acids and B vitamins and in digesting fibre. When the rumen is fully functional the ruminal microorganisms synthesize all of the B vitamins and vitamin K required by cattle, at least for growth and maintenance. Therefore ruminating cattle should not require supplementation with B vitamins or vitamin K. Supplementation with niacin (B_3) and thiamine (B_1) is practised to counter some stress conditions in conventional production, but this is not practised in organic production.

Nutrient Requirements

Energy

Energy is obtained when the feed is digested in the gut. The energy is then either released as heat or is trapped chemically and absorbed into the body for metabolic purposes such as maintenance, growth or production of milk and meat. It can be derived from protein, fat or carbohydrate in the diet. In general, forage products and cereal grains provide most of the energy in the diet. Energy in excess of requirement is converted to fat and stored in the body. The provision of energy accounts for the greatest percentage of feed costs.

The total energy (gross energy) (GE) of a feedstuff can be measured in a laboratory by burning it under controlled conditions and measuring the energy produced in the form of heat. Digestion is never complete under practical situations; therefore measurement of GE does not provide accurate information on the amount of energy available to the animal. A more precise measurement of energy is digestible energy (DE), which takes into account the energy lost during incomplete digestion.

More accurate measures of useful energy contained in feedstuffs are metabolizable energy (ME) (which takes into account energy lost in the urine) and net energy (NE) (which in addition takes into account the energy lost as heat produced during digestion). Consequently, in the 1980s ME began to be used in ruminant nutrition and is still used in the feeding of young cattle. Later the more meaningful NE came into use. NE is defined as ME minus the heat increment, which is the heat produced (and thus energy used) during digestion of feed, metabolism of nutrients and excretion of waste. The energy left after these losses have been deducted is the energy actually used for maintenance and for production (growth, gestation, lactation). Thus the NE system is the only one that describes the energy that is actually used by the ruminant animal. NE is therefore used as the most accurate way to quantify the energy content of feeds. For ruminant feeding it has been refined into NEM, NEL and NEG, these being defined as the net energy required per unit of maintenance, lactation and gain, respectively.

The NRC (2001) considered the question of whether maintenance requirements vary with milk production. Although very few direct comparisons have been made, it has been found that although milk yields were greater for Holstein cows than for Jersey cows, energy output in milk as a function of metabolic weight was similar. Also there was no evidence to suggest that energy requirements for maintenance or production differed between breeds. The requirements set out in the *Nutrient Requirements of Dairy Cattle* (NRC, 2001) and the *Nutrient Requirements of Beef Cattle* (NRC, 2000) are based on NE, expressed as megacalories (Mcal) per kg feed. This energy system is used widely in North America and in many other countries. In the case of dairy animals, the energy requirements for maintenance and milk production are expressed in net energy for lactation (NEL) units since it has been found that ME is used with similar efficiencies for maintenance and milk production. The energy values of feed are also expressed in NEL units. Thus in the tables and in the computer model, one feed value (NEL) is used to express the requirements for maintenance, pregnancy, milk production and changes in body reserves (not growth) of adult cows.

Many countries have adopted energy systems based on NE, although there are often differences in how the NE values are derived. A common basis for the calculation of the NE value of a feedstuff is the chemical analysis of the feedstuff (see Feed Analysis, this chapter). The adoption of NE supersedes the use of total digestible nutrients (TDN) as the preferred method of energy evaluation, although TDN systems are still in use in several countries (mainly in beef feeding).

TDN is calculated from laboratory analysis as:

$$\text{TDN} = \text{digestible NFE} + \text{digestible CF} + \text{digestible CP} + (\text{digestible EE} \times 2.25).$$

The ether extract (EE) is multiplied by 2.25 because the energy value of fat is approximately 2.25 times greater than carbohydrate.

Another less accurate method of calculating TDN is based on the percentage of acid-detergent fibre (ADF) in the dry matter of the feed:

$$\text{TDN} = 96.35 - (\%\text{ADF} \times 1.15).$$

TDN values can be converted into ME values.

Another energy unit that is being superseded by the NE system is the Scandinavian Feed Unit (SFU) system, one SFU being equivalent to the energy content of 1 kg barley (85% dry matter). The advantages of this system are the additivity of energy values of feeds, the simplicity of estimating the composition of the feed mixture for a given level of production, and the expected production from a defined ration.

Energy units used in some countries are based on joules (J), either kilojoules (kJ) or megajoules (MJ). A conversion factor can be used to convert calories to joules, i.e. 1 Mcal = 4.184 MJ, 1 MJ = 0.239 Mcal and 1 MJ = 239 kcal. Therefore the tables of feedstuff composition in this publication show NE values expressed as Mcal and MJ per kg (also ME and DE for use in situations utilizing these energy measures).

Protein

The term protein usually refers to crude protein (CP) (measured as nitrogen content × 6.25). As explained above, the abomasum in the ruminating animal receives protein from two sources: (i) undigested protein that has passed through the rumen (bypass protein); and (ii) protein produced by the microorganisms in the rumen. Both types of protein provide amino acids (AA), which are the building blocks for the formation of muscle tissue, milk, products of conception, etc. Any undigested protein remaining in the small intestine is passed to the large intestine and expelled in the faeces.

A lack of protein in the diet adversely affects microbial protein production in the rumen, which in turn reduces the utilization of low-protein feeds. Thus, much of the potential nutritive value of roughages (especially energy) may be lost if protein levels are inadequate.

Measuring feedstuffs in terms of CP does not provide accurate information on how well the dietary protein is digested and provides an optimal supply of AA. Feedstuffs vary greatly in protein digestibility. For example, the digestibility of the protein in common cereal grains and most protein supplements is around 75–85%, while in lucerne hay it is around 70% and in grass hay is around 35–50%. Thus, even though total protein intake may appear to be adequate, the animal may be deficient in this nutrient. Therefore more accurate measures of protein quality have been introduced for ruminant feeding. One of these is metabolizable protein (MP), now used in the National Research Council (NRC) publications on ruminants. Other countries have adopted a similar approach, e.g. the UK MP system, the protein disulfide isomerase (PDI) system (true protein digested in the small intestine) in France, and the Dutch MP system (DVE/OEB system) in the Netherlands. MP is defined as the true protein absorbed in the form of amino acids in the small intestine. It is a calculated value based on research findings related to the extent of undegradability of various protein feedstuffs in the rumen (also called bypass protein) and the amount of microbial protein produced in the rumen. The term undegradability refers to the extent of resistance to breakdown in the rumen, with the result that the protein can pass to the small intestine intact.

Some ruminant animals such as growing heifers, dry cows and cows in mid to late lactation may meet their MP needs solely from microbial protein produced in the rumen. However, high-yielding dairy cows have AA requirements that cannot be met from microbial protein alone and require a supplement of protein in the diet. In this situation the diet should include proteins of low degradability in the rumen so that they escape breakdown until they reach the small intestine. This escape or bypass protein is now termed rumen undegraded protein (RUP).

Researchers are also paying attention to the AA make-up of the dietary protein since it is known, for instance, that lysine and methionine are the most limiting amino acids in MP for dairy cattle. Microbial protein is relatively constant in AA composition and is relatively high in lysine. However, the estimates of requirement are not yet at the stage that recommendations of the optimal AA profile in the diet of ruminants can be quantified. Generally, a 3:1 ratio of lysine:methionine is considered to be an optimal amino acid balance for these AA in diets for dairy cows and growing beef cattle.

Minerals

Several inorganic elements (minerals) are essential for normal growth, lactation and reproduction in cattle. Those required in substantial quantities in the diet are referred to as macro-minerals and include calcium (Ca), phosphorus (P), sodium (Na), chlorine (Cl), potassium (K), magnesium (Mg) and sulfur (S). The macro-minerals are important structural components of bone and other tissues and serve as important constituents of body fluids. Other minerals are required at very low levels in the diet, hence the name 'trace minerals'. They are iron (Fe), iodine (I), manganese (Mn), copper (Cu), cobalt (Co), zinc (Zn) and selenium (Se). Signs of mineral deficiencies are shown in Table 3.1.

Dairy cattle need a dietary source of calcium, phosphorus, magnesium, sulfur, potassium, sodium, chlorine, iron, iodine, manganese, copper, cobalt, zinc and selenium. Beef cattle require the same mineral elements as do dairy cattle; however, the relative quantities of these minerals are different because of the higher milk production in dairy cows. The minerals most likely to be deficient in beef cattle diets are sodium, calcium, phosphorus and magnesium.

Calcium and phosphorus

Calcium and phosphorus make up over 70% of the mineral content of the animal body, mainly combined with each other. Approximately 80% of the P and 98% of the Ca are present in the skeleton. These figures indicate the importance of an adequate supply of Ca and P in the diet and the role they play in giving rigidity and strength to the skeletal structure. An inadequate supply of either one in the diet will limit the utilization of the other. These two minerals are usually discussed together because there is a close relationship between them.

Calcium is the most abundant mineral element in the body. In addition to being a structural component of bones and teeth, it is involved in such vital functions as blood clotting, membrane permeability, muscle contraction, transmission of nerve impulses, cardiac regulation, secretion of certain hormones and activation and stabilization of certain enzymes (NRC, 2000, 2001). A deficiency of Ca is more likely than a deficiency of P. Calcium is particularly important because of its high content in milk, and because a shortage in the diet can lead to a common metabolic disease in dairy cows – milk fever (parturient paresis). This is not a true fever in that body temperature is not elevated. Milk fever is

Table 3.1. Signs of mineral deficiencies in cattle (from Merck Veterinary Manual, 2010).

Mineral	Deficiency signs
Calcium (Ca)	Rickets, slow growth, weak bones that fracture easily, reduced milk yield, milk fever
Phosphorus (P)	Weak, fragile bones; poor growth, reduced appetite, impaired reproductive performance
Sodium (Na)	Craving for salt, reduced appetite, impaired growth, incoordination, weakness, shivering
Potassium (K)	Decrease in feed intake, loss of hair condition, impaired growth, emaciation, inability to coordinate muscle movement
Magnesium (Mg)	Irritability, nervousness, tetany – increased excitability, muscular twitching, convulsions
Sulfur (S)	Slow growth, reduced milk production, reduced feed efficiency
Copper (Cu)	Severe diarrhoea, abnormal appetite, poor growth, coarse bleached hair coat
Cobalt (Co)	Failure of appetite, anaemia, decreased milk production, rough hair coat, wasting
Iodine (I)	Goitre, 'big neck' in calves, goitrogenic substances in diet may cause deficiency
Iron (Fe)	Nutritional anaemia, pale mucous membranes, poor growth, listlessness, enlarged heart, enlarged fatty liver
Manganese (Mn)	Delayed or decreased signs of oestrus, poor conception, abnormal skeletal growth
Selenium (Se)	White muscle disease, retained placenta, impaired reproduction, unthriftiness, reduced immunity
Zinc (Zn)	Decreased weight gains, lowered feed efficiency, mastitis, skin/wound problems

characterized by low blood Ca and paralysis and is usually seen within 48 h after calving in cows beyond their first lactation. There is evidence that a high intake of Ca during the dry period increases the incidence of the condition, and that limiting Ca intake before calving but increasing it at calving time decreases the incidence. Signs of this condition include a loss of appetite, a dull and listless attitude and an unsteady gait. Usually the animal collapses and is unable to rise. Treatment involves administration of Ca solution intravenously. Because lactating beef cows do not produce the large amounts of milk that dairy cattle do, their Ca requirement is much lower and the occurrence of milk fever is less likely.

Phosphorus is likely to be deficient in cattle diets because roughages are often low in this mineral. Mature and weathered forages are a poor source of this mineral since its content declines as forage plants mature. As a result, P is regarded as the most prevalent mineral deficiency for grazing cattle worldwide (Merck Veterinary Manual, 2010). Most protein supplements and grains are relatively good sources of P.

Phosphorus deficiency results in reduced growth rate, decreased appetite, impaired reproduction, reduced milk production and weak, fragile bones. It is necessary to supplement most ruminant diets with Ca and P. Cereal hays, silages and crop residues are relatively low in Ca. Forages do not provide sufficient Ca for most classes of cattle, though legumes have a higher content than grasses. Roughages may supply adequate Ca for maintenance of beef cattle. Cereal grains are quite low in Ca but the P content of cereal grains is higher. Concentrate feeds used for dairy cattle are deficient in Ca. Wheat middlings, corn distiller's grain with solubles, and soybean meal are common feeds that are high in P but low in Ca.

Sodium, potassium and chloride

Sodium, potassium and chloride are the primary dietary ions that influence the electrolytic balance and acid–base status. Chloride is present in gastric juices and Cl is part of the HCl molecule which assists in the breakdown of feed in the abomasum. Sodium is essential for nerve membrane stimulation and ionic transport across cell membranes.

Salt (NaCl) is generally not found in feedstuffs at levels sufficient to meet the needs of cattle and a supplement is necessary. Cattle like salt and will seek it out if it is not readily available. The preferred method of feeding salt is to include it in concentrate mixtures or complete feeds at about 0.5% of the total dietary dry matter for lactating cows and at 0.25% for dry cows and other non-lactating cattle. Allowing free access to salt lick blocks is a practical way of meeting the requirement of cattle not receiving concentrates.

A deficiency of salt can result in loss of appetite and reduced feed intake, growth and milk production. In contrast, cattle can tolerate high dietary levels of NaCl (4–9% of dietary dry matter) provided they have access to ample non-saline drinking water. If non-saline water is limited or if the level of NaCl in water is high, toxicity can result. The high Na ion concentration is responsible for adverse physiological reactions, apparently because of a disturbance in water balance. The signs of Na toxicity include nervousness, salivation, vomiting, increased thirst, weakness, staggering, blindness, epileptic seizures, paralysis and death. Affected cattle may show belligerent and aggressive behaviour.

Potassium is the third most abundant mineral in the body after Ca and P, and is the most abundant mineral in muscle tissue. It is a major cation in intracellular fluid and is important in acid–base balance; it is involved in regulation of osmotic pressure, water balance, muscle contractions, nerve impulse transmission and several enzymatic reactions. The content of K in cattle diets is usually adequate, but should be checked regularly to ensure adequacy. Signs of K deficiency include anorexia, decreased feed intake and rate of gain, emaciation, inactivity and ataxia (inability to coordinate movement of the muscles).

Magnesium

Magnesium is involved in the maintenance of electrical potentials across nerve endings, as a cofactor in several enzyme systems and is a constituent of bone. The Mg present in cattle diets is usually adequate; however, deficiencies can occur. Usually, an Mg deficiency is seen in the spring in grazing cattle under field conditions. The initial signs are nervousness, reduced feed intake and muscular twitching about the face and ears. Animals are uncoordinated and walk with a stiff gait. In advanced stages, affected cows fall down, exhibit convulsions and die shortly thereafter. A blood sample from affected cows can be used to confirm the condition. Treatment involves supplementation of the diet with Mg salts. Magnesium deficiency has also been reported in calves, resulting in excitability, anorexia, hyperaemia, convulsions, frothing at the mouth and salivation.

Sulfur

Sulfur is an essential element but is present in the diet in adequate amounts, making supplementation unnecessary.

Trace minerals

Seven trace minerals have been shown to be needed as supplements in ruminant diets: copper, iron, cobalt, zinc, manganese, iodine and selenium. They are needed in very small or trace amounts in the diet, hence the name ‘trace minerals’. Subclinical trace mineral deficiencies probably occur more frequently than recognized by producers. Some soils are naturally deficient in trace minerals; for instance, areas in North America with a high rainfall that results in leaching of the soil and Se deficiency. Selenium deficiencies have been observed in animals in Asia when fed US-produced maize and soybean meal but not when fed locally grown feed. Feed suppliers are usually aware of deficient (and adequate) levels of the trace minerals present in feedstuffs and will provide trace mineral mixes formulated appropriately.

COBALT. Cobalt is required for normal rumen metabolism, as a component of vitamin B_{12}. When the intake of Co is inadequate, the bacterial population in the rumen is altered and the synthesis of vitamin B_{12} is greatly reduced. In some areas of the USA, Australia and South America, forages are low in this mineral because the soil is deficient in Co. A wasting disease can result, due to a deficiency of vitamin B_{12}. Deficient animals suffer from a lack of energy at the cellular level and become emaciated. Appetite is greatly depressed. Supplementation of cattle diets with Co is necessary when a deficiency has been identified. Alternatively a Co-iodized salt can be used.

COPPER. Copper is required for the activity of enzymes associated with iron metabolism, tissue elastin and collagen formation, melanin production and the integrity of the central nervous system. It is required with iron for normal red blood cell formation. Copper is also required for bone formation, brain cell and spinal cord structure, the immune response and hair pigmentation. Fetal demands for Cu are high in the last trimester of pregnancy. Copper antagonists such as S, Mo, Zn and Fe increase the need for Cu. Organic Cu (e.g. Cu proteinate) has been reported to reduce the severity and duration of mastitis.

Copper deficiency is usually regional and associated with low soil levels. Signs of deficiency include severe diarrhoea, abnormal appetite, poor growth and coarse, depigmented hair. Recommended levels of Cu should be provided in the diet, either by supplementation of the total diet or as part of the free-choice mineral mix or supplement.

IODINE. It has been known for over 100 years that I is required for the proper functioning of the thyroid gland and that an I deficiency causes goitre ('big neck'). Iodine is required for the synthesis of thyroxine in the thyroid gland. This hormone influences basal metabolic rate and growth, reproduction and lactation. In the newborn calf, goitre can occur when the maternal I intake is deficient. The I requirement is increased by goitrogenic substances in feeds, such as kale, turnips and rape. Pasture plants vary greatly in their ability to take up I from the soil. Iodine deficiency develops on deficient soils around the Great Lakes and westward to the Pacific coast of North America. Deficiencies can be prevented by supplementation of the diet with stabilized iodized salt or the use of an iodized salt lick. Most feedstuffs contain only low levels of I. An exception is seaweed, which can contain 4000–6000 mg I/kg. Coastal regions that are subjected to spray-carrying winds off the ocean have abundant supplies of I in the soil. However, inland soils generally do not contain enough I to meet the needs of livestock. Iodine requirements in cattle can be adequately met by feeding stabilized iodized salt.

Excessive quantities of I can lead to hyperthyroidism and high levels in milk.

IRON. Most of the Fe in the body is in the form of haemoglobin in red blood cells and myoglobin in muscle. The remainder is in the liver, spleen and other tissues. Haemoglobin is essential for the proper function of every organ and tissue of the body. Iron also plays a role in other enzymes involved in oxygen transport and the oxidative process. A deficiency results in anaemia. The symptoms of Fe deficiency include poor growth, listlessness, rough hair coat, anoxia, wrinkled skin, paleness of mucous membranes, hypochromic microcytic anaemia, enlarged heart and spleen, enlarged fatty liver and ascites. A characteristic sign is laboured breathing after minimal activity, from which the term 'thumps' arose. Soil contains Fe, providing sufficient levels for livestock on pasture.

MANGANESE. Manganese is essential for the synthesis of chondroitin sulfate, required for the organic matrix of bone. Manganese is also required to activate enzymes involved in the synthesis of polysaccharides and glycoproteins and it is a key component of pyruvate carboxylase, an important enzyme in carbohydrate metabolism. Lipid metabolism is also dependent on Mn. Manganese is found in many different feeds, therefore a deficiency is less likely than of other trace minerals. Signs of Mn deficiency include: abnormal skeletal growth, with an altered ratio of fat to lean body tissue; absence of, or irregular, oestral cycles; poor mammary development and lactation; and resorption of fetuses. Decreased growth rate and feed efficiency also occur with Mn deficiency.

SELENIUM. Selenium is part of the enzyme glutathione peroxidase, which catalyses the reduction of hydrogen peroxide and lipid hydroperoxides, thus preventing oxidative damage to the body tissues. Vitamin E is also effective as an antioxidant. Therefore, both Se and vitamin E act to prevent peroxide damage to body cells. This aids the body's defence mechanisms against stress. Most feeds contain compounds that can form peroxides. Unsaturated fatty acids are a good example. Rancidity in feeds causes formation of peroxides that destroy nutrients. Vitamin E, for example, is easily destroyed by rancidity. Selenium spares vitamin E by its antioxidant effect, but supplementation with one will not remedy a deficiency of the other. White-muscle disease in calves, which is characterized by degeneration and necrosis of skeletal and heart muscles, is the result of Se deficiency. Vitamin E plays a role in preventing such conditions. Other signs of a Se deficiency include unthriftiness, weight loss, reduced immune response and decreased reproductive performance. Selenium deficiencies can lead to a slow return of the uterus to normal after calving, retained placenta, metritis, reduced fertility and weak heats. Signs of Se toxicity seen in the Plains states of the USA include lameness, sore feet and loss of hair from the tail.

Selenium is generally included in trace mineral premixes. Common sources are sodium selenite and sodium selenate. Selenium yeast can also be used in conventional diets. Excess dietary Se has to be avoided and the various feed regulations are designed to prevent this occurrence.

ZINC. Zinc is widely distributed throughout the body and is present in many enzyme systems involved in metabolism. It is required for normal protein synthesis and metabolism, and since it is also a component of insulin it functions in carbohydrate metabolism. Thus it is an essential mineral for normal growth and health, affecting energy and protein metabolism, skin integrity and cell repair, and immune function. Low Zn status in dairy cows leads to lower-quality milk with higher somatic cell counts and an increase in mastitis. Supplemental Zn has been shown to increase reproductive performance by increasing the conception rate. Field studies have shown an improvement in hoof hardness and a reduced incidence of 'white line' disease of the hooves with supplemental Zn.

Vitamins

Vitamins are certain organic (carbon-containing) compounds required for normal growth and the maintenance of animal life. Some vitamins can be synthesized by the ruminant animal in sufficient amounts to meet its needs, while others must be supplemented.

Classification of vitamins

Vitamins are either fat-soluble or water-soluble and are commonly classified in this way. Vitamin A was the first vitamin discovered and is fat-soluble. Others were later discovered in this group, vitamins D, E and K. Being fat-soluble these vitamins are absorbed into the body with dietary fat, by similar processes. Their absorption is influenced by the same factors influencing fat absorption. Fat-soluble vitamins can be stored in appreciable quantities in adipose tissue. When they are excreted from the body they appear in the faeces. A deficiency of vitamin A, D or E is relatively rare in cattle fed on natural mixtures of high-quality feeds. White-muscle disease due to a deficiency of vitamin E or Se is not uncommon in dairy calves in areas where the soil is low in Se. Injections of vitamins A, D and E at the time of drying off and prior to calving are sometimes given on conventional dairy farms, but researchers report limited value with cows fed normal diets. Milk replacers should be fortified with these vitamins.

The first water-soluble vitamin discovered was called vitamin B to distinguish it from vitamin A. Later, other B vitamins were discovered and given names such as vitamin B_1, B_2, etc. Over time, the specific chemical names became used. In distinction from the fat-soluble vitamins, the water-soluble vitamins are not absorbed with fats and they are not stored in appreciable quantities in the body (with the possible exception of B_{12} and thiamine). Excesses of these vitamins are excreted rapidly in urine.

Cattle require 14 vitamins, but most do not have to be provided in the diet. While cattle have a metabolic requirement for all the known vitamins, dietary sources of vitamins C and K and the B-vitamin complex are not necessary except for calves. Vitamin K and the B vitamins are synthesized in sufficient amounts by the ruminal microflora, and vitamin C is synthesized in the tissues of all cattle. However, if rumen function is impaired, by feed deprivation, inadequate feed intake or nutrient deficiencies, synthesis of these vitamins may be inadequate.

VITAMIN A. Either vitamin A or a precursor must be provided in the diet. This vitamin occurs in various forms or vitamers, i.e. retinol (alcohol), retinal (aldehyde), retinoic acid and vitamin A palmitate (ester). Relative activity is measured in international units (1 IU = 0.3 μg retinol) or retinol equivalents (1 RE =1 μg retinol). Vitamin A has essential roles in vision, bone and muscle growth, reproduction and maintenance of healthy epithelial tissue. A chief role is maintenance of epithelial tissue (skin and lining of respiratory, digestive and reproductive tracts) in a healthy condition. It also functions in visual purple, a compound in the eye needed for sight when an animal adapts from light to dark. Vitamin A is essential for proper kidney function and normal development of bones, teeth and nerve tissue.

Naturally occurring precursors of vitamin A are found in leafy green vegetables and forages such as lucerne (alfalfa). The common precursor is β-carotene, which can be converted into vitamin A in the intestinal wall. Carotene is present in considerable quantities in pasture, lucerne hay or meal and yellow maize. Carotene and vitamin A are rapidly destroyed by exposure to air, light and rancidity, especially at high temperature. Since it is difficult to assess the amount present in the feed, diets should be supplemented with this vitamin whenever there is doubt about its adequacy in the feeds being used.

The ability to convert β-carotene to vitamin A varies among breeds. Holstein cattle are probably the most efficient converters of carotene, while some of the beef breeds are much less efficient. It has been suggested that ruminants have a specific requirement for β-carotene, separate from its requirement as a source of vitamin A. This is based on research showing a connection between the content of β-carotene in the diet and a reduction in reproductive problems in cows and heifers. However, research data are limited and conflicting, and a specific need for supplementation with carotene is not yet recommended.

Vitamin A is one of the few vitamins that cattle store in their livers, as much as a 6-month supply. This explains why cattle fed a diet deficient in vitamin A may not begin to show signs of deficiency for several weeks. Newborn calves, which have low stores of vitamin A, depend on colostrum and milk to meet their needs. If the dam is fed a diet low in carotene or vitamin A during gestation (e.g. in winter), severe deficiency signs may become apparent in the young suckling calf within 2–4 weeks of birth, while the dam may appear normal.

One of the first signs of vitamin A deficiency in cattle is night blindness. Other early signs are loss of appetite, rough hair coat, dull eyes, reduced rate of gain and reduced feed efficiency. Diarrhoea and pneumonia may be seen in young animals. Other deficiency signs are excessive watering of the eyes, staggering gait, lameness or stiffness in knee and hock joints, and swelling of the legs and brisket (and sometimes in the abdominal region). Night blindness is the only symptom unique to vitamin A deficiency. Depressed vitamin A concentrations in blood or liver, increased spinal fluid pressure, or changes to the eye (detected by examination of conjunctival smears) are used to confirm deficiency. Cattle with advanced vitamin A deficiency often pant excessively at high temperatures and go into convulsions when excited. Signs of vitamin A deficiency in breeding herds include lowered fertility and calving percentage. Cows abort, drop dead or weak calves, and show difficulty in becoming pregnant. When fed poor-quality, damaged forage for long periods, dairy cattle may show reproductive failure from vitamin A deficiency. Under such conditions, supplementation with vitamin A is necessary.

Cattle on lush green pasture may accumulate substantial reserves of vitamin A in the liver, fat and other organs, which can meet requirements for up to several months. Conversely, if cattle are grazing weathered range or poor-quality forage, their reserves will be low. Vitamin A stored in the liver may be unavailable to animals that are deficient in Zn. Carotene that escapes conversion to vitamin A is stored mainly in the liver and in the body fat. Yellow fat and yellow milk are due to the presence of carotene.

Body deposits of vitamin A are low at birth and young animals have lower reserves than older animals that have consumed diets high in vitamin A activity. This explains why young animals fed vitamin A-deficient diets usually show deficiency symptoms sooner than older animals.

VITAMIN D. Vitamin D is required for absorption of Ca and P, normal mineralization of bone, Ca metabolism and immune function. The two major forms of vitamin D are cholecalciferol (vitamin D_3, the animal form) and ergocalciferol (vitamin D_2, the plant form). One international unit (IU or ICU) of vitamin D is defined as being equivalent to the activity of 0.025 μg crystalline D_3.

Both vitamin D_2 and D_3 are biologically active for cattle. Like other fat-soluble vitamins, dietary vitamin D is absorbed in the gut with other lipids. The natural source of vitamin D for newborn calves is cow's milk.

Most feedstuffs, except sun-cured forage, are low in this vitamin and therefore supplementation is necessary, especially during winter. Under normal conditions, cattle receive adequate vitamin D from exposure to direct sunlight or from consumption of sun-cured forage. Vitamin D can be synthesized in the body by the action of sunlight on a precursor (7-dehydrocholesterol) in the skin, which in summer can provide the entire requirement for vitamin D in animals housed outdoors. Glass blocks the ultraviolet rays from sunlight, therefore animals kept indoors do not form vitamin D. Ergosterol, a sterol in green plants, is converted to D_2 when the plant is harvested and cured in sunlight. Many commercial products of vitamin D are sold in concentrated form. Irradiated yeast is a potent source of vitamin D_2.

Latitude and season affect both the quantity and quality of solar radiation reaching the earth's surface, especially in the ultraviolet band (UVB) region of the spectrum. Studies (Webb *et al*., 1988) have shown that 7-dehydrocholesterol in human skin exposed to sunlight on cloudless days in Boston (42.2°N) from November to February produced no previtamin D_3. In Edmonton (52°N) this ineffective winter period extended from October to March. Further south (34°N and 18°N), sunlight effectively photoconverted 7-dehydrocholesterol to previtamin D_3 in the middle of winter. Presumably a similar situation prevails in the southern hemisphere. These results demonstrate the dramatic influence of changes in solar UVB radiation on vitamin D_3 synthesis in skin and indicate the effect of latitude on the length of the 'vitamin D winter' during which dietary supplementation of the vitamin is necessary for animals housed outdoors. Organic cattle producers need to be aware of these findings. Without supplementation there is a seasonal fluctuation in body stores of the vitamin in animals housed outdoors, requiring dietary supplementation during winter.

Lack of photo-production of vitamin D or inadequate dietary supplementation of vitamin D leads to a failure of bones to calcify normally. Deficiency symptoms include depressed appetite, irritability, tetany, swollen and stiff joints, rickets and convulsions. Rickets is characterized by soft, porous, poorly developed bones. Early signs of vitamin D deficiency in calves are poor appetite, decreased growth, stiff gait, weakness and laboured breathing. Later signs include swollen joints, slight arching of the back, bowed legs and bent knees. Bones that are easily broken are a sign of vitamin D deficiency in all ages of animals. A deficiency in pregnant animals may result in dead, weak or deformed calves.

VITAMIN E. Vitamin E is required for normal reproduction and growth. The most important natural source is α-tocopherol, found in plant oils and seeds. The ester form (e.g. vitamin E acetate) can be synthesized and is used for feed supplementation. One international unit (IU) is defined as being equivalent to the activity of 1 mg dl-α-tocopherol acetate.

The nutritional role of vitamin E is closely interrelated with that of Se and is involved mainly in the protection of lipid membranes such as cell walls from oxidative damage. The primary function of vitamin E is as an antioxidant. Normal metabolism in the body generates toxic, reactive oxygen by-products, which must be deactivated. Because it is fat-soluble, vitamin E is particularly important in protecting cell membranes from damage. Vitamin E maintains the structure and function of all muscles (skeletal, heart, smooth muscle), and is essential for the immune system. An Se-containing enzyme, glutathione peroxidase, is an important antioxidant in muscle, but does not eliminate the vitamin E requirement.

White-muscle disease in calves is caused by a deficiency of either Se or vitamin E, and is treated by injection of vitamin E and Se and by correcting dietary deficiencies. Vitamin E is added to dairy diets to minimize mastitis risk and severity, improve immune function and improve reproductive performance.

Heat, oxygen, moisture, fat, trace minerals and nitrates reduce vitamin E stability in feeds. Thus the concentration of vitamin E in feeds declines during storage, particularly in high-moisture feeds. Consequently, synthetic vitamin E is used to ensure that the vitamin E requirements are met.

VITAMIN K. This vitamin occurs naturally in various forms: phylloquinone (K_1) in plants and menaquinone (K_2), which is synthesized in the gut by microbes. Vitamin K is required for normal clotting of blood. A deficiency can result in excessive bleeding or death from haemorrhage. Vitamin K deficiency is rare in cattle, but may be caused by consumption of mouldy sweet clover.

WATER-SOLUBLE (B) VITAMINS. Eight B vitamins are important in calf nutrition. Milk replacers should contain all the added fat- and water-soluble vitamins. Calves up to 4–5 weeks old should also receive all known vitamins in their feed. Ruminating cattle normally do not require a dietary source of these vitamins.

In general, the water-soluble vitamins participate in biochemical reactions as enzyme cofactors that mostly affect the transfer of energy. Thiamine, riboflavin, niacin, pantothenic acid, folic acid, pyridoxine, vitamin B_{12}, biotin and choline are essential B vitamins for all animals, including cattle. B-vitamin concentration of the diet usually has very little influence on the B-vitamin status of cattle. Bacteria in the rumen synthesize most B vitamins in excess of the probable requirements. Microbial synthesis of most B vitamins increases with increasing energy intake, so is generally higher for grain compared with forage diets. If B vitamins are added to the diet, rumen bacteria either reduce B vitamin synthesis, resulting in no net change to supply, or destroy the added B vitamins. Depending on the B vitamin, virtually none to a high proportion of the dietary B vitamin may escape ruminal degradation. Whereas cattle can accumulate nutritional reserves of vitamins A, D and E, storage of B vitamins is limited except for vitamin B_{12}.

Cattle with reduced intakes due to stress or disease may suffer from short-term B-vitamin deficiencies, due to reduced synthesis, increased requirements and limited reserves of B vitamins within the body. Some evidence suggests that activating the immune system to fight off infection or develop immunity rapidly depletes B vitamins important to the immune response.

Biotin plays a role in the synthesis of lipids and in glucose metabolism. Good sources of this vitamin include groundnut meal, safflower meal, yeasts, lucerne meal, cottonseed meal and soybean meal. Clinical signs of biotin deficiency are dermatitis, cracking of soles and hooves, spastic paralysis of the hind legs, decreased rate of gain and poor reproductive performance (NRC, 2000, 2001).

Choline is not a vitamin in the strict sense, but is generally included in the water-soluble group (NRC, 2000, 2001). It is a structural component of cells and is involved in nerve impulses. Animals synthesize it but this process is often inefficient in young animals, making supplementation advisable. It is contained in some feed ingredients.

Cobalamin (vitamin B_{12}) is closely related to folic acid in its metabolism. All plants, fruits, vegetables and grains are devoid of this vitamin. Microorganisms produce all of the cobalamin found in nature. Any occurring in plant materials is the result of microbial contamination; therefore calf diets containing no animal products require supplementation. Deficiency signs include a characteristic anaemia (macrocytic and hyperchromic), reduced growth, poor reproduction and increased mortality (NRC, 2000, 2001). Vitamin B_{12} is synthesized by rumen bacteria. It contains a trace mineral, Co, which must be provided in the diet. Cobalt concentrations in feeds are not well known and therefore ruminant diets are commonly supplemented with Co to ensure adequate production of vitamin B_{12}. Vitamin B_{12} is the only B vitamin stored in substantial amounts in the liver. Deficiency of this vitamin is unlikely unless diets are deficient in Co for a prolonged period. The symptoms can include poor appetite, retarded growth and poor condition.

Folacin (folic acid) is involved in the metabolism of single-carbon fragments and in the biosynthesis of purine and pyrimidines. Folic acid is very stable but does not occur naturally in feedstuffs. Instead it occurs in reduced forms as polyglutamates, which are converted to folic acid in the body. Diets commonly contain sufficient folacin but calf diets may be inadequate. Deficiency signs include a characteristic anaemia (macrocytic and hyperchromic), reduced antibody response and poor reproduction (NRC, 2000, 2001).

Niacin (nicotinic acid) is a constituent of two coenzymes (NAD and NADP). Legumes are good sources of this vitamin. Signs of niacin deficiency include a rough skin condition and diarrhoea (NRC, 2000, 2001). Ulcers may be found in the mouth. As bacterial function develops in the rumen, the B vitamins are synthesized in large amounts and a dietary supply is no longer needed. However, evidence suggests that, under some conditions, high-yielding cows in early lactation may be less prone to ketosis when fed supplemental niacin.

Pantothenic acid is a component of coenzyme A. Diets are often deficient in this vitamin since cereal grains and plant proteins are a poor source of this vitamin. A deficiency can result in an uncoordinated gait, as well as diarrhoea and poor growth rate (NRC, 2000, 2001).

Pyridoxine is a component of several enzyme systems involved in nitrogen metabolism. In general, diets provide an adequate amount, in the free form or combined with phosphate. Deficiency signs include convulsions and a reduced antibody response (NRC, 2000, 2001). Some feedstuffs such as linseed and certain varieties of beans may contain pyridoxine antagonists. Pyridoxine is one vitamin that can be destroyed during feed processing: 70–90% of the content in wheat is lost during milling.

Riboflavin is required as a component of two coenzymes (FAD and FMN). Diets are often deficient in this vitamin, since cereal grains and plant proteins are poor sources of riboflavin. Milk products are good sources of riboflavin. Signs of deficiency include loss of appetite, rough hair, vomiting, inability to stand normally and slow growth rate (NRC, 2000, 2001).

Thiamine is important as a component of the coenzyme thiamine pyrophosphate (cocarboxylase). Good sources are lucerne, grains and yeast. Deficiencies (NRC, 2000, 2001) are less frequently encountered than deficiencies of other vitamins. Polioencephalomalacia is a thiamine-responsive disorder, associated with high concentrate feeding and lush pastures. It occurs sporadically in cattle and is most common in cattle fed high-grain diets. It results from destruction of thiamine in the rumen by a thiamine-degrading enzyme or production of compounds structurally similar to thiamine (analogues) that block the action of thiamine. Symptoms of deficiency include reduced appetite, apathy, incoordination, progressive blindness, convulsions and death. The disease is reversible if treated before the brain is severely damaged. The treatment is intravenous or intramuscular injection of thiamine (thiamine hydrochloride or other forms). Of all the B vitamins, thiamine is usually the most limiting, especially with diets containing a high content of grain.

Water

Water is also a required nutrient, the requirement being about two to three times the weight of feed eaten. The most important consideration is to ensure that there is an adequate supply of fresh, uncontaminated water available at all times. Water should always be available *ad libitum*, from water bowls or nipples (bowls are easier to check; nipples are cleaner).

Water quality is important. The general guidelines are based on total dissolved solids, with pH between 6 and 8. Some specific salts are important. Common guidelines specify nitrates up to 100 mg/l, total dissolved solids (salinity) up to 3000 mg/l and sulfates up to 500 mg/l as being acceptable. According to the NRC (2001) cattle should not be provided with drinking water containing 7000 mg/l or more total soluble salts, and water containing 5000–6999 mg/l should not be given to pregnant animals. Concentrations of 3000–4999 mg/l may be refused initially and may cause temporary diarrhoea. Water quality is particularly important during the summer for grazing cattle with access to ponds and small lakes. Water demand increases at higher temperatures and at the same time quality deteriorates due to consumption and evaporation. This can result in increased salinity of the water. A further concern is that higher temperatures can also promote bacterial growth, which may require that the water be tested for safety.

Lardner *et al.* (2005) showed that improving water quality with aeration and pumping to a trough improved weight gain of cattle by 9–10% over a 90-day grazing period.

Signs of Nutritional Problems

Problems related to feed include the following (Merck Veterinary Manual, 2010).

Ataxia is found predominantly in calves and is most often attributed to a chronic Mn deficiency. Deformities of affected animals include weak legs and pasterns, enlarged joints, stiffness, twisted legs, general weakness and reduced bone strength. It can also be caused by a K deficiency.

'Blind staggers' is a sign of acute Se toxicity. Affected cattle show dullness, ataxia, rapid weak pulse, laboured respiration, diarrhoea and lethargy; the head is lowered and the ears droop. Death is due to respiratory failure.

Bloat or tympanites of the rumen occurs in ruminants when the gases produced during fermentation cannot be expelled through eructation. The condition may require veterinary attention. Accumulation of gases causes inflation and swelling of the rumen. Bloat can be seen in cattle grazing lush, young legumes or in those fed large amounts of concentrates. In severe bloat, the distension of the rumen pushes the diaphragm forward, making breathing difficult. Symptoms of bloat include swelling at the left flank above the rumen, arched back with feet drawn under the abdomen, staggering gait, laboured breathing and suffocation. The primary factor associated with bloat in pastured cattle is the legume content of pasture. The legumes are rapidly fermented by bacteria in the rumen, leading to a high rate of gas production and foaming that prevents eructation. It is advised, therefore, that animals be introduced gradually to pastures containing legumes. Some animals may have a genetic predisposition to bloating and should be culled from the breeding herd.

Cardiac arrhythmia is usually associated with a prolonged and severe deficiency of Na in the diet.

Corneal lesions are usually associated with advanced vitamin A deficiency.

Delayed puberty is largely attributable to an inadequate content of energy in the diets fed to young, growing animals.

Depraved appetite (pica) is seen when cattle consume non-feed materials such as soil, sand or fine stone, or engage in persistent licking, chewing or eating of wood and many other substances for no apparent reason. Many suggest that these habits can be explained on the basis of nutrient deficiency, but this has not been confirmed by research. Sporadic cases may indicate a brain disorder or poisoning from ingestion of a weed such as ragwort. More extensive outbreaks may be due to parasitism or mineral deficiency and should be investigated by blood and feed tests.

Dermatitis can be seen in calves and older cattle, due to Zn deficiency. Generally, it is most severe on the legs, neck and head and around the nostrils. Wounds are slow to heal. Additional signs associated with Zn deficiency include decreased testicular growth, listlessness, development of swollen feet with open scaly lesions, and alopecia (hair loss).

Dystrophic tongue, in which the tongue surface is degenerated, is the most common of the overall Se deficiency syndromes. It can also be caused by a deficiency of vitamin E.

Goitre (thyroid gland enlargement) is a sign of an I deficiency. Affected cows may give birth to hairless calves. The condition may occur in cattle consuming diets with an adequate level of I when fed crops of the Cruciferae family, such as turnips or cabbage. These crops may contain a goitrogen which interferes with I uptake by the thyroid gland. The cyanogenetic goitrogens include a thiocyanate found in white clover and glucosinolates found in some *Brassica* forages such as kale, turnips and rape. They impair I uptake by the thyroid gland and their effect can be overcome by increasing the dietary I content.

Hair coat roughness may be related to deficiency of energy, P, salt, vitamin A, Co or Cu.

Heart failure is often associated with an Se deficiency.

Haemoglobinaemia most often is a manifestation of Cu deficiency.

Haemorrhaging (generalized) is usually due to a relative vitamin K deficiency.

Hypomagnesaemic tetany (grass tetany) is due to a relative deficiency of Mg, in that the dietary Mg may be tied up in such a manner that it is not bioavailable. Among the signs of experimentally produced Mg deficiency in both young and mature cattle are anorexia, hyperaemia, greatly increased excitability and calcification of soft tissues in a chronic deficiency condition. An affected animal exhibits convulsions, falling on its side with its legs alternately extended and relaxed. Death may occur during the convulsions. Frothing at the mouth and profuse salivation are evident. The signs appear to progress much more rapidly in adult cows. Animals showing clinical signs require treatment immediately with combined solutions of Ca and Mg. The problem can be prevented by ensuring an adequacy of bioavailable Mg in the diet.

Ketosis (acetonaemia) is a metabolic disorder that can occur in dairy cattle when the energy demands for high milk production exceed energy intake. A negative energy balance results and the cow draws on large amounts of body fat as an energy source. It occurs most commonly in cows with poor appetites or newly calved cows producing high amounts of milk. Cows suffering from this condition usually have a low concentration of glucose in the blood. As a result of the rapid mobilization of body fat, ketone production from fat breakdown exceeds the capacity of the liver to metabolize these compounds (acetoacetic acid, acetone and beta-hydroxybutyric acid), and ketosis follows. Ketosis is important because it decreases feed intake in affected cows and greatly increases the risk of other diseases and problems such as displaced abomasum. Ketone precursors are known to be present in some legume and grass silages containing high levels of butyric acid, and can increase the risk of ketosis by increasing the supply of ketone precursors in the diet.

Lactic acid acidosis, founder and laminitis can develop when unadapted cattle consume a large amount of concentrate over a short period of time. Acute indigestion often develops, introducing greatly increased levels of lactic acid into the rumen and lowering the rumen pH to a dangerous level. Frequently, lamina of the feet are severely damaged (laminitis), which is often permanent. A rapid onset may result in death.

Mastitis is inflammation of the mammary gland. Mastitis may possibly be alleviated by supplementation with β-carotene. This disease and resulting infection can significantly reduce milk production. Mastitis is most commonly found in dairy herds, but it can also occur in beef herds, resulting in a reduction in weaning weight. Treatment of dairy cows requires that the milk be rejected for human use for a specified period, and possibly resulting in a permanent loss of organic status.

Milk fever is not a true fever in that body temperature during the disease is usually below normal. The condition is most common in the first few days of lactation, when demand for Ca for milk production exceeds the body's ability to mobilize Ca reserves. It is characterized by low blood Ca and paralysis. A low blood Ca level interferes with muscle function throughout the body, causing general weakness, loss of appetite and eventually heart failure. High Ca intake during the dry period increases the incidence; limiting Ca intake before calving but increasing it at calving time decreases the incidence. Treatment generally involves Ca injection by intravenous, intramuscular or subcutaneous routes. Hypocalcaemia (low blood Ca) is more common in older animals, which have a reduced ability to mobilize Ca from bone. It is reported to occur more frequently in certain dairy breeds such as Jerseys.

Osteomalacia, which is characterized by weak, brittle bones that may fracture when stressed, can develop after demineralization of the bones of aged animals. Feeding a diet low in Ca to lactating cows over a long period of time may cause a depletion of Ca and P, resulting in fragile, easily fractured bones plus decreased milk production, without affecting Ca level in the milk produced.

Polioencephalomalacia is characterized by listlessness, muscular incoordination, progressive blindness, convulsions and death. It is linked to some aspect of the diet that produces high levels of thiaminase, which destroys thiamine (one of the B vitamins). Affected cattle are very responsive to treatment with thiamine, preferably via intramuscular injection. Thiamine is involved in the normal functioning of the central nervous system as well as other systems.

Retained placenta. The nutritional causes of retained placenta appear to be rather complex and include deficiencies of Se, vitamin A, Cu and I. The incidence increases with parturient hypocalcaemia and appears to be related to fat cow syndrome. Pre-partum injection of Se has reduced the incidence of retained placenta. There is a genetic factor and such cows should be considered strong candidates for culling.

Rickets is characterized by improper calcification of the organic matrix of bone during growth, which results in weak, soft bones that lack density. Signs include: swollen, tender joints; enlarged bone ends; an arched back; stiffness of the legs; and development of beads on the ribs. Rickets is a disease of young animals and may be caused by deficiencies of Ca, P or vitamin D.

White-muscle disease may be seen in young calves and is associated with deficiencies of Se or vitamin E, or both. Affected animals have chalky white striations, degeneration and necrosis of cardiac and skeletal muscle. In addition, paralysis of the hindlimbs and a dystrophic tongue may be observed and an increased level of AST (aspartate aminotransferase, an enzyme used in monitoring muscle and liver function) may be detected in the blood.

Xerophthalmia is a degenerative condition of the eye associated with a vitamin A deficiency.

Feed Analysis

A feedstuff or diet can be analysed chemically to provide information on the contents of the components discussed above. However, this does not provide information on the amount of the nutrient that is biologically available to the animal.

Proximate (approximate) analysis is a scheme developed originally in 1865 by Henneberg and Stohmann of the Weende Experiment Station in Germany to analyse the main components in feeds. It is often referred to as the Weende system and has been refined over time. The system consists of determinations of water (moisture), ash, crude fat (ether extract), crude protein (CP) and crude fibre (CF). It attempts to separate carbohydrates into two broad classifications, CF (indigestible carbohydrate) and nitrogen-free extract (NFE; digestible carbohydrate). NFE is measured by difference rather than by direct analysis.

The information gained is as follows.

1. *Moisture (water)*: this can be regarded as a component that dilutes the content of nutrients and its measurement provides more accurate information on nutrient contents.
2. *Dry matter (DM)*: amount of dry material present after the moisture (water) content has been deducted.
3. *Ash*: information on mineral content after the sample has been incinerated. Further analyses on the ash can provide exact information on specific minerals present.
4. *Organic matter*: the amount of protein and carbohydrate material present after ash has been deducted from DM.
5. *Crude protein*: determined as nitrogen content (N) × 6.25. It is a measure of protein present, based on the assumption that the average N content is 16 g N/100 g protein. Some of the N in most feeds is present as non-protein nitrogen (NPN); therefore the value calculated by multiplying N content by 6.25 is referred to as crude rather than true protein. True protein is made up of AA, which can be measured using specialized techniques.
6. *Non-nitrogenous material*
– *Fibre*: obtained as CF. Part of this fraction is digestible; therefore more exact methods of fibre analysis were later developed by Van Soest *et al.* (1991). One method separates feeds into two fractions: (i) plant cell contents, a highly digestible fraction consisting of sugars, starches, soluble protein, pectin and lipids (fats); and (ii) plant cell wall constituents, a fraction of variable digestibility consisting of insoluble protein, hemicellulose, cellulose, lignin and bound N. The method involves boiling a sample in a neutral-detergent solution. The soluble fraction is termed neutral-detergent solubles (NDS; cell contents) and the fibrous residue is called neutral-detergent fibre (NDF; cell wall constituents).

NDF is a measure of hemicellulose, cellulose and lignin and represents the fibrous bulk of the forage. These three components are classified as cell wall or structural carbohydrates. Hemicellulose and cellulose can be broken down by microbes in the rumen to provide energy to the animal. NDF is negatively correlated with intake. Unlike CF and NFE, both NDS and NDF accurately predict the proportions of more and less digestible fractions, respectively, found in a wide variety of feedstuffs. One problem with samples high in protein or starch is that NDF can be overestimated, leading to the inclusion of sodium sulfite and amylase in the extraction procedure (designated aNDF) to provide a more accurate measure of true fibre. A further modification (designated aNDFom) involves the addition of an ashing step to remove inorganic components such as minerals, soil and sand (M. Reuter, personal communication, 12 June 2020). A second method is the acid-detergent fibre (ADF) analysis, which further breaks down NDF into a soluble fraction containing primarily hemicellulose and some insoluble protein and an insoluble fraction containing cellulose, lignin and bound N. Lignin has been shown to be a major factor influencing the digestibility of forages. Tables of feedstuff composition increasingly quote NDF and ADF values rather than CF values, since these data are being used by nutritionists. It is important to note, however, that CF is still the fibre component required by feed regulatory authorities to be stated on the feed tag of purchased feed, at least in North America, with additional guarantees for ADF and/or NDF.
– *Nitrogen-free extract*: the digestible carbohydrates, i.e. starch and sugars.
7. *Fat*: measured as crude fat (sometimes called oil or ether extract since ether is used in the extraction process). More detailed analyses can be done to measure individual fatty acids.

Vitamins are not measured directly in the Weende system, but can be measured in the fat- and water-soluble extracts by appropriate methods.

Eventually, rapid methods based on techniques such as near-infrared reflectance spectroscopy (NIRS) are expected to replace chemical methods for routine feed analysis, but bioavailability is expected to continue to be measured in animal studies.

Publications on Nutrient Requirements

Publications on the nutrient requirements of livestock have been issued by authorities in several countries, based on research findings related to conventional production. For example, estimates of the nutrient requirements of dairy and beef cattle have been published in the USA, Australia, several European countries and the UK. Unfortunately, no comparable publications on organically raised livestock have been published to date. Nevertheless, organic livestock require the same nutrients as conventional stock; therefore it is possible to use these estimates of requirement in formulating recommendations for the feeding of organic cattle.

In addressing a similar issue with the feeding of pigs and poultry, Blair (2018a,b) recommended that the established requirements for these species be modified to allow for the fact that the values had been derived from research involving modern, fast-growing hybrid stock. The rationale for the modification was that organic production favours the use of heritage, pure-bred stock that grows more slowly and has a lower productivity than hybrid stock. The modification suggested dietary mixtures containing essential nutrients at a lower concentration, more in keeping with the level of production expected in organic stock.

It is questionable whether, in the case of cattle, such a modification should be applied in extrapolating from the established requirements for conventionally raised stock. One reason is that there is much less of a difference in the type of stock used in organic and conventional cattle production than in pig or poultry production. Both organic and conventional cattle production favour the use of pure-breds, with a lower usage of hybrids and cross-breds. Therefore the established requirements for conventional cattle are likely to have been derived from stock more similar to the stock used in organic production than in the case of organic pigs and poultry. In spite of this, productivity is generally lower in organic cattle than in conventionally raised cattle. The most likely reason for this is the high level (50–60%) of forage mandated in organic cattle diets. Therefore the difference in productivity can be attributed to diet rather than genetic make-up of the animals. Another relevant factor is that the aim on many dairy and beef cattle farms is to maximize the feed resources available on-farm rather than maximize production using supplemental purchased feeds.

An additional reason relates to environmental issues. As explained above in the section on Digestion of Carbohydrates, fibrous diets promote a higher production of methane than more readily digested diets. This explains why organic milk production inherently increases methane emission, as reported by De Boer (2003), unless the animals are fed highly digestible diets. Similarly, organic beef cattle emit more methane than conventional beef cattle.

These factors, i.e. the type of stock used and the environmental issues (in particular the greenhouse gas emission potential), suggest that the most recent estimates of requirement and the most up-to-date recommendations should be used as the basis for feeding organic cattle. This allows us to take advantage of all relevant knowledge relating to the mitigation of methane emissions. The high level of forage mandated in the diet of organic cattle does make these requirement values more difficult to attain in practice than with conventional cattle and requires that the forages used be of high quality. The benefit for the organic cattle industry is that low-quality forages are discouraged, with a reduction in the accompanying problem of greenhouse gas emissions.

Nutrient requirement tables used in North America are based on the recommendations of the National Research Council (NRC), National Academy of Sciences (NAS), Washington, DC. The recommendations cover food, laboratory and companion animals and are published as a series of books. The recommendations for each species are updated periodically, the most recent updates being *Nutrient Requirements of Beef Cattle* (NRC, 2016) and *Nutrient Requirements of Dairy Cattle* (NRC, 2001). A specially appointed committee of experts meets to review published research findings and to derive estimates of requirements. These are then published as recommendations. The information is used widely by the feed industry in North America and in many other regions.

Other estimates of nutrient requirements include *Nutrient Requirements of Domesticated Ruminants* published by CSIRO (2007). This publication by Australian scientists draws on updated research findings on the energy, protein, mineral, vitamin and water requirements of beef and dairy cattle, sheep and goats. The report defines the responses of animals in terms of weight change, milk production and wool growth to quantitative and qualitative changes in their feed supply in a series of mathematical models. One useful feature of the report is that it has particular application to grazing animals. However, the interactions between the grazing animal, the pasture and any supplementary feeds are complex, involving herbage availability, diet selection and substitution. To apply the recommendations to particular grazing situations, readers are directed to decision-support tools and spreadsheet programs. Thus a higher degree of technical knowledge is required in applying the recommendations to particular situations than in applying the NRC recommendations. Another disadvantage of the report in its applicability to organic production is that, as was pointed out by Corbett (1980), the feed available to many grazing animals in Australia is regularly of a much lower quality than that described in other reports, there are problems in the availability and quality of water supplies, and inadequacies in mineral supply are widespread in Australia.

The most recent French publication is the INRA (1989) report on *Ruminant Nutrition: Recommended Allowances and Feed Tables*. Although the requirement data have not been updated recently, this publication provides a valuable source of data on the composition of a wide range of feeds.

Table 3.2. Daily energy and protein requirements of dairy calves fed milk and starter or milk replacer and starter (from NRC, 2001).

Live weight (kg)	Gain (g)	Dry-matter intake (kg)	Energy			Protein	
			NEM (Mcal)	NEG (Mcal)	ME (Mcal)	Digestible protein (g)	Vitamin A (IU)
30	0	0.32	1.10	0	1.34	23	3300
	200	0.42	1.10	0.28	1.77	72	3300
	400	0.56	1.10	0.65	2.33	122	3300
35	0	0.36	1.24	0	1.50	25	3850
	200	0.47	1.24	0.30	1.96	75	3850
	400	0.61	1.24	0.68	2.55	125	3850
40	0	0.40	1.37	0	1.66	25	4400
	200	0.51	1.37	0.31	2.14	78	4400
	400	0.66	1.37	0.72	2.76	128	4400
	600	0.83	1.37	1.16	3.44	178	4400
45	0	0.44	1.49	0	1.81	31	4950
	200	0.56	1.49	0.32	2.31	80	4950
	400	0.71	1.49	0.75	2.96	130	4950
	600	0.88	1.49	1.21	3.67	180	4950
50	0	0.47	1.62	0	1.96	33	5500
	200	0.60	1.62	0.34	2.48	83	5500
	400	0.76	1.62	0.77	3.15	133	5500
	600	0.94	1.62	1.26	3.89	183	5500
	800	1.13	1.62	1.78	4.69	233	5500
55	0	0.51	1.74	0	2.11	36	6050
	200	0.63	1.74	0.35	2.64	85	6050
	400	0.80	1.74	0.80	3.33	135	6050
	600	0.99	1.74	1.30	4.10	185	6050
	800	1.18	1.74	1.84	4.93	236	6050
60	0	0.54	1.85	0	2.25	38	6600
	200	0.67	1.85	0.36	2.80	88	6600
	400	0.84	1.85	0.83	3.51	138	6600
	600	1.04	1.85	1.34	4.31	188	6600
	800	1.24	1.85	1.90	5.16	238	6600

The most recent British report was issued in 1993 by the Agricultural and Food Research Council (AFRC, formerly ARC), as an advisory manual prepared by the AFRC Technical Committee on Responses to Nutrients (AFRC, 1993). The basis for the report was the ARC (1988) report on *The Nutrient Requirements of Ruminant Livestock*.

Accordingly, the nutrient requirements set out in *Nutrient Requirements of Beef Cattle* (NRC, 2000) and *Nutrient Requirements of Dairy Cattle* (NRC, 2001) are suggested as the basis for the establishment of nutritional standards applicable in average herds of organic cattle, the animals being genotypes drawn from traditional breeds. Many producers use this source of nutritional data. Producers who wish to take advantage of the more advanced data and prediction equations set out in the 2016 report to derive feed formulas may wish to use this source instead.

Examples of the tabulated requirements are shown in Tables 3.2–3.4.

Producers in countries that have established alternative sets of nutritional requirements and which are based on feed composition databases

Table 3.3. Daily nutrient requirements of lactating and pregnant dairy cows (from NRC, 1989).

Live weight (kg)	Energy					Minerals	
	NEL (Mcal)	ME (Mcal)	DE (Mcal)	TDN (kg)	Total CP (g)	Ca (g)	P (g)
Maintenance of mature lactating cows							
400	7.16	12.01	13.80	3.13	318	16	11
450	7.82	13.12	15.08	3.42	341	18	13
500	8.46	14.20	16.32	3.70	364	20	14
550	9.09	15.25	17.53	3.97	386	22	16
600	9.7	16.28	18.71	4.24	406	24	17
650	10.3	17.29	19.86	4.51	428	26	19
700	10.89	18.28	21.0	4.76	449	28	20
750	11.47	19.25	22.12	5.02	468	30	21
800	12.03	20.2	23.21	5.26	486	32	23
Maintenance plus last 2 months of gestation of mature dry cows							
400	9.3	15.26	18.23	4.15	875	26	16
450	10.16	16.66	19.91	4.53	928	30	18
500	11.0	18.04	21.55	4.9	978	33	20
550	11.81	19.37	23.14	5.27	1027	36	22
600	12.61	20.68	24.71	5.62	1074	39	24
650	13.39	21.96	26.23	5.97	1120	43	26
700	14.15	23.21	27.73	6.31	1165	46	28
750	14.9	24.44	29.21	6.65	1209	49	30
800	15.64	25.66	30.65	6.98	1254	53	32
Milk production, nutrients per kg milk of different fat percentages							
Fat %							
3.0	0.64	1.07	1.23	0.28	78	2.73	1.68
3.5	0.69	1.15	1.33	0.301	84	2.97	1.83
4.0	0.74	1.24	1.42	0.322	90	3.21	1.98
4.5	0.78	1.32	1.51	0.343	96	3.45	2.13
5.0	0.83	1.4	1.61	0.364	101	3.69	2.28
5.5	0.88	1.48	1.7	0.385	107	3.93	2.43
Nutrients per kg wt. change during lactation							
Wt. loss	–4.92	–8.25	–9.55	–2.17	–320	–	–
Wt. gain	5.12	8.55	9.96	2.26	320		

MP, metabolizable protein; NEG, net energy required per unit of gain; NEL net energy required per unit of lactation; NEM, net energy required per unit of maintenance.

applying to the local conditions may wish to use these alternative requirement data as the basis for organic dairy and beef feeding systems.

The NRC (2001) publication on *Nutrient Requirements of Dairy Cattle* is much more complex and comprehensive than previous issues. A very useful feature is that responses to nutrient levels in the diet have been modelled mathematically so that requirements (as in the 2016 NRC Beef report) can be generated using a CD-ROM issued with the book or a downloaded feed formulation program from the NRC site. In addition to animal and production data, these programs allow environmental factors such as temperature, wind speed and distance walked to be taken into account, so that the feed requirements can be tailored more exactly to the particular situation in question. The fact that these environmental factors, particularly those related to grazing, are now built into the NRC programs suggests that they will be of considerable value to organic producers. A key question is whether the range of data used by the NRC to generate the mathematical models includes values likely to be encountered in herds of organic cattle. Correspondence between the author of this book and the NRC indicates that such is the case.

Some organic producers may prefer to use the earlier (NRC, 1989) version of *Nutrient Requirements of Dairy Cattle*. An example of the requirement data contained in this publication is shown in Table 3.3.

Table 3.4. Nutrient requirements of growing and finishing cattle (from NRC, 2000). (Example Angus cattle weighing 200–450 kg and gaining 0.5–2.5 kg per day.)

Body wt. (kg)	200	250	300	350	400	450
Maintenance						
NEM (Mcal/d)	4.1	4.84	5.55	6.23	6.89	7.52
MP (g/d)	202	239	274	307	340	371
Ca (g/d)	6	8	9	11	12	14
P (g/d)	5	6	7	8	10	11
Growth (kg/d)						
			NEG (Mcal/d)			
0.5	1.27	1.50	1.72	1.93	2.14	2.33
1.0	2.72	3.21	3.68	4.13	4.57	4.99
1.5	4.24	5.01	5.74	6.45	7.13	7.79
2.0	5.81	6.87	7.88	8.84	9.77	10.68
2.5	7.42	8.78	10.06	11.29	12.48	13.64
			MP required for gain (g/d)			
0.5	154	155	158	157	145	133
1.0	299	300	303	298	272	246
1.5	441	440	442	432	391	352
2.0	580	577	577	561	505	451
2.5	718	712	710	687	616	547
			Calcium (g/d)			
0.5	14	13	12	11	10	9
1.0	27	25	23	21	19	17
1.5	39	36	33	30	27	25
2.0	52	47	43	39	35	32
2.5	64	59	53	48	43	38
			Phosphorus (g/d)			
0.5	6	5	5	4	4	4
1.0	11	10	9	8	8	7
1.5	16	15	13	12	11	10
2.0	21	19	18	16	14	13
2.5	26	24	22	19	17	15

MP, metabolizable protein; NEG, net energy required per unit of gain; NEL net energy required per unit of lactation; NEM, net energy required per unit of maintenance.

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4

Ingredients for Organic Diets

Forage

Pasture is the natural feed for dairy and beef cattle; therefore forages, either grazed or conserved, comprise a major proportion of the diet of organic animals. Forages may be the sole feed provided for low-production stock and whether fed fresh or conserved may provide all the nutrients required.

Grass types

C3-type grasses, i.e. grasses such as ryegrass and fescue with the C3 photosynthetic pathway, predominate in northern latitudes and higher elevations and are generally considered to be more nutritious for animal feeding than C4-type grasses such as Bermuda grass and bahia grass, which predominate in warmer climates (Barbehenn *et al*., 2004). In general the C3-type grasses have higher levels of protein, non-structural carbohydrates and water, lower levels of fibre and toughness, and lower total carbohydrate:protein ratios than C4 grasses. A current concern of agronomists is that global warming may lead to the C3-type grasses being replaced by less nutritious C4-type grasses. In partial response to this concern Barbehenn *et al*. (2004) concluded that C3 grasses will generally remain more nutritious than C4 grasses at elevated atmospheric CO_2 concentrations.

Forage utilization

Haas *et al*. (2007) analysed the feeding pattern on 26 organic dairy farms in Germany. Particular emphasis was placed on the amount and proportion of concentrates and purchased feed. These data were then related to the production on a per cow and per hectare basis. The researchers calculated that, on an energy basis (MJ NEL), 74% of the annual average milk yield of 6737 kg/cow was derived from roughage, 23% from concentrates and cobs, and 3% from commercial processing by-products (e.g. spent grains). Approximately 65% of the concentrates and commercial processing by-products were purchased. Milk yield was almost 7000 kg/ha. It was calculated that 0.96 ha/cow was needed to produce the feed requirement, of which 0.85 ha was farmland and the production area for purchased feed was 0.11 ha.

These data confirm that forage is the main feed of organic cattle and that supplementary feeding with grains and other feedstuffs may be necessary, especially for dairy cows.

Grazed forage

In temperate countries, grazed forages are utilized in late spring, summer and early autumn, while some regions, such as Australia/New Zealand and South America, may support cattle production on year-round grazing of forages.

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In some regions the forage may be deficient in certain trace elements, requiring that the deficiency be remedied by providing the necessary nutrients in the form of supplementary feed, feed blocks or mineral licks.

The pasture is generally based on grasses (e.g. perennial ryegrass, *Lolium perenne*) with a legume such as white clover (*Trifolium repens*) included in the mix to fix atmospheric nitrogen and improve the nutritive quality of the forage. When young and lush, such forage is a feed of high nutritive value and may provide most of the requirements of a good dairy ration. Higher milk yields usually require supplementary feeding, especially when the pasture is of low quality.

Forage species, agronomic conditions, fertilizer practices, maturity at harvest and storage procedures are among the factors that determine the quality of the forage when fed to the animal. The most important grasses worldwide are orchard-grass, ryegrass, fescue and timothy. Various species of wheatgrass are used commonly in range conditions for beef cattle in the western USA. An example is tall wheatgrass which, because of its late maturity, provides a long grazing period when used for pasture. In the early heading stage, it is higher in digestible protein and in total digestible nutrients than other wheatgrasses. The period of most rapid growth is in June and hay is cut in the flower stage in late July. Tall wheatgrass produces high yields of hay, which is readily eaten by cattle if it is cut before or shortly after heading. However, it is not as palatable as most other wheatgrasses or other pasture grasses. When planted in pure stands and fenced, tall wheatgrass is readily grazed by cattle, especially the coarse leaves, and supports excellent gains. It must be grazed to maintain the plants in the vegetative state. It can also be utilized for silage. Tall wheatgrass does not exhibit temperature dormancy like many native wheatgrasses and makes a good recovery after cutting and good autumn growth.

A major pasture grass in North America is tall fescue (*Lolium arundinaceum*). However, the presence of a wild-type fungal endophyte in the most commonly grown cultivar reduces its suitability for many forage-livestock producers, because it results in reduced animal productivity. A survey conducted by Ball *et al*. (1987) found that over 90% of the fescue fields in the USA were endophyte-infected. The endophytic fungus (*Neotyphodium coenophialum* or *Epichloë coenophiala*) produces ergot alkaloids that are toxic to livestock (Ball *et al*., 2002). A broad range of other alkaloids is also produced by the endophyte, but ergopeptide alkaloids are most closely associated with animal toxicity. Because the endophytic fungus itself produces alkaloids, endophyte-free (E−) tall fescue does not contain the toxic alkaloids that are produced in endophyte-infected fescue and therefore does not adversely affect animals consuming it.

It is now known that pastures based on endophyte-free tall fescue are more difficult to manage and sustain, because the presence of endophyte provides enhanced heat stress and insect tolerance. As a result, new cultivars of tall fescue containing endophyte strains that provide fitness benefits similar to the wild-type but produce low or no ergot alkaloids have been introduced (Shymanovich *et al*., 2020).

Legumes are also used as forage crops. The major species used worldwide are lucerne, clovers and bird's-foot trefoil. Legumes have a lower content of neutral-detergent fibre and a higher content of crude protein than grasses. Thus legumes are generally higher in feed value than grasses.

In addition to the mix of plants forming the sward, forage quality is determined by its stage of development and by the soil and climatic conditions.

Clovers and other legumes are highly desirable species in pastures and hay meadows (Jennings, 2005; Jennings *et al*., 2005) and serve several useful functions. Legumes are able to obtain nitrogen from the air through their symbiotic relationship with *Rhizobium* bacteria and, therefore, are not dependent on nitrogen fertilizer. According to Jennings (2005), under ideal conditions clovers can add up to 240 kg N/ha/year to the soil, which can be used by other forage species.

A second valuable role of clovers is to increase the forage quality of pastures, hays or silages, as stated above. Intake is generally higher when cattle are pastured on grass/legume mixtures or fed grass/legume hays than when they are fed grass alone. As a result, animal productivity often improves when a clover is included in pastures, even though total forage yield may not increase.

A third advantage is that clovers can help to extend the grazing season by allowing continued peak grazing at a time when other forages are not as active. The grazing management system should ensure that herbage is grazed at the stage when its nutritive value is highest. In some grazing situations the forage may only supply the maintenance needs of the animal.

Clovers are implicated in some health problems for livestock. Many clovers can cause bloat in grazing ruminants but generally problems only occur when the proportion of clover in the stand is greater than 50%. A few clovers synthesize oestrogen-like compounds called phytoestrogens that can cause reproductive problems in livestock, more especially in sheep.

The common forages and forage mixtures used in the USA were outlined by Jennings *et al.* (2005) (Table 4.1).

Lucerne

Lucerne (*Medicago sativa*), also known as alfalfa, is the most important forage legume worldwide. It can be grown over a wide range of soil and

Table 4.1. Seasonal yield distribution of common forages and forage mixtures in the USA (from Jennings *et al*., 2005).

	Approximate forage yield distribution[a] Percentage of total annual yield			
	Spring	Summer	Autumn	Winter
Cool-season grasses (CSG)				
Tall fescue	65	10	25	0
Fescue – S Arkansas	75	5	20	0
Stockpiled fescue	60	10	0	30
Orchard-grass	65	20	15	0
Annual ryegrass	85	0	10	5
Small grains – N Arkansas	85	0	10	5
Small grains – S Arkansas	75	0	10	15
Small grains/ryegrass – S Arkansas	70	0	10	20
CSG/legume mixtures				
CSG/clover	55	20	25	0
CSG/lespedeza	40	40	20	0
CSG/lucerne	50	30	20	0
Warm-season grasses (WSG)				
Bahia grass	25	70	5	0
Bermuda grass	20	70	10	0
Stockpiled Bermuda grass	20	60	20	0
Crabgrass	5	90	5	0
Dallis grass	15	75	10	0
Native WSG[b]	20	75	5	0
Old World bluestems	20	60	20	0
Warm-season grass mixtures				
Bermuda/annual clovers	35	60	5	0
Bermuda/vetch	40	55	5	0
Bermuda/ryegrass	40	50	10	0
Bermuda/small grains – N Arkansas	35	40	20	5
Bermuda/small grains – S Arkansas	30	40	20	10
Bermuda/fescue	40	40	20	0
Bermuda/stockpiled fescue – S Arkansas	30	40	0	30
Bermuda/stockpiled fescue – N Arkansas	40	30	0	30

[a]Growing season is split into three 100-day periods with a 65-day winter period. Spring = 100 days from 1 March–8 June; Summer = 9 June–16 September; Autumn = 17 September–25 December; Winter = 26 December–28 February.

[b]Autumn growth is left to maintain stand vigour – grazing is not recommended during this period.

climatic conditions and has the highest yield and feeding value of all perennial forage legumes. This versatile crop can be used for pasture, hay, silage, green chop and processed products such as meal, pellets and cubes.

The deep rooting system of lucerne makes it more drought-tolerant than cool-season legumes and grasses. Although lucerne does not make maximum growth during summer droughts, it usually provides good summer pastures. During extreme drought, this aspect is even more important since cool-season grasses become dormant.

Grazing the early spring growth provides quality feed and delays the first hay cut until more favourable weather conditions for harvesting. Grazing during midsummer can provide forage when cool-season grasses are often less productive. In grazing trials and demonstrations, the forage quality of lucerne pasture has been found to be excellent, resulting in total season average daily gains of over 1 kg/day. In addition, milk yield from dairy cows is greater when these animals graze lucerne compared with grass.

Grazing can extend the useful life of a stand by 1 year or more for mature lucerne hay fields where some of the stand has been lost or has become weedy. Grazing may also rejuvenate some stands by reducing grass and weed competition. Research has shown that lucerne stands with fewer than 30 plants/m^2 may not produce maximum yields of hay.

Alternative temperate forages

Researchers in New Zealand studied alternative temperate forages containing secondary compounds for improving sustainable productivity in grazing ruminants (Ramirez-Restrepo and Barry, 2005). Of the forages reviewed, chicory (*Chicorium intybus*) and legumes containing condensed tannins (*Lotus corniculatus*) and sulla (*Hedysarum coronarium*) offered the most advantages (Table 4.2). Chicory and sulla promoted faster growth rates in young sheep and deer infested with internal parasites. Grazing on *L. corniculatus* was associated with increases in reproductive rate in sheep, increases in milk production in both ewes and dairy cows and reduced methane production, effects that were mainly due to its content of condensed tannins (CT). Risk of ruminal frothy bloat in cattle grazing legumes was reduced when the forage contained at least 5 g CT/kg (DM basis). These researchers concluded that the key plant characteristics for improved sustainable productivity were a high ratio of readily fermentable structural carbohydrate and the presence of CT and certain other secondary compounds. Taking into account both nutritional and agronomic considerations, chicory was considered to be one of the best emerging plants for grazing livestock, with *L. corniculatus* being more suitable for areas with dry summers and warm winters. Some of the agronomic limitations of *L. corniculatus* and sulla could be reduced by mechanical harvesting and their inclusion as a component in total mixed rations instead of grazing.

Conserved Forages

Green chop is very similar to grazed forage except that a machine is used to harvest the crop. Harvesting and storage losses are generally very low. However, equipment and energy usage and labour costs are high. Harvesting and storage losses are greatest with hay and silage, but if proper practices are followed these losses can be minimized.

All of the species mentioned above are suitable for organic feeding. Grasses such as Bermuda grass (*Cynodon dactylon*) which are not mentioned specifically in the lists of approved organic feedstuffs appearing below are probably acceptable for organic diets, but this should be checked with the local certifying body.

As stated in section 1.6 of Table 4.6 later in this chapter, relating to forages and roughages, only the following substances are included in this category: lucerne, lucerne meal, clover, clover meal, grass (obtained from forage plants), grass meal, hay, silage, straw of cereals and root vegetables for foraging. They can be conserved by haymaking, silage, etc. As worded, this section applies only to harvested forages and does not apply to grazed forage.

Hay

As described by Sullivan (1973) and McDonald *et al.* (1995), haymaking is the traditional method of conserving green crops and is popular with

Table 4.2. Concentration of secondary compounds in temperate forage species with pastoral value for New Zealand farming systems, dry matter (DM) basis (from Ramirez-Restrepo and Barry, 2005).

Forage	Total condensed tannin content CT g/kg DM	Other known plant secondary compounds	Morphology under grazing[a]
Grasses			
Lolium perenne (perennial ryegrass)	1.8	Endophyte alkaloids 2–30 mg/kg DM	Short
Legumes			
Lotus corniculatus (bird's-foot trefoil)	47	0	Medium
Lotus pedunculatus (big trefoil)	77	0	Medium
Hedysarum coronarium (sulla)			
Spring	84	0	Tall
Autumn	51	0	Tall
Trifolium repens (white clover)			
Normal	3.1	Cyanogenic glycosides	Short
High CT selection	6.7		
Trifolium pratense (red clover)	1.7	Isoflavones 7–14 g/kg DM	Tall
Medicago sativa (lucerne)	0.5	Coumestrol 0–100 mg/kg DM	Tall
Herbs			
Chicorium intybus (chicory)	4.2	Sesquiterpene lactones 3.6 g/kg DM	Tall
Sanguisorba minor (sheep's burnet)	3.4	0	Medium
Plantago lanceolata (plantain)	14	Iridoid glycosides Catalpol 8 g/kg DM Acubin 22 g/kg DM	Medium

[a] Short: recommended grazing height 10 cm for cattle under set stocking (Hodgson, 1990).
Tall: recommended grazing height approximately initial 30 cm down to 15 cm under a rotational grazing.
Medium: in between these heights under rotational grazing.

organic producers in Western Europe and other regions. It is made mainly by the sun-drying of grass and other forage crops. After the crop has been cut, its treatment in the field is intended to minimize losses of valuable nutrients caused by the action of plant respiration, microorganisms, oxidation, leaching and by mechanical damage. The aim in haymaking is to reduce the moisture content of the cut crop to a level low enough to inhibit the action of plant and microbial enzymes and allow the hay to be stored satisfactorily for later feeding.

During the early phase of drying, enzymes break down or reduce simple sugars and organic acids to carbon dioxide, resulting in an overall loss of dry matter (DM) and digestible components, hence the need for drying to be as rapid as possible. Losses of forage DM in the field can range from less than 5% to more than 50%, depending on weather conditions and how long it takes the plants to dry. In warm, dry, windy weather the wet herbage, if properly handled and mechanically agitated, will dry rapidly and losses arising from plant enzyme activity will be low. Some producers use field machinery and barn drying equipment to speed up the process.

Even under good conditions the overall loss of DM may be about 20%. Rainfall can leach protein, phosphorus, potassium, carotene and digestible energy components during hay cutting and drying.

The moisture content of a green crop may range from about 650 to 850 g/kg, falling as the plant matures. For satisfactory storage the moisture content must be reduced to 150–200 g/kg. It is not advisable to wait until the crop is mature and drier before cutting. The more mature the crop, the lower is its nutritional value. Moisture content can be measured by taking a sample from the windrow and drying it using a microwave or convection oven. Wet and dry weights can be measured with a scale.

Lacefield *et al*. (1996) outlined the recommended stage of harvest for a range of forage crops for hay production (Table 4.3). The recommendations apply to Kentucky in the USA and might not apply exactly to other regions. Advisory or extension personnel in these regions should be able to provide similar recommendations.

Hay may become mouldy if not dried sufficiently. Mouldy hay is unpalatable to livestock and may be harmful to farm animals and humans because of the presence of mycotoxins. Such hay may also contain actinomycetes, which are responsible for the allergic disease affecting humans known as 'farmer's lung'.

A traditional method of haymaking, which is still practised in some parts of the world such as Switzerland, Italy, Germany and Scandinavia, is to make hay on racks, frames or tripods. Hays made using a tripod and traditional field curing differ in crude fibre, digestible crude protein, digestible organic matter and metabolizable energy values.

Various types of machinery can be used to crimp and crush the crop during the haymaking process and speed up the rate of drying. Leaves of forage plants dry more quickly than stems, due to the higher water content of stems. Physical breaking or bending of stems with machinery increases air penetration and circulation. Also, increasing the movement of air through the cut results in a more rapid drying speed. Orchard-grass, tall fescue and timothy dry faster and more uniformly than legumes, clovers and ryegrasses. Legume leaf surfaces are more waxy than most grasses, resulting in a slower rate of drying.

During the drying process the leaves lose moisture more rapidly than the stems, becoming brittle and readily shattered by handling. If the herbage is bruised or flattened, the drying rates of stems and leaves are more similar. Excessive mechanical handling is liable to cause a loss of leafy material and, since the leaves at the hay stage are higher in digestible nutrients than the stems, the hay produced may be of low nutritive value. Loss of leaves during haymaking is particularly likely to occur with legumes such as lucerne. Machines are now available which reduce the losses caused by leaf shattering. Baling the crop in the field at a moisture content of 300–400 g/kg and subsequent drying by artificial ventilation have been shown to reduce mechanical losses considerably. Lacefield *et al*. (1996) provided data on the effect of handling procedures on field losses in lucerne (Table 4.4).

Overall losses during haymaking can be appreciable under poor weather conditions. In a study on six commercial farms carried out over a

Table 4.3. Recommended stage of harvest of various forage crops for hay production (Lacefield *et al*., 1996).

Plant species	Time of harvest
Lucerne	Late bud to first flower for first cutting, first flower to 1/10 bloom for second and later cuttings
Bluegrass, orchard-grass, tall fescue and timothy	Boot[a] to early head stage for first cut, aftermath cuts at 4- to 6-week intervals
Red clover and crimson clover	First flower to 1/10 bloom
Oats, barley and wheat	Boot to early head stage
Rye and triticale	Boot stage or before
Soybeans	Mid- to fullbloom and before bottom leaves begin to fall
Annual lespedeza	Early bloom and before bottom leaves begin to fall
Ladino clover and white clover	Cut at correct stage for companion plant
Sudan grass, sorghum hybrids, pearl millet and Johnson grass	100 cm height or early boot stage, whichever comes first
Bermuda grass	Cut when height is 38–40 cm
Caucasian bluestem	Boot to early head stage
Big bluestem, Indian grass and switchgrass	Early head stage

[a] Boot is defined as the stage of growth of a grass just prior to seed-head emergence. This stage can be identified by the presence of an enlarged or swollen area near the top of the main stem.

Table 4.4. Effect of handling procedures on yield in lucerne (Lacefield *et al*., 1996).

		Losses			
	Raked and baled correctly (kg/ha)	Raked too dry (kg/ha)	Baled too dry (kg/ha)	Raked and baled too dry (kg/ha)	Total loss (%)
Dry hay	3306	798	114	1140	34
Crude protein	752	239	68	331	44
Total digestible nutrients	1949	547	103	787	40

3-year period in north-east England by the Agricultural Development and Advisory Service (ADAS, 2005), losses of nutrients were measured between harvesting and feeding. Total DM losses averaged 19.3%, made up of 13.7% field loss and 5.6% loss in the bale. The losses of digestible organic matter and digestible crude protein were both about 27%.

Prolonged drying of hay increases the loss of some vitamins and pigments. Carotene, the precursor of vitamin A, is unstable in the presence of sunlight and losses can be high if the hay is not dried quickly. On the other hand, sunlight increases the vitamin D content of hay due to irradiation of the ergosterol present in the green plants.

Artificial drying (known commercially as dehydration) is a very efficient but expensive method of conserving forage crops. It tends to be a commercial process rather than one found on organic farms. In northern Europe, grass and grass–clover mixtures are the commonest crops dried by this method, whereas in North America lucerne is the primary crop that is dehydrated.

The nutritive value of hay is determined by the stage of growth when it is cut and by the plant species of the parent crop. Yields are higher with late cuts but the nutritional value and voluntary intake by cattle are lower. Thus hay made from early cuts is invariably of higher quality than hays made from mature crops.

The importance of stage of cutting in relation to animal productivity is shown in Table 4.5.

As stated above, hays made from legumes are generally higher in protein and minerals than grass hay. Lucerne is a very important legume, which is grown as a hay crop in many countries. The value of lucerne hay lies in its relatively high content of crude protein, which may be as high as 200 g/kg DM if it is made from a crop cut in the early bloom stage. Cereals are sometimes cut green and made into hay, usually when the grain is at the ‘milky’ stage. The nutritive values of cereal hays cut at this stage of growth are similar to those of hays made from mature grass.

The nutritive value of hay is also affected by field losses of nutrients and by changes taking place during storage (which can be reduced by the use of chemical preservatives). Even under good conditions the overall loss of DM may be about 20%. Artificially dried forages are higher in nutritive value than hays. However, they are expensive to produce and may be used with non-ruminant livestock as sources of minerals and vitamins.

One point to note is that most weeds are not palatable and in pasture will be avoided by livestock if adequate forage is available. However, most livestock cannot differentiate weeds from beneficial long-stemmed forage in hay, resulting in accidental ingestion and possibly a loss in productivity or death. Thus an effective weed control programme is required.

Hay preservatives may be used to allow hay to be stored at moisture levels that would otherwise result in severe deterioration and moulding. These chemical preservatives include propionic acid, lactic-acid-forming bacteria and other biological products. They may be acceptable in organic hay production but this should be checked with the local certifying agency.

Straws consist of stems and leaves of plants after the removal of the ripe seeds by threshing and are produced from most cereal crops and from some legumes. Chaff consists of the husk or glumes of the seed, which are separated from the grain during threshing. Modern combine harvesters put out straw and chaff together, but older

Table 4.5. Effect of stage of harvest of fescue hay on forage quality and live weight gain in Holstein heifers of 227 kg initial weight (Lacefield *et al*., 1996).

Stage of harvest	Crude protein (g/kg)	Digestibility (%)	Dry-matter intake (kg/day)	Live weight gain (kg/day)	Ratio of hay to gain (kg/kg)	Hay (1st cutting) (t/ha)
Late boot to head	138	68	5.9	0.63	10.1	1.494
Early bloom stage	102	66	5.31	0.44	13.5	2.058
Early milk stage–seed formation	76	56	3.9	0.19	22.5	3.162

methods of threshing (e.g. hand threshing) yield the two by-products separately. All the straws and related by-products are extremely fibrous. Most have a high content of lignin and all are of low nutritional value. In rice-growing regions rice straw is used as ruminant feed. It is similar to barley straw in nutritional value. In contrast to other straws, the stems are more digestible than the leaves. A by-product similar in composition to straw is sugarcane bagasse, used for ruminant feeding in tropical countries. Of the straws likely to be available on organic farms, oat straw is preferred for cattle feeding. Apart from the low digestibility of these cereal straws, a major disadvantage is the low intake obtained when they are given to ruminant animals. Whereas a cow will consume up to 10 kg of medium-quality hay, it may eat only about 5 kg of straw. Improvements in both digestibility and intake of straw can be obtained by the addition of protein to the feed mixture.

Cereal hay is suitable as the forage component of rations for all classes of beef cattle, sheep and dairy cattle and should be equal in value to good-quality brome-grass hay.

Fresh cereal straw is a good alternative in wintering rations for cows and sheep if properly supplemented with an energy source such as grain and with added minerals and vitamins. All cereal straws can be fed, with oat and barley straws being preferred because they are more palatable. Straw can be used in combination with other feeds as the sole roughage for beef cows. However, its use should be limited to 4–5 kg/day in order to maintain milk production in dairy cows.

Silage

Ensilage is the name given to the process of conserving a crop of high moisture content by controlled fermentation that results in the production of volatile fatty acids (VFAs). The product is known as silage. Almost any crop can be preserved as silage, but the commonest are grasses, legumes and whole cereals, especially maize. The type and amount of the different acids produced have a direct effect on storage and feeding quality.

Lactic acid has the greatest preservative effect and should make up at least 65–70% of the total silage acids. In addition, fermentations that produce lactic acid result in the lowest losses of DM and energy from the crop during storage. Generally acetic acid production is considered less desirable since the formation of this VFA results in higher losses of DM and energy. Butyric acid may also be produced but – like acetic acid – high levels are considered undesirable since its production results in high DM losses and reductions in feed value.

The dairy industry in North America uses a VFA score to evaluate silages (Dairy One Forage Laboratory, Ithaca, New York). The score is based on the relative contents of lactic, acetic and butyric acids, a score of 8–10 being rated as good, 6–8 as satisfactory and less than 3 as poor.

There are two major objectives in making hay or grass silage. The first is to remove excess herbage from pasture following its rapid growth in the spring, allowing the land to be grazed subsequently without wastage of surplus grass. The second objective is to conserve the material so that it provides a nutritious feed for cattle when grazing is limited or unavailable. Silage production is an alternative to haymaking. Often it is difficult to make hay satisfactorily because of climatic conditions. In order to produce grass hay it is necessary to reduce the moisture content to less than 16% to avoid mould development during storage.

To ensure a stable fermentation, the ensiled material is stored in a silo or other container and sealed to maintain anaerobic conditions. The three most important requirements for good silage production are: (i) rapid removal of air; (ii) rapid production of lactic acid, which results in a rapid drop in pH; and (iii) continued exclusion of air from the silage mass during storage and feeding. In practice this is achieved by chopping the crop during harvesting, rapid filling of the silo and adequate consolidation and sealing. After chopping, plant respiration continues for several hours and plant enzymes such as proteases are active until all the air is used up. These enzymes break down the protein in the forage. Rapid removal of air is also important because it prevents the growth of undesirable aerobic bacteria, yeasts and moulds that compete with beneficial bacteria for substrate. If air is not removed quickly, high temperatures and prolonged heating are commonly observed.

Fermentation begins once anaerobic conditions are achieved. Aerobic fungi and bacteria are the dominant microorganisms on fresh herbage, but as anaerobic conditions develop in the silo they are replaced by bacteria able to grow in the absence of oxygen. During the ensilage process these lactic acid bacteria continue to increase, fermenting the water-soluble carbohydrates in the crop to organic acids (mainly lactic acid), which reduce the pH. Plant material in the field may range from a pH of about 5 to 6. This decreases to 3.6–4.5 after acid is produced. A rapid reduction in silage pH helps to limit the breakdown of protein in the plant material by inactivating plant proteases. In addition, a rapid decrease in pH inhibits the growth of undesirable anaerobic microorganisms such as enterobacteria and clostridia. Eventually, continued production of lactic acid and a decrease in pH inhibit growth of all bacteria.

In general, good silage remains stable, without a change in composition or temperature once air is eliminated and the silage has achieved a low pH.

Several factors can affect the fermentation process. For example, achieving the critical pH is more difficult with crops of high buffering capacity. Legumes are more highly buffered than grasses and are consequently more difficult to ensile satisfactorily, for example lucerne has a higher buffering capacity than maize. Thus, a higher level of acid production is required to lower the pH in lucerne than in maize silage, resulting in lucerne silage being more difficult to make.

The DM content of the forage can also have major effects on the ensiling process. Drier silages do not pack well, making it difficult to exclude all the air from the forage mass. Also, as the DM content increases, growth of lactic acid bacteria is curtailed and the rate and extent of fermentation are reduced. On the other hand, wilting forage above 30–35% DM prior to ensiling can reduce the incidence of undesirable organisms such as clostridia. Wet crops are very difficult to ensile satisfactorily.

In order to assist in the fermentation process, various silage additives have been used to improve the nutrient and energy recovery in silage, often with subsequent improvements in animal performance (Bolsen *et al.*, 1995; Kung and Muck, 1997). These include live organisms such as lactobacilli, enzymes and propionic acid. Molasses, which is a by-product of the sugarbeet and sugarcane industries, is one of the earliest silage additives.

Producers need to check with the local certifying agency to determine whether these additives are acceptable for organic production.

The nutritional value of silage depends upon the species and stage of growth of the harvested crop and on changes that occurred during the harvesting and ensiling period. Thus it can be quite variable. Knowledge of the DM, digestible organic matter and ammonia nitrogen contents is important since these have been shown to be the major determinants of silage DM intake. Periodic sampling is therefore advised, at cooperative, government or commercial laboratories.

The highly degradable nature of the nitrogen in most silages points to the need for adequate supplementation of silage-based diets with a readily available supply of carbohydrate, so that the rumen microbes can cope with the rapid influx of ammonia following an intake of silage (McDonald *et al.*, 1995). This maximizes the synthesis of microbial protein and minimizes the loss of both nitrogen and energy. Silage-based diets must, therefore, contain a supplemental source of energy to maximize the utilization of the nitrogen of the diet. A similar benefit has been obtained by supplementing silage diets with soybean meal, presumably by making amino nitrogen available to rumen microorganisms, which would otherwise be dependent upon ammonia as their main source of nitrogen.

Other Approved Feed Ingredients

Both dairy and beef cattle at certain stages usually require other feedstuffs in the feed mixture in addition to forage. This is especially the case with young animals and with high-producing dairy cows. This section outlines which feedstuffs can be used by the organic producer to supplement the feed of dairy and beef cattle.

New Zealand is one of the few countries to include a list of approved feed ingredients in the organic regulations (Table 4.6). This is a very useful feature of the feeds regulations in New Zealand. In addition, the regulations stipulate that the feeds must meet the ACVM (Agricultural Compounds and Veterinary Medicines 2001) Act and regulations and the HSNO (Hazardous Substances and New Organisms 1996) Act, or are exempt, thus providing additional assurance for the consumer. This list appears to be based on the EU list, possibly because of export requirements. The EU has a somewhat similar list (Table 4.6), but one detailing non-organic feedstuffs that can be used in limited quantities in organic feeds. It may be inferred from the EU list that organic sources of the named ingredients are acceptable.

Most countries follow the EU system and do not publish an approved list, stating that all feedstuffs used must meet organic guidelines. An example is the USA, where the regulations also state that all feed, feed additives and feed supplements must comply with FDA (Food and Drug Administration) regulations.

Based on the information in Table 4.6, which is drawn from both the northern and southern hemispheres, the following sections can be suggested as a potential list of the feedstuffs available for organic cattle production in many countries. Not all of the feed ingredients in the tables are suitable for inclusion in cattle diets, since the lists include those more suited for poultry and pig feeding. In addition, some of the ingredients are not usually available in sufficient quantity.

One of the questions raised by the publication of lists of approved feed ingredients in organic regulations is how new ingredients are added. An example is lentil, which can be grown organically (mainly for the human market) and is available in some countries for animal feeding. Therefore the sections below contain feed ingredients that are not included in Table 4.6 but meet the criteria for inclusion on organic diets. The status of other products such as potato protein could be questioned as being organic in the conventional sense, as they are industrial by-products. Again, their inclusion in approved lists of organic feed ingredients is fortunate since they are valuable sources of amino acids. Their designation as organic may therefore be based on expediency rather than organic principles.

Approved lists are also open to interpretation. An example is calcium carbonate, an approved organic source of calcium. Is ground limestone, a natural and common source of calcium carbonate and prepared from mined calcareous rock, approved as ‘calcium carbonate’? It is a well-established ingredient in conventional cattle diets and one assumes that it is acceptable in organic diets. In cases such as this the producer should verify with the certifying agency that this interpretation is correct.

This example adds weight to suggestions that it would be helpful if lists of approved feedstuffs could be very specific.

The nutritional characteristics of the above feedstuffs which are considered most likely to be used in organic cattle diets are set out in Table 4.18 at the end of this chapter. In Tables 4.14, 4.16 and 4.18 below, each feed has been listed with its International Feed Number (IFN), since some feedstuffs are known under several common names internationally. Professor Lorin Harris, Director of the International Feedstuffs Institute at Utah State University, devised an International Feed Vocabulary to overcome the confusion in naming feeds. The system is now used universally. In this system, feed names are constructed by combining components within six facets: (i) origin, including scientific name (genus, species, variety), common name (genus, species, variety) and chemical formula where appropriate; (ii) part fed to animals as affected by process(es); (iii) process(es) and treatment(s) to which the origin of part eaten was subjected prior to being fed to the animal; (iv) stage of maturity and development (applicable to forages and animals); (v) cutting (primarily applicable to forages); and (vi) grade (official grades and guarantees, etc.).

Table 4.6. Comparison of approved organic feedstuffs in New Zealand and approved non-organic feedstuffs in the EU (herbivores).

	NZ approved list (only those named in each category) MAF Standard OP3, Version 7.1 Appendix Two (2011)	EU approved list of non-organic feedstuffs (up to defined limits) EC No. 1804/1999 and amendments
1. Feed materials from plant origin	1.1 Cereals, grains, their products and by-products.	1.1. Cereals, grains, their products and by-products.
	Oats as grains, flakes, middlings, hulls and bran; barley as grains, protein and middlings; rice germ expeller; millet as grains; rye as grains and middlings; sorghum as grains; wheat as grains, middlings, bran, gluten feed, gluten and germ; spelt as grains; triticale as grains; maize as grains, bran, middlings, germ expeller and gluten; malt culms; brewer's grains. (Rice as grain, rice broken, rice bran, rye feed, rye bran and tapioca were delisted in 2004.)	Oats as grains, flakes, middlings, hulls and bran; barley as grains, protein and middlings; rice germ expeller; millet as grains; rye as grains and middlings; sorghum as grains; wheat as grains, middlings, bran, gluten feed, gluten and germ; spelt as grains; triticale as grains; maize as grains, bran, middlings, germ expeller and gluten; malt culms; brewer's grains.
	1.2 Oilseeds, oil fruits, their products and by-products.	1.2. Oilseeds, oil fruits, their products and by-products.
	Rapeseed, expeller and hulls; soybean as bean, toasted, expeller and hulls; sunflower seed as seed and expeller; cotton as seed and seed expeller; linseed as seed and expeller; sesame seed as expeller; palm kernels as expeller; pumpkin seed as expeller; olives, olive pulp; vegetable oils (from physical extraction). (Turnip rapeseed expeller was delisted in 2004.)	Rapeseed, expeller and hulls; soybean as bean, toasted, expeller and hulls; sunflower seed as seed and expeller; cotton as seed and seed expeller; linseed as seed and expeller; sesame seed as expeller; palm kernels as expeller; pumpkin seed as expeller; olive pulp; vegetable oils (from physical extraction).
	1.3 Legume seeds, their products and by-products.	1.3. Legume seeds, their products and by-products.
	Chickpeas as seeds, middlings and bran; ervil as seeds, middlings and bran; chickling vetch as seeds submitted to heat treatment, middlings and bran; peas as seeds, middlings and bran; broad beans as seeds, middlings and bran; horsebeans as seeds, middlings and bran; vetches as seeds, middlings and bran; lupin as seeds, middlings and bran.	Chickpeas as seeds, middlings and bran; ervil as seeds, middlings and bran; chickling vetch as seeds submitted to an appropriate heat treatment, middlings and bran; peas as seeds, middlings and bran; broad beans as seeds, middlings and bran; horsebeans as seeds, middlings and bran; vetches as seeds, middlings and bran; lupin as seeds, middlings and bran.
	1.4 Tuber roots, their products and by-products.	1.4. Tuber roots, their products and by-products.
	Sugarbeet pulp, potato, sweet potato as tuber, potato pulp (by-product of the extraction of potato starch), potato starch, potato protein and manioc (cassava).	Sugarbeet pulp, potato, sweet potato as tuber, manioc, potato pulp (by-product of the extraction of potato starch), potato starch, potato protein.

Continued

Table 4.6. Continued.

	NZ approved list (only those named in each category) MAF Standard OP3, Version 7.1 Appendix Two (2011)	EU approved list of non-organic feedstuffs (up to defined limits) EC No. 1804/1999 and amendments
	1.5 Other seeds and fruits, their products and by-products. Carob, carob pods and meals thereof, pumpkins, citrus pulp, apples, quinces, pears, peaches, figs, grapes and pulps thereof; chestnuts, walnut expeller, hazelnut expeller; cocoa husks and expeller; acorns.	1.5. Other seeds and fruits, their products and by-products. Carob, carob pods and meals thereof, pumpkins, citrus pulp, apples, quinces, pears, peaches, figs, grapes and pulps thereof; chestnuts, walnut expeller, hazelnut expeller; cocoa husks and expeller; acorns.
	1.6 Forages and roughages. Lucerne (alfalfa), lucerne meal, clover, clover meal, grass (obtained from forage plants), grass meal, hay, silage, straw of cereals, and root vegetables for foraging.	1.6. Forages and roughages. Lucerne (alfalfa), lucerne meal, clover, clover meal, grass (obtained from forage plants), grass meal, hay, silage, straw of cereals, and root vegetables for foraging.
	1.7 Other plants, their products and by-products. Molasses, seaweed meal (obtained by drying and crushing seaweed and washed to reduce iodine content), powders and extracts of plants, plant protein extracts (solely provided for young animals), spices and herbs.	1.7. Other plants, their products and by-products. Molasses, seaweed meal (obtained by drying and crushing seaweed and washed to reduce iodine content), powders and extracts of plants, plant protein extracts (solely provided for young animals), spices and herbs.
2 Feed materials of animal origin	2.1 Milk and milk products. Raw milk, milk powder, skimmed milk, skimmed-milk powder, buttermilk, buttermilk powder, whey, whey powder, whey powder low in sugar, whey protein powder (extracted by physical treatment), casein powder, lactose powder, curd and sour milk.	2.1. Milk and milk products. Raw milk, milk powder, skimmedmilk, skimmed-milk powder, buttermilk, buttermilk powder, whey, whey powder, whey powder low in sugar, whey protein powder (extracted by physical treatment), casein powder, lactose powder, curd and sour milk.
3 Feed materials of mineral origin	Sodium products: unrefined sea salt, coarse rock salt, sodium sulfate, sodium carbonate, sodium bicarbonate, sodium chloride. Calcium products: lithotamnion and maerl, shells of aquatic animals (including cuttlefish bones), calcium carbonate, calcium lactate, calcium gluconate. Phosphorus products: defluorinated dicalcium phosphate, defluorinated monocalcium phosphate, monosodium phosphate, calcium-magnesium phosphate, calcium-sodium phosphate. Magnesium products: magnesium sulfate, magnesium chloride, magnesium carbonate, magnesium oxide (anhydrous magnesia), magnesium phosphate. Potassium product: potassium chloride. Sulfur product: sodium sulfate.	Sodium products: unrefined sea salt, coarse rock salt, sodium sulfate, sodium carbonate, sodium bicarbonate, sodium chloride. Calcium products: lithotamnion and maerl, shells of aquatic animals (including cuttlefish bones), calcium carbonate, calcium lactate, calcium gluconate. Phosphorus products: defluorinated dicalcium phosphate, defluorinated monocalcium phosphate. Magnesium products: magnesium oxide (anhydrous magnesia), magnesium sulfate, magnesium chloride, magnesium carbonate and magnesium phosphate. Potassium product: potassium chloride. Sulfur product: sodium sulfate.

Feed additives	Trace elements. E1 Iron products: ferrous carbonate, sulfate monohydrate and/or heptahydrate, ferric oxide. E2 Iodine products: calcium iodate anhydrous, calcium iodate hexahydrate, sodium iodide. E3 Cobalt products: cobaltous sulfate monohydrate and/or heptahydrate, basic cobaltous carbonate monohydrate. E4 Copper products: copper oxide, basic copper carbonate monohydrate, copper sulfate pentahydrate. E5 Manganese products: manganous carbonate, manganous oxide, manganic oxide, manganous sulfate mono- and/or tetrahydrate. E6 Zinc products: zinc carbonate, zinc oxide, zinc sulfate mono- and/or heptahydrate. E7 Molybdenum products: ammonium molybdate, sodium molybdate. E8 Selenium products: sodium selenate, sodium selenite.	Additives listed must have been approved under Regulation (EC) No. 1831/2003 of the European Parliament and of the Council on additives for use in animal nutrition. Trace elements. E1. Iron products: ferrous carbonate, ferrous sulfate monohydrate and/or heptahydrate, ferric oxide. E2. Iodine products: calcium iodate anhydrous, calcium iodate hexahydrate, sodium iodide. E3. Cobalt products: cobaltous sulfate monohydrate and/or heptahydrate, basic cobaltous carbonate monohydrate. E4. Copper products: copper oxide, basic copper carbonate monohydrate, copper sulfate pentahydrate. E5. Manganese products: manganous carbonate, manganous oxide, manganic oxide, manganous sulfate mono- and/or tetrahydrate. E6. Zinc products: zinc carbonate, zinc oxide, zinc sulfate mono- and/or heptahydrate. E7. Molybdenum products: ammonium molybdate, sodium molybdate. E8. Selenium products: sodium selenate, sodium selenite.
Vitamins, provitamins and chemically well-defined substances having a similar effect, and other items also legally available.	Vitamins approved for use under NZ Legislation: • derived from raw materials occurring naturally in feeds, or • synthetic vitamins identical to natural vitamins only for mono-gastric animals. By derogation from the first paragraph, the TPA may authorize the use of synthetic vitamins A, D and E for ruminants in so far as the following conditions are met: • the synthetic vitamins are identical to the natural vitamins, and • the authorization issued by the TPA is founded on precise criteria. Producers may benefit from this authorization only if they have demonstrated to the satisfaction of the MAF that the health and welfare of the animals cannot be guaranteed without the use of these synthetic vitamins. When the organic feed or organic meat product is to be exported to the US, the vitamins and trace minerals used have to be FDA-approved.	Vitamins derived from raw materials occurring naturally in feedingstuffs. Synthetic vitamins A, D and E identical to natural vitamins for ruminants with prior authorization of the Member States based on the assessment of the possibility for organic ruminants to obtain the necessary quantities of the said vitamins through their feed rations.

Continued

Table 4.6. Continued.

	NZ approved list (only those named in each category) MAF Standard OP3, Version 7.1 Appendix Two (2011)	EU approved list of non-organic feedstuffs (up to defined limits) EC No. 1804/1999 and amendments
Enzymes	Enzymes approved for use under NZ legislation.	Enzymes authorized under Directive 70/524/EEC.
Microorganisms	Microorganisms approved for use under NZ legislation.	Microorganisms authorized under Directive 70/524/EEC.
Preservatives	E 236 Formic acid for silage E 260 Acetic acid for silage E 270 Lactic acid for silage E 280 Propionic acid for silage E 200 Sorbic acid E 330 Citric acid	E 200 Sorbic acid E 236 Formic acid only for silage E 260 Acetic acid only for silage E 270 Lactic acid only for silage E 280 Propionic acid only for silage E 330 Citric acid
Binders, anti-caking agents and coagulants	E 551b Colloidal silica E 551c Kieselguhr E 558 Bentonite E 559 Kaolinitic clays E 561 Vermiculite E 562 Sepiolite E 599 Perlite E 470 Calcium stearate of natural origin E 560 Natural mixtures of stearites and chlorite	E 470 Calcium stearate of natural origin E 551b Colloidal silica E 551c Kieselguhr E 558 Bentonite E 559 Kaolinitic clays E 560 Natural mixtures of stearites and chlorite E 561 Vermiculite E 562 Sepiolite E 599 Perlite
Antioxidant substances	E 306 Tocopherol-rich extracts of natural origin.	E 306 Tocopherol-rich extracts of natural origin.
Certain products used in animal nutrition	Brewer's yeast (*Saccharomyces cerevisiae*)	Yeasts *Saccharomyces cerevisiae* *Saccharomyces carlsbergiensis*
Silage additives	Enzymes, yeasts and bacteria can be used as silage additives.	Sea salt, coarse rock salt, enzymes, yeasts, whey, sugar, sugarbeet pulp, cereal flour, molasses.

In addition, feeds are separated into eight classes: (i) dry forages and roughages; (ii) pasture, range plants, or forages fed green; (iii) silages; (iv) energy feeds; (v) protein supplements; (vi) mineral supplements; (vii) vitamin supplements; and (viii) additives. Each class represents a special characteristic peculiar to a given group of feed products. A six-digit International Feed Number (IFN) is assigned to each feed. The first digit of this number denotes the class of feed. The remaining digits are assigned consecutively but never duplicated. The reference number is used in computer programs to identify the feed for use in calculating diets, for summarization of the data, for printing feed composition tables and for retrieving online data on a specific feed.

Due to a lack of data on feedstuffs that have been grown organically, the data refer mainly to feedstuffs which have been grown conventionally. It is inferred that organic feedstuffs are similar in composition and nutritive value to conventional feedstuffs, except where a difference is stated. In time, a database of organic feedstuffs will be developed.

Cereals, Grains, their Products and By-products (NZ and EU Category 1.1)

Cereal grains are mainly energy sources. The main component of the dry matter is starch, which is concentrated in the endosperm. Of the grains as harvested, oat has the lowest energy value and maize has the highest. Organic producers are most interested in those grains that can be grown on-farm. There do not appear to be any GM varieties of wheat, sorghum, barley or oats being grown, unlike the situation with maize. In the USA, for example, substantial quantities of GM maize varieties developed with insect and herbicide resistance are being grown. Such bioengineered varieties are obviously unsuitable for organic cattle production.

Nutrient composition can be quite variable, depending on differences in crop variety, fertilizer practices and growing, harvesting and storage conditions. Variability may be higher in organic grains than in conventional grains, because of the fertilizer practices in organic grain production, but the data are inadequate at present. Cereal by-products tend to be more variable than the grains.

The total content of protein in grains is very variable. Expressed as crude protein (CP), it normally ranges from 80 to 120 g/kg DM, although some cultivars of wheat contain as much as 220 g/kg DM. The lipid content of cereal grains varies with species. Wheat, barley, rye and rice contain 10–30 g/kg DM, sorghum 30–40 g/kg DM and maize and oats 40–60 g/kg DM. Cereal oils are unsaturated, the main acids being linoleic and oleic, and because of this they tend to become rancid quickly. The crude fibre content of the harvested grains is highest in those such as oats or rice which contain a husk. The cereal grains are all deficient in calcium, containing less than 1 g/kg DM. The phosphorus content is higher, being 3–5 g/kg DM, but part of this is present as phytate. Cereal phytates have the property of being able to bind dietary calcium and probably magnesium, thus interfering with their absorption from the gut. Oat phytates are more effective in this respect than barley, rye or wheat phytates. The cereal grains are deficient in vitamin D and, with the exception of yellow maize, in provitamin A (carotene). Cereal grains are good sources of vitamin E.

It is common for heat processing to be used commercially to improve the nutritive value of cereal grains. Steaming and flaking are known to increase the proportion of propionic acid in the volatile fatty acids during fermentation in the rumen. While about 75% of the starch of ground maize is digested in the rumen, this is increased to about 95% following steaming and flaking. Even greater effects have been recorded with sorghum (ground 42% versus steam processed 91%). However, the starch of ground barley is well digested in the rumen, as is that of ground wheat.

Cereals generally form a low proportion of the total diet of cattle, although they are the major component of the concentrate ration. Calves depend upon cereal grains for their main source of energy, and at certain stages of growth as much as 90% of their diet may consist of cereals and cereal by-products.

Oats (*Avena sativa*)

Oats are grown in cooler, wetter regions. Before 1910 the area seeded to oats often exceeded the area for wheat in Canada, in order to feed horses. Today the world's leading oat producers are

Russia, the European Union, Canada, the USA and Australia.

Oats have traditionally been used successfully as a grain for feeding to cattle, but are no longer the predominant grain used in conventional cattle feeding systems. Higher-energy cereals such as barley and maize are now more popular for the supplementary feeding of dairy cows and beef cattle. An advantage in using oats is that they require little or no processing before being fed.

Nutritional features

Oats are lower in energy and more bulky than other common feed grains, because the hull remains on the grain after harvesting. The hull content can vary from about 24% to 30% by mass. The nutrient composition of oats is variable, due to environmental and genotypic factors as well as harvesting conditions and hull-to-kernel ratio. The net energy content of oat grain is lower than that of wheat, barley or maize. Oats of high hull content are higher in crude fibre and have a lower net energy value than low-hulled oats. Energy content of oats varies directly according to bushel test weight, which in turn is dependent upon size of groat (whole seed minus the hull) and kernel plumpness.

Oats usually contain 110–140 g/kg CP on a DM basis. However, some high-producing varieties have 100 g/kg or less CP. The neutral-detergent fibre (NDF) content of oat may exceed 300 g/kg (DM basis). The acid-detergent fibre (ADF) content is around 100–150 g/kg (DM basis).

Oat grains tend to be lower in potassium content than most other comparable grains. Calcium level is essentially negligible. Phosphorus content of oats is about 4 g/kg. The CP content, which ranges from 70 to 150 g/kg DM, is increased by the application of nitrogenous fertilizers. The oil content of oats is higher than that of most of the other cereal grains and about 60% of it is present in the endosperm. The oil is rich in unsaturated fatty acids.

Cattle diets

Creep-feeding programmes based on oats have been used with young beef and dairy animals. Schingoethe *et al.* (1982) reported similar weight gains in Holstein calves fed 3.6 kg/day of whole milk supplemented with pelleted diets containing oats or maize. No differences in weight gain occurred from 5 to 12 weeks when the calves were fed the pellets to appetite. The need to process oat grains before feeding to cattle remains a controversy. An Australian study by Toland (1976) observed that only 5% of total DM intake of whole oats was voided in the faeces, and dry rolling made only a small improvement in organic matter digestibility. Cuddeford (1995) cited another Australian study reporting that rumination accounted for 66% and 44% of the total breakdown of whole light and heavy oat as opposed to 27% and 17% for whole soft and hard wheat, respectively. The additional rumination in oat-fed cattle may explain why researchers find increased digestibility of whole oat in comparison with other unprocessed cereal grains. Contrary to this, another Australian study found that dairy cows excreted 24% of whole oat grain when fed oats at a level of 3.5 or 7.0 kg DM daily as a supplement to pasture (Valentine and Bartsch, 1989). This study reported no difference in production parameters when the grain was fed whole or hammer-milled.

Moran (1986) conducted a lactation production trial comparing whole and rolled oats in the diet and observed no significant difference in DM intake or milk production. In the same study wheat, barley and oats were compared as a cereal source for Friesian cross-bred cows (69 days post-partum, 500 kg live weight). Three grain-based diets consisting of 60% rolled cereal grain, 17% oat silage, 17% lucerne hay and 6% protein/mineral supplement were fed to appetite for 3 weeks. Milk production was measured over the last 7 days (Table 4.7). No difference was found in the milk yield of cows fed diets based on barley, wheat or oats. The milk fat yield of oat-fed cows was significantly higher and, as a result, fat-corrected milk yield was also significantly higher. The concentration of milk protein was significantly lower in oat-fed cows. Moran (1986) concluded that, when coarsely rolled oats were offered at 60% total DM to cows yielding 25 kg of fat-corrected milk per day, oats were superior to wheat and barley as a cereal grain source. It is likely that at grain levels of 60% the oat diet was providing more fermentable NDF than the other grains. This may be the reason that yield was highest in oat-fed cows, even though intake of DM was not different.

Table 4.7. Effect of cereal source on productivity (kg/head/day) of Friesian cross-bred dairy cows (Moran, 1986).[a]

	Diet			
Measure	Barley	Wheat	Oat	SEM
Dry-matter intake	16.89	18.10	17.69	1.06
Milk yield	22.9	24.0	25.1	0.7
FCM	24.6b	24.9b	27.6a	0.7
Milk fat yield	1.03b	1.01b	1.18a	0.04
Milk protein yield	0.80b	0.89a	0.78b	0.03
Milk fat (%)	4.54	4.19	4.72	0.19
Milk protein (%)	3.52a	3.84a	3.12b	0.11

[a]Values on the same line with different letters (a,b) are significantly different ($P > 0.05$).

Tommervik and Waldern (1969) reported similar yields of fat-corrected milk with diets containing wheat, barley, oat, sorghum or maize at 47% total DM. Milk fat and milk protein yields were not significantly different.

A study by Fisher and Logan (1969) compared supplements based on maize or oat grain for dairy cows. The maize-based supplement yielded more milk, which had a higher concentration of metabolizable protein. However, cows in this trial consumed significantly more of the maize-based supplement than the oat-based supplement.

Oats have also been used successfully in supplementary feed for beef cattle.

Grinding of oats is usually not required for young calves, unless the grain fed with the oats is also ground. Grinding ensures a more complete mixing of the feeds.

Feeding rolled or ground oats to yearlings has been shown to result in a 5% improvement in feed efficiency compared with feeding oats whole. In some studies, cattle fed whole oats consumed more grain per day but gained at the same rate compared with cattle fed rolled or ground oats. This suggests a lower utilization of whole oats by older cattle. The probable reason for this is that calves chew the oats more thoroughly than older cattle.

Oat forage (whole crop) is a good feed for ruminants. It is the small grain most commonly used for forage purposes in areas where it can be grown successfully. Oats can be grazed when 15–20 cm tall. Grazing should be managed to remove the forage before the proportion of stem to leaf is high. Oats are typically planted in late summer and used for grazing during autumn. Medium- to late-maturing varieties produce the most forage.

Oat hay makes a satisfactory hay crop if cut when stems and leaves are still green. The hay is higher in protein content when cut in the soft dough stage.

Barley (*Hordeum sativum*)

Barley is a versatile feed grain used throughout the world for a wide variety of livestock species. It is grown in temperate to subarctic climates with varieties developed for optimum production in respective regions. Barley is an important feed grain in many areas of the world not typically suited for maize production, especially in northern climates. Barley is the principal feed grain in northern Europe, Canada and in the northern USA. It is the grain most widely used in the supplementary feeding of cattle. Barley is widely used in diets for all types of dairy animals, including young calves and growing animals as well as lactating and non-lactating dairy cows. Barley is also imported and used successfully in temperate and warmer semi-arid regions as a protein and energy source for milking herds.

Nutritional features

In most varieties of barley the kernel is surrounded by a hull, which forms about 10–14% of the weight of the grain. Barley contains about 64.6% starch, compared with maize at 71.9%, wheat at 63.8% and oats at 44.7%. The metabolizable energy value is about 13.3 MJ/kg DM for ruminants. The CP content of barley grain ranges from about 60 to 160 g/kg DM with an average value of about 120 g/kg DM. The lipid content of barley grain is low, usually less than 25 g/kg DM.

Waldo (1973) reported that 94% of barley starch was digested in the rumen, compared with 74% for maize starch.

Certain hazards, such as rumen acidosis (rapid fermentation of the starch to lactic acid, resulting in depression of digestion of fibre and feed intake) and bloat, can be encountered with high-concentrate diets given to ruminants. Therefore it is necessary to introduce this type of feed gradually over a period. It is also recommended that a protein concentrate with added vitamins A and D and minerals be used to supplement high-cereal diets of this type. Coarse grinding is strongly recommended over fine grinding.

Tempered rolled barley is the preferred method of processing barley for dairy cows, according to Christen *et al.* (1996). Tempering is the addition of water to bring the moisture content of barley to 180–200 g/kg. Barley should be allowed to temper for 24 h prior to rolling unless a wetting agent is used. The large number of small particles or 'fines' produced by dry rolling or grinding provide more surface area for starch digestion to occur, resulting in increased rate of starch degradation. Fewer small particles are produced with tempered barley compared with dry rolling, resulting in reduced rate of fermentation. Rapid fermentation can lead to reduced pH and acidosis conditions in the rumen. Compared with dry-rolled barley, tempering improved milk yield by 5%, feed efficiency by 10%, apparent digestibility of dietary DM by 6%, NDF digestibility by 15%, ADF digestibility by 12%, CP digestibility by 10% and starch digestibility by 4% (Christen *et al.*, 1996). Tempering is also recommended when barley is fed whole, since whole kernel digestibility is greater than with dry, untempered grain. The explanation for the improved digestibility is that the rapid rate of passage in mixed diets with substantial amounts of forage allows little time for degradation of the intact kernel.

Cattle diets

Barley included in balanced feed mixtures for lactating cows in place of maize did not affect milk yield when both grains were steam rolled (Beauchemin and Rode, 1997; Beauchemin *et al.*, 1997), in complete mixed cubed diets (DePeters and Taylor, 1985), when barley was dry rolled and maize was ground (Grings *et al.*, 1992), or when both grains were ground (Park, 1988; Rode and Satter, 1988). Diets containing dry-rolled sorghum or dry-rolled barley produced similar milk yield, with a tendency for improved feed efficiency with barley diets (Santos *et al.*, 1997). Diets with ground barley and rolled hull-less oat diets resulted in similar milk yield and milk protein production (Fearon *et al.*, 1996).

Other researchers reported slightly lower milk production and DM intake in cattle fed barley in place of maize (Casper and Schingoethe, 1989; McCarthy *et al.*, 1989). A possible explanation is that an increase in ruminal fermentation of starch from barley may alter the ruminal pH and potentially decrease cellulolytic activity of rumen bacteria.

Organic producers may wish to use grain as a supplementary feed when supplies of forage are low. Fredrickson *et al.* (1993) evaluated the effect of different grains (barley, maize, wheat, sorghum) on forage intake and digestion in beef steers fed grass hay. No differences in hay intake or digestibility were noted with the various grain supplements when these were formulated into the diets based on their nutritional characteristics.

Whole barley is not well utilized by beef cattle (Mathison *et al.*, 1991) and a degree of processing is advised. These researchers fed diets containing either 33% or 67% barley grain (fed either whole or rolled) and found no significant interactions with barley processing method. Steers fed whole barley had reduced feed conversions regardless of level of barley feeding. They also noted a higher proportion of cattle bloating when fed diets containing whole barley versus rolled barley. These results have been confirmed in other studies, animal performance being improved when processed barley was used in place of whole barley. In addition, Beauchemin *et al.* (1994) found that whole barley kernels were relatively undamaged during mastication compared with maize. This emphasizes the need for mechanical processing if barley is to be effectively utilized in beef cattle diets.

As with dairy cows, tempering and rolling generally result in marked increases in digestibility of barley. Combs and Hinman (1985) noted energy savings during grain processing of

11.3% for temper-rolling over dry rolling. Because of the rapidly fermentable nature of barley, the grain should only be coarsely cracked, not finely ground. Fine grinding barley is liable to result in problems such as acidosis. In addition, the dusty nature of finely ground barley diets may cause problems with feed intake unless molasses, fat, liquid supplements or other ingredients are added to the diet to improve acceptance. The goal of a dry processing system for barley should be to break the kernel into large pieces and to minimize the amount of fines.

These recommendations apply also to young stock. Staigmiller and Adams (1989) compared whole barley, rolled barley and rolled oats for young, early-weaned beef calves. They noted that calves fed whole or rolled barley had similar average daily gains, but feed efficiency was improved by rolling. Economides *et al.* (1990) found similar results in young calves fed high-grain rations. Calves fed pelleted barley diets had growth rates similar to calves fed whole barley diets. However, feed efficiency was better with the pelleted diet than with the whole barley diet.

Several studies have evaluated barley as a supplement to grass silage for beef cattle (Veira *et al.*, 1990; Flipot *et al.*, 1992; Steen, 1993; Berthiaume *et al.*, 1996). Similar results were reported by these researchers. Adding rolled barley to grass silage-based diets increased weight gains and improved feed efficiencies.

Barley has also been shown to give improved production in breeding herds on range. Cochran *et al.* (1986) used a barley-based protein supplement (0.9 kg/head/day: 700 g/kg barley and 300 g/kg cottonseed meal) for dry gestating cows grazing native range in south-eastern Montana. Cows fed the barley–cottonseed meal cake gained 14 kg during the trial. Cows fed 1.25 kg lucerne/day had similar gains. Unsupplemented cows lost an average of 10.9 kg during the study period.

Barley by-products

Barley by-products can also be used in cattle diets. The by-products obtained from the brewing process include malt culms (sprouts), brewer's grains, spent hops and brewer's yeast.

Malt culms are relatively rich in CP (about 280 g/kg DM). They are also produced as a by-product of the distilling industry. Malt culms have a bitter flavour owing to the presence of the amino acid asparagine, which forms about one-third of the crude protein. However, when mixed with other feeds they are accepted readily by cattle and have been included in concentrate mixes at levels up to 500 g/kg.

Brewer's grains consist of the insoluble residue left after removal of the wort. In addition to the barley residue this product may contain residues of maize and rice used in the brewing process. Consequently the composition of the product can be very variable.

Fresh brewer's grains contain about 700–760 g water/kg and may be given to cattle, sheep and horses in this state or alternatively preserved as silage. The rumen degradability of the protein of the dried product is about 0.6 compared with about 0.8 in the original barley. Brewer's grains are a concentrated source of digestible fibre, and energy losses from the rumen as methane are lower than with high-starch feeds. They are high in phosphorus but low in other minerals. Brewer's grains are used widely in dairy feed.

Dried brewer's yeast is a protein-rich concentrate containing about 420 g CP/kg. It is highly digestible and may be used for all classes of farm animals. The protein is of fairly high nutritive value. This yeast is relatively rich in phosphorus but has a low calcium content.

By-products of the distilling industry include distiller's grains. The composition depends on the grains used in the fermentation process and can vary widely. As with brewer's grains, distiller's grains are a useful feed for dairy cows and are often ensiled for winter feeding. Most of the lipid in the original grain is retained in this by-product and it has a high content of unsaturated fatty acids, which reduces microbial digestibility of fibre in the rumen and depresses intake. Digestibility and intake can be improved by the addition of calcium carbonate, which forms insoluble calcium soaps of the unsaturated fatty acids, thereby overcoming their effects on the rumen microbes.

The spent wash is often mixed with the distiller's grains and dried together to yield a material marketed as distiller's dried grains with solubles or dark grains. Dark grains generally are a balanced feed for ruminants but the degradability of the protein may vary according to the drying process. Additionally, the quality of the undegradable protein may be low, as a result of heat damage. Like other distillery by-products, dark grains are a good source of phosphorus but the copper content may be high, originating from the metal used in the stills.

Rice (*Oryza sativa*)

Rice requires a subtropical or warm temperate climate and is the main cereal crop of eastern and southern Asia. It is also grown in the southern USA and in Australasia.

The polished white rice that is an important staple food for a large section of the human population is obtained by milling the harvested rice. When harvested from the field, rice is in the form of paddy (or 'rough') rice and the kernel is fully enveloped by the rice hull. After being dried, the first stage in milling is removal of the hull, yielding about 80% brown rice and 20% hulls. Brown rice is still covered by the bran, which is removed with the aleurone layer and the germ by further milling to produce polished rice. The yield from the brown rice is approximately 60% white rice, 10% rice bran and 10% polishings plus broken rice. The main by-product – rice bran – is marketed as a mixture of hulls, germ, bran, polishings and broken grains and is suitable for cattle feed.

Rough rice can be used in cattle diets but is generally not available. Rice after processing that does not meet the quality standards for humans is a good feed ingredient for cattle diets, provided it is not mouldy or contaminated with toxic fungi. Elevated levels of aflatoxin M1 were observed in routine checks of consumer milk in southern Sweden in early 2006 (Nordkvist *et al*., 2009) and 68 farms were banned from delivering milk to dairies for varying periods. An investigation revealed that rice feed meal present in the commercial feed used (at levels less than 10%) was contaminated with this mycotoxin. The rice feed meal was a by-product from the preparation of Basmati rice for human consumption.

The comparative ruminal degradability of rice, maize, oats and wheat was studied by Mizubuti *et al*. (2007). Rice meal showed the lowest potential degradable fraction (29.24%) and the lowest effective degradation rate of DM (49.16%) and CP (66.65%).

Rice by-products

Rice bran is the most important rice by-product. It is suitable as a grain substitute, equivalent to oats in crude protein, fat, fibre and energy contents. It is a palatable feedstuff, which has been used effectively in cattle diets (White and Davis, 1962). However, the composition of rice bran can be quite variable due to the degree of milling and the relative quantity of constituents.

Full-fat rice bran and defatted rice bran may be available. The full-fat product is higher in energy content but one of the problems is the high oil content (140–180 g/kg), which is very unsaturated and unstable. At high ambient temperature and in the presence of moisture the oil breaks down to glycerol and free fatty acids. The result is an unpleasant taste and odour and reduced palatability.

Rice bran is finely ground and has a powdery texture, making handling and storage in bins difficult due to stacking and bridging. Blending with other concentrates, such as grain, improves the flow characteristics. The small particle size, starch and fat content all add to the risk of digestive upset and the potential for nutritional imbalances. In general, beef cattle diets should not contain more than 6% fat on a DM basis. Therefore, full-fat rice bran should be limited to less than 33% of the diet. Because of its high phosphorus content, calcium supplementation may be required to maintain an adequate calcium:phosphorus ratio of the diet.

Rice mill feed in the USA usually contains about two-thirds rice hulls and one-third rice bran, but can be highly variable in composition due to the varying amounts of rice hulls and rice bran included. There is considerable difference in the nutritive value of rice bran and rice mill feed. Rice bran is much higher in CP and energy content and is considerably more costly than rice mill feed. Handling characteristics of the mill feed are similar to those of rice bran, but rice mill feed has a longer storage life due to its lower fat content. It is more suitable for maintenance diets due to its high content of rice hulls. Rice mill feed is very palatable to cattle. Stacey and Rankins (2004) found that growing beef cattle could be fed diets containing up to 60% rice mill feed (DM basis) for up to 112 days with no digestive problems.

Rice bran produced in the USA may contain a high calcium level due to varying amounts of calcium carbonate added at the mill. When the amount of added calcium carbonate exceeds 3% (total calcium exceeding 12 g/kg), it is required under the feed regulations that the percentage of calcium carbonate must be stated on the feed tag.

Millet

The name 'millet' is frequently applied to several species of cereals which produce small grains and are widely cultivated in the tropics and warm temperate regions of the world. According to McDonald *et al.* (1995) the most important members of this group include *Pennisetum americanum* (pearl or bulrush millet), *Panicum miliaceum* (proso or broomcorn millet), *Setaria italica* (foxtail or Italian millet), *Eleusine coracana* (finger or bird's-foot millet), *Paspalum scorbiculatum* (kodo or ditch millet) and *Echinochloa crusgalli* (Japanese or barnyard millet).

The most common types of millet grown in the North Plains of the USA are proso millet (*P. milaceum*) and foxtail millet (*S. italica*). Foxtail millet is grown primarily for hay. Other types of millet grown in the USA are pearl millet (*Pennisetum glaucum*) and Japanese millet (*E. crusgalli* var. *frumentacea*). Pearl millet is used extensively in the south-eastern USA as a forage crop, and Japanese millet, a close relative of barnyard grass, sometimes is grown for forage.

Nutritional features

The composition of millet is very variable, the CP content being generally within the range 100–120 g/kg DM, the ether extract 20–50 g/kg DM and the crude fibre 20–90 g/kg DM (McDonald *et al.*, 1995). Millet has a nutritive value very similar to that of oats and contains a high content of indigestible fibre owing to the presence of hulls, which are not removed by ordinary harvesting methods. Millet is a small seed and is usually coarsely ground for inclusion in cattle feed.

Cattle diets

Dairy cows receiving ground millet at a concentration of 40% of the grain mix produced as much milk and gained in body weight more than cows fed equal amounts of oats, maize or barley (Berglund, 2007). Similar results were obtained in a second trial by this author.

Mustafa (2010) reported on the performance of lactating dairy cows fed pearl millet grain. Three diets with a similar content of CP and a 57:43 forage:concentrate ratio were formulated. Diets contained 300 g maize/kg, 300 g pearl millet/kg, or 310 g maize and pearl millet mixed 1:1 (wt/wt)/kg. Dry-matter intake and energy-corrected milk were similar for all dietary treatments and averaged 23.8 and 33.5 kg/day, respectively. Dry-matter intake (percentage of body weight) was unaffected by dietary treatments and averaged 3.40%. Milk fat, protein, lactose and total solids concentrations were not influenced by grain type. Ruminal ammonia–nitrogen concentration was unaffected by dietary treatment. However, ruminal pH tended to be lower for cows fed pearl millet than those fed the maize and pearl millet mix. It was concluded that pearl millet grain can replace maize in dairy cow diets up to 30% of the diet DM with no adverse effects on milk yield or milk composition.

Similar or slightly improved average daily gain was reported when pearl millet replaced maize or sorghum in beef cattle diets (Hill and Hanna, 1990; Hill *et al.*, 1996). These findings are of interest in that the expanded production and use of pearl millet grain may allow cattle diets to be formulated without supplemental protein. Inclusion of pearl millet and maize (or other grain) in cattle diets allows for the production of all dietary ingredients on-farm with the exception of vitamins and minerals.

Rye (*Secale cereale*)

Rye has an energy value intermediate to that of wheat and barley and a CP content similar to that of barley and oats. Like wheat, rye should be crushed or coarsely ground for inclusion in cattle diets.

Rye may contain several anti-nutritional factors such as high levels of arabinoxylans (pentosans) and is regarded as being the least palatable of the cereal grains and sticky when chewed. Rye may be contaminated with the ergot fungus (*Claviceps purpurea*), which is dangerous to animals, causing abortion in cattle; lameness can also occur and necrotic lesions in the feet, tail and ears.

These features probably explain why few published findings are available on the utilization of rye in cattle diets. It is not a major cereal grain used in the supplementary feeding of dairy or beef cattle; for example, Mowrey and Spain (1999) reported that in the USA rye comprised low amounts of dairy concentrate (0–10%).

Some results of feeding studies are available. In a Canadian study, Sharma *et al*. (1981) evaluated rye grain in the diets of young Holstein calves and lactating dairy cows. The calves were fed diets containing various amounts of rye grain up to 18 weeks of age. Average daily gain and feed intake were similar during the first 6 weeks. However, during the next 12 weeks calves receiving a diet containing 60% rye ate less feed and gained more slowly than calves fed a barley control diet or a diet containing 80% roasted rye. Ratios of feed to gain were not different among the various treatments. Apparent digestibilities of the calf diets measured at 10 weeks of age did not differ, but calves fed the diets with 60% and 80% rye tended to have lower digestibilities than those fed the barley control diet. Roasting the rye improved the digestibility of ADF and ether extract but slightly reduced protein digestion.

Holstein cows were fed four diets containing 0, 250, 500 and 750 g rolled rye/kg in the grain mixture, together with grass silage. The silage and grain mixtures were offered separately in a 40:60 ratio (DM basis) twice daily on a free-choice basis. Replacement of barley with rye in the grain mixtures reduced the total DM intake by lactating cows but had little effect on average daily milk production, milk composition and milk prolactin.

Sorghum (*Sorghum vulgare*), milo

Sorghum, commonly called grain sorghum or milo, is the third most important cereal crop grown in the USA and the fifth most important cereal crop grown in the world. Much of it is used in the human market. As a continent, Africa is the largest producer of sorghum. Other leading producers include India, Mexico, Australia and Argentina. Sorghum is one of the most drought-tolerant cereal crops and is more suited than maize to harsh weather conditions such as high temperature and less consistent moisture.

Proper grinding of grain sorghum is important because of the hard seedcoat; grinders should be set to break all of the kernels without producing a fine, dusty feed.

A high proportion of the sorghum grown in the USA is used for ethanol production, yielding by-products such as distiller's dried grains with solubles (sorghum-DDGS) for animal feeding.

Nutritional features

Research findings indicate that sorghum and maize are somewhat similar in nutritive value as supplementary grains for cattle feeding, but sorghum is generally higher in CP than maize. One disadvantage of grain sorghum is that it can be more variable in composition because of growing conditions. Crude protein content usually averages around 89 g/kg, but can vary widely from 70 to 130 g/kg; therefore a protein analysis prior to formulation of diets is recommended.

The hybrid yellow-endosperm varieties are more palatable to livestock than the darker brown sorghums, which possess a higher tannin content to deter wild birds from damaging the crop. For example, Larraín *et al*. (2009) found that growth rate and production efficiency were reduced in steers fed high-tannin sorghum compared with steers fed maize. The estimated NEM of high-tannin sorghum was reported by these researchers to be 1.91, and the estimated NEG was 1.35 Mcal/kg, DM basis.

Cattle diets

Sorghum in ground and processed forms has been used successfully in a range of cattle feeds. Ground maize, sorghum and dehydrated cassava were compared as supplementary energy sources in starting mixtures for Schwyz × Zebu dairy calves (Mello *et al*., 1981). Whole milk and skimmed milk were fed initially. The milk was then supplemented with maize, sorghum or cassava. No effect of energy source was found when whole milk was fed. Skimmed milk in combination with maize meal gave the best weight gains, compared with the other skimmed milk combinations. Weight gain from birth to 161 days was best when the grains were fed in combination with whole milk.

Mitzner *et al.* (1994) found in two trials with dairy cows that ground sorghum in the grain supplement supported milk yield and composition similar to those obtained with maize. Santos *et al.* (1997) found that dry-rolled sorghum and dry-rolled barley gave similar milk yields, with a tendency for improved feed efficiency with barley. Better results with barley than with sorghum were reported in an Australian study in which dairy cows grazing tropical grass pasture were fed barley- or sorghum-based concentrates and lucerne hay (Moss *et al.*, 2000). Milk yields of cows fed sorghum-based concentrate were lower than those of cows fed equivalent levels of barley-based concentrate.

Several investigations have been carried out on heat processing to improve the nutritive value of sorghum for inclusion in diets for dairy cattle. Theurer *et al.* (1999) reviewed the available literature on effects of processing and showed that the NEL of steam-flaked maize and sorghum grain was about 20% greater than for the dry-rolled grain sorghum. Based on milk yield and composition, steam-flaked sorghum grain was of equal value to steam-flaked maize. Steam flaking consistently improved milk production and milk protein yield over steam rolling. This result was explained by a greater proportion of dietary starch being fermented in the rumen, enhanced digestibility of the reduced fraction of dietary starch reaching the small intestine, and increased total starch digestion. Steam flaking increased cycling of urea to the gut, microbial protein flow to the small intestine and mammary uptake of amino acids. Optimal flake density of steam-processed maize or sorghum grain appeared to be about 360 g/l. Nikkhah *et al.* (2004) found that the inclusion of steam-flaked rather than ground broom sorghum in diets significantly improved the efficiency of feed conversion. Similar findings were reported by other researchers. Santos *et al.* (1997) found greater efficiency of feed utilization and conversion of feed protein to milk protein in cows fed sorghum grain that had been steam-flaked at 437 and 360 g/l compared with those fed dry-rolled sorghum or sorghum that had been steam-flaked at 283 g/l.

Organic farmers would have difficulty in steam-flaking sorghum on-farm, but might find it worthwhile to purchase the processed sorghum from a feed supplier or feed processor.

Wheat (*Triticum aestivum*)

Wheat grain consists of the whole seed of the wheat plant. This cereal is widely cultivated in temperate countries and in cooler parts of tropical countries. Several types of wheat are grown in North America. These include soft white winter, hard red winter, hard red spring and soft red winter wheat. Hard red spring wheat has the highest protein content, with hard red winter wheat and durum being slightly lower. The types grown in Europe and Australia include white cultivars.

Wheat is not traditionally used as a feed grain because its milling properties make it desirable for use as human food. Some wheat is grown, however, for feed purposes. In some situations wheat may be competitively priced with other feed grains due to damage from disease, drought or sprouting. Feed-grade wheat is a palatable, digestible source of nutrients, which can be used in cattle diets if fed with caution to avoid digestive upsets. By-products of the flour milling industry are also very desirable ingredients for livestock diets.

The use of home-grown wheat in dairy cattle feeding has gained interest over the past few years for different reasons. As a result of the Common Agricultural Policy, the price of wheat has been lowered since the end of the 1990s. Furthermore, there is an increased interest among farmers to reduce feeding costs by using home-grown feeds, such as wheat.

Whole-crop wheat is a valuable alternative for grass silage in drier climates or in climates where other forages such as maize are difficult to grow. In climatic regions favourable for production of maize silage and grass or grass silage, home-grown wheat grain can partially substitute for commercial concentrates in cattle diets.

Nutritional features

During threshing, the husk – unlike that of barley and oats – detaches from the grain, leaving a less fibrous product. As a result, wheat is close to maize in metabolizable energy content but it contains more CP. Therefore it can be used as a replacement for maize as a high-energy ingredient in supplementary grain mixtures and it requires less protein supplementation than maize.

Wheat is very variable in composition. The CP content, for example, may range from 60 to 220 g/kg DM, though it is normally between 80 and 140 g/kg DM. Climate and soil fertility as well as type and variety influence the protein content. Therefore a concern in using wheat in livestock diets is that the energy and CP contents are more variable than in other cereal grains such as maize, sorghum and barley. Researchers at the University of Saskatchewan in Canada (Zijlstra *et al*., 2001) analysed a large range of Canadian wheat samples and reported that CP ranged from 122 to 174 g/kg, NDF from 72 to 91 g/kg and soluble non-starch polysaccharides (NSPs) from 90 to 115 g/kg. The crude fibre content was low overall and showed little variation. Kernel density was high (77–84 kg/hl) overall. The variation found in composition and nutritive value was related to the different wheat classes and cultivars grown for human consumption, and to growing conditions and fertilizer practices. The results indicated a variation in CP content of 50%. Therefore periodic testing of batches of wheat for nutrient content is necessary.

Wheat is low in fibre and high in starch content. It is higher in CP than maize (as indicated above), barley or oats. Like all other cereal grains, wheat is deficient in calcium and adequate in phosphorus for cattle.

The type of protein present in wheat is referred to as gluten. All glutens possess the property of elasticity. Strong glutens are preferred for bread making, and form a dough that traps the gases produced during yeast fermentation and causes the dough to rise. This property of gluten is considered to be the main reason why finely ground wheat is unpalatable when fed to animals. Wheat, especially if finely milled, forms a paste-like mass in the mouth and rumen and this may lead to digestive upsets. Newly harvested wheat has the reputation of being more harmful in this respect than wheat that has been stored for some time.

Cattle diets

Processing wheat substantially improves its digestibility. Because of its small kernel size, the increase in digestibility is large: 20–25% compared with an improvement in processed barley of 12–15%. According to research published in Australia, whole wheat has a digestibility of 60% compared with 86% for rolled wheat.

Wheat is very palatable if not ground too finely; good results have been obtained when wheat was coarsely ground (hammer mill screen size of 4.5–6.4 mm). When excess fines are present, an increase in digestive problems such as bloat, founder and acidosis can be expected. This is attributed to a faster rate of starch digestion, which increases the potential for digestive upsets such as those noted. In addition, finely ground wheat readily absorbs moisture from the air and saliva in the feeder, which can result in feed spoilage and reduced feed intake. Feed containing finely ground wheat can bridge and not flow well in feeding equipment.

In general, wheat grain is fed dry and rolled or ground. However, some heat treatments have been claimed to improve the feeding value and therefore the productivity of dairy cattle.

The rapid rate of starch digestion, as well as the gluten component of the protein, makes wheat more difficult to feed than other grains. Dry-rolled wheat has the fastest rate of starch digestion of all feed grains. This is followed by dry-rolled barley. Maize and whole oats have the slowest rate of starch digestion. These effects probably explain the finding by Leddin *et al.* (2009) that increasing amounts of crushed wheat fed with pasture hay reduced dietary fibre digestibility in lactating dairy cows. These researchers also reported that rumen fluid pH declined as the proportion of wheat in the diet increased.

A general recommendation is that coarse rolling should be used, to break the kernel into two or three pieces. Tempering wheat (by adding moisture) has been shown to be effective in reducing fines and maintaining milk yield and composition.

Doepel *et al.* (2009) studied the effects of dietary wheat levels on the production and ruminal fermentation pattern in Holstein cows. The second-lactation Holstein cows were given one of three diets containing 0, 100 or 200 g/kg steam-rolled wheat (DM basis) at the expense of steam-rolled barley. Cows were fed and milked twice daily. Diet did not affect DM intake (20.9 kg/day), yields of milk (36.1 kg/day) or milk components (1.25, 1.10 and 1.67 kg/day for fat, protein and lactose, respectively). Fat percentage was not different among the treatments but protein content of the milk was reduced by the wheat diets, and was lower with 100 g/kg than with 200 g/kg. Cows fed wheat had lower ruminal pH (6.36 versus 6.44), higher ammonia-N (11.49 versus

8.10 mg/dl) and total volatile fatty acid (121 versus 113 mM) concentrations than cows not fed wheat. The acetate:propionate ratio was lower for cows fed wheat than for those not fed wheat (3.21 versus 3.36), but was not different between cows fed 100 or 200 g/kg wheat. Wheat feeding did not alter the apparent digestibility of DM, CP, ADF or NDF. Results of this study show that up to 200 g steam-rolled wheat/kg can be included in the diet of dairy cows without compromising production or causing subacute ruminal acidosis, provided adequate fibre is supplied and the diets are properly formulated and mixed.

Some researchers recommended that wheat should make up no more than 400–500 g/kg of the grain mix for milking cows. However, more conservative levels are the norm. An adaptation period of 2–3 weeks should always be provided, with an initial level not exceeding 100 g/kg in the grain mix.

Milling by-products

The main product of wheat milling is flour. Several by-products are available for animal feeding and are used extensively in livestock diets because of their valuable properties as feed ingredients. Their use in this way minimizes the amount of whole grain that has to be used in supplements. These by-products are usually classified according to their crude protein and crude fibre contents and are traded under a variety of names that are often confusing, such as pollards, offals, shorts, wheat-feed and middlings.

After cleaning (screening), sifting and separating, wheat is passed through corrugated rollers, which crush and shear the kernels, separating the bran and germ from the endosperm. Clean endosperm is then sifted and ground to flour for human consumption. The mill may further separate the remaining product into middlings, bran, germ and mill run. Some bran and germ is used for human consumption as well as animal diets. Mill run includes cleanings (screenings) and all leftover fines and is often used for cattle feeding.

AAFCO (2005) defined the flour and wheat by-products for animal feeding in the USA as follows.

WHEAT FLOUR. Wheat flour is defined as consisting principally of wheat flour together with fine particles of wheat bran, wheatgerm and the offal from the 'tail of the mill'. This product must be obtained in the usual process of commercial milling and must contain not more than 15 g crude fibre/kg [IFN 4-05-199 Wheat flour less than 15 g fibre/kg].

WHEAT BRAN. Wheat bran is the coarse outer covering of the wheat kernel as separated from cleaned and scoured wheat in the usual process of commercial milling [IFN 4-05-190 Wheat bran]. Sometimes screenings are ground and added to the bran. Generally, wheat bran has a CP content of 140–170 g/kg, crude fat (oil) 30–45 g/kg and crude fibre 105–120 g/kg. Therefore, while wheat bran may have a CP content as high as or higher than the original grain, the higher fibre level results in this product being lower in energy.

WHEATGERM MEAL. Wheatgerm meal consists chiefly of wheatgerm together with some bran and middlings or shorts. It must contain not less than 250 g CP and 70 g crude fat/kg [IFN 5-05-218 Wheatgerm ground].

A wide variety of wheatgerm grades is produced, depending on region, type of grain processed and the presence of screenings and other wheat by-products. Generally, wheatgerm meal has a CP content of 250–300 g/kg, crude fat (oil) 70–120 g/kg and crude fibre 30–60 g/kg. As with other feedstuffs containing a high level of plant oil that contains unsaturated fatty acids, a problem that may result on storage is rancidity due to peroxidation of the fat.

A defatted product is also marketed. Defatted wheatgerm meal is obtained after the removal of part of the oil or fat from wheatgerm meal and must contain not less than 300 g/kg CP [IFN 5-05-217 Wheatgerm meal mechanically extracted].

The amount of wheatgerm meal available for livestock feeding will usually be very limited due to availability and cost, since there are competing markets for these by-products.

WHEAT RED DOG. Wheat red dog consists of the offal from the 'tail of the mill' together with some fine particles of wheat bran, wheatgerm and wheat flour. This product must be obtained in the usual process of commercial milling and must contain not more than 40 g crude fibre/kg [IFN 4-05-203 Wheat flour by-product less than 40 g fibre/kg].

Wheat red dog is a very fine, floury, light-coloured feed ingredient. The colour may range from creamy white to light brown or light red, depending on the type of wheat being milled. Wheat red dog can be used as a pellet binder, as well as a source of protein, carbohydrate, minerals and vitamins. The average composition is around 155–175 g CP/kg, 35–45 g crude fat/kg and 28–40 g crude fibre/kg.

WHEAT MILL RUN. Wheat mill run consists of coarse wheat bran, fine particles of wheat bran, wheat shorts, wheatgerm, wheat flour and the offal from the 'tail of the mill'. This product must be obtained in the usual process of commercial milling and must contain not more than 95 g crude fibre/kg [IFN 4-05-206 Wheat mill run less than 95 g/kg crude fibre].

Wheat mill run usually contains some grain screenings. This by-product may not be available in areas where the by-products are separated into bran, middlings and red dog. Wheat mill run generally has a CP content of about 140–170 g/kg, crude fat 30–40 g/kg and crude fibre 85–95 g/kg.

WHEAT MIDDLINGS. Wheat middlings consists of fine particles of wheat bran, wheat shorts, wheatgerm, wheat flour and some of the offal from the 'tail of the mill'. This product must be obtained in the usual process of commercial milling and must contain not more than 95 g crude fibre/kg [IFN 4-05-205 Wheat flour by-product less than 95 g/kg crude fibre].

The name 'middlings' derives from the fact that this by-product is somewhere in the middle between flour and bran. It is low in starch. This by-product is known as pollards in Europe and Australia. The composition and quality of middlings vary greatly due to the proportions of fractions included, and also the amount of screenings added and the fineness of grind. A cooperative research study was conducted by members of the US Regional Committee on Swine Nutrition to assess the variability in nutrient composition of 14 sources of wheat middlings from 13 states, mostly in the Midwest (Cromwell *et al*., 2000). The bulk density of the middlings ranged from 289 to 365 g/l. The middlings averaged (g/kg) 896 DM, 162 CP, 1.2 Ca, 9.7 P, 369 NDF, 6.6 lysine, 1.9 tryptophan, 5.4 threonine, 2.5 methionine, 3.4 cystine, 5.0 isoleucine and 7.3 valine; and 0.53 mg Se/kg. The variation in nutrient composition was especially high for Ca (0.8–3.0 mg/kg) and Se (0.05–1.07 mg/kg). 'Heavy' middlings (high bulk density, ≥ 335 g/l) had a greater proportion of flour attached to the bran and were lower in CP, lysine, P and NDF than 'light' middlings (≤ 310 g/l). Other studies have shown that 'heavy' middlings were superior in nutritional value to 'light' middlings (Cromwell *et al*., 1992). The feed manufacturing industry prefers high bulk density middlings to light bulk density middlings, since they produce diets of higher nutritive quality.

Wheat middlings are generally very palatable and readily consumed by all classes of cattle, with no additional processing. They are often an economically competitive source of protein or energy in cattle diets. The protein in wheat middlings is highly degraded in the rumen and well utilized by cattle on low-quality forages that are usually low in rumen-degradable protein. Mature forages are usually low in phosphorus and wheat middlings are a good source of this mineral and other trace minerals. Since they contain higher levels of fibre and lower levels of starch than whole wheat, digestive disturbances are less of a concern. However, an adjustment period to introduce cattle to this feedstuff is recommended. Wheat middlings can be an effective supplement for beef cows grazing low-quality winter range or being fed low-quality forages.

Pelleted wheat middlings compare favourably with grains due to a higher protein content, comparable energy values and ease in feeding. Several studies have evaluated the replacement of cracked maize with wheat middlings in cattle diets (Ovenell *et al*., 1990, 1991; Dalke *et al*., 1993). The findings suggest that pelleted wheat middlings can replace 10–20% of the grain portion of the diet without affecting productivity. In general, a linear decrease in feed intake, daily live weight gain and feed efficiency was observed with increasing levels of wheat middlings above this level.

WHEAT SHORTS. Wheat shorts consists of fine particles of wheat bran, wheatgerm, wheat flour and the offal from the 'tail of the mill'. This product must be obtained in the usual process of commercial milling and must contain not more than 70 g crude fibre/kg [IFN 4-05-201 Wheat flour by-product less than 70 g/kg fibre]. (Note:

the Canadian feed regulations have the IFNs for middlings and shorts reversed.)

Spelt (*Triticum aestivum* var. *spelta*)

Spelt is a subspecies of wheat grown widely in central Europe. It has been introduced to other countries, partly for the human market because of its reputation as being low in gliadin, the gluten fraction implicated in coeliac disease. The grain resembles barley in appearance.

This crop appears to be generally more winter hardy than soft red winter wheat, but less winter hardy than hard red winter wheat. The yield is generally lower than that of wheat but equal to wheat when the growing conditions are less than ideal.

Expansion of this crop is likely in Europe because of the current shortage of high-protein organic feedstuffs.

Nutritional features

A main difference between spelt and wheat is that the hull is not usually detached from the kernel during threshing. As a result the energy value is lower, so that spelt may resemble oats in nutritive value (Ingalls *et al.*, 1963). The report by Ingalls *et al.* (1963) was based on findings with spelt from ten different sources.

The available data indicate a wide variability in the chemical constituents of this grain. Ranhotra *et al.* (1995) presented data which showed few differences between a hard red wheat cultivar and a Canadian spelt selection. The grains were evaluated for gluten traits, chemical composition, amino acid composition and protein efficiency. The data suggested that spelt may be easier for humans to digest than wheat.

Other studies reported a considerable variation in protein, amino acid, vitamin, ether extract, mineral and gliadin/glutenin ratio in spelt cultivars (Abdel-Aal *et al.*, 1995; Ranhotra *et al.*, 1996a). A comparison was conducted to evaluate three spelt cultivars and two hard red wheat cultivars for yield and nutrient content over five environments in Montana and North Dakota (Ranhotra *et al.*, 1996b). Results indicated that the CP content of all spelt cultivars grown at all locations was consistently higher (18–40%) than that of the hard red wheats, the average crude protein value of spelt being 166 g/kg versus 134 g/kg in wheat. However, the nutrient profile of both grains was found to be greatly influenced by cultivar and location.

Findings by Ranhotra *et al.* (1996a) indicated that this grain may be similar to wheat in nutritive value for pigs, but with a higher level of CP. This result suggests that spelt could be substituted for wheat in cattle diets.

The available findings indicate that spelt should be analysed for nutritive content so that it can be formulated correctly in concentrate feeds for dairy or beef cattle.

Cattle diets

Spelt is traditionally recognized in France as a high-quality feed for cattle and calves. However, there is a lack of scientific publications on the use of this grain in cattle diets.

Digestion coefficients in dry Holstein cows indicated that the digestible energy value was approximately the same as for oats (Ingalls *et al.*, 1963). Research in Czech Republic (Chrenková *et al.*, 2000) on spelt grown in Slovakia and Sweden confirmed the above findings on spelt composition and reported no significant differences between spelt and wheat on the basis of growth in rats. Crude protein digestibility was higher in spelt than in wheat (0.85 versus 0.81). The quality of the protein in spelt wheat was higher than in winter wheat cv. Samanta, as reflected by higher net protein utilization and utilizable protein values.

Based on the limited information available it appears that spelt can be utilized in cattle diets as a replacement for other feed grains, depending on its nutritive content. Spelt should be rolled or cracked prior to feeding, as with wheat.

Triticale (*Triticale hexaploide*, *T. tetraploide*)

Triticale is a hybrid of wheat (*Triticum*) and rye (*Secale*) developed with the aim of combining the grain quality, productivity and disease resistance of wheat with the vigour, hardiness and high lysine content of rye. The first crossing of wheat and rye was made in Scotland in 1875 (Wilson, 1876), although the name 'triticale' did not appear in the scientific literature until later. Triticale can be synthesized by crossing rye with either tetraploid (durum) wheat or hexaploid (bread) wheat. It is grown mainly in Poland, China, Russia, Germany, Australia and France, although some is grown in North and South America. It is reported to grow well in regions not suitable for maize or wheat. Globally, triticale is used primarily for livestock feed. Grain yields in Canada (Briggs, 2002) are competitive with the highest yielding wheat varieties, and may exceed those of barley. Also, the high quality of the protein has been maintained in the newer varieties. Both spring and winter types are now available (including a semi-awnless winter variety) and have provided a new crop option for breaking disease cycles in cereal cropping systems. According to Briggs (2002), the greatest potential for its use as a grain feedstuff is in livestock operations that grow at least part of their own feed grain supply, using lands that are heavily manured.

Triticale production in such conditions is generally more productive and sustainable than barley or other cereals for feed grain. Its greater disease resistance compared with wheat or barley is another advantage. Thus triticale is of particular interest to organic cattle producers.

Nutritional features

The use of many varieties and crosses to improve yield and grain quality in triticale as well as adaptation to local conditions has resulted in a variation in nutrient composition. The CP content of newer varieties is in the range from 95 to 132 g/kg, similar to that of wheat (Briggs, 2002; Stacey *et al*., 2003). Metabolizable energy values have been reported as being generally equal to or higher than in wheat (Evans, 1998; Hede, 2001). According to Jaikaran (2002), the newly developed Canadian varieties (X Triticosecale Wittmack L.) possessed more of the characteristics of the wheat parent than the rye parent, resulting in improved palatability and nutritional value. In addition, they were low in anti-nutritional factors such as ergot, which have been found in the older varieties. These findings suggested that triticale could replace part of the grain and protein feeds included in supplements for cattle.

The digestibility of triticale in ruminants was shown to be similar to that of maize (Felix *et al*., 1985), but it is known that the rate of ruminal starch digestion varies considerably with source (Allen, 1991). Maize starch is fermented more slowly than the more easily solubilized starch from barley, wheat or triticale.

As with other grains, processing by rolling, milling or crushing has been shown to improve the digestibility. However, processing can make grain more likely to cause acidosis. Coarse-rolling the grain using a roller mill is preferable to fine-milling with a hammer mill.

Cattle diets

Smith *et al*. (1994) tested the effects of replacing maize with triticale in dairy cow and beef cattle diets and concluded that the grain portion of lactating dairy cow diets could contain up to 67% triticale grain and diets for beef cattle could contain up to 75%. Nutrient digestibility and daily DM intake of dairy cows did not differ when triticale replaced maize either partially or completely. However, daily DM intake of beef cattle was reduced when triticale reduced all of the maize in the grain supplement. These findings agree with the work of Hill and Utley (1986), who found that nutrient digestibility and productivity did not differ when maize was replaced with 'Beagle 82' triticale in diets for steers.

As with rye, triticale is subject to ergot infestation. Studies using this hybrid have demonstrated increased liver abscesses in steers when compared with sorghum diets. As a consequence, it is recommended that triticale be limited to a maximum of 50% of the grain portion of livestock diets.

Maize (*Zea mays*)

This cereal is also known as corn in the Americas, and can be grown in more countries than any other grain crop because of its versatility. It is the most important feed grain in the USA because of its palatability, high energy value and high yields of digestible nutrients per unit of land. As a consequence, it is used as a yardstick in comparing other feed grains for animal feeding. The Plains of the USA provide some of the best growing conditions for maize, making it the world's top maize producer. Other major maize-producing countries and regions are China, Brazil, the European Union, Mexico and Argentina.

A number of different types of maize exist and the grain appears in a variety of colours, including yellow, white and red. Yellow maize is the only cereal grain to contain vitamin A, due to the presence of provitamins (mainly β-carotene). It is the main type of maize grown in the USA for animal feed. Yellow maize tends to colour the fat in beef, though the effect is less than that produced by grass.

Nutritional features

Maize is an excellent energy source for cattle but it is low in protein, averaging about 85 g CP/kg. The oil content of maize varies from 40 to 60 g/kg DM and is high in linoleic acid. Maize contains about 730 g starch/kg DM, is very low in fibre and has a high energy value. The starch in maize is more slowly digested in the rumen than the starch in other grains, and at high levels of feeding a proportion of the starch passes into the small intestine, where it is digested and absorbed as glucose. This has advantages in treating conditions such as ketosis. When the starch is cooked during processing it is readily fermented in the rumen.

Maize is very low in calcium (about 0.2 g/kg) but contains a higher level of phosphorus (2.5–3.0 g/kg). It is low in potassium and sodium, as well as in trace minerals.

The quality of maize is excellent when harvested and stored under appropriate conditions, including proper drying to 100–120 g moisture/kg. Varieties differ markedly in storage characteristics due to husk coating and endosperm type. Fungal toxins (zearalenone, aflatoxin and ochratoxin) can develop in grain that is harvested damp or allowed to become damp during storage. These toxins can cause adverse effects in livestock.

Cattle diets

Maize is suitable for feeding to all classes of cattle. It should be ground medium to medium-fine. The grain should be mixed into feed immediately after grinding, since it is likely to become rancid during storage.

Maize by-products

Grain and alcohol processing plants offer by-products that are suitable for livestock use, if acceptable by organic certification agencies.

In producing ground maize for the human market the hull and most of the germ are removed, leaving hominy feed, consisting of bran, some germ and some endosperm. It resembles the original grain in composition, but has higher contents of fibre, protein and oil. Hominy feed is an excellent feed that is similar to whole maize in energy value because of the higher oil content. One of the benefits of using maize by-products such as this is that the grain used is of very high quality since the main product is intended for the human market. This helps to ensure that the maize is free from mycotoxin contamination and insect and rodent infestation.

MAIZE GLUTEN FEED. Several by-products are obtained in the manufacture of starch and glucose from maize, which are suitable for feeding farm animals. The cleaned maize is first soaked in a dilute acid solution and is then coarsely ground. The maize germ floats to the surface and is removed for further processing. The de-germed grain is then finely ground and the bran is separated by wet screening. The remaining liquid consists of a suspension of starch and protein (gluten), these components being separated by centrifugation. The process gives rise to three by-products: germ, bran and gluten. These by-products are frequently mixed together and sold as maize gluten feed. Maize (corn) gluten feed is a maize by-product that is available in some regions as a wet or dry product. The dry product is traded internationally. Wet maize gluten feed (450 g/kg DM) is a perishable product that has to be used within 6–10 days and must be stored in an anaerobic environment.

This feed has a variable protein content, normally in the range 200–250 g/kg DM, of which about 60% is degraded in the rumen. Dark brown material indicates heat damage, which decreases the digestibility of the protein. Maize gluten feed has a crude fibre content of about 80 g/kg DM, and metabolizable energy values of about 12.5 MJ/kg DM for cattle, and typically contains 210 g protein/kg, 25 g fat/kg and 80 g crude fibre/kg. The dried maize gluten feed is made into pellets to facilitate handling. Since it is a milled product the fibre does not have the same effect as long roughage in ruminant diets. Nevertheless, maize gluten feed has been used as a substantial proportion of the concentrate feed of dairy cows.

Because its method of production can vary, maize gluten feed tends to be of variable feed value depending on the exact process in use. Therefore it should be purchased on the basis of a guaranteed analysis.

MAIZE GLUTEN MEAL. Maize gluten meal can be used as a protein supplement for cattle but is more suitable for dry cows than milking cows because of its relatively low palatability. One useful feature of this product is that it has a high content of methionine. It may no longer be available or economic for feed use as it is being used extensively as a natural weedkiller in horticulture.

DISTILLER'S DRIED GRAINS. This maize by-product is used commonly in cattle feeding. It is derived from ethanol production (as a fuel source or as liquor). This North American by-product is exported to several regions, including Europe. In the production process dry-milling is used, followed by cooking and fermentation of the starch fraction with yeast, to produce ethanol. Removal of the starch leaves the nutrients in the remaining residue at about three times the content in the original grain. Evaporation of the remaining liquid produces solubles which are usually added back to the residue to produce distiller's dried grains with solubles. This product is usually dehydrated and marketed as dry distiller's grains plus solubles (DDGS). One of the benefits of this product is the contribution of nutrients provided by yeast. DDGS typically contains 270 g protein/kg, 110 g fat/kg and 90 g crude fibre/kg. Cromwell *et al*. (1993) reported considerable variability in the nutritional value of DDGS, depending on source. The reported range was 234–287 g CP/kg, 29–128 g crude fat/kg, 288–403 g NDF/kg, 103–181 g ADF/kg and 34–73 g ash/kg.

Miscellaneous grains

Screenings

Grain screenings contain mixed grains, wild oats, weed seeds, chaff, hulls and some dust, and may be available from feed mills. They are the residues from the preparation, storage and shipment of cereal products. Screenings are commonly ground finely and pelleted, though they may be available from feed mills in the raw state. Their properties and nutritional quality vary widely according to the type of grain in question and its method of processing. Screenings may be from individual cereals or a mixture.

Organic farmers planning to use grain screenings should check their acceptability with the local regulations.

Screenings are commonly regarded as being similar to light oats in nutritional composition. A general recommendation is that the amount fed to milking cows should not exceed 3–4 kg/head/day. They can also be used to supplement roughage (replacing cereal grains) in feeding beef calves and cows and replacement dairy heifers. Because of their fine particle size and the characteristics of some of their ingredients, digestive upsets such as bloat might occur if the ground screenings are fed at a high level. Possible problems associated with their use include the presence of weed seeds and, after prolonged storage, mycotoxin contamination and rancidity.

*Buckwheat (*Fagopyrum *spp.)*

Buckwheat, a member of the Polygonaceae family, is cultivated in some countries as a fodder crop and for the production of buckwheat honey. The leaves and stalks may also be used for human consumption. The protein quality of buckwheat is considered to be the highest of the grains, being high in lysine. However, buckwheat is relatively low in energy relative to other grains, due to its high fibre and low oil contents.

This plant and its seed are best avoided by organic farmers. Buckwheat contains an antinutritional factor, fagopyrin, which causes photosensitization in animals that have light-coloured skin (including cattle, goats, sheep, pigs and turkeys). The result is skin lesions and intense itching when such livestock are exposed to sunlight. Humans can also be affected. The antinutritional factor occurs mainly in the leaves and flowers, and at a lower concentration in the stem, hull and grain.

The grain has been used successfully in diets for cattle (Nicholson *et al*., 1976) and pigs, but can only be recommended for animals housed indoors.

Protein Supplements

Oilseeds, Oil Fruits, their Products and By-products (EU Category 1.2)

The major protein sources used in animal production are oilseed meals. Only those meals resulting from mechanical extraction of the oil from the seed are acceptable for organic diets.

Soybeans, groundnuts, rapeseed, canola and sunflowers are grown primarily for their seeds, which produce oils for human consumption and industrial use. Cottonseed is a by-product of cotton production and its oil is widely used for food and other purposes. In the past, linseed (flax) was grown to provide fibre for linen cloth production. The invention of the cotton gin made cotton more available for clothing materials and the demand for linen cloth decreased. Production of linseed is now mainly for industrial oil production. The soybean is clearly the predominant oilseed produced internationally.

Moderate heating is generally required to inactivate anti-nutritional factors present in oilseed meals. Overheating needs to be avoided since it can result in damage to the protein. The potential problems of overheating are usually well recognized by oilseed processors.

As a group, the oilseed meals are high in CP content, except safflower meal with hulls. The CP content of conventional meals is usually standardized before marketing by admixture with hull or other materials. Most oilseed meals are low in lysine, except soybean meal. The extent of dehulling affects the protein and fibre contents, whereas the efficiency of oil extraction influences the oil content and thus the energy content of the meal. Oilseed meals are generally low in calcium and high in phosphorus, although a high proportion of the phosphorus is present as phytate. The biological availability of minerals in plant sources such as oilseeds is generally low, and this is especially true for phosphorus because of the high phytate content.

Rapeseed (canola) (*Brassica* spp.)

Rape is a crop belonging to the mustard family, grown for its seed, which contains about 40% oil. The leading countries in rapeseed production are China, Canada, India and several countries in the EU.

Rapeseed has been important in Europe for a long time as a source of feed and oil. There has been an increased demand for rapeseed oil for the human food market and for biodiesel in the EU, suggesting that farmers in Europe will be encouraged to expand rapeseed production there. Production of this crop increased in North America during the Second World War as a source of industrial oil, the crushed seed being used as animal feed. At that time, rapeseed production was used primarily for industrial oils. Rapeseed oil was high in erucic acid, which was used as a slip agent. The meal contained high levels of glucosinolates, sulfur-containing compounds that have a bitter flavour, which can result in reduced palatability of the feed and cause thyroid dysfunction in humans and animals.

Canola was developed from industrial rapeseed by plant breeders in Canada during the 1960s, resulting in seed containing a food-grade oil and an improved meal for animal feeding. Canola is a small diameter seed (1–2 mm) containing approximately 42–43% oil. The hull makes up a significant amount of the seed weight, about 16%. The name 'canola' was registered in 1979 in Canada to describe 'double-low' varieties of rapeseed, i.e. the extracted oil containing less than 20 g erucic acid/kg and the air-dry meal less than 30 μM of glucosinolates (any mixture of 3-butenyl glucosinolate, 4-pentenyl glucosinolate, 2-hydroxy-3-butenyl glucosinolate or 2-hydroxy-4-pentenyl glucosinolate) per gram of air-dry material. In addition to the above standards for conventional canola, the meal is required to have a minimum of 350 g CP/kg and a maximum of 120 g crude fibre/kg. The commercial varieties of canola have been developed from two species, *Brassica napus* (Argentine type) and *B. campestris* (Polish type). The designation is licensed for use in at least 22 countries.

Canola is now the main type of rapeseed grown in North America. Since 1991, virtually all rapeseed production in the EU has shifted to rapeseed 00 (double zero), i.e. similar to canola with low content of erucic acid and low content of glucosinolates.

Canola ranks fifth in world production of oilseed crops, after soybeans, sunflowers, groundnuts and cottonseed. The crop is widely adapted but appears to grow best in temperate climates, being prone to heat stress in very hot weather. As a result, canola is often a good alternative oilseed crop to soybeans in regions not suited for growing soybeans. Some of the canola being grown is from GM-derived seed; therefore caution must be exercised to ensure the use of non-GM canola for organic cattle feeding.

Canola seed that meets organic standards can be further processed into oil and a high-protein meal, so that the oil and meal are acceptable to the organic industries. In the commercial process in North America, canola seed is purchased by processors on the basis of grading standards set by the Canadian Grain Commission or the National Institute of Oilseed Processors. Several criteria are used to grade canola seed, including the requirement that the seed must meet the canola standard with respect to erucic acid and glucosinolate levels.

Canola meal is produced from canola seed following oil extraction. It is traditionally produced by heating and crushing, followed by solvent (hexane) extraction of the remaining oil in the press-cake. However, the solvent-extraction process is not acceptable to organic producers. Only the by-product from physically crushing the seed, called expeller rapeseed meal, is acceptable as an organic feedstuff. The main difference between expeller and solvent-extracted meal is a lower content of oil in the solvent-extracted product.

Nutritional features

Canola seed contains about 400 g oil, 230 g CP and 70 g crude fibre/kg. The oil is high in polyunsaturated fatty acids (oleic, linoleic and linolenic), which makes it valuable for the human food market. It can also be used in animal feed. However, the oil is highly unstable due to its content of polyunsaturated fatty acids.

As stated above, for organic feed use the extraction of oil has to be done by mechanical methods such as crushing (expeller processing). Two features of expeller processing are important. The amount of residual oil in the meal varies with the efficiency of the crushing process, resulting in a product with a more variable energy content than the commercial, solvent-extracted product. Also, the degree of heating generated by crushing may be insufficient to inactivate myrosinase in the seed, an enzyme that hydrolyses the biologically inactive glucosinolates to goitrogenic compounds that affect thyroid gland function. Therefore more frequent analysis of expeller canola meal for oil and protein contents is recommended and more conservative limits should be placed on the levels of expeller canola meal used in cattle diets.

Most of the laboratory studies on canola meal have been conducted on commercial solvent-extracted meal. Canola meal is lower in crude protein than soybean meal. Meal from *B. campestris* contains about 350 g CP/kg, whereas the meal from *B. napus* contains 38–400 g CP/kg. Because of its higher fibre content (> 110 g/kg), canola meal contains less energy than soybean meal. The higher fibre content is due to the increased proportion of hull (as a percentage of seed or meal weight) in canola meal. The hull represents about 16% of the seed weight and about 30% of the meal by weight. As a result, canola meal contains up to three times as much crude fibre as soybean meal. The fibre tends to be lower in digestibility and consequently results in a lower energy content of the meal. With current processing and crushing technology, canola is primarily crushed as intact seed and consequently the hulls remain in the meal.

Compared with soybean, canola seed is a good source of calcium, selenium and zinc, but a poorer source of potassium and copper. Canola meal is generally a better source of many minerals than soybean meal.

Depending on the processing method, ruminal escape or bypass protein of canola meal is slightly lower or similar to soybean meal (Hill, 1991). Kendall *et al.* (1991) reported that variations in protein degradability for canola meal differed between processing plants. However, when these researchers measured essential amino acid content of residues following *in situ* ruminal incubation for 12–16 h there was little difference between samples. Zinn (1993) reported ruminal degradabilities for canola meal to be slightly lower than for soybean meal, giving canola meal a higher ruminal escape value than soybean meal.

Several studies have examined methods to increase ruminal bypass of canola meal as a way of improving its value as a protein supplement. For example, McKinnon *et al.* (1991) reported that heating canola meal for 10 min at 125°C reduced protein degradability from 58% to 30%.

DePeters and Bath (1986) reported that canola meal was similar in degradability to cottonseed meal when incubated ruminally *in situ*.

Anti-nutritional factors

Glucosinolates represent the major anti-nutritional factor found in canola, occurring mainly in the embryo. This feature limited the use of rapeseed or rapeseed meal in livestock diets in the past. Although glucosinolates themselves are biologically inactive, they can be hydrolysed by myrosinase in the seed to produce goitrogenic compounds that affect thyroid gland function. These cause the thyroid gland to enlarge, resulting in goitre. They can also result in liver damage and can have a negative effect on reproduction. Fortunately the modern cultivars of canola contain only about 15% of the glucosinolates found in rapeseed. In addition, heat processing is effective in inactivating myrosinase.

Tannins are present in some varieties of canola but only at very low levels (Blair and Reichert, 1984). Canola, rapeseed and soybean hull tannins are not capable of inhibiting α-amylase (Mitaru *et al.*, 1982), in contrast to those in other feedstuffs such as sorghum. Sinapine is the major phenolic constituent of canola and although bitter tasting (Blair and Reichert, 1984) it is not regarded as presenting any practical problems in cattle feeding. It occurs mainly in the seed germ.

Cattle diets

Most of the published research has been conducted using commercial solvent-extracted meal. The results can be used as a guide to the use of expeller canola meal in cattle feeding, provided the differences in composition of the two types are taken into account in formulating the diets.

Mawson *et al.* (1993) reviewed the relevant literature relating to the effects of glucosinolates on the palatability of rapeseed meal. They found that diet palatability could be adversely affected by rapeseed meal inclusion and that the response was related to glucosinolate level. However, the response was variable and depended also on the species of animal, age and stage of growth. Younger animals, particularly chicks, piglets and calves, appeared to be more severely affected and to exhibit reduced intake and hence depressed growth with diets containing high levels of glucosinolate rapeseed meal. Palatability was substantially improved by the use of low-glucosinolate rapeseed meal containing 10–30 μg/g and very low-glucosinolate rapeseed meal containing 1–5 μg glucosinolates/g. The findings of this review suggested that the low- and very low-glucosinolate meals can be included at levels up to 20% and 30% for calves and dairy cows, respectively. When the low-glucosinolate rapeseed meal was given as the sole high-protein source in dairy cow concentrates, there was no evidence of negative effects of glucosinolate metabolites on the sensory quality of milk or on consumer health (Mawson *et al.*, 1995). Also, these researchers found no published data indicating that glucosinolates have negative effects on beef flavour.

DePeters and Bath (1986) compared canola meal and cottonseed meal as protein sources for lactating dairy cows. No differences in milk yield or milk composition were recorded, and there were no differences in ruminal fermentation patterns for ammonia or volatile fatty acids with either protein source.

Canola meal has been found to be comparable to cottonseed meal and soybean meal as a supplementary protein source for lactating dairy cattle, with no differences in production when substituted for the other (Sanchez and Claypool, 1983; Harrison *et al.*, 1989). Canola meal gave results similar to those obtained with maize gluten meal (Robinson and Kennelly, 1988).

Spörndly and Åsberg (2006) studied the eating rate and preference for different concentrate feeds by dairy cows. A control feed of ground barley was included in each experiment. In all, a total of 41 feeds was studied. The categories of feeds studied were basal feeds (as cereals, soybean meal and rapeseed products) and feed mixtures based on ground barley with additives. Pelleted concentrate mixtures were also evaluated. The results indicated that the following were the most preferred feeds: pelleted feeds, heat-treated rapeseed meal, barley with an additive of 10% rapeseed fatty acids, barley with 10% palm oil and barley with 10% glycerol. Palm-kernel expeller meal was least preferred.

Canola meal has also been used successfully in beef cattle production. Ravichandiran *et al.* (2008) compared soybean meal and high- and low-glucosinolate rapeseed-mustard cakes as protein supplements for growing cross-bred calves weighing 62.9 kg at the start of the experiment. The three dietary treatments were soybean meal, low-glucosinolate *B. napus* and high-glucosinolate *B. juncea*. Although daily intake of total DM and wheat straw did not differ significantly among the dietary treatments, intake of concentrate decreased significantly with increasing glucosinolate levels in the diet. Also, average daily gain decreased and feed-to-gain ratios increased significantly with increasing glucosinolate levels. These findings confirmed previous findings on the effect of glucosinolate concentration on diet palatability and productivity. The researchers therefore concluded that high-glucosinolate rapeseed-mustard cakes reduce the palatability and growth rate in cross-bred calves and that soybean meal can be replaced completely by low-glucosinolate rapeseed without compromising calf performance.

Research conducted at Colorado State University investigated the effectiveness of canola meal as a supplement for range cows (Patterson *et al.*, 1999a). This research indicated that canola meal supported similar production compared with cull field beans fed at the same level of CP or sunflower meal fed at either 50% or 100% of the CP level of canola meal. Calves from dams fed canola meal had greater weight gains during the supplementation period than did calves from cows fed cull field beans or the low level of sunflower meal. The same research group (Patterson *et al.*, 1999b) evaluated the effects of these supplements on ruminal fermentation and digestion kinetics. They noted no differences between treatments for DM or nitrogen degradation rates. However, there was a tendency for the DM in canola meal to be digested to a greater extent than in sunflower meal.

Claypool *et al.* (1985) compared soybean meal, cottonseed meal and canola meal as ingredients in starter diets for Holstein calves. They reported no differences in intake or productivity during pre-weaning or post-weaning. British researchers reported no adverse effects on intake or calf performance when canola meal replaced soybean meal as a protein supplement for 160 kg calves (Hill *et al.*, 1990). Beauchemin *et al.* (1995) compared canola meal, heat-treated canola meal, lignosulfate-treated canola meal and dried distiller's grains as the main ingredients in creep feeds for nursing calves grazing irrigated pastures. Calves fed creep feed gained more weight than calves not offered creep feed. No differences among the various canola meal treatments were detected. These authors also measured ruminal degradability of the various canola meals using the *in situ* procedure and found that chemical or heat treatment of canola meal reduced the protein degradability of the meal. However, no differences in calf growth were noted, suggesting that the escape or metabolizable protein was not limiting for the calves in this experiment.

Petit and Veira (1994a) reported increased weight gains in growing calves fed grass silage-based diets and supplemented with canola meal. Petit and Veira (1994b) reported digestibility characteristics of various combinations of molasses and canola meal as supplements in diets based on timothy silage. Supplemental canola meal improved crude protein and energy digestibility but decreased fibre digestibility.

Flachowsky *et al.* (1994) showed that addition of rapeseed meal to the diet of bulls increased the content of vitamin E in the meat, which was attributed to the high level of α-tocopherol in the rapeseed meal.

Full-fat canola (canola seed)

A more recent approach with double-zero rapeseed and canola is to include the unextracted seed in cattle diets, as a convenient way of providing both supplementary protein and energy (e.g. Mogensen *et al.*, 2004). Good results have been achieved with this feedstuff, especially with the lower-glucosinolate cultivars. This could be a good use of the product by organic farmers who are able to grow the crop on-farm.

The seed needs to be processed frequently and stored for short periods only. Once ground, the oil in full-fat canola becomes highly susceptible to oxidation, resulting in undesirable odours and flavours. The seed contains a high level of α-tocopherol (vitamin E), a natural antioxidant, but additional supplementation with an acceptable antioxidant is needed if the ground product is to be stored. A practical approach to the rancidity problem is to grind just sufficient seed for immediate use.

A research group in Denmark (Mogensen *et al*., 2004) compared the production of Danish Holstein dairy cows fed organically on rapeseed, rapeseed cake or cereals as supplements to silage fed to appetite. The three dietary regimes were: 5 kg cereals, 3 kg of a rapeseed/cereal pelleted mixture, or 1 kg rapeseed cake fed with a mixture of clover grass silage, whole crop silage and grass pellets to appetite. In comparison with cereals alone the supplement of rapeseed/cereal pellet tended to decrease both milk fat and protein content, whereas fat and protein yields were unaffected. Milk yield was increased on the rapeseed/cereal pellet diet compared with cereals in one experiment, but was unaffected in a second experiment. Supplementation with rapeseed cake in comparison with cereal grains did not alter the milk yield or composition, or the risk of subclinical ketosis and other metabolic disorders. One possible explanation put forward for different responses in milk yield in the two experiments was differences in roughage quality. Based on the findings, these researchers calculated that 100 ha could provide the cereal requirements for 71–76 cows, the rapeseed cake diet for 83 cows and the rapeseed/cereal diet for 73–77 cows.

Soybean (*Glycine max*) and soybean products

Soybeans are grown mainly as a source of oil for the human market, a by-product being soybean meal, which is used widely in animal feeding. Whole soybeans are also being used in animal feeding. The USA, Brazil, Argentina and China are the main producers of soybeans.

Several bioengineered strains of soybeans are now being grown; therefore organic producers have to be careful to select non-GM product. The major GM crops grown in North America are soybeans, maize, canola and cotton.

Soybean meal is generally regarded as one of the best plant protein sources in terms of its nutritional value. It also has a complementary relationship with cereal grains in meeting the amino acid requirements of farm animals. As a consequence, it is the standard with which other plant protein sources are compared. Researchers at the University of Arizona (Santos *et al*., 1998) conducted an extensive literature review of the use of protein supplements and the protein nutrition of lactating dairy cows. The review involved 108 studies published during the period 1985–1997. In 127 comparisons, from 88 lactation studies, the effects of replacing soybean meal with other protein ingredients significantly increased milk yields in only 17% of the comparisons.

Whole soybeans contain 150–210 g oil/kg, which is removed in the oil-extraction process. Initially soybeans were mechanically processed using hydraulic or screw presses (expellers) to remove much of the oil. Later, most of the industry converted to the solvent-extraction process. Features of the mechanical process are that it is less efficient than the solvent process in extracting the oil and that the heat generated by friction of the screw presses, while inactivating antinutritional factors present in raw soybeans, subjects the product to a higher processing temperature than in the solvent-extraction process. As a result the protein becomes less digestible and may be damaged if the product is overheated.

Expeller soybean meal is favoured for dairy cow feeding since the higher content of rumen bypass protein results in improved milk production (Reynal and Broderick, 2003). Consequently, most of the expeller soybean meal available commercially is used in the dairy feed industry.

More recently a process known as extruding-expelling has been developed. Extruders are machines in which soybeans or other oilseeds are forced through a tapered die. The frictional pressure causes heating. In the extruding-expelling process a dry extruder in front of the screw presses eliminates the need for steam. These plants are relatively small, typically processing 5–25 t soybeans/day. The dry extruding-expelling procedure results in a meal with a higher oil content than in conventional solvent-extracted meal, but with similar low trypsin-inhibitor values. The nutritional characteristics of extruded-expelled meal have been shown to be similar to those of screw-pressed meal. This process should be of interest to organic cattle producers since the soy product qualifies for acceptance in organic diets.

Yet another process being used in small plants is extrusion, but without removal of the oil, the product being a full-fat meal. Often these plants are operated by cooperatives and should be of interest to organic producers, since the product also qualifies for acceptance in organic diets. Another interesting development with soybeans is the introduction of strains suitable for cultivation in cooler climates, for instance the Maritime region of eastern Canada. This development, together with the installation of extruder plants, allows the crop to be grown and utilized locally, providing the opportunity for regions that are deficient in protein feedstuffs to become self-sufficient in feed needs. Developments such as this may help to solve the ongoing problem of an inadequate supply of organic protein feedstuffs in Europe.

Nutritional features

Whole soybeans contain 360–370 g CP/kg, whereas soybean meal contains 410–500 g CP/kg, depending on the efficiency of the oil extraction process and the amount of residual hulls present. The oil has a high content of the polyunsaturated fatty acids, linoleic (C18:2) and linolenic (C18:3). It also contains high amounts of another unsaturated fatty acid, oleic (C18:1), and moderate amounts of the saturated fatty acids, palmitic (C16:0) and stearic (C18:0).

Conventional soybean meal is generally available in two forms, 440 g CP/kg meal and dehulled meal, which contains 480–500 g CP/kg. Apparent digestibility of protein has been shown to be similar for both types of soybean meal (hulled and dehulled). Because of its low fibre content, the energy content of soybean meal is higher than in most other oilseed meals. Soybean meal has a good amino acid profile. The content of lysine is exceeded only in pea, fish and milk proteins. Soybean meal is an excellent source of tryptophan, threonine and isoleucine, complementing the limiting amino acids in cereal grains. Methionine is more limiting. In addition, the amino acids in soybean meal are highly digestible in relation to other protein sources of plant origin. Holstein bull calves weaned at 6 weeks of age were used in four experiments to identify the limiting amino acids in a maize/soybean meal diet (Abe *et al.*, 1998). The results indicated that methionine was the first-limiting amino acid, followed by lysine and tryptophan.

Soybean meal is generally low in minerals. Liener (2000) estimated that about 66% of the phosphorus in soybeans is bound as phytate and is mostly unavailable to animals. This compound also chelates mineral elements including calcium, magnesium, potassium, iron and zinc, rendering them unavailable. Therefore diets based on soybean meal (or other feedstuffs high in phytate) should be supplemented with adequate amounts of these trace minerals.

Conventional soybean meal is one of the most consistent feed ingredients available to the feed manufacturer, with the nutrient composition and physical characteristics varying very little between sources. Suppliers of organic soybean meal need to adopt similar quality control measures to ensure similar consistency in composition.

Proper processing of soybeans requires precise control of moisture content, temperature and processing time. Adequate moisture during processing ensures destruction of antinutritional factors. Both over- and under-toasting of soybean meal can result in a meal of lower nutritional quality. Under-heating produces incomplete inactivation of the anti-nutritional factors and over-toasting can reduce amino acid availability.

The feed industry monitors soybean meal quality by using urease activity to detect underheating and potassium hydroxide (KOH) solubility to detect overheating. The urease assay procedure measures urease activity based on the pH increase caused by ammonia release from the action of the urease enzyme. Destruction of the urease activity is correlated with destruction of trypsin inhibitors and other anti-nutritional factors. To measure KOH solubility, soy products are mixed with 0.2% KOH and the amount of nitrogen solubilized is measured. The amount of nitrogen solubilized decreases as heating time increases, indicating decreased amino acid availability.

Anti-nutritional factors

Natural anti-nutritional factors are found in all oilseed proteins. Among these in raw soybeans are protease inhibitors, affecting the digestive enzymes. These are known as the Kunitz inhibitor and the Bowman-Birk inhibitor, which are active against trypsin, while the latter is also active against chymotrypsin (Liener, 1994). These protease inhibitors interfere with the digestion of proteins in pre-ruminants, resulting in decreased growth in calves. They are inactivated when the beans are toasted or heated during processing. However, care has to be taken that the ingredient is not overheated. As indicated above, when proteins are heat-treated at too high a temperature the bioavailability of protein and amino acids may be reduced.

Lectins (haemagglutinins) in raw soybeans can inhibit growth and cause death in animals. They are proteins that bind to carbohydrate-containing molecules and cause blood clotting. Fortunately lectins are degraded rapidly by heating.

Cattle diets

An appropriate combination of soybean meal and cereal grains provides an excellent dietary protein mixture for all classes of cattle.

Reynal and Broderick (2003) tested the effects of feeding different protein feedstuffs on milk production in Holstein cows. Rumen-undegradable protein values for solvent-extracted (conventional) soybean meal, expeller soybean meal, blood meal and maize gluten meal were determined to be 27%, 45%, 60% and 73%, respectively. This result indicated that a higher percentage of expeller soybean meal than conventional soybean meal was not degraded in the rumen and passed into the abomasum and small intestine for subsequent digestion. The finding confirms that expeller soybean meal is a quality protein source that is important in meeting the cow's daily nutrient requirements for milk production. Similar results were obtained by Awawdeh *et al.* (2007). No differences among dietary treatments were observed for DM intake, body weight gain, milk and component yields, or efficiency of milk production when expeller soybean meal was compared with conventional solvent-extracted soybean meal processed in several ways.

Several studies have compared sources of protein for calf starters. For example, Fiems *et al.* (1985) reported lower weight gains when canola meal replaced soybean meal. Intake of the canola meal diet was lower than that of a soybean meal diet, suggesting that lower palatability was the explanation for the slower growth. Sharma *et al.* (1986) observed a lower gain and digestibility of diets when canola seed or extruded or pelleted whole cottonseed replaced soybean meal. However, they observed similar growth performance in calves fed unprocessed whole cottonseed seed, unprocessed whole sunflower seed and soybean meal-based diets. Fiems *et al.* (1986) reported lower digestibility, live weight gain and efficiency of gain when cottonseed meal replaced soybean meal in calf starters.

Soybean meal and sunflower meal were compared as supplementary protein sources in growth and digestibility trials with male Holstein-Friesian calves (Nishino *et al.*, 1980). The calves were fed calf starter supplemented with soybean meal or sunflower seed meal from 3 to 12 weeks of age. All calves were weaned at 7 weeks of age. Each calf then received calf starter limited to 2.7 kg/head/day, together with grass hay to appetite. Results showed that daily gain before weaning was not affected by diet. However, daily gain of weaned calves was significantly lower with sunflower meal than with soybean meal. Similarly, feed-to-gain ratio (kg DM intake/kg gain) was significantly higher in weaned calves fed on sunflower meal. In a digestion trial, feed intake was restricted to 2.58 kg DM/head/day. Dry-matter digestibility was significantly lower in weaned calves fed on sunflower meal. Digestibilities of CP, ADF and cell walls were not affected by diet, nor were nitrogen balance, blood urea or ruminal ammonia nitrogen concentration.

The conclusions of these and related studies suggest that calves fed soybean meal-based diets grow as well or better than calves fed diets based on other sources of protein.

Soybean meal has been shown to be a valuable protein supplement for beef cattle consuming low-quality prairie forage (Mathis *et al.*, 1999). Results indicated that supplemental soybean meal increased forage OM intake and digestibility. Beef cows grazing on low-quality, tall-grass prairie forage showed optimal growth when the cows were supplemented with soybean meal at 0.30% of their body weight per day. Below this level, the cows lost weight.

Full-fat soybeans

Whole soybeans have the potential to provide substantial amounts of protein and energy in the diet. Use of full-fat beans is a good way of increasing the energy level of the diet, particularly when they are combined with low-energy ingredients. In addition, this is an easier way to blend fat into a diet than by the addition of liquid fat.

Davenport *et al.* (1987, 1990) observed in several trials that soybeans were an acceptable protein supplement for growing cattle. However, calves fed maize silage and supplemented with soybeans did not perform as well as calves supplemented with soybean meal. The explanation might be attributed to the method of processing. Soybeans are highly degradable in the rumen, resulting in a decreased flow of amino acids to the small intestine. It has been shown that roasting soybeans can increase their bypass potential (Cosby *et al.*, 1995). Kansas State University researchers reported that Holstein calves offered starter diets for 8 weeks containing soybeans roasted at an exit temperature of 146°C had greater DM intakes and body weight gain than calves fed a starter diet containing soybean meal (Abdelgadir *et al.*, 1996), but no comparison was made with raw soybeans.

Dhiman (2002) conducted a study with dairy cows receiving a basal diet composed of 470 g forage and 530 g grain. The dietary treatments were solvent-extracted (conventional) soybean meal, extruded-expelled soybean meal and full-fat extruded soybeans. The soybean meal treatments were included at 112 g/kg dietary DM. The three diets provided equal amounts of energy, CP, fat, fibre and minerals. Cows fed the three dietary treatments had similar feed intake, milk yield, energy-corrected milk yield, milk yield/feed intake, milk fat content, milk fat yield, milk protein yield and milk urea content. Milk protein content and yield were 28.4, 27.8 and 28.0 g/kg and 1.03, 1.01 and 1.03 kg/day for the conventional, extruded-expelled soybean meal and full-fat extruded soybeans, respectively. Correspondingly, the content of conjugated linoleic acid in milk was 0.54, 0.64 and 0.77 g/100 g of fat. Due to the higher fat content of the extruded-expelled soybean meal (91 g/kg) and the full-fat extruded soybeans (200 g/kg) the diets containing these protein supplements required 0.4% and 0.8% less supplemental fat compared with the diet containing conventional soybean meal. These results indicated that cows fed diets containing conventional soybean meal, extruded-expelled soybean meal or full-fat extruded soybeans had similar milk yield responses when the diets were balanced for content of net energy of lactation.

Albro *et al.* (1993) reported similar weight gains in steers fed low-quality (less than 70 g CP/kg) grass hay supplemented with either soybean meal, raw soybeans or extruded soybeans in comparison with unsupplemented calves. Gain-to-feed ratio tended to be better with extruded beans than with raw soybeans.

Felton and Kerley (2004) conducted a feeding trial with steers in which whole soybeans replaced all or part of the dietary soybean meal. The dietary treatments were 173.0, 116.0, 58.0 and 0.00 g soybean/kg meal together with 0, 80, 160 and 240 g whole soybeans/kg. Average daily gain and feed efficiency were unaffected by diet. Carcass measurements showed that ribeye area, kidney-pelvic-heart fat content, back-fat thickness, dressing percentage and yield grade were also similar.

Cosby *et al.* (1995) observed a slight numerical decrease in quality grade when feeding roasted whole soybeans.

Although it is not necessary to heat-treat soybeans for ruminants, roasting can be used as a method of drying with the added benefits of reduced mycotoxin level, increased level of undegraded intake protein (UIP or bypass) and an increased safe upper feeding level. Rumsey *et al.* (1999) did not observe any significant differences in performance of finishing cattle given roasted soybeans in place of soybean meal.

Trenkle *et al.* (1995) noted that feeding soybeans to beef cattle increased the amount of polyunsaturated fatty acids in the meat. Unsaturated fats are preferred to saturated fat in the human diet; therefore this may be a way of improving the nutritive value of beef. Feeding whole soybeans to ruminants appears to partially protect the oil from degradation in the rumen. In related work, Graham *et al.* (2001) reported that feeding whole soybeans can be an economical way of providing a level of unsaturated fatty acids necessary to increase early conception rates in beef cows. In these studies beef cows fed diets containing whole soybeans (1.5 kg/head/day for 50 days prior to breeding) produced more calves than cows fed traditional supplements (containing maize gluten feed and soybean meal). First-service conception for the cows fed the whole soybeans showed a 15% improvement in conception rate compared with the cows receiving the traditional supplement.

Because of possible rancidity problems, diets based on full-fat soybeans should be used immediately and not stored, unless an approved antioxidant is added to the diet. Cooking or other high-heat treatment of soybeans will inactivate the enzymes that cause the fat to become rancid, allowing a potentially longer storage time.

Soy protein isolates

Soybean protein concentrate [IFN 5-08-038 Soy protein concentrate] is the product obtained by removing most of the oil- and water-soluble non-protein constituents from selected, sound, cleaned, dehulled soybeans. The traded product in North America contains not less than 650 g CP/kg on a moisture-free basis. Soybean protein isolate [IFN 5-24-811 Soy protein isolate] is the dried product obtained by removing most of the non-protein constituents from selected, sound, cleaned, dehulled soybeans. The traded product contains not less than 900 g CP/kg on a moisture-free basis.

Both soy protein concentrate and isolate can be used successfully in calf diets as a replacement for dried skimmed milk (Lalles *et al.*, 1995).

Sunflower seeds and meal (*Helianthus annuus*)

Sunflower is an oilseed crop of considerable potential for organic cattle production since it grows in many parts of the world. The main producers are Europe (France, Russia, Romania and Ukraine), South America, China and India. Sunflower is grown for oil production, leaving the extracted meal available for animal feeding. The oil is highly valued for the human market, owing to its high content of polyunsaturated fatty acids and stability at high temperatures.

Sunflower seed surplus to processing needs and seed unsuitable for oil production may also be available for feed use. On-farm processing of sunflower seed is being done in countries such as Austria.

Nutritional features

The seeds contain approximately 380 g oil/kg, 170 g CP/kg and 159 g crude fibre/kg and are a good source of dietary lipids. Sunflower meal is produced by extraction of the oil from sunflower seeds. The nutrient composition of the meal varies considerably, depending on the quality of the seed, method of extraction and content of hulls. As a result of the variation in the extent of dehulling before extraction, the meals vary widely in composition and nutritive value. As with similar crops, only the pressure crushing (expeller) method of oil extraction, i.e. without a solvent step, is acceptable in the production of organic sunflower meal.

The crude fibre content of whole (hulled) sunflower meal is around 300 g/kg and with a complete decortication (hull removal) the fibre content is around 120 g/kg. Sunflower meal is lower in lysine and higher in sulfur-containing amino acids than soybean meal. However, the energy value of sunflower meal is lower than that of canola or soybean meal, with an ME value of about 13 MJ/kg DM for cattle. Energy value varies substantially with fibre level and residual oil content. Higher levels of hulls included in the final meal lower the energy content and reduce the bulk density. The mechanical process of oil extraction leaves more residual oil in the meal, often 50–60 g/kg, depending on the efficiency of the extraction process. The higher oil content in mechanically extracted meals provides greater energy density, which is a valuable attribute for animals with higher energy requirements or where limited amounts of supplement are available. The oil content of sunflower meal adds to its value as a useful feed source for dairy cows. Lactating cows often respond to supplementation of the diet with fat.

Sunflower oil has a high content of polyunsaturated fatty acids. As a result, the oil is very susceptible to oxidation and the meals have a short shelf life owing to the development of rancidity, which renders them unpalatable. Calcium and phosphorus levels compare favourably with those of other plant protein sources. Sunflower meal tends to be lower in trace elements compared with soybean meal. In general, sunflower meal is high in B vitamins and β-carotene.

As discussed in the section on soybeans above, sunflower meal is not recommended for young calves but can be utilized by older calves and cows.

Anti-nutritional factors

In contrast to other major oilseeds and oilseed meals, sunflower seeds and meals appear to be relatively free of anti-nutritional factors.

Cattle diets

Sunflower meal has been shown to be suitable as the sole source of supplemental protein in diets for dairy cows. Milk production was similar when partially dehulled (Schingoethe *et al.*, 1977) or fully dehulled (Parks *et al.*, 1981) sunflower meal replaced soybean meal in dairy cow diets.

Research conducted by Patterson *et al.* (1999a) found that calves from beef cows receiving a low level of supplementary sunflower meal had lower weight gains during the supplementation period than calves from cows fed cull Great Northern beans or canola meal. Patterson *et al.* (1999b) evaluated the effects of these supplement treatments on ruminal fermentation and digestion kinetics. They noted no differences between treatments for DM or nitrogen degradation rates.

Patterson *et al.* (1999b) fed beef cows grazing a winter range on protein supplements from edible beans, sunflower meal, a mix of edible beans and sunflower meal or canola meal at 182 g CP/day or sunflower meal at 91 g/day. Cows fed sunflower meal at 91 g/day lost more weight during gestation than cows fed the other diets, but no other differences were detected, suggesting that a supplemental protein level of 182 g/day was more adequate than 91 g/day. No differences were observed in weaning weight or pregnancy rate. Edible beans fed alone resulted in some palatability problems; however, mixing edible beans and sunflower meal eliminated the problem.

Lactating mature beef cows were fed 2 kg sunflower meal (381 g CP/kg), 2.25 kg lupins (332 g CP/kg) or 2.25 g/kg wheat screenings (166 g CP/kg) in straw-based diets. No differences were observed for weight change, cow condition score or reproductive success (Anderson, 1993). Calf gains were 0.96 kg/day on the sunflower treatment compared with 0.91 kg/day for the wheat screenings treatment and 0.92 kg/day for the lupin treatment.

The results indicate that, as with dairy cows, sunflower meal can be used as the sole source of supplemental protein in diets for beef cattle. In trials comparing sunflower meal with other protein sources for growing beef animals, similar animal performance has been reported with diets providing equal amounts of CP and of crude fibre (e.g. Milton *et al.*, 1997).

Patterson *et al.* (1999a) compared diets based on sunflower meal (335 g CP/kg) and providing 91 g/day or 182 g/day of protein with 182 g/day of protein from canola meal, edible beans or a mixture of edible beans and sunflower meal and fed to steer calves. No significant treatment differences were observed in degradability of DM, NDF or ADF in the forage. However, differences were observed in the digestibility of the protein supplements, with edible beans and canola meal being more digestible than sunflower meal.

Whole seed feeding

Limited findings suggest that whole sunflower seed can be fed to dairy cows as an alternative to other oilseeds and that it can be used without any processing of the seeds. There appears to be no advantage in cracking or rolling sunflower seeds prior to feeding. The size of the seed results in cows chewing and breaking down the product during digestion. Feeding sunflower seed in a mixed diet eliminates any issues of feed preference or palatability.

Sarrazin *et al.* (2004) compared the production of dairy cows fed raw or roasted sunflower seed. The level of sunflower seed used was 78 g/kg dietary DM. The results showed that cows fed sunflower seed diets consumed 8% less than cows fed a diet with no sunflower seed but produced similar amounts of milk. However, milk fat content (30.7 versus 33.5 g/kg) and milk fat yield (1.33 versus 1.47 kg/day) were lower for cows fed sunflower seed than for cows fed no sunflower seed. Supplemental sunflower seed had no effect on concentrations and yields of other milk components, and ruminal pH, ammonia nitrogen and total volatile fatty acids were not affected by dietary treatments. Total tract nutrient digestibilities were not affected by sunflower seed supplementation or by heat treatment, but the concentrations of short-chain (C4:0 to C12:0) and medium-chain (C14:0 to C16:0) fatty acids in milk were altered by inclusion of sunflower seed in the diet, being 27% and 29% lower, respectively, while those of long-chain fatty acids (C18:0 to C18:3) were 51% higher. Feeding either raw or roasted sunflower seed reduced the concentration of acetate and increased the concentration of propionate in ruminal fluid. It was concluded that supplementing dairy cow diets with unheated or roasted sunflower seed improves the efficiency of milk production and increases the concentrations of long-chain and polyunsaturated fatty acids in milk. Feeding sunflower seed at up to 78 g/kg (DM basis) had no adverse effects on nutrient utilization. Roasting had no additional benefits on milk yield or milk fatty acid composition.

Feeding whole sunflower may be most economical in areas where sunflower is being produced. Transporting sunflower seed over long distances can be costly because of the low density of the seed.

Cottonseed meal (*Gossypium* spp.)

Cottonseed is an important oilseed crop, major producing countries being the USA, China, India, Pakistan, Latin America and Europe. Demand for cottonseed oil has increased in recent years as the food industry has introduced zero trans-fat products.

Cottonseed meal is the second most important protein feedstuff in the USA. Most of the meal available is used in ruminant diets.

Whole cottonseed is a widely used feed for dairy cattle because of its combination of high fibre, energy (from fat) and protein. In a nationwide survey to determine the types of feedstuffs fed to lactating dairy cows, it was reported that approximately 40% of dairy producers in the USA fed whole cottonseed (Mowrey and Spain, 1999).

Nutritional features

The nutrient content of cottonseed meal was reviewed by Coppock *et al.* (1987), Tanksley (1990) and Chiba (2001). According to these reviews the CP content of cottonseed meal may vary from 360 to 410 g/kg, depending on the contents of hulls and residual oil. Amino acid content and digestibility of cottonseed meal are lower than in soybean meal. Although fairly high in protein, cottonseed meal is low in lysine and tryptophan. Lysine digestibility is low in expeller meal (Tanksley, 1990), perhaps because of the formation of an insoluble complex between the ε-amino group of lysine and free gossypol due to heating. The fibre content is higher in cottonseed meal than in soybean meal, and its energy value is inversely related to the fibre content. Cottonseed meal is a poorer source of minerals than soybean meal. The content of carotene is low in cottonseed meal, but this meal compares favourably with soybean meal in water-soluble vitamin content, except biotin, pantothenic acid and pyridoxine.

DePeters and Bath (1986) reported that cottonseed meal was similar in degradability to canola meal when incubated ruminally *in situ*.

Bertrand *et al.* (2005) made the important observation that since 1969 cottonseed in the USA has decreased in fat and ash content and increased in fibre content, resulting in a 20% decrease in energy content. This has been accompanied by a reduction in seed size for most seed grown in the USA. Users need to be aware of this information and ensure that cottonseed is formulated into cattle diets based on an up-to-date guaranteed analysis.

Another issue with cottonseed is whether or not it contains lint, a source of fibre. Moreira *et al.* (2004) compared the production of lactating dairy cows fed diets containing either mechanically delinted whole cottonseed (DWCS; 3.7% lint) or linted whole cottonseed (LWCS; 11.7% lint). The cows were fed a total mixed ration containing 130 g/kg (DM basis) of DWCS or LWCS. Milk yield, 3.5% fat-corrected milk, energy-corrected milk, milk composition and DM intake were not affected by whole cottonseed type. Body condition score tended to increase more with DWCS (0.22 versus 0.11) for first-lactation cows, although this was not reflected in body weight change. Dry-matter digestibility, based on indigestible ADF, was 63.5% and 64.8%, respectively, for the DWCS and LWCS diets. It was calculated that 2.5% and 1.5% of the consumed seeds were excreted as whole cottonseeds in faeces with the DWCS and LWCS diets, respectively. Although statistically significant, treatment differences in the proportion of intact seeds in the faecal DM would have little nutritional consequence. Based on these findings the researchers concluded that the mechanically delinted WCS gave similar results to LWCS in diets for dairy cows.

Anti-nutritional factors

The inclusion of cottonseed meal in pig diets is limited because of the deleterious effects produced by the residual free gossypol found in the pigment glands of the seed. However, cattle and sheep are less susceptible than pigs to gossypol poisoning, because gossypol binds to proteins in the rumen. This problem does not occur in glandless cultivars of cottonseed. The general signs of gossypol toxicity are constipation, depressed appetite, loss of weight and death from circulatory failure. Toxicity signs in cattle usually occur when free gossypol levels in the diet approach 800 mg/kg. The free gossypol content of cottonseed meal decreases during processing and varies according to the methods used. In new seed, free gossypol accounts for 0.4–1.4% of the weight of the kernel. Screw-pressed materials have 200–500 mg free gossypol/kg. Processing conditions have to be controlled to prevent loss of protein quality owing to binding of gossypol to lysine at high temperatures. Fortunately the shearing effect of the screw press in the expeller process is an efficient gossypol inactivator at temperatures that do not reduce protein quality (Tanksley, 1990).

Gossypol toxicity and mycotoxin contamination are potential hazards from feeding cottonseed and cottonseed meal. Although gossypol toxicity can occur in ruminants, it is rare and is unlikely at an intake of 3–4 kg/day of either feedstuff, but may occur in diets if a large amount of the seed or meal is included (Coppock *et al*., 1987). Where high moisture and temperature occur pre-harvest, aflatoxin contamination is a potential hazard and preventive measures should be taken.

Cattle diets

The use of cottonseed and its by-products in cattle feeding has been reviewed by several authors. Coppock *et al*. (1987) found that few other feed ingredients possess the high energy and the digestible fibre contents found in cottonseed. However, one important finding was that the nutrient content was highly variable. There was also an assertion that the nutritional values listed by the NRC at that time (1982) were higher than other reported values. Review of the published research findings found that, although the feeding of whole cottonseed to cattle was not new, an appreciation of its special nutritive properties for high-yielding dairy cows was now evident. The reasons included a high genetic potential for lactation in the dairy cow population, a requirement for energy-concentrated but minimum-fibre diets by these cows, and a generally positive effect of whole cottonseed on milk fat content. A comparison of the nutrient profile of whole cottonseed with other oilseeds and protein supplements showed that only groundnut kernels with skins and hulls have similar energy and crude fibre contents, and that both feedstuffs exceed other commonly used protein supplements in energy content. Results from 18 comparative feeding trials with whole cottonseed showed no consistent difference in DM intake when whole cottonseed was included at up to 250 g/kg diet. This suggests that, in most studies, an increase in NEL occurred when whole cottonseed was fed.

In most trials, an increase in milk fat percentage has been reported, which was reflected in a numerical increase in the yield of fat-corrected milk. About half the studies showed a depression in milk protein content, but only about 25% showed a significant decrease. The only consistent effect of whole cottonseed on digestibility of nutrients was an increase in the digestibility of lipid.

Compared with soybean meal, cottonseed meal had a consistently lower feeding value, attributable to lower energy and lysine contents. Controlled heating improved the protein value of both whole cottonseed and cottonseed meal by causing a lower degradation in the rumen and a greater transfer of amino acids to the small intestine.

A situation in which cottonseed (and other lipid sources) might be especially useful as dietary components is in feeding cows during hot weather. In summer, high-producing dairy cows often fail to consume sufficient feed to meet their nutrient requirements, especially for energy. Skaar *et al*. (1989) found that cows calving during warm weather and consuming diets supplemented with 50 g fat/kg produced more milk than herd-mates not receiving fat-supplemented feed. Milk composition was not affected by treatment. Knapp and Grummer (1991) reported that adding 50 g fat/kg to diets for cows during hot weather increased milk fat content, and that milk yield and milk protein content and yield were not affected. Holter *et al*. (1992) reported that addition of 150 g whole cottonseed/kg to diets for lactating cows reduced total heat production by 6% and reduced heat in excess of maintenance by 8%.

Anderson *et al.* (1984) compared whole cottonseed, extruded soybeans and whole sunflower seeds as supplements for lactating dairy cows. The dietary DM composition was 60% concentrate, 24% lucerne hay and 16% maize silage. Diets contained either 10% whole cottonseed, 5% extruded soybeans or 12% whole sunflower seeds (DM basis). All diets were approximately isoenergetic and isonitrogenous. Cows were fed to appetite. Feed intake was highest for the extruded soybean diet, intermediate for the whole cottonseed diet and lowest for the whole sunflower seed diet. Yield of milk, fat-corrected milk, fat, protein and solids-not-fat were lower among cows fed the whole sunflower seed diet than for the other two diets. Cows on the whole cottonseed diet produced milk most efficiently. There were no differences among diets for DM digestibility or in body weights of cows. The researchers concluded that diets containing whole cottonseed or extruded soybeans were better for lactating cows than diets containing whole sunflower seeds.

A comparison of whole cottonseed and cottonseed meal was conducted by Belibasakis and Tsirgogianni (1995). Friesian cows, 70–140 days post-partum, were fed one of two diets, i.e. concentrate containing either 200 g whole cottonseeds/kg plus 130 g soybean meal/kg or 140 g cottonseed meal/kg plus 185 g soybean meal/kg, together with maize silage and straw in the proportions 8:1 (fresh weight) to appetite. Results showed that supplementation with whole cottonseed rather than cottonseed meal significantly increased milk yield (25.1 versus 23.1 kg/day), 4% fat-corrected milk yield (25.0 versus 21.5 kg/day), milk fat content (3.98 versus 3.56%) and milk fat yield (1.0 versus 0.82 kg/day). Dry-matter intake, milk protein content and yield, as well as content of milk lactose, total solids and solids-not-fat, were not significantly affected by dietary treatment. No significant differences were observed in blood plasma concentrations of glucose, total protein, urea, sodium, potassium, calcium, phosphorus and magnesium. However, increased concentrations in plasma of triglycerides (18.8 versus 15.9 mg/100 ml), cholesterol (225.1 versus 173.2 mg/100 ml) and phospholipids (225.6 versus 169.6 mg/100 ml) were found when the cows were fed on the diet containing whole cottonseeds.

A later review confirmed the value of whole cottonseed in dairy cattle feeding (Arieli, 1998). According to this author the ratio of about 1 g crude protein to 40 kJ NEL makes whole cottonseed a favourable supplement that meets the combined energy and crude protein requirements of high-producing dairy cows.

Anderson *et al.* (1982) studied the effects of feeding whole cottonseed on intake, body weight and development of the reticulo-rumen in young Holstein calves. The diets were: (i) concentrate and hay (control); (ii) concentrate containing 25% whole cottonseed and hay; and (iii) concentrate containing 25% whole cottonseed and no hay. Milk was fed at 2.8 l/day/head. Results showed that feed intake, body weight, thickness of rumen epithelium and number of rumen papillae/cm^2 were greater at 12 weeks for calves fed whole cottonseed compared with controls. No differences in pH of rumen fluid, total and individual volatile fatty acid concentrations, thickness of rumen wall, length of rumen papillae, weight of stomach compartments (individually and combined), or capacity of reticulo-rumen and abomasum due to diet were recorded. This research suggested that cottonseed could be utilized by calves.

Claypool *et al.* (1985) compared soybean meal, cottonseed meal and canola meal as ingredients in starter diets for 45-day-old Holstein calves. They reported that calves fed canola, cottonseed and soybean meal diets gained on average in the pre-weaning period 0.58, 0.62 and 0.62 kg/day and in the post-weaning period 0.89, 0.89 and 0.92 kg/day, respectively. Consumption of starter feed in the pre-weaning period was 20.6, 26.7 and 24.6 kg; consumption of milk was 161, 176 and 174 kg; packed blood cell volume was 24.4, 22.9 and 24.9%; blood triiodothyronine concentration was 1.78, 1.68 and 1.72 ng/ml; and blood thyroxine concentration was 21.1, 23.6 and 21.1 ng/ml, respectively. There were no significant differences, suggesting that cottonseed meal is acceptable nutritionally as a protein supplement for calf starters. However, Fiems *et al.* (1986) reported lower digestibility, gain and efficiency of gain when cottonseed meal replaced soybean meal in calf starters.

Cochran *et al.* (1986) used a barley-based protein supplement (0.9 kg/head/day; 700 g/kg barley, 300 g/kg cottonseed meal) for dry gestating cows grazing native range in southeastern Montana. Cows fed the barley–cottonseed meal cake gained 14 kg during the trial. Cows fed 1.25 kg lucerne cubes/cow/day gained similarly. Unsupplemented cows lost 11 kg during the study period.

An interesting issue raised by Arieli (1998) was that of methane production. Direct measurement of methane production revealed a 12–14% reduction in sheep fed 250 g whole cottonseed seed/kg and in dairy cattle fed a diet containing 150 g whole cottonseed seed/kg. The reduction in methane production by feeding the whole cottonseed seed was attributed to the oil in the seed having a greater effect in lowering methane production than the effect of fermentable carbohydrates in the seed on increasing methane production. Since methane serves as a major hydrogen sink in the rumen, its altered production was associated with complementary modifications in rumen fermentation characteristics.

Arieli (1998) concluded that, due to its high fat and protein contents, whole cottonseed seed might be defined as a concentrate. Its fibre is as effective in the rumen as that of other forages. A large part of the effect of whole cottonseed seed on the milk production of dairy cattle can be explained by effects on ruminal processes.

The high degradability of CP in the rumen and the possible effect of the fat contained in whole cottonseed seed in reducing microbial activity may limit the amount that can be included in supplements for high-yielding dairy cattle. The current recommendation is to include whole cottonseed seed at no more than 150 g/kg diet.

Processing of whole cottonseed seed, especially heat treatment, may aid in providing more undegraded fat and protein in the small intestine. Heat treatment may also be a useful tool in reducing free gossypol in whole cottonseed seed. Thus, heat treatment may allow an increase in the inclusion rate of the seed in dairy cattle diets.

Whole cottonseed and cottonseed products are also being successfully used in beef cattle diets (e.g. Cranston *et al.*, 2006). In general, it was found that daily gain was not affected by diet type, but that DM intake increased and gain-to-feed ratio decreased in animals fed diets based on cottonseed compared with animals fed a control diet. Dressing percentage and marbling scores of carcasses of steers fed the cottonseed diets were found to be lower in one experiment than those of steers fed a control diet. However, the effects on carcass quality were not consistent between experiments.

Linseed (Flax) (*Linum usitatissimum*)

Linseed is grown mainly to produce linseed oil for industrial applications, western Canada, China and India being leading producers. Other important areas of production are the Northern Plains region of the USA, Argentina, the former USSR and Uruguay. Linseed is grown typically under dry-land conditions. In Canada, linseed is produced only as an industrial oilseed crop and not for textile use as in some countries.

The oil content of linseed ranges from 400 to 450 g/kg and the by-product of mechanical oil extraction – linseed (flaxseed) meal – can be used in organic cattle feeding. Expeller processing reduces the oil content to 50–80 g/kg in the extracted meal. Linseed meal is regarded as a high-quality, palatable, protein feedstuff for dairy and beef cattle, though most of the available product is used in the dairy industry.

There is also interest in feeding the ground whole oil-containing seed to cattle for two main reasons: to produce milk and meat with a fatty acid profile in the fat that confers health benefits on the consumer and imparts an enhanced flavour to the meat.

The whole seed is too hard for animal feeding and must be either crushed or softened by soaking and boiling. Because it is rich in oil, linseed can be used as a concentrated energy feed for growing and lactating cattle.

Nutritional features

As with most grains and oilseeds, the composition of linseed varies, depending on cultivar and environmental factors. Typical values are 410 g oil/kg and 200 g CP/kg (DeClercq, 2006; DM basis). Reported CP values range from 188 g/kg to 244 g/kg (Daun and Przybylski, 2000). As with other oilseeds, mechanical extraction results in a higher residual oil content in the meal than in the solvent-extracted product.

The term linseed meal is used for ground unextracted seed, for ground linseed cake and for meal from the extraction process. Since these have different oil contents, formulating linseed meal into cattle diets should be done on the basis of a guaranteed analysis. In general, the term linseed meal refers to the ground product following oil extraction.

As reviewed by Maddock *et al.* (2005), several reports have indicated possible human health benefits associated with consumption of flaxseed. The oil contains about 65 g linoleic acid/kg and about 230 g α-linolenic acid/kg, an essential omega-3 fatty acid that is a precursor for eicosapentaenoic acid (EPA). EPA is a precursor for the formation of eicosanoids, which are hormone-like compounds that play an essential role in the immune response. Additionally, some evidence suggests that EPA can be converted to docosahexaenoic acid (DHA), an omega-3 fatty acid that is essential for cell membrane integrity, as well as brain and eye health. Recent research indicates that milk and meat from animals fed flax contain increased levels of omega-3 fatty acids. Highly saturated long-chain fatty acids boost both milk yield and fat content, whereas unsaturated fatty acids contained in groundnut, soybean, sunflower, maize and linseed oils tend to enhance yield but depress milk fat content.

Linseed is the richest plant source of the lignan precursor secoisolariciresinol diglycoside (SDG), which is converted by microorganisms in the rumen to mammalian phytoestrogens (Zhou *et al.*, 2009) and is deposited in milk and meat. These phytoestrogens are believed to have potential value in hormone replacement therapy and cancer prevention.

Linseed meal is palatable and mildly laxative. The nutrient content of linseed meal has been reviewed by Chiba (2001) and Maddock *et al.* (2005). The CP content averages about 370 g/kg (DM basis), but is variable and may be as high as 420 g/kg. Linseed meal is deficient in lysine and contains less methionine than other oilseed meals. Protein degradability in the rumen is high and similar to that of soybean meal. The fibre content is higher and the energy content lower than in soybean meal.

Because of the hulls, which are coated with high quantities of mucilage, the crude fibre content of linseed meal is relatively high. The contents of major macro-minerals in linseed meal are comparable with those in other oilseed meals, although the levels of calcium, phosphorus and magnesium are higher than the levels found in soybean meal. Linseed meal is a good source of selenium, possibly because it has been grown in Se-adequate areas.

Anti-nutritional factors

Immature linseed contains the glucoside linamarin. At certain temperatures (optimum 40–50°C), conditions of acidity (pH 2–8) and in the presence of moisture, an associated enzyme – linase – acts on linamarin to produce hydrogen cyanide (HCN). This is extremely toxic to animals. Death results from combination of the cyanide with cytochrome oxidase, leading to a rapid cessation of cellular respiration and anoxia. The mature seed contains little or no linamarin and presents much less of a problem; this enzyme is normally destroyed by heat during oil extraction. Linase is destroyed by sufficient heating; therefore boiling for 10 min can be used to make the feed safe. Ruminants have been reported to be more susceptible to HCN poisoning than non-ruminants, and cattle slightly more so than sheep. Hereford cattle have been reported to be less susceptible than other breeds.

In the UK, linseed cake or meal must, by law, contain less than 350 mg hydrocyanic acid/kg feed with a moisture content of 120 g/kg.

Cattle diets

Linseed (flaxseed) meal is a by-product of the flax industry and is a good protein supplement. Linseed meal is obtained by grinding the cake or chips that remain after removing the oil from flaxseed. It is an excellent protein supplement for dairy cattle and aids in producing bloom and making the hair soft. The meal is readily eaten by dairy cows but tends to produce a soft milk fat which is susceptible to the development of oxidative rancidity. The cake in large amounts is laxative, and an excess has an undesirable softening effect on the butterfat and may give the milk a rancid taste (McDonald *et al.*, 1995). Several studies have been conducted on the whole seed as a feed ingredient for cattle. As with other oilseeds containing oil that is subject to rancidity, the ground seed should be mixed into diets and used quickly after processing.

Petit *et al.* (2001) reported increased first-service conception rates (87.5% versus 50.0%) in dairy cows fed diets with 170 g flaxseed/kg, compared with dairy cows fed other sources of fat.

The authors attributed this response to increased energy balance for the cows fed the flax diet.

Other research has also been conducted on the value of flaxseed in diets for dairy cows. Goodridge *et al.* (2001) fed lactating dairy cows a casein-protected flax at either 1.76 or 3.53 kg/kg milk fat produced and Ward *et al.* (2002) fed lactating dairy cows either solin (or linola, a cultivar of flax), regular flax or canola at 80 g/kg diet (DM basis). No differences in milk production were found in either trial. However, Goodridge *et al.* (2001) reported that flax-fed cows produced milk higher in protein. Ward *et al.* (2002) reported that cows fed flax diets had a lower yield of milk protein than cows fed the control diet. Kennelly and Khorasani (1992) fed four dietary levels of flax (0, 50, 100 and 150 g/kg diet on a DM basis) and noted no differences in feed intake or milk yield but that the content of milk protein decreased as dietary flax levels increased.

In addition to its effect on milk protein, it has been shown that inclusion of flaxseed in the diets can alter the milk fatty acid profile beneficially for the human consumer. Kennelly and Khorasani (1992), in the study referred to above, reported linear increases in the content of milk long-chain fatty acids and polyunsaturated fatty acids, including α-linolenic acid (ALA). Other researchers have made similar findings. Goodridge *et al.* (2001) reported that milk levels of ALA increased linearly with increasing dietary flax inclusion.

The effects of extruded flaxseed supplementation of high-yielding dairy cows on milk production and milk fatty acid composition were reported by Moallem (2009). The treatments were: (i) control, cows fed a lactating-cow diet; and (ii) extruded flaxseed, cows were fed the same diet plus a supplement at 40 g/kg DM that contained extruded flaxseed and wheat bran at 700 and 300 g/kg, respectively. Average daily milk yield was 2.7% higher in the supplemented group than in the control group (45.4 and 44.2 kg/day), milk fat content was lower in the supplemented group (34.1 and 36.3 g/kg, respectively), and milk fat yield was unaffected. The results also showed that the concentration of n-3 fatty acids and yield in milk fat were 2.8 times as high and the n-6:n-3 ratio was 2.8 times lower in the supplemented group than in the control group. The proportion of saturated fatty acids in milk fat decreased and the proportions of monounsaturated acids and polyunsaturated fatty acids increased in response to supplementation with flaxseed.

Several investigators have researched the utilization of flaxseed in diets for beef cattle. Drouillard *et al.* (2002) included flaxseed at dietary levels of 0, 50, 100 and 150 g/kg (DM basis) and found that a level of 50 g flaxseed/kg increased the intake of DM but had no effect on gain or the efficiency of gain. Drouillard *et al.* (2004) fed beef steers diets containing 0, 50, 100 and 150 g flaxseed/kg and noted a linear decrease in DM intake with increasing level of flaxseed. Maddock *et al.* (2004) fed whole or processed (rolled or ground) flax at a dietary level of 80 g/kg (DM basis), and reported significant increases in gain and efficiency of gain and no differences in DM intake, when compared with a maize-based control diet. The data from this study suggested that processing flax is necessary to optimize gain and nutrient utilization. When flax was rolled or ground, gain and gain efficiency increased compared with feeding whole flax.

The possibility that flaxseed might enhance the fat marbling in beef muscle has been investigated in several studies. Maddock *et al.* (2003) included 30 or 60 g ground flax/kg in finishing diets for feedlot steers fed for 56 days prior to marketing. No differences were found for carcass characteristics, including 12th-rib fat thickness, ribeye area and USDA yield and quality grades. In a second experiment, Maddock *et al.* (2004) included flax at 80 g/kg (DM basis) in diets for heifers and determined that there was a tendency for flax to increase marbling scores.

Drouillard *et al.* (2002) fed weaned calves for 36–40 days on diets that contained tallow or flax at 0, 50, 100, 150 or 200 g/kg. Animals fed the tallow and 100 g flax/kg diets were then given a common finishing diet. Results showed that cattle fed the diet containing 100 g flax/kg had higher marbling scores than the steers given the diet containing tallow (Sl60 versus SM00, respectively). Drouillard *et al.* (2004) fed Holstein steers on diets containing 0 or 50 g flax/kg for either 109 or 157 days and reported that flax inclusion increased the number that achieved a USDA choice grade.

The possibility that dietary inclusion of flax might alter the fatty acid profile of beef, similar to that reported with milk, has also been investigated. The nutritionally important polyunsaturated (n-3) fatty acids include ALA, EPA and DHA, which cannot be synthesized in the human body. Muscle from steers fed diets that included flax had higher ALA content (47 g lipid/kg), compared with steers fed either maize (34 g lipid/kg) or barley (39 g lipid/kg) diets (Maddock *et al*., 2003). Other studies report similar findings. Steers fed a diet with 50 g flax/kg had higher muscle levels of ALA than steers fed a diet without flax (Drouillard *et al*., 2002). Drouillard *et al*. (2004) reported an increased ALA content in both muscle and fat samples collected from Holstein steers fed a diet containing 50 g flax/kg for either 109 or 157 days, compared with control steers.

Because of the reported increase in content of unsaturated fatty acids in flax-fed beef, Drouillard *et al*. (2004) investigated the use of vitamin E as an antioxidant in flax-supplemented diets. They found that beef from cattle supplemented with vitamin E had a brighter retail colour score than beef from cattle not fed flax, but that consumers did not consider beef from either treatment group to be unacceptable. Drouillard *et al*. (2004) noted no differences in lipid oxidation of fatty acids in beef from flax-fed cattle and cattle fed a control diet containing no flax. Sensory panel results (Maddock *et al*., 2003, 2004) suggested that flax-fed steers produced steaks that were less juicy compared with steers fed maize-based diets. In contrast, Drouillard *et al*. (2004) reported no differences in sensory panel observations for juiciness, tenderness or flavour from flax-fed cattle and cattle fed a control diet containing no flax.

Maddock *et al*. (2004) found that feeding a diet containing 80 g flax/kg to heifers resulted in steaks that had lower Warner-Bratzler shear force values. This result suggested that steaks from flax-fed cattle should be more tender than steaks from cattle fed a maize-based control diet. However, Drouillard *et al*. (2004) reported no differences in steak shear force values from flax-fed cattle and from cattle fed a control diet.

The presence of flaxseed in the diet has been shown to have a beneficial influence on the immune response. Drouillard *et al*. (2002) conducted two experiments with newly weaned calves to evaluate the effect of dietary inclusion of flax on morbidity. In experiment 1, steer calves were fed diets with 0, 50, 100, 150 or 200 g flax/kg or 40 g tallow/kg for 36–40 days. No differences were observed for cases of bovine respiratory disease (BRD). In experiment 2, weaned heifer calves were fed diets with no flax, 40 g flax/kg, 100 g flax/kg, 40 g flax oil or linseed meal/kg with 40 g tallow/kg for 40 or 41 days. Incidence of BRD was highest in heifers fed the control diet. Compared with the diet containing tallow, the diets containing flax and flax oil resulted in fewer heifers having to be re-treated for BRD.

Related work was conducted by Farren *et al*. (2002), who fed diets containing 40 g tallow/kg, 129 g flax/kg or an algal source of DHA to evaluate effects on immune response. Diets were fed to steers for 14 days prior to an injection of lipopolysaccharide (LPS) endotoxin as an immune challenge. Flax-fed steers had lower rectal temperatures 3–6 h after LPS injection compared with tallow- and algae-fed steers, and flax-fed steers had higher blood levels of haptoglobin, a positive indicator of immune response, compared with tallow-fed steers.

Sesame meal (*Sesamum indicum*)

Sesame is grown mainly in China, India, Africa, South-east Asia and Mexico as an oil crop. It is known as the 'queen of the oilseed crops' because of the excellent culinary properties of the oil (Ravindran and Blair, 1992). After oil extraction the meal can be used for animal feeding. However, sesame meal is not of significant importance for cattle feeding.

Several aid agencies are providing small oil presses for villages in countries such as The Gambia. This development should encourage the growth of small ruminant feeding systems in areas of sesame production.

Nutritional features

Chiba (2001) reviewed the nutrient properties of sesame seed and meal. On average, the seed contains 250 g CP/kg, 500 g oil/kg, 40 g crude fibre/kg, 50 g ash/kg and 50 g moisture/kg. The nutrient composition of dehulled, expelled-extracted meal is similar to that of soybean meal, with an average CP content of 400 g/kg and a crude fibre value of 65 g/kg (Ravindran and Blair, 1992). Sesame meal is an excellent source of methionine, cystine and tryptophan, but is low in lysine. Although sesame meal is a good source of minerals such as calcium, their availability may be low because of high levels of oxalates and phytate acids in the hull (Ravindran, 1991). Vitamin levels in sesame meal are comparable to those in soybean meal and most other oilseed meals (Ravindran, 1991).

Anti-nutritional factors

Although sesame seed is not known to contain any protease inhibitors or other anti-nutritional factors, high levels of oxalic and phytic acids may have adverse effects on palatability and on availability of minerals and protein (Ravindran, 1991). Decortication of seeds almost completely removes oxalates, but it has little effect on phytate (Ravindran, 1991). Complete decortication is difficult because of the small size of the seeds.

Cattle diets

Published information on the use of sesame meal in cattle feeding is limited. Shultz *et al.* (1970) fed young bulls of 255 kg on maize silage to appetite and 1.5 kg daily of concentrate with 250 g sesame meal/kg or with half or all of the meal replaced by equivalent N from urea, with extra starch. The cattle gained 541, 429 and 304 g/day and consumed 6.49, 6.37 and 6.30 kg silage, respectively. Daily loss of nitrogen was 1.03, 10.85 and 17.42 g, respectively, but groups did not differ significantly in apparent digestibility of DM or nitrogen or in blood urea or ruminal fatty acids. This result indicated an adverse effect of replacing sesame meal with urea.

Effects of feeding sesame meal on growth performance, nutrient digestibility and carcass characteristics of Awassi lambs were reported by Obeidat *et al.* (2009). The results suggested that sesame meal could replace 8% of soybean meal in the diet without any detrimental effect on lamb growth or meat quality.

The response of young dairy calves to diets containing sesame and groundnut oils had been investigated by Shrivastava and Kendall (1961). No beneficial effects were recorded. The dietary treatments were: (i) whole milk; (ii) dried skimmed milk, fortified with vitamins A and D and antibiotic; (iii) dried skimmed milk, fortified with vitamins A and D and antibiotic, plus 150 or 200 g sesame oil/kg and 20 g lecithin/kg; (iv) dried skimmed milk, fortified with vitamins A and D and antibiotic, plus 150 or 200 g/kg sesame oil and 20 g/kg lecithin. All calves were given calf starter and hay *ad libitum*. Total milk consumption and live weight gains to 42 days for the dietary groups were: (i) 656 and 21.6 kg; (ii) 235 and 17.8 kg; (iii) 236.8 and 17.0 kg; and (iv) 217.7 and 15.1 kg, respectively.

Sesame meal may have a role as a natural antioxidant in feeds for small-scale farmers using diets based on rice bran, which is very unstable and can become rancid on storage. For instance, pig production is a very important income source for small-scale farmers in the Mekong Delta area of Vietnam, where rice bran, broken rice, protein concentrate and vegetables, etc. are used for pig feeding. In this environment rice bran, which is the major regional feed resource, must be used within a few weeks of production (Yamasaki *et al.*, 2003), because it is generally not defatted. As described in the section on rice bran, the oil is prone to peroxidation and loss of palatability. Yamasaki *et al.* (2003) tested the inclusion of 10–35 g ground white sesame/kg into the diet of growing pigs and reported an improvement in feed intake and feed conversion efficiency. These researchers recommended the use of small amounts of sesame meal as a natural antioxidant for use with rice-bran diets, but only when the sesame meal was fresh. Presumably the sesame meal acted in this way due to its content of vitamin E. Sesame meal might be used in a similar way in cattle production.

Palm kernel

Palm kernel cake or meal is the by-product of the mechanical extraction of oil from the fruit of the oil palm. It contains 80–110 g oil/kg, depending on the efficiency of the extraction process.

Malaysia is a main producer and exporter of palm kernel meal, where it is a major feed ingredient in beef and dairy feed. The meal is also produced in parts of Australia.

A current concern with palm kernel cake is whether the quality control of the product is adequate and whether it presents a possible risk of introducing insect pests into importing countries.

Palm kernel cake or meal is obtained by two stages of oil extraction from the palm fruit. The first stage is the primary extraction of palm oil from the pericarp portion of the fruit, which also produces the kernel and by-products palm oil sludge (POS) and palm pressed fibre (PPF). The extraction of oil from the crushed kernel then results in the production of palm kernel cake (PKC) as a by-product. Two methods are used for the extraction of oil from the crushed kernels. These are the conventional mechanical screw-press method that results in expeller palm kernel cake and the solvent (usually hexane) extraction method that results in solvent-extracted palm kernel cake.

Nutritional features

About 60% of palm kernel cake is cell wall components, consisting of about 580 g mannan/kg, 120 g cellulose/kg and 40 g xylan/kg (Jaafar and Jarvis, 1992). As a result the product has a high fibre content of approximately 550–600 g NDF/kg. The fibre appears to be well digested in cattle. No estimates of net energy appear to be available but the metabolizable energy value for ruminants has been reported as 10.5–12.5 MJ/kg (Alimon, 2005), similar to that of cereal grains. However, palm kernel cake contains little or no starch.

The CP content is typically in the range 160–180 g/kg, air-dry basis. The mineral content has been reported as calcium 4.5, phosphorus 8.0 and magnesium 4.6 g/kg (Alimon, 2005). Palm kernel cake is regarded as a good source of the trace minerals copper, zinc and manganese.

Expeller cake contains a higher content of oil (80–100 g/kg) than the solvent-extracted oilseed meals, such as those produced in Australia.

Most of the published research findings on palm kernel cake or meal relate to the solvent-extracted products and, although useful, do not necessarily provide accurate information for application with the expeller products.

Digestibility of solvent-extracted cake was determined, using the Kedah-Kelantan breed of cattle, at 651 g/kg DM, 727 g organic matter/kg, 697 g CP/kg and 867 g nitrogen-free extract/kg (Miyashige *et al.*, 1987). Digestibility coefficients for expeller palm kernel cake of 700 g DM/kg, 630 g CP/kg, 520 g ADF/kg, 530 g NDF/kg and 880 g gross energy/kg were obtained using sheep (Suparjo and Rahman, 1987). On this basis, the expeller product contained 110 g digestible CP/kg, 210 g digestible ADF/kg, 400 g digestible NDF/kg and 14.89 MJ digestible energy/kg.

Further data on digestibility were obtained by Hindle *et al.* (1995), using 15 samples representative of palm kernel cake imported in the Netherlands. The origins of the cake were Malaysia, Indonesia and Nigeria. Laboratory analysis confirmed that two samples were of solvent-extracted products (12 g oil/kg DM), the others being from expeller products (89–144 g oil/kg DM). The CP content of the expeller samples ranged from 158 to 217 g fat-free organic matter/kg. It was found that the digestibility of the solvent-extracted products was lower (64.6%) than in the expeller products (67–83%). All the samples contained high levels of cell wall constituents (700–800 g fat-free organic matter/kg). The rumen-undegradable fraction of NDF varied between 23% and 37%. The solvent-extracted products contained larger fractions of rumen-undegradable protein than expeller products. Calculations suggested a slow rate of outflow from the rumen of cell wall and protein constituents in palm kernel by-products.

Dias *et al.* (2008) studied the digestibility of expeller cake in cows. Results showed that the expeller cake had a significantly lower soluble protein fraction (258 and 355 g/kg) than pasture (414 and 523 g/kg) and a significantly greater degradable protein fraction (610 and 602 g/kg) than pasture (545 g/kg and 465 g/kg). There was also evidence that adaptation to palm kernel cake is necessary to achieve its potential as a supplement for grazing cows.

Cattle diets

The milk of dairy cattle fed palm kernel cake tends to produce a firm butter, and a ration of 2–3 kg of cake daily has been reported as being satisfactory for adult cattle (Gohl, 1981). Palm kernel cake has been reported to be a common ingredient in German and Dutch rations with dairy cow diets containing approximately 100 g/kg, whereas in Malaysia dairy farmers included more than 500 g/kg (Osman and Hisamuddin, 1999).

A supplement of palm kernel cake to grass–molasses-based diets was shown to improve the daily weight gains of growing Zebu-Holstein dairy bulls (Camoens, 1979).

Carvalho *et al.* (2006) tested the effects of increasing levels of solvent-extracted palm kernel meal (0, 50, 100 and 150 g/kg) in maize silage-based diets on feed intake and milk production of

Holstein cows. During a 3-week preliminary period, cows averaging 100 days in milk were fed a standard diet. They were then given one of four experimental diets. The control diet consisted of (DM basis) 400 g maize silage, 50 g coarsely chopped wheat straw and 550 g concentrate/kg. Increasing dietary levels of palm kernel meal were achieved by partial replacement of protein sources and citrus pulp with the palm product and urea. There were no significant treatment effects on DM intake, milk yield or milk composition. However, inclusion of palm kernel meal tended to increase protein and lactose contents of milk. The control diet, containing no palm kernel meal, resulted in a loss of body weight.

Palm kernel cake is reported as being used widely in Malaysia as the main ingredient in diets for beef cattle and buffalo, the diets containing up to 800 g/kg and providing live weight gains of 0.6–0.8 kg/day for local cattle (Kedah-Kelantan) and 1–1.2 kg/day for cross-bred cattle (Zahari and Alimon, 2005). An example dietary formulation for beef cattle provided by these authors is palm kernel cake 800 g/kg, grass/hay 175 g/kg, ground limestone 15 g/kg and mineral and vitamin premix 10 g/kg. According to this report, palm kernel cake as almost the entire ration has been fed to feedlot cattle with no negative effect, provided that a sufficient supply of calcium and vitamins A, D and E is maintained. Carcass analysis indicated that the beef cuts were of superior quality when compared with those for cattle fed on grass or pasture. In dairy cattle diets, palm kernel cake is used as a source of energy and fibre at an inclusion level of 300–500 g/kg, with the remainder of the ration being grass and other concentrates. Under Malaysian local conditions, a milk yield of 10–12 l/head/day or more can be achieved. An example of dairy cattle feed formulation is palm kernel cake 500 g/kg, molasses 50 g/kg, grass/hay 420 g/kg, ground limestone 15 g/kg, mineral and vitamin premix 10 g/kg and salt (NaCl) 5 g/kg (Zahari and Alimon, 2005).

Olives (*Olea europaea*)

Most of the world's production of olive oil is based in the countries of southern Europe, the Middle East and North Africa, where olive cultivation is a centuries-old tradition. The crop is also grown in Australia. World production of olives is around 3 million tonnes, Spain being the largest producer of olive oil. Production there is likely to increase further because of a continued increase in olive tree cultivation.

The olive fruit comprises pulp (70–90%), stone (9–27%) and seed (2–3%) on a total weight basis. The pulp contains around 17 g oil/kg, depending on variety of plant and the stage of harvesting.

Traditionally the fruit is crushed to express the oil, leaving a crude olive cake that can be used as animal feed. The cake may be further refined to yield additional oil by solvent extraction. Centrifugation is also being used as a means of separating the oil from the fruit.

In addition to olive cake being available as animal feed, the leaves are also used as feed. Olive leaves contain a mixture of leaves and branches from the pruning of olive trees as well as the harvesting and cleaning of olives prior to oil extraction. Production of olive leaves has been estimated at around 25 kg per tree.

Nutritional features

Olive cake consists of pulp, skin, stone, remaining oil and water. Table 4.8 shows the average composition of olive leaves and olive cake (Hadjipanayiotou, 1994; Molina-Alcaide and Yáñez-Ruiz, 2008). Table 4.9 shows the data on the digestibility of olive leaves and olive cake (Molina-Alcaide and Yáñez-Ruiz, 2008).

Rowghani *et al.* (2008) reported on the chemical composition, rumen degradability, *in vitro* gas production, energy content and digestibility of olive cake ensiled with additives. The samples were: (i) olive cake silage untreated; (ii) olive cake silage supplemented with 80 g molasses/kg and 4 g formic acid/kg (DM basis); and (iii) olive cake silage supplemented with 80 g molasses/kg, 4 g formic acid/kg and 5 g urea/kg (DM basis). Addition of molasses, formic acid and urea resulted in higher contents of DM, crude protein, pH and ammonia-nitrogen. Ruminal degradability and effective degradability of DM and crude protein were higher for the third treatment. Total gas production was higher for the last two treatments and was associated with increased *in vitro* organic matter digestibility and a non-significant increase in metabolizable energy content. Only CP digestibility was affected by treatment and

Table 4.8. Reported chemical composition (g/kg dry matter) of olive leaves and olive cake.

	Source		
	Molina-Alcaide and Yáñez-Ruiz (2008)		Hadjipanayiotou (1994)
	Olive leaves	Olive cake	Olive cake
Dry matter (g/kg fresh matter)	777	805	470
Organic matter	880	901	
Ether extract	56.4	54.5	104
Gross energy (MJ/kg DM)	19.7	19.7	
In vitro digestibility	–	–	114
Crude protein	100	72.6	48
Amino acid N (g/kg N)	887	846	
Acid detergent insoluble N	8.16	10.7	
Crude fibre	–	–	443
Neutral detergent fibre	406	676	691
Acid detergent fibre	302	544	551
Acid detergent lignin	199	289	278
Total extractable polyphenols	25.3	13.9	
Total extractable tannins	1.0	9.78	
Total extractable condensed tannins	2.28	0.81	
Total condensed tannins	9.49	12.4	
Free condensed tannins	2.98	1.64	
Fibre bound condensed tannins	2.30	4.00	
Protein bound condensed tannins	3.65	5.87	

was highest for the third treatment. *In vitro* DM and organic matter digestibilities improved in the last two treatments. The results indicated that treating olive cake before ensiling with molasses, formic acid and urea resulted in a satisfactory and economical source of a non-conventional feed for ruminants. However, it is doubtful if the results are applicable in organic production: a substitute for urea would have to be found.

Anti-nutritional factors and contaminants

Olives are known to contain polyphenols and tannins, leading to speculation that they might interfere with protein utilization when used as feed. However, no data are available on this issue and it is possible that these compounds are removed or reduced during expeller crushing. Analyses of olive cake by Nefzaoui (1978) showed that tannin concentration was below 10 g/kg and not sufficient to depress the number of rumen microflora. This author showed also that polyphenol concentrations were between 1.5 and 7.5 g/kg DM, insufficient to inhibit rumen fermentation and reduce the digestibility of protein.

Another aspect of possible concern in relation to the feeding of olive leaves is that of copper contamination. Conventional olive crops are likely to have been treated with chemicals such as copper compounds after harvesting to protect against fungal (peacock spot) and bacterial (olive knot) infections. No data on this potential problem appear to have been published. The problem should be absent in olive trees grown organically.

Cattle diets

There is a paucity of recent data on the use of olive cake in milk cow or beef animals in the published literature. A report was published by Raimondi (1937), based on an experiment in which 30% of the concentrate in the diet of dairy cows was replaced by extracted olive pulp. The pulp was readily consumed by the cows. When the pulp was given with additional concentrate to compensate for its lower content of digestible protein and its high cellulose content, milk yield was maintained at the level obtained with the control diet. There was no unfavourable effect on the fat content of the milk.

Table 4.9. Digestibility of olive leaves and olive cakes in sheep and goats (Molina-Alcaide and Yáñez-Ruiz, 2008).

	Olive leaves	Olive cakes
***In vitro* apparent digestibility**		
Dry matter	0.46	0.27
Organic matter	0.43	0.21
Crude protein	0.13	0.10
Neutral detergent fibre	0.20	0.15
Ruminal degradability		
Dry matter (estimate 1)	0.28	0.19
Crude protein (estimate 1)	0.11	0.13
Dry matter (estimate 2)	0.41	0.31
Crude protein (estimate 2)	0.27	0.34
Dry matter (estimate 3)	0.024	0.076
Crude protein (estimate 3)	0.088	0.075
Potential degradability		
Dry matter	0.69	0.50
Crude protein	0.38	0.47
Effective degradability		
Dry matter	0.46	0.42
Crude protein	0.33	0.44
Organic matter		0.51
Acid detergent fibre		0.37
Amino acid-N ruminal degradability	0.75	0.91
Rumen undegraded protein		
Amino acid N (g/kg N)	612	431
Total N (g/kg DM)	10.8	7.30
Apparent intestinal digestibility of rumen undegraded protein	0.42	0.37
Apparent intestinal digestibility of dietary crude protein	0.71	0.78
Apparent intestinal digestibility of rumen undegraded amino acid N	0.28	

Most of the available data relate to the use of olive by-products in the feeding of goats and sheep, suggesting that the by-products are being utilized mainly or exclusively in these species. Results obtained with these species may provide useful data on the potential utilization of olive by-products in dairy cow and beef cattle feeding.

Effects of supplementation of a basal diet with crude olive cake or olive leaves on feed intake and productivity of goats and sheep are shown in Table 4.10 (Molina-Alcaide and Yáñez-Ruiz, 2008).

Hadjipanayiotou (1999) studied the utilization of olive cake silage in lactating Chios ewes, Damascus goats and Friesian cows. The silage was very well preserved, based on its aroma, colour, pH (4.7) and a lack of any mould. Partial replacement of conventional roughage (barley hay and barley straw) with olive cake silage had no effect on milk yield. Cows lost weight on the olive silage diet, however, daily gain being 34 g on the control diet compared with a loss of 312 g on the silage diet. Milk fat content was increased by 3.1–5.8 g/kg milk. Although the olive cake silage constituted only 15% of the total diet, it raised the fat content of the total diet by 65%. Other researchers had reported similar effects. Chiofalo *et al.* (2004) included crude olive cake (200 g/kg of the concentrate DM) in the diet of lactating ewes and observed an increase in total milk yield. The olive cake also increased milk fat and protein. Milk of ewes fed diets containing olive cake showed a higher content of oleic acid, linoleic acid and total monounsaturated fatty acids and a lower content of saturated fatty acids. Hadjipanayiotou (1999) speculated that meat quality might be affected similarly.

Molina-Alcaide *et al.* (2005) studied the effect of replacing 50% of a concentrate with multi-nutrient blocks including crude olive cake in diets for lactating goats. No differences in milk

Table 4.10. Effect of supplementation of different forages with crude olive cake or olive leaves on feed intake and productivity of goats and sheep (Molina-Alcaide and Yáñez-Ruiz, 2008).

		Dry-matter intake			
Basal feed	Animals	Forage	Olive cake	Growth rate (g/day)	Milk yield (g/day)
Grass hay	Goats	206	293	46	–
Vetch hay	Ewes	1500	140	–	772
Lucerne hay	Goats	1000	23	–	1031
Sulla hay	Lambs	–	–	191	–
Olive leaves only	Lambs	–	–	77	–
Wheat straw, concentrate	Ewes	1450	1200	–	1021

yield were reported. They also reported an increased content of oleic acid, linoleic acid, cis-9-trans-1 CLA and unsaturated fatty acids in the milk of animals fed the diet containing olive cake.

Subsequent to these studies, Molina-Alcaide and Yáñez-Ruiz (2008) reviewed the available findings on the use of olive by-products in ruminant feeding. They concluded that olive leaves are fibrous with a low digestibility (Table 4.9), especially of CP, and they promote very poor rumen fermentation. However, if adequately supplemented, they may be used successfully in animal diets. The nutritive value of olive leaves is greater when fed fresh, although dry leaves may be incorporated in the diet. When olive leaves are rich in oil, the numbers of ruminal protozoa decrease and this could increase the efficiency of microbial protein synthesis in the rumen. It has also been observed with lactating animals that olive leaves result in an improvement in milk fat quality compared with diets based on conventional forages. The use of olive cakes in ruminant diets promotes different responses in rumen fermentation, depending on the method of administration and the proportion in the diet. Both feeding as silage and incorporation into feed blocks have proved to be satisfactory. The authors concluded that olive cake is a cheap source of energy and fibre for ruminant feeding and that high-fat olive cake may be used to improve the quality of the fat in the animal products. This assessment was based mainly on results with sheep.

Groundnuts (*Arachis hypogaea* L.)

Groundnuts (also known as peanuts) are not included as an approved feedstuff in either the EU or New Zealand lists but should be acceptable for organic cattle diets if grown organically. The reason for omission may be that groundnuts are grown mainly for the human market. This crop is grown extensively in tropical and subtropical regions and is too important to be rejected for use in organic cattle diets. However, this issue should be clarified with the local certifying agency. China and India are the largest producers of groundnuts. Those not suitable for human consumption are used in the production of groundnut (peanut) oil. The by-product of oil extraction, groundnut meal, is widely used as a protein supplement in livestock diets. Conventional processing involves solvent extraction of the oil, leaving a product that is not suitable for feeding to organic animals.

Nutritional features

The nutrient contents of groundnuts and extracted groundnut meal were reviewed by Chiba (2001). Raw groundnuts contain 400–550 g oil/kg. Groundnut meal is the ground product of shelled groundnuts, composed principally of the kernels, with some hull (fibre) and oil remaining after oil extraction. Mechanically extracted meal may contain 50–70 g oil/kg; thus it tends to become rancid during storage, especially during summer. In the USA the conventional meal is usually adjusted to a standard protein level with ground groundnut hulls. The traded product in the USA must contain not more than 70 g crude fibre/kg and only such amount of hulls as is unavoidable in good factory practice. The CP content of extracted meal ranges from 410 to 500 g/kg. Groundnut protein is deficient in lysine and is low in methionine and tryptophan. It is low in calcium, sodium and chloride, and much of the phosphorus occurs as phytate.

Anti-nutritional factors

Chiba (2001) reviewed the anti-nutritional factors present in groundnut kernels. Groundnuts contain protease inhibitors and tannins, but generally not at levels high enough to cause concern. Groundnuts are subject to contamination with moulds. *Aspergillus flavus*, which produces aflatoxin, can grow in groundnuts and occur in groundnut meal. Aflatoxin is carcinogenic and acutely toxic to animals and humans, depending on the level of contamination.

McDonald *et al.* (1995) reported findings on the effects of feeding contaminated groundnut meal to cattle. Deaths occurred in calves under 6 months of age. Older cattle were found to be more resistant. Deaths occurred in 6-month-old steers given 1 mg aflatoxin B_1/kg in the diet for a period of 133 days and live weight gains were generally reduced significantly. Administration of 0.2 mg aflatoxin B_1/kg in the diets of Ayrshire calves significantly reduced live weight gains. Experiments on the inclusion of 130–200 g toxic groundnut/kg in dairy cow diets showed significant reductions in milk yield.

Aflatoxins are relatively stable to heat, making their elimination from the meal difficult. The best method of control is suitable storage to prevent mould growth, although aflatoxins may be produced in the growing crop. Most countries now have prescribed maximum limits for aflatoxins in animal feed, an upper limit of 20 ng/g being common.

Cattle diets

Quality proteins are required in calf diets; therefore Sahoo and Pathak (1998) investigated the comparative value of a plant source of protein (groundnut meal) in relation to an animal source of protein (fishmeal). Calf starter diets containing fishmeal or groundnut meal were fed to young calves during the pre-ruminant period of 13 weeks. Average DM intake (kg/day) was 2.26 and 2.19, respectively. Average daily weight gain was 212 and 206 g, with a feed-to-gain ratio of 3.91 and 3.93 (kg feed/kg gain), respectively. Crude protein intake (g/kg gain) was 493 and 506, respectively. The slight benefit shown by the fishmeal was not significant and the authors concluded that pre-ruminant calves can be reared successfully on a calf starter devoid of fishmeal.

Few other reports on scientific studies of expeller groundnut meal have been published, suggesting that the product is not of importance in cattle feeding, at least in importing countries. However, groundnut cake is still used in tropical countries where it is an indigenous crop. For example, Little *et al.* (1991) studied the effect of groundnut cake supplementation during the dry season on productivity characteristics of N'Dama cows under village husbandry conditions in The Gambia. Lactating cows maintained under village conditions and grazing local pasture were supplemented with groundnut cake at rates of 0, 425 or 850 g/day for the last 3 or 5 months of the dry season. Supplementation produced significant increases in milk yield and also in rates of growth of the suckling calves, and significantly decreased losses of maternal live weight during these feeding periods. Post-partum resumption of reproductive activity was significantly improved only in the groups fed for 5 months. The authors concluded that the supplementary feeding provided a promising basis for improvement of village husbandry systems in the Sudano-Sahelian zone of sub-Saharan Africa.

Various by-products of the groundnut industry are being used as feedstuffs for cattle in areas of the USA where groundnuts are grown.

Groundnut by-products, including groundnut meal and raw groundnuts, groundnut skins and hulls, groundnut hay and silages, are important feed sources for cattle in regions where groundnuts are produced. They can be incorporated into a variety of supplements and diets for cow herds, growing–finishing cattle and dairy cattle. Residual groundnut hay is the by-product most widely fed to beef cattle, and it is comparable to good-quality grass hays in nutrient content if properly harvested and stored. Groundnut skins produced when groundnuts are blanched are utilized in cattle diets as protein and energy sources, but skins contain 160–230 g tannins/kg, which can cause protein deficiencies and severely reduce beef cattle performance if diets do not contain a sufficiently high protein content (above 150 g CP/kg). Groundnut hulls are economically priced because of inherently low protein and high fibre contents. They can be used as a roughage source in beef finishing diets.

Myer *et al.* (2009) conducted two trials to evaluate the suitability of whole in-shell groundnuts as an energy and protein supplement feed for beef cattle. A digestion trial used 18 steers of 265 kg average body weight. The steers were fed Bermuda-grass hay plus one of three supplements: (i) maize and cottonseed meal (50:50); (ii) maize and whole groundnuts (50:50); or (iii) whole groundnuts. The supplements were fed at 1.4 kg/head/day. Hay and diet DM intake and apparent digestibility of DM, ADF and NDF were reduced with the whole groundnut supplement and were similar with the two other supplements. Digestibility of CP was similar with the two supplements containing groundnuts. A trial was conducted using mature cows of 573 kg body weight to determine the effects of feeding whole groundnuts on performance of the cows and their progeny. The cows were fed free-choice Bermuda-grass hay and either the combined (50:50) or whole groundnut supplements three times weekly to provide an average of 1.1 kg/head/day. Supplement source did not affect body condition score but live weight gain tended to be lower with the whole groundnut supplement. Subsequent calf birthweight, survival rate and weaning weight and subsequent cow AI conception rate were not affected by treatment. The whole groundnut product used in the cow trial averaged 930 g DM/kg, 220 g CP/kg, 410 g ether extract/kg, 250 g ADF/kg and 340 g NDF/kg. The authors concluded that whole groundnuts may have potential as an energy and protein supplement for mature beef cows.

Safflower meal (*Carthamus tinctorius*)

Safflower is an oilseed crop cultivated mainly in tropical regions. Safflower oil is high in polyunsaturated fatty acids, particularly linoleic acid, making it an important oil for human use, like canola and olive oils. India, the USA and Mexico are major producers of safflower. However, it can be grown in cooler areas. Because it is a long-season crop, safflower extracts water from the soil for a longer period than cereal crops, and the long taproot can draw moisture from deep in the subsoil. These properties can help prevent the spread of dry-land salinity in areas such as the Canadian prairies, using up surplus water from areas that otherwise would contribute to the development or expansion of salinity. Safflower meal is not included in the above lists of approved feedstuffs but should be acceptable if produced organically.

Nutritional features

Chiba (2001) reviewed the nutrient content of safflower seed and meal. The seed is composed of a kernel surrounded by a thick fibrous hull that is difficult to remove, and comprises approximately 400 g hull/kg, about 170 g CP/kg and 350 g crude fat/kg. As a result much safflower meal is made from unhulled seed, suitable only for feeding to ruminants. Australian researchers (Ashes and Peck, 1978) described a simple mill and screening device for dehulling safflower seed and other seed and grains. The device operates by bouncing the seed between a ‘squirrel cage’-type rotor and a ripple plate, thus forcing the hull from the kernel in contrast to conventional milling or rolling. Thirteen seed and grain types were dehulled during a single pass through the mill and screening device. Safflower seed was effectively dehulled by the device but required two passes through the mill. The efficiency of dehulling with other seed and grains after one pass varied, but was 90% with sunflower seed and 95% with cottonseed. The extent of the dehulling was proportional to the velocity of the rotor tips and could be varied readily. Results showed that the mill was able to process a wide variety of seed and also other ingredients such as dry lucerne hay.

Oil extraction produces an undecorticated (hulled) safflower meal with approximately 200 to 220 g CP/kg and 400 g crude fibre/kg. The undecorticated meal is also called whole pressed seed meal, whereas the decorticated meal is referred to as safflower meal. Decortication of the meal yields a high protein (420–450 g CP/kg), less fibrous (150–160 g crude fibre/kg) meal.

Safflower meal is a poor source of lysine, methionine and isoleucine. The mineral content of safflower meal is generally less than that of soybean meal, but safflower meal is a comparable source of calcium and phosphorus. Safflower meal is a rich plant source of iron.

Anti-nutritional factors

Safflower meal contains two phenolic glucosides, matairesinol-β-glucoside, which gives a bitter flavour, and 2-hydroxyarctiin-β-glucoside, which has cathartic properties (Darroch, 1990). Both glucosides are associated with the protein fraction of the meal and they can be removed by extraction with water or methanol or by the addition of β-glucosidase.

Cattle diets

As pointed out by Lennerts (1989), the nutritional composition of safflower meal varies considerably depending on degree of decortication. Purchase on the basis of a guaranteed analysis would therefore be advised. According to this author, safflower meal can be used in mixed cattle feeds at levels up to between 50 and 100 g/kg, provided adjustment is made to the diet to account for the low energy content of safflower meal. Feed mixtures containing undecorticated safflower seed are not suitable for inclusion in high-quality concentrates.

Rode and Schaalje (1989) conducted a comparison of whole cottonseed, whole safflower and extruded soybeans in the diets of lactating Holstein-Friesian dairy cows. These sources were included to provide 0, 8, 16 and 25 g supplemental fat/kg in the diet. Effects of cottonseed meal and extruded soybeans on the production of 4% fat-corrected milk, milk protein content, milk fat production and DM intake were generally non-significant. However, the production of fat-corrected milk, milk fat and milk protein responded to increasing levels of safflower meal in the diet. The optimal level of supplemental oilseed for fat-corrected production and milk fat percentage was estimated at 8 g/kg.

Juknevičius *et al.* (2005) investigated the inclusion of safflower oilcake in the diet of dairy cows. Three groups of Lithuanian Black-White cattle were used and the dietary treatments were: (i) control; (ii) supplement of 1 kg safflower oil meal; and (iii) 1 kg concentrate replaced by 1 kg safflower oil meal. Milk yield and milk fat were increased by 1.4% and 0.37%, respectively, in the second treatment compared with the first, with the third treatment showing the same trend. Compared with the first dietary treatment, the content of milk fat increased by 0.20%, whereas the increase in milk yield was insignificant.

Research has also been conducted on the effects of inclusion of safflower meal in the diet of beef cattle. Voicu *et al.* (2009) conducted a study with steers of initial body weight of 285 kg and assigned to three groups: control and groups 2 and 3 with 180 and 350 g safflower meal/kg, respectively, in the concentrate feed provided together with wheat silage. Feed intake was similar in the three groups, and average daily gain was over 1400 g in each group. Daily gain was highest in the second group, receiving the diet containing 180 g safflower meal/kg.

High-linoleic safflower seed has received attention as a feedstuff for cattle breeding herds because its content of polyunsaturated fatty acids might have a beneficial effect on reproduction and calf growth. Encinias *et al.* (2001) investigated the effects of pre-partum safflower supplementation in beef cows on cold tolerance and performance of calves. In a first experiment, cross-bred cows of 601.4 kg initial weight received diets with similar contents of energy and CP and containing either 25 or 51 g dietary fat/kg beginning 45 days prior to calving. Rolled safflower seeds (320 g ether extract/kg, 800 g linoleic acid/kg) were included in the higher-fat diet. Safflower meal was included in the lower-fat diet. Body weight and condition were similar initially and at weaning, as was the final weight. Cows fed the diet with a lower level of fat had a higher body condition score at the end of the supplementation period. Birthweights and weaning weights of calves were not different on the two treatments. In a second experiment cows of 729.4 kg initial weight, 56 days pre-partum, were allotted randomly to dietary treatments similar to those used in the first experiment. Cows fed the higher-fat diet tended to have higher feed intakes; however, body weights and condition scores were similar on all treatments. Neither calf birthweight nor weaning weight differed by treatment. On the basis of these findings the researchers concluded that a supplement of safflower seed in the diet of breeding cows did not improve cow or calf performance.

Further research on the possibility that the lipids contained in safflower seed might have a beneficial influence on reproduction in beef cows was carried out by Scholljegerdes *et al.* (2009). The type of safflower seed used was a high-linoleate seed. In a first experiment primiparous, crossbred beef cows of 411 kg live weight were fed foxtail millet hay starting 1 day post-partum and either a low-fat control concentrate (637 g cracked maize, 334 g safflower seed meal and 29 g liquid molasses; DM basis) or a high-linoleate concentrate (containing 953 g cracked high-linoleate (790 g 18:2n-6 fatty acid/kg) safflower seeds and 47 g liquid molasses; DM basis). Cows were slaughtered at 37 days post-partum for collection of hypothalami, anterior pituitary glands, liver, ovarian follicles and uterine tissue. Dietary treatment did not influence ovarian follicular development, hypophyseal concentrations of LH, or concentrations of IGF-I in the liver. In contrast, anterior pituitary glands from linoleate cows contained more follicle-stimulating hormone (FSH) than control cows and linoleate cows had less IGF-I in the medial basal hypothalamus and the preoptic area and in follicular fluid from follicles less than 15 mm in diameter. In a second experiment, 3-year-old multiparous beef cows of 473.9 kg initial weight were fed chopped bromegrass hay starting 1 day post-partum and either a low-fat (control) concentrate or a high-linoleate concentrate (linoleate) until 80 days post-partum. Cows were observed for oestrus twice daily from day 30 to day 80 post-partum and treated with GnRH between 40 and 45 days post-partum. Seven days after GnRH administration, cows were given PGF2α and were checked for oestrus and artificially inseminated until 80 days post-partum. The magnitude of GnRH-induced release of LH or FSH did not differ between treatments. However, peak serum concentrations of oestradiol during pro-oestrus after treatment with PGF2 were less in linoleate than in control cows. It was concluded that lipid supplementation with high-linoleate safflower seeds did not improve the development of ovarian follicles and had a detrimental effect on early post-partum fertility. This was attributed possibly to a reduction in IGF-I concentrations in tissues essential to reproduction.

These data suggest that safflower seed and meal can be utilized in cattle diets based on their nutritional properties, without ascribing any special value to the lipid profile.

A protein concentrate has been obtained from safflower seed for use in calf diets. Madrigal and Ortega (2002) isolated the concentrate from safflower paste by isoelectric precipitation. The concentrate contained 78.6 g moisture/kg, 629.8 g CP/kg, 10.4 g crude fibre/kg and 43.7 g ash/kg. The concentrate was deficient in lysine (21.9 g CP/kg), but had an adequate content of the other essential amino acids in comparison with milk. Protein efficiency ratio and net utilization of the protein were higher with a casein control diet (3.07, 60.44) than with the safflower paste concentrate (1.00, 16.95, respectively). The concentrate was found to be free of antinutritive factors such as trypsin inhibitors, haemagglutinins, cyanogenic glucosides and saponins. Based on these findings, the researchers concluded that safflower protein concentrate can be incorporated in milk replacers for calves with the addition of lysine to correct a deficiency of this amino acid.

Legume Seeds, their Products and By-products (NZ and EU Category 1.3)

Field peas

Field peas are grown primarily for human consumption, but they are now used widely in animal feeding in several countries. They are of particular interest to organic farmers since they can be grown and used on-farm. Peas are a good cool-season alternative crop for regions not suited to growing soybeans. They may be particularly well suited for early planting on soils that lack water-holding capacity and they mature early. There are green and yellow varieties, which are similar in nutrient content. Those grown in North America and Europe, both green and yellow, are derived from white-flowered varieties. Brown peas are derived from coloured-flower varieties. They have higher tannin levels, lower starch, higher protein and higher fibre contents than green and yellow peas. These varietal differences account for much of the reported variation in nutrient content.

Pea protein concentrate from starch production may also be available as a feed ingredient.

Nutritional features

Peas are similar in energy content to high-energy grains such as maize and wheat, but they have a higher CP content (about 230 g/kg) than grains and are therefore regarded primarily as a protein source. As with most crops, environmental conditions can affect the protein content. Hot, dry growing conditions tend to increase the CP content. Pea protein is particularly rich in lysine, but is relatively deficient in tryptophan and sulfur amino acids. Compared with soybean meal, peas have a lower ruminal undegradable protein content (200 versus 346 g/kg) and a higher content of ADF. Peas contain a high level of starch, which is highly digestible. The starch type is similar to that in cereal grains. Starch content has been found to be correlated inversely with CP content. Ether extract (oil content) of peas is around 14 g/kg. The fatty acid profile of the oil in peas is primarily polyunsaturated, similar to that of cereal grains. The proportions of major unsaturated fatty acids are linoleic (50%), oleic (20%) and linolenic (12%) (Carrouée and Gatel, 1995). Feed peas, like cereal grains, are low in calcium but contain a slightly higher level of phosphorus (about 4 g/kg). They contain about 12 g phytate/kg, similar to that in soybeans (Reddy *et al.*, 1982). The levels of trace minerals and vitamins in peas are similar to those found in cereal grains.

As indicated above, pea protein is characterized by a high ruminal degradability and a low bypass protein value. This was confirmed by Pol *et al.* (2009), who studied the effect of inclusion of peas as a partial replacement for dietary soybean meal on ruminal fermentation, digestibility and nitrogen losses in dairy cows. The treatments were: (i) control diet; (ii) diet containing 150 g dry-rolled peas/kg; and (iii) diet containing 150 g peas/kg coarsely ground through a hammer mill. Diet had no effect on ruminal pH or total and individual volatile fatty acids. Acetate to propionate ratio was increased with the diet containing rolled peas, compared with the other diets. Ruminal ammonia concentration was greater for the diet containing ground peas, compared with the control diet. Total tract apparent digestibility of dry and organic matter, nitrogen, NDF and starch was not different between the control and ground-pea diets. Compared with the control and ground-pea diets, the rolled-pea diet had a lowered total tract digestibility of dry and organic matter and nitrogen. Peas were found to have a higher solubility of nitrogen in the rumen than soybean meal (290 g/kg versus 135 g/kg, respectively). Compared with the control diet, the pea diets reduced milk yield, primarily due to decreased DM intake. The results indicated that pea protein was more soluble in the rumen than soybean protein and that inclusion of 150 g ground peas/kg in the diet of dairy cows resulted in elevated ruminal ammonia concentration. Consequently, the researchers recommended that peas should be coarsely ground for inclusion in dairy cow diets to avoid depression in total tract digestibility of nutrients.

Anti-nutritional factors

Peas contain amylase-, trypsin- and chymotrypsin-inhibitors, tannins (proanthocyanidins), phytate, saponins, haemagglutinins (lectins) and oligosaccharides. However, there are no reports of their causing any problems in calves or mature cattle.

Cattle diets

Peas have been found to be palatable in dairy cow diets. Dry-matter intake of oat hay and concentrate by lactating Friesian cows was significantly higher when cows were given peas in place of barley grain (8.6 versus 6.6 kg/day) (Valentine and Bartsch, 1987). Several authors have investigated the effects of dietary inclusion of peas on milk production. Variable results have been obtained, due mainly to the stage of lactation when peas were introduced to the diet. Since pea protein has a high ruminal degradability and a low bypass protein value, it can be hypothesized that milk production may decrease with pea-based diets in early lactation when the demand for rumen undegraded protein (RUP) is high. An additional consideration is that young cows have a protein requirement for growth. The hypothesis has been confirmed in some studies. First-lactation cows produced 17% less milk when given a diet containing field peas (Khasan *et al.*, 1989). On the other hand, peas have been substituted for soybean meal with no effects on production of late-lactation cows (Khorasani *et al.*, 1992). Daily milk production, 4% fat-corrected milk (FCM) production and DM intake were not affected as the level of peas was increased.

Further reports suggest that peas can be effectively substituted for a combination of soybean meal and canola meal as a protein source for high-producing dairy cows. For example, Corbett *et al.* (1995) compared two concentrate mixtures for high-producing Holstein cows. The cows were in different stages of lactation and the trial lasted 6 months. The mixtures were formulated to complement the forages available and contained 185 g CP/kg. The control mixture contained standard protein sources (mainly soybean meal and canola meal) while the test mixture was formulated to contain 250 g peas/kg as the major source of protein (as-fed basis). Both mixtures were formulated to the same nutrient specifications and balanced for 6.8 g RUP/kg. Feeding levels of the mixtures were adjusted according to milk yield within each stage of lactation, the cows being fed individually. Milk yield and protein content were not affected by diet at any stage of lactation (Table 4.11). However, milk fat content was higher with the pea concentrate.

Christensen *et al*. (1998) reported no differences in the production of high-producing dairy cows (41 kg/day) fed concentrates based on raw peas, soybean meal or micronized peas. Milk fat content was also similar.

Table 4.11. Milk production and milk composition of cows fed a pea- or soybean meal/canola meal bean concentrate (from Corbett *et al*., 1995).

	Concentrate	
	Soybean meal/canola meal	Pea
All cows		
Production (kg/day)		
Milk	32.1	30.5
Fat	0.97	1.03
Protein	0.96	0.94
Fat-corrected milk	27.4	27.8
Milk composition (g/kg)		
Fat	31.3	34.8
Protein	30.1	31.1
Early-lactation cows		
Production (kg/day)		
Milk	34.8	34.5
Fat	1.05	1.17
Protein	1.04	1.06
Fat-corrected milk	29.7	31.3
Milk composition (g/kg)		
Fat	31.3	34.7
Protein	29.9	31.0
Mid-lactation cows		
Production (kg/day)		
Milk	35.6	32.1
Fat	1.0	1.05
Protein	1.04	0.97
Fat-corrected milk	29.2	28.2
Milk composition (g/kg)		
Fat	28.1	33.1
Protein	29.1	30.4
Late-lactation cows		
Production (kg/day)		
Milk	25.8	24.9
Fat	0.87	0.9
Protein	0.8	0.78
Fat-corrected milk	23.4	23.4
Milk composition (g/kg)		
Fat	34.5	36.7
Protein	31.4	31.7

Pol *et al.* (2008) conducted research to test whether peas can replace soybean meal and maize grain in dairy cow diets. Cows received either a control diet or a diet supplying the same level of nutrients but containing peas. Approximately 45% of the maize grain and 78% of the soybean meal in the control diet were replaced with 15% (DM basis) field peas in the test diet. The peas used in the trial contained 250 g CP/kg and an estimated 1.98 Mcal of net energy for lactation (NEL)/kg. The experiment lasted for 70 days. Dry-matter intake (25.9 and 26.3 kg/day for control and pea diets, respectively), milk yield (35.4 and 35.6 kg/day), 4% fat-corrected milk yield (33.0 and 34.6 kg/day), milk fat content (35.4 and 37.6 g/kg) and protein content (30.0 and 29.9 g/kg) and yields were not affected by diet. Intake of organic matter and protein were not affected by diet, but intake of NDF was lower and that of starch greater with the control diet. Total tract apparent digestibility of starch was lower (92.1% versus 88.3%, respectively) and that of DM and organic matter tended to be lower with the pea diet compared with the control diet. Consumer panel evaluation of milk from the two diets found no differences in the organoleptic characteristics of milk. On the basis of these findings, the authors concluded that field peas can be successfully fed to high-producing dairy cows at a 150 g/kg inclusion rate, replacing soybean meal and maize grain.

Since peas have been shown to be an effective protein supplement for high-producing cows it is logical that they can be considered for use in feeding cows with a lower requirement for ruminal bypass protein, such as late-lactating cows or cows with moderate milk production, possibly as the sole source of protein. This was confirmed by Bartsch and Valentine (1986) and Valentine and Bartsch (1987) in Australia.

Results suggest that peas can be used as a replacement for other protein and barley sources in the diets of young calves (Boer *et al.*, 1991). The calves in this study averaged 95 days of age and were 1–4 weeks post-weaning at the start of the experiment. Average daily gain, DM intake of concentrate and hay, and feed conversion efficiency were not different for the control and pea-based diets. In another study, pre-weaned and weaned dairy calves were fed a grain starter diet containing field peas at 400 g/kg, DM basis (Marx, 2000). Calves fed the starter diet containing field peas grew as well as those fed a starter diet containing maize grain. According to Lalles (1993), peas can be provided as the sole supplementary protein source for young ruminating calves.

Field peas are very palatable for all classes of beef cattle. This suggests that peas should be used in diets in which nutrient density and palatability are important, such as creep feeds. Anderson (1999) conducted a study on the inclusion of peas in creep feed for beef calves and found that feeds containing 330–670 g field peas/kg produced optimal animal performance.

Other reports suggest that peas can provide most or all of the supplementary protein required in diets for weaned calves and older beef animals. For example, Simmental bull calves (29 days old) were given free access to conventional maize–soybean starter and finisher diets (Pichler, 1990). Peas replaced soybean meal at 0, 50, 75 and 100%. Average live weight did not differ at 125 days, but at 365 days live weights were 472, 466, 417 and 442 kg, respectively. Carcass characteristics were similar and unaffected by treatment.

Birkelo *et al.* (1999) presented results of a field study on the performance of finishing beef cattle fed diets in which whole or rolled peas replaced all of the supplementary protein provided by soybean meal. Results showed that peas could be used to replace the dietary soybean meal and that processing the peas by rolling was beneficial (Table 4.12).

Lardy *et al.* (2009) presented more detailed findings on the utilization of peas in diets for finishing beef cattle. Three experiments were conducted. In the first experiment, yearling heifers of 418 kg initial weight were assigned to one of four treatments (0, 100, 200 or 300 g dry-rolled field peas/kg, DM basis). Inclusion of field peas decreased daily feed intake but daily gain and gain-to-feed ratio were not affected by treatment. The level of dietary NEG increased with increasing field pea level. Carcass fat thickness was greatest in heifers fed the diet with the 200 g field peas/kg. Heifers fed the diet with 300 g/kg had the lowest carcass fat thickness. Carcass marbling tended to increase with increasing inclusion of dietary peas. No differences were observed for other carcass measurements.

In a second experiment, beef steers of 433 kg initial weight were assigned to treatments similar to those used in the first experiment. In this experiment daily feed intake, daily gain, gain-to-feed

Table 4.12. Effect of replacement of soybean meal by field peas in the diet of finishing steers (Birkelo *et al*., 1999).

	Dietary treatment		
	Control	Whole peas	Rolled peas
Dietary composition (g/kg)			
Maize grain	728	666	666
Maize silage	200	200	200
Peas	0	100	100
Soybean meal	40	0	0
Nutrients (g/kg)			
Dry matter	656	656	656
Crude protein (DM basis)	125	125	125
Animal performance			
Initial body weight (kg)	416	414	415
Final body weight (kg)	605	600	604
Daily gain (kg)	1.79	1.77	1.81
Dry-matter intake (kg/day)	11.01	10.78	10.84
Feed/gain (kg DM/kg)	6.18	6.09	5.99
Dressing percentage	59.0	59.1	58.1
Grade Prime and Choice (%)	76.5	82.5	84.3

ratio, dietary NEG and all carcass measurements were unaffected by dietary treatment.

In a third experiment, beef steers of 372.4 kg initial weight were assigned to one of four treatments (0, 180, 270 or 360 g cracked field peas/kg, DM basis). It was found that carcass marbling score increased, fat thickness increased and USDA yield grade tended to increase as the content of field peas in the diet increased. Field pea inclusion did not affect daily feed intake, daily gain, gain-to-feed ratio, dietary NEG, value or other carcass measurements.

These results indicate that field peas can be included successfully into diets of beef cattle at levels up to 36% of DM without negatively affecting growth performance and most carcass characteristics of finishing beef cattle. Effects on marbling score may be variable. The data also indicate that the energy content of field peas is similar to that of cereal grains such as maize and barley, when included in high-concentrate finisher diets.

Faba beans (*Vicia faba*)

The faba bean, also known as field bean, horse bean and broad bean, is an annual legume that grows well in cool climates. An advantage of faba beans is that – like peas – the crop can be grown and used on-farm. Another advantage is that beans are legumes and, like peas, are able to fix atmospheric nitrogen in the soil and reduce fertilizer need. Faba beans are well established as a feedstuff for horses and ruminants and are now receiving more attention as a feedstuff for all classes of farm animals, particularly in Europe because of the deficit in protein production. In 2010, the EU used over 20 million t of protein feeds annually, but produced only 6 million t. The most suitable expansion in locally produced protein feedstuffs may be from crops of the legume family (beans, peas, lupins and soybeans). Field beans grow well in regions with mild winters and adequate summer rainfall and the beans store well for use on-farm.

Nutritional features

Field beans (faba beans) are often regarded nutritionally as high-protein cereal grains. They contain about 240–300 g CP/kg, the protein being high in lysine and (like most legume seeds) low in sulfur amino acids. The energy value is similar to that of barley. Total starch content (DM basis) is 350–390 g/kg. The crude fibre content is around 80 g/kg (air-dry basis). The oil content of the bean is relatively low (10 g/kg DM), with a high proportion of linoleic and linolenic acids. This makes the beans very susceptible to rancidity if stored for more than about

1 week after grinding. When fresh they are very palatable. As with the main cereal grains, faba beans are a relatively poor source of calcium and are low in iron and manganese. The phosphorus content is higher than in canola meal.

Various investigations have been conducted to determine whether faba beans can be improved as animal feed by heat treatment. For example, Aguilera *et al*. (1992) autoclaved beans at 120°C for 30 min and then measured their disappearance from the rumen of sheep. More than 88% of the protein in untreated beans disappeared from the bags by 24 h. Disappearance was markedly reduced by heat treatment, indicating a beneficial effect on ruminal degradability.

Yu (2005) conducted similar research with dairy cows. In this study, faba beans were pressure-toasted at 100, 118 and 136°C for 3, 7, 15 and 30 min. The treatments improved the protein bypass value and the total metabolizable protein supply value, except for the highest heat treatment. These findings are of relevance to the feed industry in relation to the feeding of high-producing cows, but are of less interest to the organic cattle industry.

Other methods of processing have been examined. Larsen *et al*. (2009) found that grinding resulted in improved digestibility of starch from beans in both the rumen and the small intestine. Rolling did not provide a sufficient reduction in particle size to result in high digestibility of starch before the hind gut.

These findings suggest that faba beans should be ground before inclusion in diets for cattle.

Anti-nutritional factors

Faba beans contain several anti-nutritional factors such as tannins, protease inhibitors and lectins. These are of some significance in relation to the feeding of pigs and poultry; therefore investigations have been conducted to test their importance in relation to cattle feeding. Melicharová *et al*. (2009) conducted research on the production and metabolism of dairy cows fed European cultivars of faba beans containing different levels of anti-nutritional factors. The cows were placed on test when they were 3–6 weeks after calving. Three cultivars of faba beans, known to have low, high and reduced contents of anti-nutritional factors, were included in the concentrate at a level of 200 g/kg. No significant differences were found on feed intake, utilization of energy, nitrogen or mineral metabolism, milk yield and composition or animal health. The results suggested that the anti-nutritional factors present in faba beans are not of major significance in cattle feeding.

Cattle diets

Results of a few trials on the feeding of faba beans to dairy cows have been reported, reflecting the probable fact that this feedstuff does not constitute a major ingredient of dairy diets.

Ingalls and McKirdy (1974) conducted research on faba beans as a substitute for soybean meal or rapeseed meal. Holstein-Friesian cows, 1–3 months post-partum, were used. Each cow received 2.5 kg lucerne hay/day together with 16 kg of one of the following concentrates: (i) 170 g faba beans/kg, 493 g barley/kg, 200 g oats/kg, 75 g soybean meal/kg, 25 g molasses/kg and 37 g minerals/kg; (ii) 350 g faba beans/kg, 390 g barley/kg, 200 g oats/kg, 25 g molasses/kg and 35 g minerals/kg; (iii) 591 g barley/kg, 200 g oats/kg, 145 g soybean meal/kg, 25 g molasses/kg and 39 g minerals/kg; or (iv) 190 g rapeseed/kg, 547 g barley/kg, 200 g oats/kg, 25 g molasses/kg and 38 g minerals/kg. The faba beans were coarsely ground before being incorporated into the concentrate mixtures. Results showed no significant differences between treatments for DM intake, daily milk yield, milk protein content, milk solids-not-fat content, or content of volatile fatty acids in the rumen. Milk fat content was highest in cows fed the concentrate with 350 g faba beans/kg (28.7 versus 24.5, 23.3 and 23.9 g/kg, respectively). It was concluded that satisfactory milk production can be obtained by inclusion of faba beans in the dairy concentrate.

Brunschwig and Lamy (2002) showed that the inclusion of 300 g ground faba beans/kg in the concentrate feed for dairy cows did not alter voluntary feed intake, milk production (which exceeded 30 kg/cow/day) or the fat or protein content of the milk. The intake of feed recorded in the test represented a daily average consumption of 3.5 kg faba beans per head. A decrease in the protein content of milk was reported with a daily intake of 4.5 kg faba beans (Trommenschlager *et al*., 2003). Brunschwig *et al*. (2004) explained this effect, which has been reported in other studies, as a result of a higher level of urea in the milk, which was attributed to the high solubility of faba bean protein in the rumen.

Concentrate mixtures containing flaked faba beans have been used successfully in milking cows. Comellini *et al*. (2009) conducted two trials to investigate flaked faba beans as a partial substitute for soybean meal in the diet of Reggiana dairy cows. In both trials a control concentrate (with 120 g dehulled soybean meal/kg) was compared with a faba bean concentrate (with 75 g dehulled soybean meal/kg and 100 g flaked faba beans/kg). Forages fed to animals included hay (mixed grass and lucerne) plus fresh grass in trial 1 and hay only in trial 2. Intake of concentrate and milk yield and quality were similar in the two dietary groups. Milk urea content was lower in the faba bean group.

Leitgeb and Lettner (1992) reported a study involving growing beef animals (Simmental bulls). The findings indicated that the dietary inclusion of faba beans resulted in a lower daily weight gain at the beginning of the growing period. After an adaptation period there were no problems with high proportions of faba bean in the protein concentrate. At that stage the inclusion rate of faba beans reached 90% of the protein concentrate. The control concentrate at that stage comprised 42% soybean meal and 50% barley. The concentrate allowance was 1.5 kg/head/day.

Lupins (*Lupinus* spp.)

Lupins are becoming of increasing importance as a feed ingredient. Australia is the world's leading producer and exporter of lupin grains, representing 80–85% of the world's production and 90–95% of the world's exports.

Lupins are a valued component of cereal cropping rotations in Australia, especially across large areas of Western Australia. Benefits of this crop for the organic producer are that the plant is a nitrogen-fixing legume and, like peas and faba beans, can be grown and utilized on-farm with minimal processing. Another advantage of lupins is that the seed stores well. The shortage of organic protein feedstuffs in Europe has stimulated interest there in lupins as an alternative protein source.

The development of low-alkaloid (sweet) cultivars in Germany in the 1920s allowed the seed to be used as animal feed. Prior to that time the crop was unsuitable for animal feeding because of a high content of toxic alkaloids in the seed. In Australia, where much of the research on lupins as a feedstuff has been carried out, the main species of lupins used in animal feed are *L. angustifolius*, *L. luteus* and *L. albus*.

Nutritional features

Lupins have a thick seed-coat, comprising about 250 g/kg (air-dry basis). This results in a crude fibre content of 130–150 g/kg in *L. luteus* and *L. angustifolius* and a slightly lower content in *L. albus* (Gdala *et al*., 1996). The highest neutral-detergent value (227 g/kg) and acid-detergent value (186 g/kg) contents were reported for the *L. luteus* cv. 'Amulet', while the lowest values (201 g and 146 g, respectively) were reported in *L. luteus* 'Cybis' and *L. albus* 'Hetman'. Reported acid-detergent values ranged from 146 g/kg for *L. albus* to 249 g/kg for *L. luteus*.

The carbohydrate profile of lupins is different from that of most legumes, with negligible levels of starch and high levels of soluble and insoluble non-starch polysaccharides and oligosaccharides (up to 500 g/kg seed; Barneveld, 1999). Lupins contain pectic substances, with the major polysaccharide being galactans. The crude fibre component contains more hemicellulose than other legumes such as peas and faba beans, which have cellulose as the major component. The lignin content of lupins is also low, comparable to that in peas. These features influence the utilization of energy from lupins and may explain the range in energy values reported for lupins. Petterson *et al*. (1997) suggested an ME value for cattle of 13.3 MJ/kg for *L. angustifolius* and 13.2 MJ/kg for *L. albus*. White *et al*. (2002) reported values of > 14 MJ/kg for *L. angustifolius*, based on sheep studies. AFRC in the UK (1993) adopted an ME value for lupins of 14.2 MJ ME/kg DM and a rumen-fermentable ME of 10.2 MJ/kg DM. INRA in France (Sauvant *et al*., 2004) adopted an ME value for ruminants of 14 MJ/kg DM for *L. angustifolius* and 14.9 MJ/kg DM for *L. albus*. White *et al*. (2007) suggested, therefore, that the ME value quoted in Australian feed tables for ruminants should be closer to 14 MJ.

The crude protein content of *L. angustifolius* has been reported as ranging from 272 to 372 g/kg and of *L. albus* from 291 to 403 g/kg (air-dry basis) (Petterson *et al.*, 1997; Barneveld, 1999). Selections of *L. luteus* were found to have a higher crude protein content (380 g/kg, air-dry basis) than either *L. angustifolius* (320 g/kg, air-dry basis) or *L. albus* (360 g/kg, air-dry basis) (Petterson *et al.*, 1997) and to yield better than *L. angustifolius* on acid soils of low fertility. These cultivars show great potential as livestock feeds and have protein levels comparable to soybean meal if dehulled (Barneveld, 1999).

The crude fat content of lupins appears to vary within and between species. The range of values for common species grown in Australia has been reported as 49.4–130.0 g/kg (Barneveld, 1999), the main fatty acids being linoleic 483 g/kg, oleic 312 g/kg, palmitic 76 g/kg and linolenic 54 g/kg. Petterson (1998) reported that extracts of *L. angustifolius* oil were stable for 3 months at 51°C, indicating a high level of antioxidant activity in this material, helping to explain the good storage characteristics of lupins. Gdala *et al.* (1996) reported that the oil content in *L. albus* was almost twice as high (104 g/kg) as in *L. angustifolius* and more than twice as high as in *L. luteus*.

Lupins are low in most minerals, with the exception of manganese. *Lupinus albus* is known to be an Mn accumulator and it has been suggested that high Mn might be the explanation for a reduced voluntary feed intake with diets containing this species of lupin. However, excessive Mn levels in lupins do not appear to be the cause of the reduced feed intake.

Several studies have shown that feeding whole lupin grain to dairy cows results in a lower digestibility of energy and protein compared with cracked or ground grain. For example, Valentine and Bartsch (1986) reported an increase in DM digestibility of 11–18% when the seed was ground rather than whole. May *et al.* (1993) found that cows fed ground *L. albus* grain at 3.5 kg/day produced 2 kg/day more milk than cows fed whole grain, with no significant differences in milk fat or protein content. Coarse grinding is recommended. Treatment of lupin grain with heat or formaldehyde reduced lupin protein degradability in the rumen, but was not shown to have consistent benefits over untreated lupins in terms of increased milk yield (White *et al.*, 2007). Robinson and McNiven (1993) found no benefits from heating lupins in an experiment comparing milk production and composition in high-producing cows fed diets containing soybean meal or lupins either raw or roasted. Roasting ground lupins to 115°C increased the ruminal undigested protein (bypass) value from 70 to 330 g CP/kg, but no difference was found in the yield of milk or protein between the two sources of lupins when included in the diet of dairy cows.

Anti-nutritional factors

Commercial varieties of both *L. angustifolius* and *L. albus* grown in Australia have been selected and bred to contain very low levels of anti-nutritional factors such as alkaloids (< 0.2 g/kg DM), tannins (3.2 g/kg DM total tannins), trypsin inhibitor activity (0.14 mg/kg DM) and lectins (Petterson *et al.*, 1997). There is no evidence that the presence of these compounds at such levels restricts the amount of lupin that can be fed to dairy cows (White *et al.*, 2007).

However, Lorenzini *et al.* (2007) reported that dairy cows refused feed containing a bitter lupin (species unspecified). The problem was alleviated by mixing the bitter lupin seed with other protein feedstuffs. This result confirms the recommendation that only sweet lupins (containing very low levels of anti-nutritional factors) should be used for animal feeding.

Lupinosis is a liver disease of livestock associated with the consumption of lupin seeds or stems contaminated with the *Phomopsis* fungus. Under certain humid weather conditions or poor storage conditions, *Phomopsis* contamination of lupins can occur. Although there is evidence that lupinosis can be of practical significance in sheep, there is no evidence to indicate that *Phomopsis* is an issue of practical importance for dairy cattle, at least under Australian conditions (White *et al.*, 2007).

Cattle diets

A review of the nutritional value of lupins for dairy cows (White *et al.*, 2007) suggested that, for cows grazing pasture or being fed on diets based on conserved pasture or cereal hay, the response to lupin feeding was about 0.53 kg milk/kg lupins (DM basis), with a range of 0–0.97 kg/kg. In experiments in which diets with similar contents of energy and protein were used, substituting an oilseed protein such as soybean meal with lupin seed had no significant effect on yield of milk, fat and protein, but it reduced milk protein concentration and had mixed effects on fat concentration. There were no significant differences in milk yield or in fat or protein concentration when lupins were substituted for other pulse grains such as faba beans or peas. Substitution of cereal grains with an equivalent weight of lupins in dairy concentrate mixtures generally resulted in an increased yield of milk, fat and protein and a higher fat concentration. Feeding *L. albus* to cows significantly increased the concentration of C18:1 in milk and reduced that of C12:0–C16:0, thus altering the fatty acid profile of milk towards dietary guidelines for improved cardiovascular health in human populations.

Robinson and McNiven (1993) found that there was no difference in the yield of milk or protein between cows fed lupin seed or soybean meal in the concentrate, except for a reduced milk protein concentration with the lupin diet. In this study the cows were fed lucerne silage to appetite and a grain-based concentrate containing soybean meal or raw or roasted coarsely ground sweet white lupin seed. Roasting of lupin seed increased the calculated undegraded intake protein (bypass) proportion from 7.2% to 33.3% of total nitrogen. Intake of DM and organic matter was lower for lupin-supplemented cows, but intake of NDF was similar for all cows. Although lupin oil comprised only 1.1–1.2% of DM intake, changes in milk composition were typical of those associated with the feeding of fats, i.e. synthesis of C_{10} to C_{16} fatty acids was suppressed and synthesis of long-chain fatty acids was increased. The decrease in protein content was viewed as a concern both for the manufacture of milk products and with respect to changes in milk pricing formulas that assign a higher value to milk protein than to milk fat.

The effect on protein content of milk has been reported by other researchers, but not consistently (White *et al*., 2007). On the other hand, Mogensen *et al*. (2005) found no effect of blue lupin seed inclusion on milk protein content. These researchers examined the effect of heat treatment of lupin seed, since heating can increase the flow of undegraded feed protein (bypass) to the duodenum and the content of metabolizable protein. Theoretically this should increase milk production. Cows were fed grass–clover silage to appetite and similar amounts of protein from unheated lupin seed plus cereals, heat-treated lupin seed plus cereals, or cereals alone. Neither milk yield, protein content, milk fat content nor energy-corrected milk yield was significantly affected by type of supplement. Milk yield (energy corrected) was 24.4, 25.6 and 24.7 kg for the three dietary treatments, respectively. These findings suggested that lupin seed can be utilized effectively in dairy feed without affecting production or milk quality and that heat processing is unnecessary.

Froidmont and Bartiaux-Thill (2004) studied the responses of Holstein cows to partial replacement of soybean meal in the concentrate with ground lupin seed or peas. The control diet consisted of 500 g maize silage/kg, 110 g grass silage/kg and 360 g concentrate/kg (DM basis). Soybean meal was partially replaced (75%) by lupin seed, peas or a mixture (1:1 DM) of lupin seed and peas. Milk production was lower with peas, intermediate with the lupin seed/pea mixture and higher with lupin seed and soybean meal diets. Milk fat content increased with the lupin seed diet, which induced a lower proportion of medium-chain fatty acids and a higher proportion of long-chain fatty acids in the milk compared with the pea diet. In a follow-up study the cows received a control diet or a diet in which soybean meal was completely replaced by lupin seed or a lupin seed/pea mixture (1:1 N) on a nitrogen basis. Milk production did not differ with dietary protein source but milk fat content was reduced with the lupin seed diet, related possibly to the lipid content of that diet. Nitrogen utilization did not differ with the different protein sources. On the basis of these findings the researchers concluded that coarsely ground lupin seed can effectively replace soybean meal in diets for high-producing dairy cows.

White *et al*. (2007) theorized that the explanation for the negative effect of lupin seed on milk protein content might be that lupin substitution usually results in a reduction in dietary starch intake. Increasing levels of dietary starch have been shown to be associated with increased milk protein concentration.

A consequence of a lowered milk fat content could be that milk from cows fed lupins is less suitable for cheese-making. Data on this issue are limited (White *et al.*, 2007). A series of experiments on Holstein-Friesian cows showed that, for cows fed silage and hay, cheese yield (kg/kg milk) was unaffected by substituting 2.5 kg lupin/day for an equivalent amount of cottonseed meal or canola meal (DM basis). When lupin seed replaced wheat in the concentrate mix (6 kg DM total), cheese yield was increased. Other research showed that there were no significant differences in casein fractions or cheese-making characteristics of milk from cows fed a basal diet of pasture hay and silage and offered concentrate mixes containing lupin seed as a substitute for oilseed meals or wheat. Workers in the UK found that the reduction in CP content of milk in cows fed lupin seed as a replacement for soybean meal was associated with a significant decline in the casein fraction of milk but not in whey protein content. The effect on milk protein content would be expected to influence cheese yield, since the processing quality of milk for cheese-making is generally increased as milk casein content increases and also as the ratio of casein to CP or casein to whey protein increases. Another study compared whole lupins with whole soybeans in mid-lactation cows and reported a non-significant reduction in milk protein content (from 32.4 to 31.5 g/kg) and casein (from 40 to 38 g/kg) with the lupin seed diet. In addition, there was a significant increase in milk non-protein nitrogen (from 0.31 to 0.34 g/kg milk) and a non-significant increase in whey protein content. Despite these findings, the current data show that feeding lupin seed to dairy cows has no detrimental effects on milk quality for cheese-making and in fact may improve it under some circumstances (White *et al.*, 2007).

A consistent effect reported with lupins is that with cows fed conserved forage plus concentrates the replacement of soybean meal with lupin seed results in a decrease in the content of medium-chain saturated fatty acids in milk and an increase in longer-chain mono- and polyunsaturated fatty acids (White *et al.*, 2007). These changes are consistent with the fatty acid profile of lupin seed, indicating that a proportion of these fatty acids escapes ruminal hydrogenation and is incorporated directly into milk fat.

Research has been conducted on the inclusion of lupin seed in diets for beef animals.

Korean native bulls, with an average initial body weight of 247 kg, were used to determine the effect of dietary inclusion of flaked lupin seed at 0, 150 and 300 g/kg (Kwak and Kim, 2001). Flaking of some feedstuffs is common in Korea. The test lasted for 150 days. There were no significant differences in average daily gain or feed-to-gain ratio. However, concentrate intake and total feed intake increased with inclusion of lupin seed and intake of rice straw decreased. These effects were more marked with the higher level of inclusion. No specific changes in health status of animals were noted.

Vashchekin and Gagarina (2005) studied the effect of adding ground, low-alkaloid lupin seed (*L. angustifolius* cv. 'Kristall') to the diet of breeding bullocks of the Russian Black Pied breed. The test started when the animals were 6–7 months old and ended when they were 16–17 months old. Lupin seed meal was included initially at a level of 65 g/kg, increasing in increments to 200 g/kg as the bullocks got older. Pea seed meal was used as a control diet. Bullock growth, development, digestion and physiological status were monitored throughout the trial. Results showed that lupin seed meal could be used successfully to replace pea meal. It was concluded that inclusion of lupin meal at 65–200 g/kg diet had positive effects on growth, development and reproductive function.

Vicenti *et al.* (2009) evaluated the effect of dietary inclusion of sweet lupin seed (*L. albus* L. var. *multitalia*) as a substitute for soybean meal on production and meat quality in Podolian young bulls. The steers were divided into two groups and fed durum wheat straw and a complete pelleted feed supplement containing 200 g lupin seed/kg or 165 g soybean meal/kg. Production measures were similar for the two groups. The values of pH, measured on longissimus lumborum and semitendinosus muscles 24 h after slaughter, were similar. No differences were shown between groups regarding the colour characteristics of both muscles or the tenderness of the cooked meat. No statistical differences were found between dietary treatments in terms of the fatty acid profile of the meat, except for a significantly higher incidence of linoleic acid in the meat obtained from animals fed the diet containing soybean meal.

All of the above findings indicate that lupin seed can be used successfully to replace, wholly or in part, other commonly used protein feed in concentrates for cattle feeding. However, care has to be taken with its inclusion in diets for dairy cows.

Tuber Roots, their Products and By-products (NZ and EU Category 1.4)

Among these feedstuffs approved for inclusion in organic diets are sugarbeet pulp, dried beet, potatoes, sweet potatoes, cassava (manioc or tapioca), potato pulp (by-product of the extraction of potato starch), potato starch and potato protein. The main tubers are potatoes, manioc and sweet potatoes.

Root and tuber crops should also be suitable for feeding to organic cattle. Although sugarbeet pulp and dried beet are listed in Table 4.6, other root crops are not listed. Therefore their acceptability in organic diets should be confirmed with the local organic certifying agency.

The most important root crops used in animal feeding are turnips, swedes (rutabagas), mangolds (mangels) and fodder beet. Two by-products of the sugar extraction industry, sugarbeet pulp and molasses (from both sugarbeet and sugarcane), are important and nutritionally valuable animal feeds.

Tubers differ from the root crops in containing either starch or fructan instead of sucrose or glucose as the main storage carbohydrate. They have higher DM and lower fibre contents than root crops.

Nutritional features

The main characteristics of root crops (McDonald *et al.*, 1995) are a high moisture content (750–940 g/kg) and low crude fibre content (40–130 g/kg DM). The organic matter consists mainly of sugars (500–750 g/kg DM) and is of high digestibility (about 0.80–0.87). Roots are generally low in CP content, although like most other crops this component can be influenced by the application of nitrogenous fertilizers. The degradability of protein in the rumen is high, at about 0.80 to 0.85. Composition is influenced by weather conditions. The composition also varies with size, large roots having lower DM and fibre contents and being of higher digestibility than small roots. Winter hardiness is associated with higher DM content and keeping quality.

Swedes (*Brassica napus*) and turnips (*Brassica campestris*) have a similar composition, although turnips generally contain less DM than swedes. The metabolizable energy value of swedes is usually higher than that of turnips, i.e. about 13 and 11 MJ/kg DM, respectively.

Mangolds, fodder beet and sugarbeet are all members of the same species, *Beta vulgaris*, and for convenience they are generally classified according to their DM content (McDonald *et al.*, 1995). Mangolds are the lowest in DM content, highest in CP and lowest in sugar content of the three types. Fodder beet can be regarded as being between mangolds and sugarbeet in terms of DM and sugar content, while sugarbeet is highest in DM and sugar content, though lowest in CP. On a DM basis the metabolizable energy values range from about 12 to 14 MJ/kg, the higher values applying to sugarbeet. It is customary to store mangolds for a few weeks after lifting, since freshly lifted mangolds may have a slightly purgative effect (McDonald *et al.*, 1995). The toxic effect is associated with the nitrate present, which on storage is converted into asparagine. Unlike turnips and swedes, mangolds do not cause milk taints when fed to dairy cows.

In addition to varietal type, the DM content of fodder beet is influenced by the stage of growth at harvesting and environmental conditions. Fodder beet is a poor source of protein. It is a popular feed in some European countries for dairy cattle and young ruminants. Care is required in feeding cattle on high-DM fodder beet, since excessive intakes may cause digestive upsets, hypocalcaemia and even death (McDonald *et al.*, 1995). The digestive disturbances are probably associated with the high sugar content of the root.

In the past, root crops have been considered as an alternative to silage in ruminant diets, but their value as cereal replacements is now recognized.

Sugarbeet pulp

This by-product of sugar extraction has an initial moisture content of 800–850 g/kg and may be available in the fresh or ensiled state for feed use. However, due to its bulk and transportation expense it is frequently dried to a moisture content of 100 g/kg. The extraction process removes the water-soluble nutrients, leaving a dried residue consisting mainly of cell wall polysaccharides. The crude fibre content is relatively high (about 200 g/kg DM) and the CP content is low at about 100 g/kg DM. Beet pulp contains high amounts of pectins that can reduce the risk of ruminal disorders compared with feedstuffs high in starch (Boguhn *et al.*, 2010). Most sugarbeet pulp is now sold after drying and the addition of molasses. The molasses provides about 20% of the DM and raises the water-soluble carbohydrate (i.e. sugar) content from 200 to 300 g/kg DM. Sugarbeet pulp with added molasses is used commonly as a feed for dairy cows and is also given to finishing cattle. Sugarbeet pulp may be combined with other by-products such as distiller's grains.

Cattle diets

Castro *et al.* (2008) studied the effects of fibre from beet pulp on nitrogen utilization in dairy cows. Early-lactating dairy cows were given a diet based on lucerne silage and high-moisture shelled maize or the same diet in which beet pulp without molasses replaced 50% of the maize. Results showed that replacing part of the maize with beet pulp tended to decrease milk production, due to a reduction in DM intake. Another conclusion was that partial substitution of beet pulp had no effect on ruminal microbial protein synthesis. It was also found that partial replacement of maize with beet pulp resulted in a reduction of DM, organic matter and energy intakes without any effect on digestibility of these components. Similar effects on intake have been observed with comparable levels of beet pulp supplementation of diets for dairy cows. This effect of beet pulp may be related to distension of the reticulo-rumen, due to a decrease in the rate of passage of diets containing beet pulp.

Boguhn *et al.* (2010) investigated the effects of inclusion of pressed beet pulp silage in maize-based diets on the production of high-yielding dairy cows. Two diets were used, one containing 0 and the other 200 g beet pulp silage/kg (DM basis). The beet pulp silage mainly replaced maize silage and corncob silage. The diets were equivalent in the concentrations of energy and utilizable CP in the duodenum. The diets were fed for 118 days. Average daily milk yield was about 43 kg/day. No significant differences in milk yield and milk fat or milk protein content were detected, although DM intake was significantly reduced by the inclusion of beet pulp silage (23.0 versus 24.5 kg/day). These apparently conflicting findings were explained by the results of a digestibility study conducted with sheep. It showed a significantly higher organic matter digestibility and metabolizable energy concentration for the diet that contained beet pulp silage. *In vitro* gas production kinetics indicated that the intensity of fermentation was lower in the diet that contained beet pulp silage. *In vitro* production of short-chain fatty acids did not differ between diets. However, the inclusion of beet pulp silage in the ration caused a significant reduction in the efficiency of microbial protein synthesis *in vitro*. The amino acid profile of microbial protein remained unchanged. It was concluded that beet pulp silage has specific effects on ruminal fermentation that may depress feed intake of cows but improve digestibility. On the basis of these findings an inclusion of beet pulp silage of up to 200 g/kg DM in diets for high-yielding dairy cows was suggested, without significant effects on milk yield and milk protein or milk fat.

Sugarbeet pulp silage has also been used with beef cattle. Bendikas *et al.* (2007) fed Lithuanian Black-and-White fattening bulls on a control diet consisting of 1.0 kg hay, grass and maize silages *ad libitum*, 3.0 kg wheat and barley meal (1:1) mixture, and 0.1 kg mineral–vitamin premix. The bulls in the experimental group were offered the same amounts of feeds except that the grass and maize silages were replaced with sugarbeet pulp silage *ad libitum*. Sugarbeet pulp silage had a high lactic acid content (57.5 g/kg DM basis) and a DM digestibility *in vitro* of 90.5%. The metabolizable energy and CP values were 11.12 MJ/kg and 116.3 g/kg DM, respectively. Results showed that bulls fed the diet containing sugarbeet pulp silage gained 1440 g/day, 33.9% more than the bulls fed grass and maize silages. The carcass weight and dressing percentage of both carcass and abdominal fat were also higher. The meat quality of the bulls fed sugarbeet pulp silage was found to be similar to or of higher quality than that of the meat from the bulls fed the control diet.

Potatoes (*Solanum tuberosum*)

On a worldwide basis this crop is superior to any of the major cereal crops in its yield of DM and protein per hectare. Potatoes are especially susceptible to disease and insect problems and may have received chemical treatment. Therefore any potatoes should meet organic guidelines, including being from non-GM varieties.

This tuber crop originated in the Andes but is now cultivated all over the world except in the humid tropics. It is grown in some countries as a feed crop, while in others it is available for animal feeding as cull potatoes or as potatoes surplus to the human market. In addition to raw potatoes, the processing of potatoes as human food products has become increasingly common. Potatoes are also used in the industrial production of starch and alcohol. By-products of these industries are potentially useful feedstuffs. The nutritive value of these by-products depends on the industry from which they were derived. Potato protein concentrate provides a high-quality protein source, whereas potato pulp, the total residue from the starch extraction industry, or steamed peelings from the human food-processing industry, provide lower-quality products for animal feeding because of their higher crude fibre content and lower starch content.

Nutritional features

As with root crops, the major drawback is the relatively low DM content and consequent low nutrient density. Potatoes are variable in composition, depending on variety, soil type, growing and storage conditions and processing treatment.

The DM concentration of raw potatoes varies from 180 to 250 g/kg. Consequently, when fed raw, the low DM content results in a very low concentration of nutrients per unit of weight. Expressed on a DM basis, whole potatoes contain about 60–120 g CP/kg, 2–6 g crude fat/kg, 20–50 g crude fibre/kg and 40–70 g ash/kg.

About 70% of the DM is starch and the CP content is similar to that of maize. It follows, therefore, that potatoes are a source of energy and can be regarded as a cereal replacement. Some of the starch may be converted to sugars, particularly during storage.

Of the total nitrogen in the potato tuber, 30–50% is in the form of soluble protein, 10% is insoluble protein (located mainly in the skin) and the remainder is non-protein nitrogen (Edwards and Livingstone, 1990). Potato protein has a high biological value, among the highest of the plant proteins and similar to that of soybean. The fibre and mineral contents are low (with the exception of potassium).

Anti-nutritional factors

Potatoes contain a protease inhibitor that can reduce the digestibility not only of potato protein but also of protein in other components of the diet. The inhibitor is destroyed by heating, being absent in cooked potato (Livingstone *et al.*, 1979). It is normal practice to cook potatoes for pigs and poultry, although cooking is unnecessary for ruminating animals since the inhibitor is destroyed in the rumen.

Potatoes may contain the glycoside solanin, particularly if the potatoes are green and sprouted, and may result in gastroenteritis and toxicity. As a consequence, such potatoes should be avoided for feeding. The water used for cooking should be discarded and not fed to animals, because it may contain the water-soluble solanin. Ensiling also destroys some of the toxin so that inclusion of slightly greened potatoes with grass should be acceptable, presumably because of partial destruction of the toxin in the rumen (McDonald *et al.*, 1995).

Cattle diets

There is a lack of recent research publications on potatoes for cattle. This may be due to their use being mainly with other species such as pigs. However, potatoes have an established history of usage in dairy cow and beef cattle feeds as a cereal replacement.

Some information on potatoes for dairy cows was provided by Eriksson *et al.* (2004). The basal ration used in this study consisted of lucerne/grass silage, 1 kg of grass hay and 1 kg of heat-treated rapeseed cake supplemented with 5 kg DM from: (i) rolled barley/raw potatoes 80:20; (ii) fodder beets/raw potatoes 80:20; or (iii) rolled barley. Intake and production did not differ between diets (i) and (iii) (Table 4.13). In a subsequent study, Eriksson *et al*. (2009) reported that fodder beets were accepted more readily than potatoes by cows that had not previously been given these feeds.

These findings confirm that potatoes can be used in the diet of dairy cows as a replacement for a cereal grain such as barley. They also suggest that cows be introduced gradually to potatoes in the diet.

Potatoes can also be used in the diet of beef cattle, as a grain replacement (Murphy, 1997).

One advisory note regarding the feeding of potatoes is that choking may occur in cattle due to the ingestion of whole tubers. Some farmers regard this advice as based on myth, but field reports indicate that the problem can occur (e.g. Murphy, 1997). Common sense suggests that farmers feeding whole potatoes to cattle should be aware of the potential problem and should be aware of action to be taken to save the life of an affected animal. One way to avoid the problem would be to slice or chop the potatoes prior to feeding.

Potato by-products

Several processed potato products may be available for feeding to cattle. These include potato meal, potato flakes, potato slices and potato pulp. These products are very variable in their nutritive value, depending on the processing method. This is particularly true of potato pulp, whose protein and fibre content depends on the proportion of potato solubles added back into the material. It is therefore necessary to have such materials chemically analysed before using them for feeding to cattle or to purchase them on the basis of a guaranteed analysis.

Table 4.13. Feed intake and production of dairy cows fed lucerne/grass silage supplemented with fodder beets, potatoes and barley (Eriksson *et al*., 2004).

	Dietary supplement		
	Rolled barley + raw potatoes (80:20)	Fodder beets + raw potatoes (80:20)	Rolled barley
Feed intake (kg DM/day)			
Silage	13.6	12.7	13.5
Hay	0.65	0.68	0.68
Rapeseed cake	0.91	0.90	0.90
Fodder beets	–	3.72	–
Raw potatoes	0.86	0.87	–
Barley	3.81	–	4.85
Total DM	20.0	19.1	20.1
Consumed nutrients			
OM (kg/day)	18.35	17.25	18.43
CP (g/day)	3539	3204	3556
RDP (g/day)	2488	2269	2487
NDF (kg/day)	7.02	6.72	7.06
ADF (kg/day)	4.81	4.69	4.78
Starch (kg/day)	2.93	0.70	2.99
Sugar (kg/day)	0.58	2.77	0.54
ME (MJ)	221	206	223
Milk production			
Milk (kg/day)	23.2	21.8	23.4
Energy-corrected milk (kg/day)	24.7	23.0	25.3
Fat (%)	4.63	4.58	4.72
Protein (%)	3.16	3.15	3.21
Lactose (%)	4.79	4.77	4.78

DEHYDRATED POTATO WASTE. This product (defined by AAFCO as dehydrated potato waste meal) consists of the dehydrated ground by-product of whole potatoes (culls), potato peelings, pulp, potato chips and off-colour french fries obtained from the manufacture of processed potato products for human consumption. It may contain up to 30 g $CaCO_3$/kg added as an aid in processing. It is generally marketed with guarantees for minimum CP, minimum crude fat, maximum crude fibre, maximum ash and maximum moisture. This product can be used successfully in beef cattle diets.

POTATO PULP. This by-product comprises the residue remaining after starch removal. The composition of the dehydrated product can be quite variable (Edwards and Livingstone, 1990) depending on the content of potato solubles.

POTATO PROTEIN CONCENTRATE. Potato protein concentrate is a high-quality product, widely used in the human food industry because of its high digestibility and the high biological value of the protein. It is a high-quality protein source, suitable for use in all cattle diets. However, its high cost makes it most appropriate for use in diets for calves.

Sweet potatoes (*Ipomoea batatas*)

The sweet potato is a very important tropical plant whose tubers are widely grown for human consumption and as a commercial source of starch. The reddish cultivars are often called yams. China is the main producer of sweet potatoes, although the crop is grown extensively in Asiatic countries, Latin America, Africa and parts of the USA.

Nutritional features

The tubers are of similar nutritional value to ordinary potatoes although of much higher DM and lower CP contents. Sweet potatoes contain about 300 g DM/kg, mostly starch with some sugars. The CP content is around 50–70 g/kg (dry weight basis). Because sweet potatoes do not keep as well as potatoes, they are sometimes cut into slices and dried. Sun-drying does not destroy trypsin inhibitors present in the tubers, restricting the levels in the diets of farm animals.

Anti-nutritional factors

Problems have been reported due to the presence of sweet potatoes in cattle diets. Mawhinney *et al.* (2008) investigated a suspected case of sweet potato poisoning in a group of 15 cattle in the UK, related to sweet potato tubers that had been rejected for human consumption due to bruising. Eight days after commencement of feeding, one cow was found dead. Two others showed signs of acute respiratory distress and died the same day despite treatment with marbofloxacin and dexamethasone. Feeding of sweet potatoes to the cattle was immediately stopped. Over the next 4 days, three more cows died. Two cows were examined post-mortem, and histopathology confirmed interstitial pneumonia. Fungal culture of sweet potato tubers showed the presence of a number of fungal species, including *Fusarium solani*. This fungus belongs to a group of fungi that can colonize damaged tuber tissue. Subsequently the fungi can produce ipomeanols, a group of toxins that can be absorbed by cattle and converted in pneumocytes to a lung oedema factor, causing pneumonia.

Other similar reports have been recorded. Liu (1982) reported a respiratory problem in a dairy herd in Taiwan, with symptoms similar to those in the case above. Following an outbreak of poisoning associated with the feeding of sweet potatoes, 15 of a herd of 90 milk cows died within 1 week. In another case, two of nine dairy cows died. The disease was marked by severe respiratory distress. At autopsy the lungs were emphysematous, wet, firm and heavy. Tests showed that several genera of moulds were present in the sweet potatoes, including *Ceratocystis* spp. The conclusion was that the poisoning from the mouldy sweet potatoes was caused not by mycotoxins but by the metabolites from the potato in response to injury caused by moulds and trauma.

These reports highlight the fact that only sound, undamaged tubers of sweet potatoes, or dried product made from them, should be fed to cattle. The storage conditions should also be such that mould is prevented.

Cattle diets

Research findings on the inclusion of sweet potatoes in cattle diets have been published mainly in countries producing the crop, although findings have also been published in importing countries. The main challenge relating to the incorporation of sweet potatoes in cattle diets is the need for additional protein to counter the low CP content of this crop.

Sweet potato meal was included successfully in calf diets in Cuba (Plaza and Fernández, 1997). In this study Holstein calves were used, from 21 to 180 days of age. All calves suckled their dams during the first 48 h, then received 4 l of colostrum plus milk in buckets from 3 to 20 days of age. Concentrates were offered *ad libitum* up to 1.5 kg/day/animal with free access to forage from 21 to 180 days. Two dietary treatments were compared: (i) 21–70 days, 4 l of whole milk daily; 21–30 days, 4 l of milk plus 300 g of milk replacer (containing (g/kg) 570 torula yeast, 240 sweet potato meal, 100 raw sugar, 50 bovine tallow and 40 mineral and vitamin premix); and (ii) 31–70 days, 1 l of milk plus 500 g of the same milk replacer plus 2.5 l of water. No differences in calf growth were recorded. Body weights were 68.97 and 69.54 kg at 70 days and 137.18 and 138.64 kg at 180 days for treatments (i) and (ii), respectively.

Japanese researchers studied the effects of a total mixed ration containing dried sweet potatoes on DM intake, rumen fermentation and milk yield of lactating dairy cows (Yokoyama *et al*., 2008). Two dietary mixtures were compared: (i) containing dried sweet potato at a level of 86 g/kg (DM basis); and (ii) containing flaked barley at a level of 100 g/kg (DM basis). There were no statistical differences in mean daily DM intake, ruminal pH and protozoal number or molar percentage of volatile fatty acids in rumen fluid. Though there were no statistical differences in milk yield and milk fat content, milk protein content tended to be higher with the barley diet than with the diet containing dried sweet potato meal. These results suggested that dried sweet potato meal was similar to flaked barley in terms of effects on daily DM intake, milk yield and milk fat content, and rumen fermentation pattern. However, the protein provided in the sweet potato meal diet may have been slightly inadequate, based on the effect on milk protein content.

A study in the USA compared maize and sweet potato meal in diets for beef steers (Louis *et al*., 1988). The trial lasted 140 days and involved Angus × Hereford steers of 250 kg initial live weight. The two diets containing maize (control) or sweet potato meal as the main energy sources were formulated to contain the same level of energy and of protein. The animals were fed to appetite. Average daily weight gain was 1.1 and 0.9 kg and feed-to-gain ratio was 7.8 and 7.1 kg DM/kg gain for steers given the maize and sweet potato meal diets, respectively. Digestibilities of DM, ether extract, cell wall constituents and energy were higher in animals fed the sweet potato meal diets, but there was no difference in the digestibility of cellulose or CP. Rumen pH and volatile fatty acid concentrations were the same in both groups. Carcass dressing percentage was higher for steers fed the diet containing sweet potato meal.

Cassava (*Manihot esculenta* or *M. utilissima*)

Cassava, also known as manioc (or tapioca or sago when used as human food), is a perennial woody shrub that is grown almost entirely in the tropics. Brazil and Indonesia are the main producers, as well as several tropical African countries, especially Zaire and Nigeria. It is one of the world's most productive crops, with possible yields/ha of 20–30 t of starchy tubers. Cassava is an approved ingredient in organic cattle diets, although in many countries it will represent an imported product not produced regionally.

Nutritional features

Oke (1990) reviewed the nutritional features of cassava. Fresh cassava contains about 650 g moisture/kg. The DM portion is high in starch and low in protein (20–30 g/kg, of which only about 50% is in the form of true protein). It has a high crude fibre content (about 270 g/kg, DM basis) because of the presence of the peel. Cassava can be fed fresh, cooked, ensiled, or as dried chips or (usually) as dried meal. The meal is quite powdery and tends to produce a powdery, dusty diet when included at high levels. Cassava is an excellent energy source because of its content of highly digestible carbohydrates (700–800 g/kg), mainly in the form of starch. Its energy value is similar to that of potatoes. Cassava can be used to partly replace cereal grain in cattle diets provided the diet can be formulated to adjust for the negligible amount of protein and micronutrients provided by cassava.

Anti-nutritional factors

Fresh cassava contains cyanogenic glucosides (mainly linamarin), which on ingestion are hydrolysed to hydrocyanic acid and are poisonous to animals. Boiling, roasting, soaking, ensiling or sun-drying is used in the countries where manioc is produced, to reduce the levels of these compounds (Oke, 1990). Sulfur is required by the body to detoxify cyanide; therefore the diet needs to be adequate in sulfur-containing compounds. The normal range of cyanide in fresh cassava is about 15–500 mg/kg fresh weight.

Quality control specifications for cassava by the conventional feed industry in North America define this product as the whole root of cassava chipped mechanically into small pieces and sun-dried. It must be free of sand and other debris except for that which occurs unavoidably as a result of good harvesting practices. The levels of HCN equivalent (HCN, linamarin and cyanohydrins combined) must not exceed 50 mg/kg in the complete feed.

Cattle diets

Much of the research to establish the nutritive value of cassava and its potential as a cereal grain replacer was conducted some time ago, and mainly in developing countries that are able to grow this crop.

Research conducted in Nigeria showed that cassava meal could be included successfully in diets for growing calves as a replacement for maize (Aregheore, 1992). The study involved both a growth trial and a digestibility trial. In the growth trial, Brown Swiss × White Fulani calves 12–16 months old received concentrate based on cassava flour or maize together with 1.5 kg forage twice daily to appetite for a period of 90 days. Feed intake (concentrate plus forage) did not differ between calves fed on the carbohydrate sources, but daily live weight gain was higher in calves fed the cassava-based concentrate. Serum total protein and blood urea-nitrogen levels did not differ on the two treatments but blood glucose level was higher in calves given the cassava-based concentrate. The digestibility of DM, crude fibre, nitrogen-free extract and energy was higher and that of ether extract and CP lower for the cassava-based concentrate.

Mello *et al.* (1981) compared maize, sorghum and dried cassava as energy supplements for Schwyz × Zebu calves fed whole milk and skimmed milk. The results indicated no effect of energy source when feeding whole milk. Skimmed milk in combination with maize meal gave the best weight gains compared with the other skimmed milk combinations. The weight gains from birth to 161 days were best in combination with whole milk.

Holzer *et al.* (1997) reported that there were no significant differences in the weight gains of growing–finishing cattle when up to 40% of the grain was replaced by cassava. However, the replacement of 20% and 40% of the grains by cassava and the inclusion of soybean meal to maintain the dietary protein level led to a reduced efficiency of energy conversion into live weight.

The powdery nature of cassava meal may be the reason for the reduced feed intake reported by Holzer *et al.* (1997). A similar effect was reported in a study in Vietnam. Nguyen *et al.* (2008) conducted an experiment to test the possibility that inclusion of cassava meal powder in the diet of growing–finishing Laisind cattle at levels up to 2% of live weight per day (DM basis) would increase digestible organic matter intake and live weight gain. The basal diet was composed of elephant grass and rice straw fed *ad libitum*. The test diets contained a supplement of cassava meal powder plus 20 g urea/kg, and were provided at about 0.3, 0.7, 1.3 or 2.0% of live weight. The cattle fed the highest level of cassava did not consume all of the supplement, with actual intake similar to that with the 1.3% of live weight treatment. Based on the findings the researchers concluded that the amount of cassava meal provided for growing beef animals should be limited to between 0.7% and 1.0% of live weight. It was not clear from the results to what extent the reduction in feed intake could be attributed to the inclusion of urea in the diet.

Cassava has been found to be useful as a source of energy in supplementary diets for pastured cattle in Africa and other tropical areas. Abate and Abate (1988) compared the growth rate of Boran and Boran × Hereford calves grazed on pasture during the day in Kenya. The dietary treatments were no supplement (control), and 1 kg per head of a supplement based on cassava or maize. During supplementation, calves given maize or cassava gained weight at about twice the rate of the control group. Average daily gains with maize, cassava or grazing only were 575, 495 and 261 g/day, respectively. At 20 months of age the control calves weighed 4 and 14 kg less than those given a supplement of cassava or maize, respectively.

Campero (1994) studied the potential of banana and cassava meals as substitutes for maize in diets for dairy cows under tropical grazing in Bolivia. Pure-bred Holstein and Holstein × Criollo dairy cows were grazed on grass and legume pasture (*Brachiaria decumbens* with *Pueraria phaseoloides* or *Desmodium ovalifolium*) at a stocking rate of 2.0/ha. Cows were supplemented with yellow maize, banana meal or cassava meal at a rate of 1 kg/2 kg milk produced. Milk yield (mean 8.3 kg/day) and supplement intake (mean 3.4 kg/day, DM basis) were not significantly affected by the type of supplement. Cows supplemented with cassava meal lost body weight at a rate of 140 g/day, whereas cows supplemented with banana meal and maize gained 100 and 400 g/day, respectively. Response to supplementation was approximately 2.44 kg milk/kg supplement.

One of the issues that has to be addressed in the use of cassava meal in cattle diets is the provision of supplementary protein. Tudor *et al.* (1985) investigated the effects of three protein sources (groundnut, meat-and-bone meal and fishmeal) on the growth and feed utilization of cattle fed cassava. It was concluded that cattle fed on high-energy diets based on dried cassava tubers grew well and that cassava could replace cereal grain. Fishmeal was found to be a good supplementary protein source, better than groundnut meal. Meat-and-bone meal, fishmeal and urea are not approved for use in diets for organic cattle.

One way of avoiding the powdery nature of ground cassava is to use dried cassava chips. Sommart *et al.* (2000) used this product as an energy source for lactating dairy cows. Cross-bred (mainly Holstein-Friesian) cows in mid-lactation were given one of four concentrates along with rice straw. The concentrates contained 135, 270, 405 and 540 g cassava/kg in replacement for ground maize. Dietary treatment did not influence ruminal pH, ammonia or volatile fatty acid concentrations, or plasma glucose concentrations. Cassava and maize in a ratio of 50:50 maximized organic matter and metabolizable energy intakes, milk yield and the yield of milk protein and lactose. Milk fat yield was not affected by levels of inclusion. On the basis of the results it was calculated that the optimal level of dried cassava chips in a dairy cow diet is between 200 and 300 g/kg when fed together with rice straw.

An example of the results found with cassava in an importing country was provided in a study conducted by Brigstocke *et al.* (1981) in the UK. The study involved the inclusion of cassava in a concentrate feed provided for Friesian cows together with grass silage. The concentrate contained cassava at 0 or 400 g/kg and 600 and 103 g/kg barley, respectively. Average daily intake of silage and of concentrate was not affected significantly by inclusion of cassava. Average daily milk yield, without or with cassava, was 21.14 and 22.27 kg and milk fat content was 41.4 and 40.4, respectively. These differences and differences in the content of milk solids were not significant statistically.

Turnips

Turnips are often used to extend the grazing season or to provide supplementary feed for winter feeding. Much of the research has been done in Australia and New Zealand.

Cattle diets

The crop can be considered as a replacement for cereal grains. For example, turnips and sorghum were fed at three levels (0, 4 and 8 kg DM/day) to supplement pasture offered at a constant allowance (Harris *et al.*, 1998). Feeding 4 or 8 kg DM/day increased the yield of milk solids per cow by 29% or 36% for turnips and 26% or 32% for sorghum, respectively, compared with pasture alone. For both crops, increasing the daily allowance from 4 kg to 8 kg further increased the yield of milk solids.

Moate *et al.* (1998) investigated the response of dairy cows in mid-lactation to turnips.

There were five treatment groups. The control group was given a basal diet of pasture hay plus pasture silage. The other groups received (DM basis) either 6 kg of barley, 6 kg of a 50:50 barley/turnips mixture, 6 kg turnips, or barley plus turnips at 4 kg each. Additional milk produced with these treatments was 0.62, 0.59, 0.49 and 0.49 l/kg supplement, respectively (DM basis). Milk composition of all groups was similar.

McFerran *et al.* (1997) calculated that the optimum proportion of turnips, on a DM basis, when fed in conjunction with summer pasture was 21% of the dietary intake. For a 500 kg live weight dairy cow giving 17 l milk/day, this was equivalent to 3–5 kg turnips/day (DM basis).

Workers in Switzerland (Thomet *et al.*, 2003) found that turnips had an average yield of 6.5 t DM/ha, higher than a grass–clover ley (2.9 t/ha) or other *Brassica* species. Grazing losses were 33% on average, giving a net yield of 4.3 t DM/ha. In spite of treading damage, no indications of long-term impacts on the soil were found. There was no negative influence on animal health, milk quality or milk taste. Soiling of the cows increased the risk of contamination of the milk with anaerobic spores. Based on the results of the study and a survey with 32 farmers using turnips, it was concluded that turnips are a suitable crop to extend the grazing period in autumn.

Other research has been carried out to investigate whether protein supplementation improves the production of dairy cows fed turnips. In a study by Moate *et al.* (1999), cows in mid-lactation were given one of five diets. The control diet was 10 kg/day of a basal diet comprising pasture, pasture hay and pasture silage (DM basis). The test diets were the basal diet supplemented daily with 5 kg barley or 5 kg turnips per cow, or 3 kg turnips plus 2 kg crushed lupins, or 3 kg turnips plus 2 kg cottonseed meal per cow. Supplementation gave an increased milk yield of 0.80, 0.92, 1.15 and 1.00 l/kg of supplement, respectively (DM basis). The rate and extent of ruminal degradation of protein from the turnips and crushed barley were similar.

Feeding turnips in place of grain has been shown to alter milk composition (Thomson *et al.*, 2000). Cows on a restricted pasture allowance of 25 kg DM/cow/day were given a supplement of 0, 4 or 8 kg DM/cow/day in the form of turnips or sorghum. Chemical analysis showed that the sorghum was higher in fibre (NDF, 650 versus 230 g/kg) and total lipid (35 versus 15 g/kg) and lower for CP (96 versus 120 g/kg) than turnips. Lipid composition differed between the crops, turnips containing more lauric (C12:0) and less linolenic (C18:3) fatty acids than for those fed sorghum. These differences were reflected in differences in milk composition. Milk fat content was lower for cows fed turnips than for those fed sorghum and the effect was greater with increasing amount of turnips fed (55, 51 and 50 g/kg for 0, 4 and 8 kg/cow/day, respectively). Milk fat composition also differed for cows fed turnips. As the amount of turnips in the diet increased, the contents of short-, medium- and long-chain fatty acids increased and that of total unsaturated fatty acids decreased. As a consequence, solid fat content (SFC) (an index of milk fat hardness) also increased. Content of conjugated linoleic acid (cis-9-trans-11-C18:2) declined as the level of supplementation increased. The effect was greater with turnips than with sorghum. The treatments had minimal effects on milk protein and nitrogen fractions.

Both swedes and turnips may taint milk if given to dairy cows at or just before milking time. The volatile compound responsible for the taint is absorbed from the air by the milk and is not passed through the cow (McDonald *et al.*, 1995). However, this effect has not been reported consistently with turnip feeding.

Fodder beet

Replacing barley with fodder beet may reduce feed intake and reduce milk yield (Eriksson *et al.*, 2004). The decrease in silage intake reported was about 0.24 kg silage for each kilogram of barley replaced by fodder beet (DM basis). Milk production was reduced in proportion to the reduced intake of metabolizable energy. This effect was noted in some earlier studies but not in others. These differences may be due to the different types of feeds being fed to the cows. Dulphy *et al.* (1990) reported that only fodder beets with a low DM content (120 g/kg) had a detrimental effect on silage intake, while beets containing 210 g DM/kg did not show the effect. The effect might have been due to reduced palatability of the fodder beet, as a result of the high sugar content (Table 4.13), which affected the ruminal fermentation pattern. Ruminal acetate proportion was moderately reduced by fodder beets, while proportions of both propionate and butyrate tended to increase. The basal ration used by Eriksson *et al*. (2004) consisted of lucerne/grass silage, 1 kg of grass hay and 1 kg of heat-treated rapeseed cake supplemented with 5 kg of either rolled barley/raw potatoes 80:20, fodder beets/raw potatoes 80:20 or rolled barley (DM basis). Intake and production did not differ between diets 1 and 3 (Table 4.13). Ruminal acetate proportion of VFAs was moderately reduced by fodder beets, while proportions of both propionate and butyrate tended to increase. The results suggest that dairy cows should be introduced gradually to fodder beet.

In a subsequent study, Eriksson *et al*. (2009) reported that fodder beets were accepted more readily than potatoes by cows that had not previously been given these feeds.

Other Feed Sources

Cabbage (*Brassica oleracea*, Capitata group)

Cabbages have a high yield of nutrients per hectare and are of potential interest for organic feeding as a source of roughage. However, little research appears to have been conducted on this crop as a feed ingredient for cattle. Livingstone *et al*. (1980) reported that cabbage (cv. 'Drumhead') contained 100 g DM/kg and (per kg, DM basis) 18 MJ gross energy, 230 g CP, 79 g true protein, 7.6 g total lysine, 4.7 g methionine plus cystine, 142 g ADF and 132 g ash.

Other Plants, their Products and By-products (EU Category 1.7)

Molasses

Molasses is often used in organic diets as a pellet binder, at levels around 25–50 g/kg. This is attributed to its capacity to allow the feed granules to stick together during the pelleting process and produce pellets and compressed feed blocks for cattle feeding that are less likely to break down during transportation and passage through feeding equipment. Additional benefits of the addition of molasses are a possible increase in palatability of the diet and a reduction in dustiness of the dietary mixture.

Beet molasses is the product remaining after crystallization and separation of the sugar from the water extract of crushed sugarbeet. It is often used as an additive in silage making, because of its high content of sugars.

Cane molasses is a by-product of sugar production used extensively for animal feeding in tropical and subtropical countries where sugarcane is grown. In addition to its use as a feed additive for the purposes outlined above, cane molasses is used as a source of supplementary energy for forage-based diets. In some cases high levels of molasses are used as a replacement for maize.

Nutritional features

Molasses generally contains 670–780 g DM/kg and can vary widely in composition due to soil and growing and processing conditions. The carbohydrate content is high, being composed mainly of highly digestible sugars (primarily sucrose, fructose and glucose). The CP content is low (range 30–60 g/kg). Molasses is usually a rich source of minerals, the calcium content of cane molasses being high (up to 10 g/kg) due to the addition of calcium hydroxide during processing. However, the phosphorus content is low. Cane molasses is also high in sodium, potassium and magnesium. Beet molasses tends to be higher in both potassium and sodium but lower in calcium content. Molasses also contains significant quantities of copper, zinc, iron and manganese.

Cattle diets

Although high dietary levels are known to have a laxative effect in animals, molasses is being used in some countries as the basis for cattle production systems. A leader in this endeavour is Cuba, where molasses-based diets for beef cattle are used in which the cane molasses is offered in unrestricted amounts to provide an intake of 500–800 g total DM/kg. Other feeds are typically forage and a supplement of protein. Such diets are reported to allow live weight gains of about 1 kg/day.

In feeding systems where cattle are given molasses to appetite and restricted amounts of roughage, a condition known as molasses toxicity may occur (Rowe *et al.*, 1977). This is characterized by incoordination and blindness caused by deterioration of the brain similar to that seen in cerebro-cortical necrosis or polioencephalomalacia (which can occur in chickens due to deficiency of the vitamin thiamine). The unusual pattern of fermentation in the rumen of animals fed molasses diets low in roughage is the most likely explanation for the condition, which gives rise to volatile fatty acid mixtures rich in butyrate and low in propionate. The condition can be prevented by the provision of sufficient quantities of good-quality forage. Supplementation with thiamine has proved to be ineffective in animals with molasses toxicity.

Seaweeds

Seaweeds (kelp) contain significant quantities of minerals but tend to be low in other nutrients. The composition differs according to species and stage at harvesting. In some regions, such as China and India, seaweed is harvested for use as dried fodder for farm livestock in coastal areas. China is a major seaweed producer, growing over 2.5 million t of the brown alga *Laminaria japonica*. There is considerable potential for increasing kelp production, particularly in regions such as the Pacific coast of North America. Canada has the longest coastline of any nation, suggesting that greater use could be made of this plant resource. In addition, Canada's marine environment is probably less polluted than elsewhere. A recent development in North America is the use of seaweed as a substrate for biogas (methane) production.

Cattle and sheep like to eat seaweed, possibly because of its salty taste, to the extent that some animals have become adapted to it as a main dietary ingredient. This was shown by studies on the antiquity of the use of seaweed as a feed for domestic animals at two Neolithic sites on the Orkney Islands off the north coast of Scotland (Balasse *et al.*, 2006). The study was conducted using carbon and oxygen dating of tooth enamel from sheep and cattle teeth. At one site (the Knap of Howar, *c.*3600 BC) the studies showed evidence of grazing on terrestrial plants throughout the year for both sheep and cattle, with no contribution of seaweed to their diet. Another site (the Holm of Papa Westray North, *c.*3000 BC) indicated a significant contribution of seaweed to the sheep diet during winter. This was attributed possibly to a severe reduction of pastures during winter. Results suggest that sheep ingested fresh seaweed directly on the shore. A significant difference between the two populations was the exclusive reliance on seaweed by North Ronaldsay sheep.

The North Ronaldsay is a breed of sheep that continues to live on North Ronaldsay, the northernmost of the Orkney Islands. Unfortunately the cattle did not fare so well. The sheep belong to the northern European short-tailed sheep breeds. The breed is noted for living almost entirely on seaweed for several months of the year, except for a short lambing season. The semi-feral flock on North Ronaldsay is confined to the foreshore for most of the year to conserve the limited grazing inland.

The use of seaweed as cattle feed has been investigated in countries such as China and India, where significant quantities of seaweed are produced. For example, Ma and Tian (1998) fed diets supplemented with kelp at 0, 150, 200 and 250 g/day to lactating cows. Cows fed the supplemented diets had daily milk yields of 18.5, 19.4 and 19.5 kg; live weight gains of 1.73, 1.78 and 1.79 kg; milk fat content of 3.52, 3.52 and 3.51%; and feed conversion rates of 2.20, 2.31 and 2.32. Corresponding values for cows in the control group were 18.0 kg, 1.64 kg, 3.52% and 2.14. It was concluded that the optimum concentration of the seaweed supplement was 200–250 g/day.

Prabhu *et al.* (1978) added processed sargassum seaweed as a replacement for 20% wheat bran in the concentrate fed to dairy cows in a study in India. The seaweed contained (g/kg, DM basis), 127 crude fibre, 95.7 CP and 49 calcium. Milk yield was on average 5798 and 6263 kg, respectively, for the two groups over a 19-week period for the control and seaweed-fed groups. The difference was not statistically significant. Replacement was found to have no significant effect on intakes of DM, digestible CP or total digestible nutrients or on milk composition. Nitrogen and mineral balance studies and blood analyses indicated no adverse effects of feeding sargassum to the cows.

Several studies in North America have investigated the potential of seaweed or seaweed extracts as dietary supplements to improve the health or meat quality in cattle. This aspect is of interest to organic farmers. For example, Bach *et al.* (2008) studied the effect of feeding sun-dried seaweed (*Ascophyllum nodosum*, also known as Tasco) on faecal shedding of *Escherichia coli* bacteria by feedlot cattle. This species of seaweed is found in the northern Atlantic Ocean and is also known as Norwegian kelp, knotted kelp, knotted wrack or egg wrack. It is common on the north-western coast of Europe and the north-eastern coast of North America. In this study, steers were inoculated orally with a four-strain mixture of the nalidixic acid-resistant *E. coli* O157:H7 bacterium. Sun-dried Tasco seaweed (Tasco-14TM) was then added to the diet, which consisted of 860 g barley grain/kg and 90 g whole crop barley silage/kg (DM basis). The steers were housed in four groups and received Tasco in the diet, in place of barley, at levels (as fed) as follows: 0 (i.e. control); 10 g/kg for 14 days; 20 g/kg for 7 days; or 20 g/kg for 14 days. The dietary treatments commenced 7 days after *E. coli* inoculation. Faecal shedding patterns were examined over 14 weeks. Results showed that supplementation with Tasco decreased the shedding of *E. coli*. Rates of decline in shedding were found to be similar among treatments, but final numbers of *E. coli* were significantly lower in cattle fed the lower level of supplement for 14 days or the higher level of supplement for 7 days than in the other groups. The results showed that Tasco supplementation was effective in reducing the duration and intensity of *E. coli* O157:H7 faecal shedding by cattle. In addition it was shown that average daily gain of lambs, feed intake, feed efficiency and carcass traits were not affected by inclusion of Tasco in the diet.

The rationale for the work by Bach *et al.* (2008) and for similar investigations conducted by other researchers is that cases of food-poisoning caused by *E. coli* O157:H7 are often traced back to meat products from cattle, or to cattle production systems. Over 100 cases of *E. coli* O157:H7 infections were recorded in the Canadian disease surveillance system in 2005. Many of the more recent outbreaks of *E. coli* O157:H7 have been associated with environmental sources of *E. coli* O157:H7 as opposed to direct consumption of meat that has been contaminated with the pathogen. Therefore, if the risk of outbreak is to be reduced, strategies must be developed to lower or eliminate the presence of this bacterium during cattle production as well as during meat processing. Various strategies have attempted to reduce the prevalence of *E. coli* O157:H7 in beef production systems. These include vaccines, administration of chlorate-based sterilizers and inoculation of cattle with bacteria intended to prevent establishment of *E. coli* O157:H7 in the bovine digestive tract. None of these has been shown to be completely effective. Furthermore, it is likely that alternative strategies, such as dietary supplementation with approved additives, will be required in organic production.

At present, the main approaches used to control the microbial contamination of meat products use a combination of pre- and post-slaughter intervention strategies. These include procedures to: (i) minimize sources and levels of microorganisms reaching the slaughter facility; (ii) minimize access or transfer of microorganisms from the animal's exterior and the slaughter environment to the meat; (iii) reduce contamination that has gained access to the meat; (iv) inactivate microorganisms on the meat and meat products; and (v) inhibit or retard growth of contamination that has gained access to meat and meat products and has not been inactivated.

Other research on Tasco supplementation has been conducted in North America, to test the effects on meat quality. For example, Braden *et al.* (2007) supplemented the diet of finishing cross-bred cattle (*Bos indicus* × *Bos taurus*) with 20 g Tasco/kg and reported effects on carcass marbling score, USDA quality grade, sensory traits and retail display shelf life. Treated animals received a diet based on steam-rolled maize containing 20 g Tasco meal/kg (DM basis) for 14 days beginning at day 45 of the finishing period and again 14 days before slaughter. Control animals received the maize-based diet without Tasco at identical feeding periods. The results from this study indicate that short-term supplementation with Tasco meal in feedlot cattle increased carcass quality and improved retail shelf life. Growth rate was unaffected. Similar findings were reported by Anderson *et al.* (2006).

The suggested mechanism for the mode of action of *A. nodosum* (Tasco) in this context is that seaweeds contain phenols and polyphenols, compounds that include effective antioxidants. Seaweeds are also a source of plant growth regulators and have increased activity of the antioxidant superoxide dismutase and specific vitamin precursors (Allen *et al.*, 2001).

Seaweed has been shown to be of value in the control of parasites. Jensen (1972) reported that inclusion of seaweed in the diet of pigs markedly reduced the incidence of liver condemnations from ascarid damage at slaughter. This aspect of seaweed inclusion is of interest to organic farmers but does not appear to have been investigated further in cattle.

Milk and Milk Products (NZ and EU Category 2.1)

Milk and various milk products are used in calf and veal diets. Adequate heat treatment (pasteurization) should have been applied to all milk products to ensure that any pathogenic organisms have been destroyed. In general, the protein quality of milk products is high but it can be impaired by overheating.

Dried milk products include dried whole milk, dried skimmed milk and dried whey. The products derived from whole milk and skimmed milk are very palatable and highly digestible protein supplements with an excellent balance of amino acids. They are good sources of vitamins and minerals except fat-soluble vitamins, iron and copper. Although generally too expensive for use as a feed ingredient, dried skimmed milk is a valuable component of milk replacers when available economically.

One issue that has been investigated is the appropriate concentration of milk solids in milk replacers. It is common to feed 3.8 l of milk or milk replacer containing 210 g CP/kg and 210 g fat/kg in milk replacer powders fed at a rate of 0.44 kg/day. According to some research the growth rate of calves is improved with a higher concentration of solids.

Whey is the liquid by-product remaining after cheese production. It contains about 90% of the lactose, 20% of the protein, 40% of the calcium and 43% of the phosphorus originally present in milk. However, its DM content is low, around 70 g/kg. Most of the fat and protein are removed during processing, leaving the whey high in lactose and minerals. Whey can be included in calf diets as liquid whey, condensed whey or dried product, but at low concentrations because of the high lactose content. Dried whey contains about 650 g lactose/kg. The composition and quality of dried whey are more variable than those of other milk products, making it important to use a high-quality product.

An interesting finding with pigs was that whey feeding was found to reduce ascarid egg count in the faeces (Alfredsen, 1980), suggesting that this product might be useful as a natural dewormer.

Lammers *et al.* (1998) compared the effect of whey protein concentrate and dried skimmed milk as protein sources in milk replacer. Four treatments were compared (100% skimmed milk; 67% skimmed milk plus 33% whey protein concentrate; 33% skimmed milk plus 67% whey protein concentrate; and 100% whey protein concentrate). In a first trial, calves were fed only milk replacer from birth to 6 weeks of age. In the second trial, calves were fed milk replacer and were allowed unrestricted amounts of starter from birth to 6 weeks of age. Calves were fed milk replacer at 10% of birthweight for the first 2 weeks and at 12% of birthweight thereafter. In the first trial, average daily gains and feed efficiencies were significantly improved for calves that consumed the milk replacers containing 67% and 100% whey protein concentrate compared with calves fed the milk replacer containing 100% skimmed milk. No difference in growth or feed efficiency caused by treatment was detected in the second trial. Average daily gain in the second trial was correlated with total starter intake. In the first trial, plasma glucose concentrations were correlated with growth rates and were highest for calves fed the milk replacer containing 67% whey protein concentrate. No differences were found for faecal scores or incidence of scouring (diarrhoea). When only milk replacer was fed, higher proportions of whey protein concentrate improved calf performance, but when starter was also provided no effect of milk replacer composition was found.

Elliott *et al.* (1989) studied the effect of an isolated soy protein-based product and whey on partial replacement of dried skimmed milk and whey protein concentrate in a milk replacer for Holstein veal calves from 5 weeks of age. The calves had similar weight gains and carcass quality at 16 weeks to those of a control group given a conventional milk replacer.

Related work on the replacement of milk protein by other protein sources has been outlined previously in this chapter.

Mineral Sources

Before outlining the approved ingredients in detail, it may be useful to clarify the use of the term 'organic' which can be found in relation to certain classes of ingredients such as mineral sources. Organic minerals are minerals containing carbon, following standard chemical nomenclature. In this context the term 'organic' does not mean derived from an organic source. Minerals not containing carbon are termed inorganic, following standard chemical nomenclature. Organic minerals such as selenomethionine are used in conventional feed manufacture, but very few appear to be approved for use in organic cattle diets, although some are approved under the US regulations. These organic sources may provide minerals in a more bioavailable form than in inorganic sources. Producers wishing to use them should check their acceptability with the local certifying agency (Table 4.14)

Other sources may be permitted in organic diets and producers should check with the local certifying agency for details. The US regulations' (FDA, 2001) approved list of trace minerals with GRAS (Generally Recognized As Safe) status when added at levels consistent with good feeding practice are shown in Table 4.15.

Vitamin Sources

Vitamins from synthetic sources are permitted in organic diets for cattle, the potency of the fat-soluble vitamins being expressed in terms of International Units (IUs).

A main concern for the nutritionist and feed manufacturer in selecting vitamins for

Table 4.14. Concentrations of mineral elements in common dietary mineral sources.[a]

Source	IFN no.	Formula	Mineral	Concentration (%)
Limestone, ground	6-02-632	$CaCO_3$ (mainly)	Calcium	38
Calcium carbonate	6-01-069	$CaCO_3$	Calcium	40
Oyster shell, ground	6-03-481	$CaCO_3$	Calcium	38
Dicalcium phosphate	6-01-080	$CaHPO_4.2H_2O$	Calcium	23
			Phosphorus	18
Defluorinated phosphate	6-01-780		Calcium	32
			Phosphorus	18
Phosphate, Curaçao	6-5-586		Calcium	36
			Phosphorus	14
Salt, common	6-14-013	NaCl	Sodium	39.3
			Chloride	60.7
Copper sulfate		$CuSO_4.5H_2O$	Copper	25.4
Copper carbonate		$CuCO_3$ $Cu(OH)_2$	Copper	55
Copper oxide		CuO	Copper	76
Calcium iodate		$Ca(IO_3)_2$	Iodine	62
Potassium iodide		KI	Iodine	70
Ferrous sulfate		$FeSO_4.H_2O$	Iron	31
Ferrous sulfate		$FeSO_4.7H_2O$	Iron	21
Ferrous carbonate		$FeCO_3$	Iron	45
Manganous oxide		MnO	Manganese	77
Manganous sulfate		$MnSO_4.H_2O$	Manganese	32
Sodium selenite		$NaSeO_3$	Selenium	45
Sodium selenate		$NaSeO_4$	Selenium	41.8
Zinc oxide		ZnO	Zinc	80
Zinc sulfate		$ZnSO_4.H_2O$	Zinc	36
Zinc carbonate		$ZnCO_3$	Zinc	52

[a]The bioavailability of the named minerals in the above forms is high or very high. The exact concentration of minerals will vary, depending on the purity of the source. The above sources may also provide trace amounts of minerals other than those listed, such as sodium, fluoride and selenium. Cobalt-iodized salt is often used as a source of sodium, chloride, iodine and cobalt.

Table 4.15. FDA-approved trace minerals for use in animal feed.

Trace mineral	Approved forms
Cobalt	Cobalt acetate, carbonate, chloride, oxide, sulfate
Copper	Copper carbonate, chloride, gluconate, hydroxide, orthophosphate, pyrophosphate, sulfate
Iodine	Calcium iodate, iodobehenate, cuprous iodide, 3,5-diiodosalicylic acid, ethylenediamine dihydriodide, potassium iodate, potassium iodide, sodium iodate, sodium iodide
Iron	Iron ammonium citrate, iron carbonate, chloride, gluconate, lactate, oxide, phosphate, pyrophosphate, sulfate, reduced iron
Manganese	Manganese acetate, carbonate, citrate (soluble), chloride, gluconate, orthophosphate, phosphate (dibasic), sulfate, manganous oxide
Zinc	Zinc acetate, carbonate, chloride, oxide, sulfate

inclusion in diets is their stability. In general, the fat-soluble vitamins are unstable and must be protected from heat, oxygen, metal ions and UV light. Antioxidants are frequently used in conventional feeds to protect these vitamins from breakdown.

Vitamin A

All of the naturally occurring forms of vitamin A (retinol, retinal and β-carotene) with the exception of retinoic acid are particularly unstable and sensitive to UV light, heat, oxygen, acids and metal ions. The naturally occurring forms of vitamin E (mainly tocopherols) are readily oxidized and destroyed by peroxides and oxygen in a process accelerated by polyunsaturated fatty acids and metal ions. Because of the instabilities of their naturally occurring vitamers (forms of the vitamin), the concentrations of fat-soluble vitamins in natural foods and feedstuffs are highly variable, being greatly affected by the conditions of production, processing and storage. As a consequence, the synthetic esterified forms (acetate and palmitate), which are much more stable, are preferred for diet formulation.

Vitamin D

Vitamin D is available as D_2 (ergocalciferol) and D_3 (cholecalciferol). Cattle can utilize either source but since poultry can utilize only the D_3 form, this form is more widely available commercially. Thus it is usual to supplement all feeds (where necessary) with the D_3 form. Fish oil is allowed under the Canadian Feeds Regulations as a source of vitamins A and D.

Vitamin E

The commonly available source of stable vitamin E used in animal feed is synthetic dl-α-tocopheryl acetate. An alternative form of stable vitamin E is d-α-tocopheryl acetate, which is derived from plant oils (such as soybean, sunflower and maize oil). This form has a relative biopotency of more than 136% in comparison with dl-α-tocopheryl acetate.

Water-soluble vitamins

The water-soluble vitamins, which are included only in calf diets, tend to be more stable under most practical conditions, exceptions being riboflavin (which is sensitive to light, heat and metal ions), pyridoxine (pyridoxal, which is sensitive to light and heat), biotin (which is sensitive to oxygen and alkaline conditions), pantothenic acid (which is sensitive to light, oxygen and alkaline conditions) and thiamine (which is sensitive to heat, oxygen, acidic and alkaline conditions and metal ions). Again, the more stable synthetic forms of these vitamins are used in conventional feed formulation. Choline chloride is very hygroscopic (absorbs water when exposed to air) and the non-hygroscopic choline bitartrate is a preferred source of this vitamin.

Vitamins that are allowed for addition to animal feeds under the Canadian Feeds Regulations (Class 7. Vitamin products) are listed in

Table 4.16. All have to be labelled with a guarantee of declared potency.

Enzymes

Certain enzymes are permitted for addition to organic feed, to improve nutrient utilization, not to stimulate growth unnaturally. Their use is mainly with poultry and pigs, as an aid in releasing more of the nutrients in the feed during digestion. In addition to improving digestion, their use in pig and poultry diets is intended to result in a lower excretion of undigested nutrients and feed components into the environment, thereby helping to reduce environmental pollution and aid environmental sustainability. A main issue is nitrogen and phosphorus contents of animal manure. Excessive nitrogen yields ammonia, which can result in air pollution. Soil bacteria can convert nitrogen into nitrate, resulting in soil and water contamination. Undigested phosphorus in manure contributes to phosphorus pollution. A high proportion of undigested fibre in the manure is also undesirable, since it increases the bulk of material for land application.

The enzymes permitted for use are usually extracted from edible, non-toxic plants, non-pathogenic fungi or non-pathogenic bacteria; they may not be produced by genetic engineering technology and have to be non-toxigenic. They are termed exogenous enzymes to explain that they do not originate in the gut of animals.

Table 4.16. Vitamins that are allowed for addition to animal feeds under the Canadian Feeds Regulations (Class 7. Vitamin products).

Number	Vitamin (International Feed Number)
7.1.1	p-Aminobenzoic acid (IFN 7-03-513)
7.1.2	Ascorbic acid (IFN 7-00-433)
7.1.3	Betaine hydrochloride (IFN 7-00-722), the hydrochloride of betaine
7.1.4	D-Biotin (or Biotin, D-) (IFN 7-00-723)
7.1.5	Calcium D-pantothenate (IFN 7-01-079)
7.1.6	Calcium DL-pantothenate (IFN 7-17-904)
7.1.7	Choline chloride solution (IFN 7-17-881)
7.1.8	Choline chloride with carrier (IFN 7-17-900)
7.1.9	Fish oil (IFN 7-01-965), oil of fish origin used as a source of vitamins A and D
7.1.10	Folic acid (or Folacin) (IFN 7-02-066)
7.1.11	Inositol (IFN 7-09-354)
7.1.12, 7.1.13	Menadione and menaphthone in several forms (sources of vitamin K)
7.1.15	Niacin (or Nicotinic acid) (IFN 7-03-219)
7.1.16	Niacinamide (or Nicotinamide) (IFN 7-03-215), the amide of nicotinic acid
7.1.17	Pyridoxine hydrochloride (IFN 7-03-822)
7.1.18	Riboflavin (IFN 7-03-920)
7.1.19	Riboflavin-5'-phosphate sodium (IFN 7-17-901), the sodium salt of the phosphate ester of riboflavin
7.1.20	Thiamine hydrochloride (IFN 7-04-828)
7.1.21	Thiamine mononitrate (IFN 7-04-829)
7.1.22	Vitamin B_{12} (IFN 7-05-146), cyanocobalamin
7.1.23	Sodium ascorbate (IFN 7-00-433), the sodium salt of ascorbic acid
7.1.26	Choline bitartrate (IFN 7-18-674), a non-hygroscopic source of choline
7.1.27	Betaine, anhydrous (or Betaine) (IFN 7-32-193)
7.1.31	Vitamin A (IFN 7-05-142), the acetate ester, palmitate ester, propionate ester
7.2	Beta-carotene (IFN 7-01-134)
7.3	Vitamin A (IFN 7-05-142), as the acetate ester, palmitate ester, propionate ester or a mixture of these esters
7.4	Vitamin D_3 (IFN 7-05-699), cholecalciferol
7.5	Vitamin E (IFN 7-05-150), as the acetate ester, succinate ester or a mixture of these esters

At present these enzymes are not used routinely in adult ruminant diets because breakdown of fibre in the rumen is normally very high in these animals. It is also assumed that exogenous enzymes would be unable to survive and retain activity within the ruminal environment.

An issue for the organic industry is whether or not the products have been derived from GM organisms.

Beauchemin *et al.* (2003) reviewed the published data on the use of exogenous fibrolytic enzymes in ruminant animals. They concluded that adding exogenous fibrolytic enzymes to dairy cow and cattle diets can potentially improve cell wall digestion and the efficiency of feed utilization, and that these products could play an important role in future ruminant production systems. Positive responses in milk production and growth rate had been observed for cattle fed some enzyme products, although the results were inconsistent. Some of the variation could be attributed to product formulation, under- or over-supplementation of enzyme activity, inappropriate method of giving the enzyme product to the animal, and the level of productivity of the animals in question. Research was needed to understand the mode of action of these products so that on-farm efficacy of ruminant enzyme technology could be assured.

Enzymes permitted in animal feeds in the EC are shown in Table 4.17. Various combinations are allowed, as shown in the table. This list does

Table 4.17. Abbreviated list of currently authorized feed enzymes in the European Community (Directive 70/524/EEC and Annex to Directive 82/471/EEC).

Number	Enzyme (alone or in combination)[a]
15	Beta-glucanase
2	Phytase
20	Beta-xylanase
21	Beta-xylanase
25	Beta-glucanase and endo-beta-xylanase
25 = E 1601	Beta-glucanase and beta-xylanase
26	Beta-glucanase
27	Beta-xylanase and beta-glucanase
28	Phytase
30	Beta-glucanase and beta-xylanase
31	Beta-xylanase
34	Beta-glucanase and beta-xylanase and alpha-amylase
43	Beta-xylanase and beta-glucanase and alpha-amylase
46	Beta-glucanase and beta-xylanase and polygalacturonase
48	Alpha-amylase and beta-glucanase
52	Beta-glucanase, beta-glucanase (different source) and alpha-amylase
53	Beta-glucanase, beta-glucanase (different source), alpha-amylase and bacillolysin
54	Beta-glucanase, beta-glucanase (different source), alpha-amylase and beta-xylanase
55	Beta-glucanase, beta-glucanase (different source), alpha-amylase and bacillolysin
56	Beta-glucanase, beta-glucanase (different source), alpha-amylase and bacillolysin
57	Beta-glucanase, beta-glucanase (different source), alpha-amylase and bacillolysin
58	Beta-glucanase, beta-glucanase (different source), alpha-amylase and bacillolysin
61	Beta-xylanase and beta-glucanase
E 1601	Beta-glucanase and beta-xylanase
E 1602	Beta-glucanase, beta-glucanase (different source) and beta-xylanase
E 1603	Beta-glucanase
E 1604	Beta-glucanase and beta-xylanase
E 1605	Beta-xylanase
E 1607	Beta-xylanase
E 1608	Beta-xylanase and beta-glucanase
E 1613	Beta-xylanase

[a]Some are approved in dry and/or liquid form.

not include enzymes such as α-galactosidase, which are marketed internationally and which may be permitted by other organic agencies. Producers wishing to use enzyme products should check with the local certifying agency for a permitted list.

Microorganisms

Microorganisms approved for feed use under the EU regulations comprise *Enterococcus faecium* (in various forms) and *Saccharomyces cerevisiae*. Their use as probiotics (as an alternative to antibiotics) is based on the principle of promoting the growth of lactobacilli and reducing the numbers of enteropathogenic bacteria in the gut. Sometimes this principle is referred to as competitive exclusion. Probiotics are probably most relevant to young calves since these animals have a low immunity to enteric diseases and require time to develop a functional and balanced intestinal microflora for the effective utilization of nutrients and the inhibition of coliform bacteria.

Brewer's Yeast

Brewer's yeast (*Saccharomyces cerevisiae*) is permitted as a feed ingredient in organic diets. This by-product has been used traditionally in animal diets as a source of micronutrients in calf and dairy cow diets but has been replaced by other sources of these nutrients. The current usage of yeast in cattle diets is as a possible probiotic to replace antibiotics and as an additive to alter the pattern of rumen fermentation in a beneficial way. Live, hydrolysed and extracts of yeasts have been used. The results obtained to date have been inconsistent.

Most of the research studies on yeast have involved live yeast cultures or strains of live yeast cells of *S. cerevisiae* developed by commercial companies. Presumably these are acceptable by the various organic certifying agencies, but this aspect should be checked by producers planning to use yeast products in organic production. Other research has involved yeasts not approved as yet in organic production. The following are examples of the usage of yeast.

Hučko *et al.* (2009) studied the rumen fermentation pattern in pre-weaned Holstein male calves receiving commercial supplements of cultures obtained from *S. cerevisiae* (strain 1026: Sacc® 1026) or from *Kluyveromyces fragilis* (strain Jürgensen: Vitex). Starting at 4 days of age and continuing until the calves were 56 days of age, the calves were allocated to one of the three dietary treatments. The calves were fed 4 l of whole milk twice daily and a basal concentrate mixture to appetite. The control treatment was not supplemented with yeast culture. The yeast culture supplements Yea-Sacc® 1026 and Vitex were top-dressed at 10 g/calf/day on the basal concentrate mixture. At the end of the experiment, all calves were slaughtered and the rumen fluid was analysed. Administration of Yea-Sacc® 1026 or Vitex to calves did not affect final body weight, body weight gain, DM intake, feed conversion ratio, ruminal pH, lactic acid concentration or molar proportion of propionic acid, but it decreased the total VFA concentration and the molar proportion of butyric acid, and increased the molar proportion of acetic acid and the acetate to propionate ratio. In addition, microbial cellulolytic activity was higher in calves that received either yeast culture. The results of this study suggested that the ruminal fermentation pattern was more stable in calves receiving yeast culture supplements.

On the other hand, Titi *et al.* (2008) found that supplementation of the diet of veal calves with 20 kg yeast culture/t of feed had no effect on growth rate, feed conversion ratio, carcass characteristics or meat quality. Possenti *et al.* (2009) reported that the addition of 10 g yeast (*S. cerevisiae*)/animal/day improved DM digestibility in crossbred steers fed coast-cross grass and leucaena. Thrune *et al.* (2009) examined the effects of dietary supplementation with *S. cerevisiae* on ruminal pH and microbial fermentation in dairy cows. In this study, Holstein dairy cows in late lactation were either supplemented with 0.5 g/head/day of *S. cerevisiae*, an active dry yeast (CNCM-1077, Levucell SC20), or not supplemented (control). The basal diet consisting of 60% forage and 40% concentrate (DM basis) was fed once daily to both groups of cows throughout the entire experiment. It was found that supplementation with yeast increased the average, minimum and maximum ruminal pH, decreased the amount of time spent with subacute rumen acidosis and tended to decrease total VFA concentration in the rumen. Lethbridge *et al.* (2007) reported that the inclusion of live yeast in mixed forage diets increased milk yield and reduced lesion and locomotion score in first-lactation heifers.

Vuorenmaa and Garcilópez (2009) reported the results of field trials conducted in different countries. In an experiment conducted at Helsinki University the addition of hydrolysed yeast to cows from 2 weeks pre-partum until 8 weeks post-partum improved the utilization of energy by cows and increased milk production. In another experiment, conducted in Switzerland, nursing cows received feed composed of maize and grass silage with or without hydrolysed yeast for 15 weeks. The addition of hydrolysed yeast throughout the trial increased milk yield. Analysis of blood samples showed an increase in the content of glucose and a decrease in the content of free fatty acids. It was concluded that supplementation with hydrolysed yeast improved rumen function and increased the number of the rumen microorganisms, the rate of rumen fermentation and production of volatile fatty acids.

Robinson and Erasmus (2009) reviewed a large body of published reports on responses of lactating dairy cows to *S. cerevisiae*-based yeast products in an attempt to rationalize the perceptions relating to yeast supplementation with actual findings. As they pointed out, the number of yeast products that has undergone evaluation in controlled research studies is somewhat limited. Yet there is a widespread belief among dairy and beef producers and ruminant nutritionists that yeast products are beneficial by enhancing DM intake and overall animal performance. Various mechanisms have been proposed to explain these effects. One is that yeasts are able to grow, at least for a short period of time, in the rumen, thereby directly enhancing fibre digestion and/or producing nutrients that stimulate growth of rumen cellulolytic bacteria, which are largely responsible for fibre digestion. It has also been suggested that yeasts utilize nutrients, such as lactic acid, which, if allowed to accumulate in the rumen, could suppress bacterial growth and/or suppress DM intake by lowering rumen pH. Another suggested possibility is that growth of yeast in the rumen utilizes trace amounts of dissolved oxygen, particularly at the interface of the cellulolytic bacteria and fibre, thereby stimulating growth of rumen bacteria for which oxygen is toxic. Robinson and Erasmus (2009) argued that, for these mechanisms to be functional, the yeasts would have to be viable and have the ability to grow in the rumen. An alternative mechanism is that the yeast culture that is created in the fermentation process provides a mixture of micronutrients that stimulates bacterial growth in the rumen, thereby producing beneficial effects on fibre digestion and/or utilization of the end products of fibre digestion in order to prevent their accumulation in the rumen. Their analysis of 22 published lactation experiments involving *S. cerevisiae*-based products resulted in small (around 2–5%) increases in DM intake, milk yield, milk fat yield, milk protein yield and milk energy output. These findings were interpreted as supporting the commonly proposed mode of action of *S. cerevisiae*-based products, i.e. that they act to stimulate rumen microbes that increase fermentability of fibre.

Tabulated Nutrient Content of Feedstuffs

Table 4.18(a–i) presents data on average values of energy and nutrients for feedstuffs that may be used in organic cattle feeding. Each feedstuff is listed with its International Feed Number (IFN) (Harris, 1980) so that it can be identified correctly. The table is intended as a guide to producers in the selection of which crops to grow and which feedstuffs should be purchased to supplement those available on-farm for cattle feeding.

Feedstuffs can be highly variable in composition, especially organic feedstuffs that are grown on land fertilized with manures; therefore the values should only be used as a guide in diet formulation. There are reports that some organic feedstuffs contain less protein and more fibre than conventional feedstuffs (e.g. Jacob, 2007; Grela and Semeniuk, 2008; Kyntäjä *et al.*, 2014) but the data on this issue are incomplete. It is recommended that organic producers have domestically produced feedstuffs analysed and that they purchase feedstuffs on the basis of a guaranteed analysis, prior to formulation of the dietary mixtures.

The values in the table are based on data presented in previous volumes in this series (Blair, 2007, 2008), in the NRC publications on nutrient requirements of beef cattle (NRC, 2000) and dairy cattle (NRC, 2001) and in publications referred to in this book. Gaps in the table indicate that the database is incomplete.

Table 4.18a. Typical composition of feedstuffs for cattle (dry-matter basis).

	Forage/forage products						
Component	Bahia grass hay 2-00-464	Bermuda grass hay 1-00-703	Brome hay pre-bloom 1-0-890	Fescue hay 1-01-912	Fescue hay full-bloom	Fescue hay mature	Maize silage 3-02-8232
Dry matter (g/kg)	900	910	880	910	910	910	341
Energy							
DE (kcal/kg)	2240	2120	2530	2730			3090
DE (MJ/kg)	9.38	8.87	10.6	11.42			12.93
ME (kcal/kg)	1840	1550	2170	2310	2100	1590	2670
ME (MJ/kg)	7.70	6.49	9.09	9.67	8.79	6.66	11.18
NEM (kcal/kg)	1000	930	1310	1340	1240	750	1630
NEM (MJ/kg)	4.19	3.89	5.48	5.61	5.19	3.14	6.82
NEG (kcal/kg)	450	390	740	770	680	220	1030
NEG (MJ/kg)	1.88	1.63	3.1	3.22	2.85	0.92	4.31
NEL (kcal/kg)	1130	960	1220	1400			1600
NEL (MJ/kg)	4.73	4.02	5.11	5.86			6.7
Fibre							
CF (g/kg)	312	313	329	320			217
NDF (g/kg)	720	766	550	622	670	700	460
ADF (g/kg)	377	391	349	500			270
Fat							
Crude fat (g/kg)	16.0	27	26	55	53	47	31
Protein							
CP (g/kg)	82	98	160	150	129	108	81
Bypass (%)	63	85	79	82	77	86	28
Minerals (g/kg)							
Calcium	4.4	4.9	4.3	3.7			2.7
Phosphorus	3.0	2.7	2.1	2.9			2.0
Potassium	15.3	1.8	18.9	18.4			10.5
Chloride		6.7					
Magnesium	2.5	1.9	1.9	5.0			2.8
Sodium		0.8	0.3				0.1

Trace minerals					
(mg/kg)					
Cobalt		0.12		0.14	0.06
Copper	2.44	26.7			13.2
Iodine		0.12			
Iron		290	200		640
Manganese	40.2	109		24.5	34.4
Selenium					
Zinc	8.45	58.1			20.9
Vitamins					
β-Carotene (mg/kg)					
Vitamin A (IU/kg)					
Vitamin E (IU/kg)				135.6	

Table 4.18b. Typical composition of feedstuffs for cattle (dry-matter basis).

Component	Forage/forage products									
	Orchard-grass hay early-bloom 1-03-438	Orchard-grass/tall fescue blend silage	Reed canary grass hay 1-01-104	Ryegrass hay 1-04-077	Timothy hay mid-bloom 1-04-883	Timothy hay full-bloom 1-04-885	Timothy hay seed stage	Barley straw 1-00-498	Oat straw 1-03-283	Wheat straw 1-05-175
Dry matter (g/kg)	890	598	890	880	890	890	890	914	922	911
Energy										
DE (kcal/kg)	2530			2450	2910	2530		1970	2290	2130
DE (MJ/kg)	10.6			10.26	12.18	10.6		8.25	9.58	8.91
ME (kcal/kg)	2350		1990	2310	2060	2020	1700	1540	1860	1710
ME (MJ/kg)	9.84		8.33	9.67	8.62	8.46	7.12	6.45	7.79	7.16
NEM (kcal/kg)	1470		1140	1440	1210	1180	860	700	1020	880
NEM (MJ/kg)	6.15		4.77	6.03	5.07	4.94	3.6	2.93	4.27	3.68
NEG (kcal/kg)	880		580	860	640	610	320	160	470	330
NEG (MJ/kg)	3.68		2.43	3.6	2.68	2.55	1.34	0.67	1.96	1.38
NEL (kcal/kg)	1250	1430		1240	1300	1250		1000	1150	960
NEL (MJ/kg)	5.23	6.0		5.19	5.44	5.23		4.18	4.81	4.02
Fibre										
CF (g/kg)	320			289	338	326		415	404	380
NDF (g/kg)	596	484	640	410	637	642	720	800	700	770
ADF (g/kg)	307	327		300	364	415		462	479	499
Fat										
Crude fat (g/kg)	29.0	52	31	22	27	29	20	19.0	22	18.0
Protein										
CP (g/kg)	128	179	103	86	97	81	60	44	44	33
Bypass (%)	77	41	71	65	69	62	50	70	40	60
Minerals (g/kg)										
Ca	4.1	7.6	3.6		3.6	3.8		3.0	2.3	1.7
P	2.6	3.4	2.4	2.7	2.3	1.5		0.7	0.6	0.5
K	30.0	26.6	29.1	14.2	18.2	16.1		23.6	25.3	14
Cl	4.1	1.9								
Mg	1.9	2.0	2.2		1.3	1.7				
Na	0.2		0.2		0.1	0.7		1.4	4.2	1.4

Trace minerals (mg/kg)							
Cobalt	0.38				0.07		0.05
Copper	14.5	12	16		5.4	10.3	3.6
Iodine							
Iron	149	150.0	148.7	230	200.8	164	157.3
Manganese	182	92.4	56.2		16.6	31.5	40.9
Selenium	0.05						
Zinc	33.3		43		7.4	5.9	6.5
Vitamins							
β-Carotene (mg/kg)							
Vitamin A (IU/kg)							
Vitamin E (IU/kg)	191.1						

Table 4.18c. Typical composition of feedstuffs for cattle (dry-matter basis).

Component	Leguminous forages/forage products						
	Lucerne early-vegetative 2-00-196	Lucerne hay late-vegetative 1-00-054	Lucerne hay early-bloom 1-00-059	Lucerne hay mid-bloom 1-00-063	Lucerne hay late-bloom 1-00-068	Lucerne silage full-bloom 3-06-150	Lucerne dehydrated 1-00-024
Dry matter (g/kg)	234	897	905	910	909	400	920
Energy							
DE (kcal/kg)	2,730	2,910	2,650	2,560	2,430	2,340	2,730
DE (MJ/kg)	11.43	12.18	11.1	10.72	10.17	9.8	11.43
ME (kcal/kg)	2,240	2,390	2,170	2,100	1,880	1,990	2,240
ME (MJ/kg)	9.38	10	9.1	8.8	7.87	8.33	9.38
NEM (kcal/kg)	1,380	1,510	1,310	1,240	1,040	1,140	1,380
NEM (MJ/kg)	5.78	6.32	5.48	5.19	4.35	4.77	5.78
NEG (kcal/kg)	800	920	740	680	490	580	820
NEG (MJ/kg)	3.35	3.85	3.1	2.85	2.05	2.43	5.43
NEL (kcal/kg)	1,350	1,420	1,330	1,270	1,270	1,180	1,420
NEL (MJ/kg)	5.65	5.94	5.6	5.32	5.32	4.94	5.95
Fibre							
CF (g/kg)	265	242	285	280	301	335	227
NDF (g/kg)	471	309	393	471	488	530	510
ADF (g/kg)	368	240	319	367	387	151	294
Fat							
Crude fat (g/kg)	38	42	29	36	32	26	30
Protein							
CP (g/kg)	189	222	199	187	170	160	190
Bypass (%)	20	20	20	23	25	91	60
Minerals (g/kg)							
Ca	12.9	17.1	16.3	13.7	11.9	13.2	14.2
P	2.6	3.0	2.1	2.2	2.4	3.1	2.5
K	32	25	26	15.6	15.8	22	25
Cl	4.6	3.4	3.8	3.8			4.5
Mg	3.4	2.1	3.4	3.5	2.7	3.0	
Na	1.7	1.2	1.5	1.2	0.7	1.1	0.8

Trace minerals (mg/kg)							
Cobalt	0.35	0.3	0.29	0.39	0.23		0.28
Copper	12.4	11.4	12.6	17.7	9.8	8.5	13.3
Iodine							0.15
Iron	315.4	231.5	226.8	224.6	154.9	273.6	385
Manganese	92.7	47.2	36.2	28	42.3	50	49.4
Selenium			0.55				0.31
Zinc	36.1	37.4	30.2	30.1	26.1	20.5	23.8
Vitamins							
β-Carotene (mg/kg)			151				176
Vitamin A (IU/kg)			263,000				308,000
Vitamin E (IU/kg)			226				53

Table 4.18d. Typical composition of feedstuffs for cattle (dry-matter basis).

Component	Leguminous forages/forage products			
	Bird's-foot trefoil hay 1-05-044	Clover ladino hay 1-01-378	Clover red hay 1-01-328	Vetch hay 1-05-106
Dry matter (g/kg)	910	890	880	890
Energy				
DE (kcal/kg)	2690	2800	2700	2730
DE (MJ/kg)	11.26	11.72	11.3	11.43
ME (kcal/kg)	2130	2170	1990	2060
ME (MJ/kg)	8.92	9.1	8.33	8.62
NEM (kcal/kg)	1340	1310	1140	1210
NEM (MJ/kg)	5.61	5.48	4.77	5.07
NEG (kcal/kg)	770	740	580	640
NEG (MJ/kg)	3.22	3.1	2.43	2.68
NEL (kcal/kg)	1370	1440	1380	1400
NEL (MJ/kg)	5.74	6.03	5.78	5.86
Fibre				
CF (g/kg)	323	208	307	279
NDF (g/kg)	475	360	469	480
ADF (g/kg)	360	320	410	330
Fat				
Crude fat (g/kg)	21	27	28	30
Protein				
CP (g/kg)	159	224	150	208
Bypass (%)	82	86	80	86
Minerals (g/kg)				
Ca	17.0	14.5	14.0	13.6
P	2.3	3.3	2.2	3.4
K	19.2	24.4	24.0	21.2
Cl		3.0	6.3	
Mg	5.1	4.7	2.8	2.7
Na	0.7	1.3	3.9	5.2

Trace minerals (mg/kg)				
Cobalt	0.11	0.16		0.35
Copper	9.5	9.4		9.9
Iodine		0.3	0.07	0.49
Iron	227.5	470	700	490
Manganese	28.7	123.1	208.7	608
Selenium				
Zinc	77.2	17		
Vitamins				
β-Carotene (mg/kg)				
Vitamin A (IU/kg)				
Vitamin E (IU/kg)				

Table 4.18e. Typical composition of feedstuffs for cattle (dry-matter basis).

	Cereal grain/grain products							
Component	Barley grain 4-00-549	Maize grain 4-02-935	Maize gluten feed 5-02-903	Maize distiller's dried grains 5-02-843	Maize silage 3-02-823	Oats grain 4-03-309	Rice grain 4-03-938	Rice bran 4-03-928
Dry matter (g/kg)	881	900	899	918	346	892	890	905
Energy								
DE (kcal/kg)	3,840	3,920	3,380	3,630	3,170	3,400	3,270	2,660
DE (MJ/kg)	16.08	16.41	14.15	15.2	13.27	14.23	13.69	11.14
ME (kcal/kg)	3,030	3,250	2,960	3,222	2,600	2,780	2,850	2,400
ME (MJ/kg)	12.68	13.61	12.39	13.5	10.88	11.64	11.93	10.04
NEM (kcal/kg)	2,060	2,240	2,000	2,210	1,690	1,850	1,760	1,520
NEM (MJ/kg)	8.62	9.38	8.37	9.25	7.08	7.75	7.37	6.36
NEG (kcal/kg)	1,400	1,550	1,350	1,520	1,080	1,220	1,140	920
NEG (MJ/kg)	5.86	6.49	5.65	6.36	4.52	5.11	4.77	3.85
NEL (kcal/kg)	1,950	2,200	1,910	2,060	1,770.0	1,740	1,690	1,300
NEL (MJ/kg)	8.18	9.1	8.0	8.62	7.41	7.29	7.08	5.44
Fibre								
CF (g/kg)	44	23.0	97	99	195	132	97	117
NDF (g/kg)	198	118.0	450	440	460	293	340	300
ADF (g/kg)	77	32.0	120	180	266	140	160	257
Fat								
Crude fat (g/kg)	25.6	39.0	25	101	31	52	18.0	136
Protein								
CP (g/kg)	129	95.0	255	295	81	136	84	131
Bypass (%)	24	58		52	28	18	30	30
Minerals (g/kg)								
Ca	0.6	0.3		2.0	2.8	1.1	0.7	0.7
P	3.6	3.1		8.0	2.6	4.1	3.2	11.7
K	5.6	3.8	6.9	5.1	1.2	5.2	4.9	18.9
Cl	1.3	0.9	2.5	1.8	2.9		0.8	0.8
Mg	1.4	1.2	3.7	2.0	1.7	1.6	1.4	9.7
Na	2.0	0.2	1.3	5.2	0.1	0.4	0.7	0.3

Trace minerals (mg/kg)								
Cobalt	0.19	0.14	0.01	0.17	0.06	0.06		1.53
Copper	8.22	3.84	48.8	57.3	13.2	6.7		1.21
Iodine	0.05		0.07	0.06		0.13		
Iron	83.02	35.2	460.2	252.1	640	73.4		229.1
Manganese	17.85	6.22	25.3	26.1	34.4	40.5	20.2	396
Selenium	0.2	0.14	0.29	0.36		0.24		
Zinc	47.14	21.63	76.3	87.9	20.9	39.3	16.9	48.4
Vitamins								
β-Carotene (mg/kg)	4.5	18.7		4.0		4		
Vitamin A (IU/kg)	7,635	31,840		6,340		6,840		
Vitamin E (IU/kg)	26.2	23.8		41		16.8		46

Table 4.18f. Typical composition of feedstuffs for cattle (dry-matter basis).

Component	Cereal grain/grain products					
	Rye grain 4-04-047	Sorghum grain 4-04-444	Triticale grain 4-20-362	Wheat grain 4-05-211	Wheat middlings 4-05-205	Wheat bran 4-05-190
Dry matter (g/kg)	880	900	900	890	890	890
Energy						
DE (kcal/kg)	3570	3620	3410	3880	3310	3120
DE (MJ/kg)	14.95	15.16	14.28	16.24	13.85	13.06
ME (kcal/kg)	3040	2960	3000	3180	2890	2510
ME (MJ/kg)	12.73	12.39	12.56	13.26	12.1	10.51
NEM (kcal/kg)	2060	2000	1860	2180	1940	1620
NEM (MJ/kg)	8.63	8.37	7.79	9.13	8.12	6.78
NEG (kcal/kg)	1400	1350	1230	1500	1290	1010
NEG (MJ/kg)	5.86	5.65	5.15	6.28	5.4	4.23
NEL (kcal/kg)	1860	1830	1780	2040	1950	1580
NEL (MJ/kg)	7.79	7.66	7.45	8.8	8.16	6.62
Fibre						
CF (g/kg)	25	28	33	28	88	113
NDF (g/kg)	135	180	220	118	370	510
ADF (g/kg)	42	40	50	126	118	140
Fat						
Crude fat (g/kg)	17.0	32	16.0	24	47	42
Protein						
CP (g/kg)	138	126	165	142.0	185	174
Bypass (%)	20	55	25	28	22	28
Minerals (g/kg)						
Ca	0.7	0.7	0.5	0.5	1.3	1.4
P	3.6	3.4	3.7	4.3	10.2	12.7
K	5.1	4.7	5.7	5.0	11.5	13.7
Cl	0.3	0.6	0.3	1.1	0.4	0.6
Mg	1.2	1.7	2.6	1.5	4.5	6.3
Na	0.3	0.1	0.1	0.1	0.6	0.6

Trace minerals (mg/kg)						
Cobalt		1	0.09	0.4	0.11	0.08
Copper	8.63	4.62	9.31	6.51	17.9	14.17
Iodine		0.07		0.1	0.12	0.07
Iron	71.8	54.62	49.3	59.2	100.9	162.7
Manganese	82.3	18	47.8	47.1	128.4	134.1
Selenium	32.5	0.23		0.3	0.83	0.57
Zinc	34	19.2	35.11	34.8	109.1	109.8
Vitamins						
β-Carotene (mg/kg)				0.46	3.3	
Vitamin A (IU/kg)		112		758	5520	
Vitamin E (IU/kg)	16.6	13.8	9.9	16.6	22.2	

Table 4.18g. Typical composition of feedstuffs for cattle (dry-matter basis).

	Protein feedstuffs/oilseed products					
Component	Canola meal expeller 5-03-871	Cottonseed meal expeller 5-01-617	Faba beans 5-09-262	Field peas 5-03-600	Groundnut meal expeller 5-03-649	Linseed (flax) seed expeller 5-02-045
Dry matter (g/kg)	937	926	870	891	924	908
Energy						
DE (kcal/kg)	3380	3480		3820	3870	3350
DE (MJ/kg)	14.15	14.57		16	16.2	14.02
ME (kcal/kg)	2980	3210	3210	3310	3390	3150
ME (MJ/kg)	12.4	13.4	13.7	14.1	14.2	13.2
NEM (kcal/kg)	1840	1720	2370	2140	1850	1970
NEM (MJ/kg)	7.7	7.2	9.8	8.96	7.74	8.25
NEG (kcal/kg)	2070	2000	2250	2240	2350	2000
NEG (MJ/kg)	8.7	8.4	9.4	6.15	9.8	8.4
NEL (kcal/kg)	2120	2010	2200	2190	2350	2050
NEL (MJ/kg)	8.9	8.7	9.2	9.2	9.8	8.6
Fibre						
CF (g/kg)	129	119	81	63	67	96
NDF (g/kg)	269	235	151	146	181	210
ADF (g/kg)	204	150	112	79	101	150
Fat						
Crude fat (g/kg)	101	102	15.4	12.0	101	105
Protein						
CP (g/kg)	390	455	278	263	480	350
Bypass (%)	30	50		22	69	36
Minerals (g/kg)						
Ca	8.2	2.0	1.5	1.4	2.2	4.5
P	12.6	11.7	5.6	4.6	6.0	9.6
K	11.5	15.4	13.2	11.0	12.4	13.0
Cl	0.7	0.5	0.8	0.8	1.0	0.4
Mg	5.5	6.7	1.7	1.4	2.9	5.3
Na	0.7	0.8	0.3	0.3	0.5	1.0

Trace minerals (mg/kg)						
Cobalt	0.1	0.4			0.3	0.5
Copper	7.4	20	12.0	8.0	16.00	20
Iodine	0.5	0.2		0.3	0.5	0.07
Iron	198	184.2	82	72.5	320	194.4
Manganese	60	14.1	14.5	12.0	37.00	43.00
Selenium	1.1	0.04	0.02	0.01	0.1	0.8
Zinc	55.4	66.8	40	35.7	55.0	56.0
Vitamins						
β-Carotene (mg/kg)				1.1		
Vitamin A (IU/kg)				1875		
Vitamin E (IU/kg)	20	38	5.6	4.5	3.2	8.7

Table 4.18h. Typical composition of feedstuffs for cattle (dry-matter basis).

	Protein feedstuffs/oilseed products					
Component	Lupin seed sweet white 5-27-717	Olive pulp	Palm kernel meal	Sesame meal expeller 5-04-220	Soybean meal expeller 5-04-600	Sunflower seed meal 5-04-738
Dry matter (g/kg)	890	805	912	927	900	920
Energy						
DE (kcal/kg)			3200	3310	4350	
DE (MJ/kg)			13.4	13.85	18.2	
ME (kcal/kg)	3344	1380	2627	3500	3605	2440
ME (MJ/kg)	14	5.8	11.0	14.5	15	10.2
NEM (kcal/kg)				1790	2400	
NEM (MJ/kg)				7.49	10.0	
NEG (kcal/kg)	2570	580	1525	2350	1430	1390
NEG (MJ/kg)	10.8	2.4	6.4	9.7	10.0	5.8
NEL (kcal/kg)	2520	790	1625	2300	2410	1500
NEL (MJ/kg)	10.5	3.3	6.3	9.7	10.0	6.3
Fibre						
CF (g/kg)	137	215	185	62.0	65.0	190
NDF (g/kg)	223	556	726	224	135	350
ADF (g/kg)	183	435	440	110	80	230
Fat						
Crude fat (g/kg)	107	55	75	69	80	15.0
Protein						
CP (g/kg)	387	125	170	492	460	360
Bypass (%)	25	56			35	16
Minerals (g/kg)						
Ca	3.7	3.0	3.0	2.2	3.6	4.3
P	4.2		6.0	14.6	6.6	11.5
K			8.4	12.7	21.2	15.9
Cl	0.3		1.6	0.7	2.0	1.8
Mg	2.0		2.8	5	3.0	7.2
Na	0.2		0.2	0.2	0.4	0.4

Trace minerals (mg/kg)					
Cobalt	0.2		0.8	0.3	4.03
Copper	11.3	24	35	24.1	35.2
Iodine			0.2	0.2	0.1
Iron	59	950	120	180.4	221.6
Manganese	32	232	52.0	34.8	34.0
Selenium	0.1	0.3	0.2	0.2	1.9
Zinc	53	45	120.0	63.6	100.9
Vitamins					
β-Carotene (mg/kg)			0.2		0.33
Vitamin A (IU/kg)			350		550
Vitamin E (IU/kg)	8.9		3.2	7.3	13.1

Table 4.18i. Average composition of feedstuffs for cattle (dry-matter basis).

Component	Roots and tubers/by-products						
	Manioc (cassava) 4-01-152	Potatoes 4-03-787	Swedes 4-04-001	Beet pulp dried 4-00-669	Molasses cane 4-04-696	Molasses beet 4-00-668	Seaweed meal 1-08-073
Dry matter (g/kg)	880	210	103	910	710	770	930
Energy							
DE (kcal/kg)		3490		3100	3090	3380	
DE (MJ/kg)		14.61		13	12.94	14.15	
ME (kcal/kg)		3080		2680	2670	2940	
ME (MJ/kg)		12.9		11.22	11.18	12.31	
NEM (kcal/kg)		1920		1760	1640	1980	
NEM (MJ/kg)		8.04		7.37	6.87	8.29	
NEG (kcal/kg)		1280		1140	1030	1333	
NEG (MJ/kg)		5.36		4.77	4.31	5.58	
NEL (kcal/kg)		1820		1700	1600	1830	
NEL (MJ/kg)		7.61		7.12	7	7.66	
Fibre							
CF (g/kg)	49	20	120	210	0	0	70
NDF (g/kg)	93	40	440	460	0	0	
ADF (g/kg)	68	30	340	250	0	0	110
Fat							
Crude fat (g/kg)	55	40	18	7.0	43	2.0	33
Protein							
CP (g/kg)	33	100	120	100	60	80	70
Bypass (%)		0	0	44		0	
Minerals (g/kg)							
Ca	2.4	0.7	5.5	9.1	12.4	1.4	27.2
P	2	3.0	6.8	0.8	1.2	0.3	3.1
K	8.5	22.0	39.6	9.6	35.8	60	14.2
Cl	0.22	3.0		1.8	24	16.4	1.3
Mg	1.2	1.4	2.7	2.3	5.2	2.9	9.3
Na	0.3	0.9	2.4	3.1	13.5	14.8	0.9

Trace minerals (mg/kg)						
Cobalt			0.08		0.46	
Copper	8.35	4.7	13.8	89	21.55	49
Iodine	0.25					3850
Iron	64	61	293	255	87.4	484
Manganese	8.35	20	37.65	63.3	5.78	2.2
Selenium	0.1	1	0.11			0.44
Zinc	18.8	35	0.7	20	18.1	13.5
Vitamins						
β-Carotene (mg/kg)	0.05	0.1				
Vitamin A (IU/kg)	83.5	170				
Vitamin E (IU/kg)	0.65	30		6.2	5.2	

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5

Breeds for Organic Production

Suitability of Genotypes for Organic Production

It is common for producers transitioning to organic to keep the same breed of dairy or beef cattle until their organic status has been certified, a main advantage being familiarity with the stock in question and its productivity relative to the resources available and the prevailing environmental conditions. Assessment can then be made of the results being achieved under organic conditions, and if the stock is producing the target results economically it can be retained. If, on the other hand, profitability is lower than expected and can be attributed to the type of stock being used, then a decision has to be taken on replacing the stock with animals more suited genetically to the conditions on the farm.

The amount and quality of the forage available is usually a main factor determining the type of stock to be used, since organic cattle have to be able to thrive and produce well on a diet containing a higher proportion of forage products than animals fed conventionally. As stated in the EC regulations: ‘In organic livestock production the choice of breeds should take account of their capacity to adapt to local conditions, their vitality and their resistance to disease and a wide biological diversity should be encouraged.’

Both pure breeds and cross-breeds are being used in organic production. Some producers are returning to old breeds, a move which has advantages and disadvantages. Use of the old breeds allows the term ‘original’ or ‘traditional’ to be applied to the milk and meat products, which may be useful in marketing. These breeds may be better adapted to the region and may produce meat of better eating quality, but are likely to be unimproved in terms of growth performance and carcass quality. A survey carried out by Van Diepen *et al.* (2007) on organic farms in England and Wales listed the breeds of dairy and beef cattle being used on organic farms. The dairy breeds (and their crosses) included Ayrshire, Maas-Rijn-Ijssel (Meuse-Rhine-Yssel), Guernsey, British Friesian, NZ Friesian and Jersey cross-breds. The beef breeds (and their crosses) included Charolais, Charolais cross-breds, Aberdeen-Angus, Welsh Black, Welsh Black cross-breds, South Devon, North Devon (Devon), Limousin cross-breds, Hereford cross-breds, Hereford, Charolais, Friesian, Angus cross-breds, Simmental, Galloway and Belted Galloway. The data suggest that organic farmers have a strong preference for native breeds.

The traits important in cows include high fertility, good conformation, strong vigour, good milking ability (especially in dairy animals), good maternal behaviour, including ease of handling, and adequate fat reserves in northern regions to provide against cold conditions. No doubt these traits played a role in the selection of the native breeds listed above.

A wide range of genotypes is available for organic beef and milk production internationally, displaying greatly different production and

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carcass characteristics and responding differently to diet composition and level of feeding. Therefore the dietary regime and feeding programme should be modified according to the particular genotype of animal selected.

Domesticated cattle can be classified broadly into three types: milk breeds, beef breeds and dual-purpose breeds (bred for milk and meat, e.g. Shorthorn). Although specialized beef breeds have been developed, beef is obtained from all three types and in some countries the milking herd may provide a substantial share (sometimes all) of the beef produced.

Over 800 breeds of cattle are recognized worldwide, belonging to the genus *Bos*. The South African Stud Book and Livestock Improvement Association lists over 950 breeds used worldwide for milk and beef production. Domesticated cattle fall into two main types, which are regarded as either two closely related species or two subspecies of one species. *Bos taurus* cattle are the typical humpless cattle of Europe, north-eastern Asia and parts of Africa, and many are adapted to cooler climates. *Bos indicus* cattle, also called zebu, are adapted to hot climates. Hybrids of *taurus*/*indicus* are widely bred in many warmer regions, combining characteristics of both the ancestral types.

There are a few dual-purpose breeds of cattle, such as the Montbéliard, Normande, Shorthorn and Simmental (Swiss Fleckvieh). They are not an important sector of the conventional dairy industry but are likely to become important in the organic dairy industry.

Natural breeding is preferred in organic production rather than artificial insemination, which is used widely in conventional production. The availability of bulls is then an important consideration. Although artificial insemination is usually avoided by organic producers, its use is justified if the alternative is a marked degree of inbreeding, which is quite common in small (particularly closed) herds.

Breeds of Dairy Cattle

Research conducted by Zollitsch *et al*. (2017) under the SOLID programme (a European project on Sustainable Organic and Low Input Dairying financed by the European Union) suggested that the ideal cow for a low-input or organic dairy should possess the following attributes: ability to consume large quantities of forage per unit body weight; ability to efficiently convert the forage into high-value milk; ability to become pregnant within a defined breeding season; and having a high health status.

The most important dairy breed in many countries is the Holstein. Other dairy breeds used in organic production include Ayrshire, Brown Swiss, Canadienne, Dutch Belted, Guernsey, Jersey, Kerry, Meuse-Rhine-Yssel, Milking Devon, Dairy Shorthorn, Norwegian Red, Danish Red and Danish Red Pied, Simmental and Milking Shorthorn. Some of these breeds are dual-purpose rather than exclusively dairy breeds.

Holstein (Friesian)

The outstanding characteristic of the Holstein is its milking ability. This breed has dominated production in North America and Europe for many years and advances in artificial insemination have increased its popularity worldwide. High yields of milk of a relatively low butterfat content are typical. The breed originated in the Netherlands as the Dutch Black Pied and became known in the USA as Holstein-Friesian, simplified in the 1970s to Holstein. Over the years a number of distinctive strains have evolved within the breed. Originally these cattle were either black-and-white or red-and-white. The black-and-whites were selected for, to the extent that red animals were excluded from registration. Today the red factor is again acceptable.

The Holstein is a large-framed animal, the mature cow mass varying from 550 to 650 kg. Bulls often exceed 1000 kg. Because they are fleshy animals, the Dutch types of Holstein are often classified as dual-purpose animals rather than as dairy cattle. Although the meat lacks quality, the additional income from the sale of cull cows makes an important contribution to the total income from a dairy enterprise.

Brown Swiss (Braunvieh)

Brown Swiss includes the American Brown Swiss and the Swiss Brown. It is a popular dairy breed worldwide, second only in numbers to the Holstein. It was developed initially in Switzerland from the Braunvieh (Brown Mountain, a group that originated in the Alps from the local Swiss Brown), which is considered a dual-purpose type (for milk and beef) in Europe. Initially it was also used as a draught animal. This medium-size brown breed is known for its docile manner and a long productive life. It has a good yield of meat when slaughtered, a high ratio of milk protein to milk fat, and sound feet and legs. It also has a reputation for resistance to heat stress in hot and humid regions and for good production at all altitudes.

Selection by breeders has resulted in two genetically similar types within this breed group, Brown Swiss being used for milk production and Braunvieh (or Brown Mountain) used mainly for meat production. The original characteristics have been maintained and improved. These quiet, docile-tempered cows can be found on family-sized farms and on large commercial operations.

Jersey

The Jersey is the second most popular breed in many parts of the world. It is the smallest of the four better-known breeds of dairy cattle. Mature cows weigh between 380 and 450 kg. The breed has its origins on the island of Jersey. Jersey conformation is characterized by extreme leanness and a very good udder. An extremely good pelvic shape contributes to the very low incidence of calving problems. Lack of size and muscling, as well as a tendency for carcass fat to be yellow, makes this breed less suitable for meat. The small calves are not suitable for veal production. Jersey cows are famous for their good temperament, but the bulls are known to be very aggressive.

The outstanding characteristic of the Jersey is its milk, which has a very high butterfat content. The milk (also from Guernsey cows) has a slight yellow tinge because of the presence of carotene, which has a yellow-orange colour. Carotene is a precursor of vitamin A (see Chapter 3).

Where payment for butterfat plays a role, or where the consumer demands rich milk, this breed should be considered. Jersey milk has the highest protein content of all the dairy breeds. This is important economically when milk is priced in the marketplace on a component pricing system.

Guernsey

The Guernsey originated on the island of Guernsey. In many respects the Guernsey has similarities to the Jersey, which also originated in the Channel Islands. Ease of calving and milk with a high butterfat content are common attributes. Research carried out in the USA has shown that 60% of Guernseys carry the kappa-casein 'B' gene. This is of real economic benefit to cheese plants, since the milk from these animals has a firmer curd, increased volume and better cheese characteristics than milk from cows without the gene.

The Guernsey is a larger animal than the Jersey. Mature cows average 450 kg. Owing to the low numbers of this breed, the availability of bulls is limited.

Ayrshire

This speckled red-brown and white breed has its origins in the county of Ayrshire in south-west Scotland. It is a medium-sized dairy breed, mature cows weighing between 450 and 500 kg. The conformation is generally considered ideal, with exceptionally sound udder conformation. This is an example of what can be achieved by breeding, because there was a time when Ayrshires were criticized for having poor udders. The occasional small, meaty udder is a legacy of that period. Their size allows a reasonably good meat yield when animals are slaughtered. The milk is white, like that of the Holstein, but has a relatively high butterfat content. As in the case of the Guernsey, a small population limits the availability of bulls.

Selection of breed

The largest European countries for organic milk production are Germany, France, Austria and Denmark, followed by the United Kingdom, Sweden and Italy. It is logical, therefore, to consider the breeds in use in these countries.

It is clear from a number of studies that on average the Holsteins have the highest milk production, with the Brown Swiss also having an impressive yield. However, a main question stemming from data such as these is whether the high-producing Holstein is the ideal dairy cow for organic farms, which strive for efficient use of grazing and available feedstuffs and sustainability of local resources rather than maximum milk output per cow. The amount and quality of the forage available is usually a main factor determining the type of stock to be used, since organic cattle have to be able to thrive and produce well on a diet containing a higher proportion of forage products than animals fed conventionally.

Some breed comparisons have been made to answer this question. For instance, Dillon *et al.* (2003a,b) compared the performance of 'Dutch Holstein-Friesian', upgraded 'Irish Holstein-Friesian', French Montbéliard and French Normande dairy cow breeds on a spring-calving grass-based system of milk production. Although not exactly an organic system, production was close to it, being forage-based. It was typical of milk production in Ireland, which is characterized by having relatively low milk production per cow and a low cost of production. According to these authors the rate of genetic improvement for milk production per cow in Ireland up to the mid-1980s was low (approximately 0.5% per year) compared with North America, where it increased at 1.5% per year. The aim of the Irish system is to allow grazing to make a large contribution to the total diet of the dairy cow during lactation. Accordingly, calving dates are planned to coincide with the start of the grass-growing season. This results in a seasonal-calving, pasture-based system of production, typical of organic dairy farms.

The study recognized that the various breeds of dairy cows have been developed genetically for different goals. Breeds such as the Holstein (formerly Holstein-Friesian) had been developed for high milk yield while dual-purpose breeds such as the Montbéliard and Normande had been developed mainly to produce both milk and beef. As a consequence, the average 305-day milk yields of the Holstein, Montbéliard and Normande in Europe were quite different at 7028, 5836 and 5180 kg, respectively (Dillon *et al.*, 2003a).

The researchers found that both the chemical analysis of the feeds and the grazing measurements were typical of a spring-calving, grass-based system in Ireland. In addition, the chemical analysis of the herbage and the post-grazing sward surface heights suggested that the cows had access to adequate quantities of high-quality grass on a daily basis.

The production results are summarized in Tables 5.1 and 5.2, the differences found being attributed to the different breeding objectives for the breeds in question.

The Dutch Holstein-Friesian cows produced the highest yield of milk, fat, protein and lactose; the Normande produced the lowest, while the Irish Holstein-Friesian and Montbéliard were intermediate. The Normande produced the highest content of milk fat, protein and lactose. The Dutch Holstein-Friesian had significantly lower live weight gain from weeks 12 to 40 of lactation. Both the Dutch Holstein-Friesian and the Irish Holstein-Friesian had lower body condition score (BCS) at all stages of lactation than the

Table 5.1. Effect of breed on the 5-year production of dairy cows on a seasonal grass-based system (Dillon *et al.*, 2003a).

	Breed				
	Dutch Holstein-Friesian	Irish Holstein-Friesian	Montbéliard	Normande	Significance of difference[a]
Lactation length (days)	303	301	298	301	NS
Yield (kg/cow)					
Milk	5994	5321	5119	4561	***
SCM[b]	5560	4826	4769	4406	***
Fat	232.9	198.7	194.8	181.9	***
Protein	202.8	178.3	178.7	164.3	***
Lactose	276.7	245.7	241.7	218.5	***
Composition (g/kg)					
Fat	39.0	37.5	38.1	40.0	***
Protein	33.9	33.6	34.9	36.0	***
Lactose	46.2	46.2	47.3	47.9	***

[a] NS, not significant ($P > 0.05$); ***, $P < 0.001$.
[b] SCM = solids-corrected milk yield.

Table 5.2. Effect of breed on daily milk production, feed intake, dietary digestibility and live weight change over the 5-year production of dairy cows on a seasonal grass-based system (Dillon *et al*., 2003a).

	Breed				
	Dutch Holstein-Friesian	Irish Holstein-Friesian	Montbéliard	Normande	Significance[a]
Milk (kg/cow)	23.6	22.0	20.3	19.0	***
GDMI (kg/cow)	17.2	16.3	15.2	15.1	**
TDMI (kg/cow)	18.4	17.5	16.4	16.2	**
GOMI (kg/cow)	15.7	14.9	13.9	13.7	**
TOMI (kg/cow)	16.8	15.9	14.9	14.7	**
DMD	0.791	0.792	0.792	0.791	NS
OMD	0.811	0.816	0.815	0.814	NS
Live weight (kg)	558	571	572	588	*
Fat	39.0	37.5	38.1	40.0	***
Efficiency parameters					
SCM/kg DMI	1.17	1.12	1.14	1.11	NS
TDMI/100 kg live weight$^{0.75}$	3.30	3.09	2.87	2.80	***
TDMI/kg live weight$^{0.75}$	0.160	0.151	0.140	0.137	***

DMD, dry-matter digestibility; GDMI, grass dry-matter intake; GOMI, grass organic matter intake; OMD, organic matter digestibility; SCM, solids-corrected milk yield; TDMI, total dry-matter intake; TOMI, total organic matter intake.
[a] NS, not significant ($P > 0.05$); *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$.

Montbéliard and Normande. Compared with the Dutch Holstein-Friesian, the Irish Holstein-Friesian had similar body condition scores at week 4 of lactation. At all other stages the body condition scores were higher in the Irish Holstein-Friesians. The Dutch Holstein-Friesian had significantly greater loss of body condition score over the first 8 weeks of lactation compared with the other three breeds. Similarly, from weeks 12 to 40 of lactation the Montbéliard had greater BCS gain than the Dutch Holstein-Friesian. The dry matter (DM) and organic matter (OM) intake estimates of the Dutch Holstein-Friesian were higher than for the Irish Holstein-Friesians, while those for the Irish Holstein-Friesians were higher than for both the Montbéliard and Normande. The results of this study suggest that, although the Dutch Holstein-Friesian produced the highest milk production, much of this was achieved through greater mobilization of body reserves in early lactation and lower live weight gain from mid- to end of lactation.

The study showed large differences in DM intake between breeds, related to differences in feed requirement for milk production. For example, a difference of 13% in grass DM intake was found between the Holsteins and Normande. Differences in DM intake between dairy cow breeds have been reported previously.

Although the Holstein-Friesians produced larger volumes of milk, their overall reproductive performance was lower than that of the Irish Holsteins and the other breeds (Table 5.3), primarily associated with conception rate.

This lower reproductive rate was attributed to poorer fertility, namely a lower overall pregnancy rate and longer calving-to-conception interval. At the end of the 14 weeks after the start of breeding, significantly more of the Holstein-Friesian cows (26.3%) were not pregnant compared with the Irish Holsteins (16.1%) or the two other breeds (Montbéliard 8.8% and Normande 8.1%, respectively). Similarly, the pregnancy rate to first breeding of the Holstein-Friesians was lower than in the Montbéliard and Normande. The Holstein-Friesian cows showed a greater number of days from calving to conception than the other three breeds. Other researchers have found a negative effect of genetic selection for milk yield on reproductive performance.

Another significant finding of the Irish study was that survivability of the four breeds differed greatly. The proportion of animals that completed the 5-year production period (i.e. survived to day 2500) was 20.6, 39.7, 49.2 and 55.8% for the Holstein-Friesian, Irish Holstein, Montbéliard and Normande, respectively. The results suggest that the reproductive performance and

Table 5.3. Effect of breed on reproductive performance of dairy cows on a seasonal grass-based system over a 5-year period (Dillon *et al*., 2003b).

	Breed			
	Dutch Holstein-Friesian	Irish Holstein-Friesian	Montbéliard	Normande
Calving day (day of year)	61.4	58.1	60.4	61.9
Calving to conception (days)	99	87.3	82.1	82.9
Total breedings per pregnant cow	2.79	2.39	1.99	1.82
Pregnancy rate (%)	73.7	83.9	91.2	91.9
Gestation length (days)	284	281	288	287
Animals surviving to day 2500 (%)	20.6	39.7	49.2	55.8

survival of Holsteins bred for high milk production are low in a seasonal grass-based milk production system.

Confirmation that breeds other than high-producing Holsteins fit better with organic production principles can be obtained by reviewing the predominant dairy production systems in many countries. These systems aim at high output of milk all year round. For example, the systems used in most of the EU and in North America are high-input/high-output systems. These systems account for over 80% of total EU dairy cow numbers and about 85% of total EU milk production. The systems are characterized by having relatively large average herd sizes and specialized dairy farms. The average herd age tends to be young, which implies a relatively high replacement rate. The herds use specialist dairy breeds, with the Holstein-Friesian accounting for almost 95% of the herd animals. The stocking rates on the farms tend to be high, supported by relatively high use of fertilizers and a high level of feeding. Winter feed tends to consist predominantly of maize or grass silage, supplemented with cereals, brewer's grains, beet pulp and concentrates. Calving is mainly year-round. The cows are housed indoors during the winter months and may also be housed overnight in autumn and spring. The winter housing period may be as long as 8–10 months in the most northerly parts of the EU. The primary objective of most dairy producers is to have each cow produce a calf every 12 months. This requires that virtually all cows are inseminated artificially with frozen semen by either the farmers or specially trained AI assistants. The use of embryo technologies such as embryo transfer is increasing in some areas. In addition, hormones are used to treat reproductive disorders. It is obvious from the above that the predominant dairy production system in many countries has quite different objectives from those of organic production.

Dairying farm systems in New Zealand are mainly pasture-based; therefore it is relevant to consider developments in that country. The national dairy herd is made up of about 45% New Zealand Holstein-Friesians, but that number is declining. Jerseys, Ayrshires and cross-breeds appear to be gaining popularity. One of the reasons for the decline in numbers of Holstein-Friesians is attributed to a reduction in cow fertility, similar to that reported in the Irish study above. As in some other countries, New Zealand increased the genetic merit of cows for milk production by importation of progeny from other countries. The improvement, however, appears to have resulted in a specific decline in cow fertility as the proportion of imported genetic stock has increased in the New Zealand cow population. This decline can be measured as both a reduction in the proportion of cows that conceive early in the breeding season and an overall lower survival rate (Verkerk, 2003).

The breed issue leads to the question of whether high-producing cows such as the Holstein-Friesian can produce to their full potential on pasture-based systems alone. Kolver and Muller (1998) addressed the issue by feeding high-producing dairy cows either on pasture alone or on a total mixed diet that contained concentrate. Cows fed the total mixed diet produced 40 l/cow/day and cows grazing only high-quality pasture (to appetite) produced 30 l/cow/day. The lower milk yield of cows fed pasture only was attributed mainly to a lower intake of dry matter. It was concluded, therefore, that cows of high genetic merit cannot achieve their genetic milk potential on pasture alone. The reasons for this are a greater energy expenditure in a grazed pasture system, a lower intake capacity of the cows when fed completely on a bulky feed, and that cows are unable to maximize the utilization of pasture. Therefore, high-producing cows grazing pasture have to be supplemented with concentrates to achieve their genetic milk potential and to reduce the need to mobilize excessive amounts of body reserves in early lactation.

A review by Australian researchers (Grainger and Goddard, 2004) made the interesting observation that the Jersey cow has a larger digestive tract per unit of live weight than the Friesian or Holstein, and that this probably explains their greater intake capacity on a live weight basis. This enhanced intake capacity and ability to consume roughage could be an advantage for Jerseys in pasture-based systems.

Two issues have been reported in New Zealand with imported Holstein-Friesian genotypes (Verkerk, 2003). First, it is difficult to achieve heifer growth rates comparable to overseas rates on pasture alone. Adult stature is often less than that seen in other countries unless a significant level of supplement is included in the diet. Second, when pasture is provided as the principal or only lactation feed, the overseas genotype experiences rapid mobilization of body reserves and an excessive loss of body condition associated with the strong drive to partition energy into milk production.

These findings add weight to the conclusion that high-producing breeds and strains of dairy cows are not the animal of choice for the organic producer, unless the farm is able to supply high inputs of concentrate. Van Diepen *et al*. (2007) listed the most important traits for organic dairy breeding as assessed by several organic agencies and research groups (Table 5.4).

Nauta *et al*. (2009) reported a growing preference in Europe for Dutch breeds such as the Meuse-Rhine-Yssel breed. This dual-purpose breed already enjoys a strong position in Dutch organic dairy production. It was developed in the south-east and east of the Netherlands in the catchment areas of the Meuse (Maas), Rhine (Rijn) and Issel (IJssel or Yssel) rivers. A similar breed was developed in Germany and is known as the Rotbunt (Red Pied). The breed is known for good milk production (average 6000 l milk, 4.3% milk fat and 3.5% protein in European conditions), the protein being very suitable for cheese production. These breeds are now being used in New Zealand dairy herds as first or second crosses, to improve fertility and health status as well as milk protein production. Farmers have also observed a decreased incidence of mastitis with these cross-breds. Growth rate, feed conversion, carcass yield and meat quality are similar to those of commonly used dual-purpose breeds. A preference for ‘Groninger White Face’ (Groningen Whiteheaded) cattle was also noted by Nauta *et al*. (2009), as a result of its reputation as an efficient producer of milk on low-input grazing systems. In addition, Nauta *et al*. (2009) reported a significant increase in the use of natural breeding, with about 24% of the 326

Table 5.4. Overview of the most important traits for organic dairy breeding (Van Diepen *et al*., 2007).

	Agency		
Rank of trait	Research Institute of Organic Agriculture (FiBL) Switzerland	Scottish Agricultural College (UK)	Louis Bolk Institute (LBI) Netherlands
1	Fertility	General disease resistance	Fertility
2	Cell count	Mastitis resistance	Udder health
3	Longevity	Longevity	Long productive life
4	Milk from forage	Somatic cell count (subclinical mastitis resistance)	Good milk yield/lactation
5	Protein and fat content	Female fertility	Protein and fat content
6	Udder health	Forage intake capacity	Conformation udder
7		Feet and leg strength	Quality of legs
8		Susceptibility to lameness	
9		Resistance to parasite infestation	
10		Robustness/hardiness	

organic dairy farmers in the Netherlands in 2005 using natural service for breeding. The preference for Dutch and other native breeds in organic dairying in the Netherlands might be due to a desire to preserve traditional native breeds or to present a clear and distinct organic identity to society and consumers.

Other studies on alternative pure breeds to Holstein-Friesians in organic dairy farming have been conducted. One such study was conducted in the Netherlands with eight different breeds: Holstein-Friesian, Dutch Friesian, Brown Swiss, Montbéliard, Jersey and the dual-purpose breeds Groningen Whiteheaded, Meuse-Rhine-Yssel and Fleckvieh (de Haas *et al*., 2013). The Holstein-Friesians had the highest milk yield, followed by Brown Swiss and Montbéliard (90% and 82% of the Holstein-Friesian milk production, respectively) (Table 5.5), whereas Jerseys had the lowest yields (61% relative to the Holstein-Friesians). The protein and fat contents of the milk produced by the Jerseys were much higher than in the Holstein-Friesian milk. This superior quality in terms of protein and fat contents of milk from Jerseys was offset by an increase in somatic cell count (SCC, an index of milk quality – see Chapter 6). The finding on SCC has been reported in other studies involving conventional production, explained possibly by a dilution effect as milk yield increases (Berry *et al*., 2007; Villar and López-Alonso, 2015). The results also showed that the Fleckvieh and Groningen Whiteheaded cows had the highest scores for fertility, whereas Holstein-Friesian and Brown Swiss cows had the lowest scores.

A study conducted in Austria involved Brown Swiss and Holstein-Friesian cows (Horn *et al*., 2012). The Brown Swiss produced more milk with higher fat and protein contents, but showed lower reproductive efficiency than the Holstein-Friesians.

A recent study by Rodríguez-Bermúdez *et al*. (2017) compared the production of Holstein-Friesian, Swedish Red, Brown Swiss and crosses of Holstein-Friesian on organic dairy farms in North Spain. The results showed that the Holstein-Friesians produced more milk, but with significantly lower fat and protein contents than the other breeds. No differences were observed in SCC.

Boelling *et al*. (2003) suggested that the breed selected should fit with the type of farming enterprise. The availability of both cows and bulls is an important consideration. Jerseys are more resistant to high environmental temperatures than South Africa's Holstein Frieslands and are also better foragers; therefore Jerseys are more suited to hot areas such as the Transvaal Lowveld in South Africa and to more extensive dairying. Ayrshires have the reputation of being good foragers but also have the reputation of being more sensitive to bad stockmanship than Holstein Frieslands or Jerseys. Animals can usually adapt to a new environment, but this can be a lengthy process. Buying animals from an area with similar climatic conditions, preferably in close proximity, was therefore a practice recommended by these researchers.

Many countries with important dairy sectors have developed indexes for use in genetic selection programmes and an active area of research is the modification of the indexes for use in organic production. Research on this issue has been conducted in Scandinavia, Switzerland, Austria, Germany and Canada (Rodríguez-Bermúdez *et al*., 2019). The change would allow a greater emphasis to be placed on functional traits such as udder health, longevity and temperament and less emphasis on production potential. One barrier to the introduction of organic breeding indexes appears to be a lack of support for the research because of the relatively small size of the organic dairy industry.

The choice of breed may be less important when herds are managed under organic low-intensity production conditions (Bieber *et al*., 2020). Milk yield differences between local breeds and Holsteins in a study involving organic herds in Germany and Sweden were found to be less pronounced than those obtained under more intensive production conditions. Also, the local breeds showed equal or slightly better fertility, SCC level and health than the modern Holsteins, as well as higher milk content traits. Under more intensive conditions, milk yield showed an inverse relationship to fertility and health traits.

Cross-breeds or pure breeds

The suitability of cross-bred cows for organic milk production has been studied by several researchers. A large study was conducted on 113 Dutch organic farms by de Haas *et al*. (2013).

Table 5.5. Comparison of the 305-day production of eight breeds of dairy cows on organic farms (de Haas *et al*., 2013).

Breed	Number	Heifers (%)	Milk (kg)	Fat (%)	Fat (kg)	Protein (%)	Protein (kg)	SCC 5–350 days	Calving interval (days)
Brown Swiss	97	20	6802	4.26	290	3.49	238	1692	415
Dutch Friesian	38	44	4962	4.43	220	3.55	176	1719	389
Fleckvieh	7	40	4684	4.06	190	3.27	153	1659	376
Groningen Whiteheaded	75	26	4785	4.22	202	3.51	168	1768	380
Holstein-Friesian	6044	28	7568	4.18	317	3.38	255	1736	422
Jersey	327	31	4616	5.98	276	4.03	186	1761	406
Montbéliard	21	15	6232	4.12	257	3.38	210	1659	387
Meuse-Rhine-Yssel	221	26	5747	4.26	245	3.51	202	1737	391

Data on 33,788 lactations from 15,015 cows were obtained. Cross-breeding Holstein dairy cows with Brown Swiss, Dutch Friesian, Groningen Whiteheaded, Jersey, Meuse-Rhine-Yssel, Montbéliard or Fleckvieh resulted in decreased milk production, but generally improved fertility and udder health.

The data showed that heterosis (hybrid vigour) from cross-breeding had the greatest effect on traits related to fertility, health and survival, which are of low heritability in dairy cattle and slow to improve by genetic selection. Production traits (milk and protein yield) are moderately heritable, whereas product quality traits such as milk fat and protein content have the highest heritabilities and can be improved more readily by genetic selection. An important aspect of heterosis is that the benefits are additional to genetic improvement within a breed.

While there are potential advantages in cross-breeding Holsteins with other breeds, Rodríguez-Bermúdez *et al.* (2019) outlined the disadvantages. These include a relative scarcity of production trait indexes for breeds other than Holsteins, the ability of the producer to implement a more complex breeding programme, the fact that the effects of heterosis can be positive or negative, and that hybrid vigour is not fully passed on to the next generation.

Breeds of Beef Cattle

Beef breeds include Limousin, Charolais, Simmental, Hereford and Aberdeen-Angus. They are not represented in all countries; instead, beef is produced from surplus animals in the dairy herd. Veal may be produced from calves not required as replacements in the dairy herd.

Worldwide, there are more than 250 breeds of beef cattle, but the number used commercially is much less. They vary in terms of growth rate, reproductive efficiency, maternal ability and carcass and meat quality.

Several breeds were developed in the UK, the principal breeds being Aberdeen-Angus (or Angus, both Black and Red), Hereford (Horned and Polled) and Shorthorn. The Hereford was developed originally as a dual-purpose breed. In comparison with European breeds, the British breeds are generally smaller in mature size, reach maturity at an earlier age and have a lower growth potential. In general they have higher carcass quality. Some of these indigenous breeds, e.g. Highland cattle from Scotland, are being evaluated in countries such as New Zealand because of their ability to thrive in adverse conditions and provide crofters with milk, hair and meat. One feature of breeds such as the Aberdeen-Angus, Galloway and Red Poll is that they are naturally polled, a feature that may be of importance to producers wishing to avoid horned breeds.

European breeds include Charolais, Chianina, Gelbvieh, Limousin, Maine-Anjou, Salers and Simmental. It is likely that these breeds evolved originally as draught animals. In comparison with British breeds, they are generally larger in mature size and reach maturity later. The carcasses are leaner than in the British breeds.

Considerable research has been conducted to characterize and compare the major beef breeds in the USA. The most comprehensive studies have been conducted at the US Meat Animal Research Center in Clay Center, Nebraska. Since 1970, over 30 breeds have been evaluated in a common environment and management system for various performance traits. The data presented in the following tables show some of the results obtained (Greiner, 2002). The data provide useful comparative information on beef breeds and crosses, information that is not readily available from other sources.

Table 5.6 characterizes the breeds for relative differences in growth rate and mature size, lean-to-fat ratio (retail product yield), age at puberty and milk production. Generally, the Hereford × Angus and Shorthorn cross-breds were moderate in growth and mature size, relatively low in lean-to-fat ratio, reached puberty at a young age and were moderate in milk production. In comparison, calves sired by Gelbvieh, Maine-Anjou, Salers and Simmental bulls were moderate to high in growth rate and mature size, high in lean-to-fat ratio, moderate in age at puberty and moderate to high in milk production. The Charolais, Chianina and Limousin breed types tended to be high in growth rate/mature size, high in lean-to-fat ratio, older at puberty and low in milk production.

Breed group means for birthweight and weaning weight, as well as average daily gain and final (slaughter) weights, are shown in Table 5.7 (Greiner, 2002). Birth and weaning data are from both steers and heifers, whereas average daily gain and final weight are averages of steers only. Final weights were adjusted to a common age at

Table 5.6. Overall characteristics of selected breeds of beef cattle (from Greiner, 2002).

Breed group	Growth rate and mature size	Lean-to-fat ratio	Age at puberty	Milk production
Hereford × Angus	XXX	XX	XXX	XX
Charolais	XXXXX	XXXXX	XXXX	X
Chianina	XXXXX	XXXXX	XXXX	X
Gelbvieh	XXXX	XXXX	XX	XXXX
Limousin	XXX	XXXXX	XXXX	X
Maine-Anjou	XXXXX	XXXX	XXX	XXX
Salers	XXXXX	XXXX	XXX	XXX
Shorthorn	XXX	XX	XXX	XXX
Simmental	XXXXX	XXXX	XXX	XXXX

X, lowest; XXXXXX, highest.

Table 5.7. Average birth- and weaning weights, daily gain and final (slaughter) weights of selected breeds of beef cattle (from Greiner, 2002).

Breed group	Unassisted births (%)	Survival to weaning (%)	Birthweight (kg)	200-day weaning weight (kg)	Average daily gain (kg)	Final weight (kg)
Hereford × Angus	92.7	91.5	36.5	207.7	1.24	522.5
Charolais	86.8	89.5	39.2	217.3	1.31	554.1
Chianina	88.4	89.3	39.4	208.2	1.19	509.8
Gelbvieh	94.1	91.0	38.0	206.8	1.21	512.1
Limousin	91.8	90.8	36.6	200.9	1.13	489.9
Maine-Anjou	79.4	88.9	39.9	206.8	1.23	520.3
Salers	95.2	91.7	36.7	210.5	1.22	520.7
Shorthorn	97.6	91.9	37.4	208.7	1.24	524.4
Simmental	89.2	88.8	38.5	207.7	1.24	520.7

slaughter. Significant differences among breeds for the various traits are evident. Breeds that sire calves that were heavy at birth also tended to be the heaviest at weaning, grew the fastest and had the highest final weights (e.g. Charolais). The high-growth breeds with heavier birthweights also tended to have more calving difficulties, resulting in a lower percentage of unassisted births. Research studies confirm that heavy birthweights are the primary cause of calving difficulty. Calf survival to weaning tends to be higher in breeds that require less assistance at birth (e.g. Hereford × Angus, Shorthorn, Salers).

Carcass traits

Means for carcass data of steer progeny are presented in Table 5.8 (Greiner, 2002). Carcass weights are closely related to final weights presented above. This table demonstrates that breeds which excel in retail product yield (percentage of the carcass weight that is trimmed, saleable red meat) also have lower marbling scores and reduced percentage of USDA 'Choice' quality grades (e.g. Chianina, Limousin). Marbling score is a measurement of the amount of intramuscular fat in the ribeye muscle and is an indicator of eating quality. High-marbling breeds generally are lower in retail product yield. Fat thickness of the carcass has the largest impact on retail product yield. As fat thickness increases, a lower percentage of the carcass is a saleable retail product, due to trimming loss. Consequently, lean breeds with minimal carcass fat thickness excel in retail product yield. Ribeye area is an indicator of total muscle mass in the carcass and has a positive influence on retail product yield. These breed differences verify the importance of using a combination of British and Continental breeds that complement each other in a breeding programme to produce an

Table 5.8. Average carcass data of steers of selected breeds of beef cattle (from Greiner, 2002).

Breed group	Carcass weight (kg)	Fat thickness (cm)	Ribeye area (cm^2)	Retail product yield (%)	Marbling score[a]	% USDA Choice
Hereford × Angus	320.7	1.6	72.3	67.2	543	70.7
Charolais	338.8	0.9	81.3	70.2	523	58.9
Chianina	313.9	0.8	80.0	71.9	448	27.5
Gelbvieh	311.1	1.0	77.4	70.2	507	45.2
Limousin	302.5	1.0	79.4	71.5	477	43.8
Maine-Anjou	319.8	1.0	79.4	70.1	501	49.5
Salers	320.7	1.0	77.4	70.0	515	44.5
Shorthorn	320.7	1.2	71.6	67.0	566	74.7
Simmental	315.2	0.9	76.8	70.1	510	63.4

[a]400 = Slight degree of marbling = Select Quality Grade; 500 = Small degree of marbling = Choice Quality Grade.

end product that has acceptable carcass quality and retail product yield.

One point that is worthy of note in relation to the use of indigenous rare breeds in organic production is that their carcasses may not meet the quality standards for fat class and conformation set for conventional animals. As a result their commercial worth may be reduced. These animals may, therefore, have to be marketed outside the usual commercial channels and be marketed instead through specialized channels.

Yearling heifer traits

Yearling heifer data for growth and reproductive traits are shown in Table 5.9 (Greiner, 2002). Heifers sired by breeds that were heaviest at 400 days of age tended to be the oldest at puberty. Conversely, heifers sired by breeds with smaller mature size tended to reach puberty at a younger age (Hereford × Angus). However, some large breeds that have been selected for milk production (Gelbvieh, Simmental, Salers) reach puberty at a relatively young age. Pregnancy rate in heifers was not consistently related to age at puberty or body weight at 400 days of age, because most animals in these studies were managed to grow at rates that allowed them to express puberty well before the start of their first breeding season. Different results could occur in less intensively managed animals.

Cow production traits

The reproductive and maternal traits of cows sired by the breeds of primary interest in Virginia are presented in Table 5.10 (Greiner, 2002). Cows were mated to bulls of similar breed, and performance information was recorded on the calves to measure the maternal characteristics of the cows. Cows sired by bulls of large mature size gave birth to heavier calves. However, these heavier calves at birth did not result in an increase in calving difficulty measured in percentage of calves born unassisted. This is different from the results shown earlier, where calves that were heavy at birth required more assistance at calving. Maternal calving ease is the trait of interest, i.e. how the daughters of a particular breed of sire will calve as cows. Table 5.10 suggests that cows that have increased mature size are able to give birth to heavier calves without increases in calving difficulty. The 200-day weaning weights are reflective of both the milking ability of the cow and the growth potential of the calf. Cows with high milk production and growth (Gelbvieh) had higher calf weaning weights than cows with low milk production (Limousin). Conception rates, calving difficulty and calf liveability also contribute to calf weaning weights when calf weaning weights are expressed on the basis of per cow exposed to breeding. Breeds that sire cows that excel in this combination of traits will have heavier weaning weights per cow exposed (Gelbvieh, Shorthorn).

Table 5.9. Growth and reproductive traits of yearling heifers of selected breeds of beef cattle (from Greiner, 2002).

Breed group	400-day weight (kg)	Puberty expressed (%)	Age at puberty (days)	Pregnancy rate (%)
Hereford × Angus	153.7	97.3	366	80.1
Original Charolais	153.1	87.0	393	81.0
Current Charolais	160.7	96.3	361	79.0
Chianina	151	83.8	400	84.0
Gelbvieh	149.2	87.1	341	87.4
Limousin	147.5	88.0	391	83.7
Maine-Anjou	154.9	90.6	370	92.8
Salers	156.9	101.0	365	89.0
Shorthorn	158.2	95.8	359	89.0
Simmental	154.1	94.4	360	86.4

Table 5.10. Reproductive traits of cows of selected breeds of beef cattle (from Greiner, 2002).

Breed group	Calves born alive (%)	Calves weaned (%)	Calves born unassisted (%)	Calf birth-weight (kg)	Calf 200-day weight (kg)	Calf 200-day weight per cow exposed to breeding (kg)
Hereford × Angus	88	79	87	39.9	228.6	181
Charolais	89	80	91	41.3	230	183.3
Chianina	93	86	92	43.1	237.2	205.9
Gelbvieh	95	87	89	40.8	241.8	210.5
Limousin	89	82	88	39.9	219.5	180
Maine-Anjou	94	86	89	43.5	236.8	203.7
Salers	92	86	92	40.8	239	205.5
Shorthorn	93	87	90	42.6	240	208.7
Simmental	89	83	83	41.3	236.3	196.4

A comparison of across-breed production values for bulls has been updated by Kuehn and Thallman (2020) (Table 5.11). The values have been calculated by these geneticists at the US Meat Animal Research Center as expected progeny differences (EPDs) and the data can be used as a guide by producers in the selection of bulls to improve traits in the herd. For instance, producers experiencing a high rate of assisted births may wish to select an Angus bull to result in a lower birthweight in his calves.

A comparison of the growth traits of eight beef cattle breeds in the Czech Republic was reported by Jakubec *et al.* (2003). The data are shown in Tables 5.12 and 5.13. The comparison involved Angus, Blonde d'Aquitaine, Charolais, Czech Pied, Hereford, Limousin, Piedmont and Simmental. Live weights at birth, 210 days and 365 days and average daily gains from birth to 210 days, 210–365 days and from birth to 365 days were recorded. The averages of Blonde d'Aquitaine were highest for all growth traits except for birthweight.

An important feature of these results was the large overall genetic variation found for growth traits. The ranges of genetic levels were between 79% and 154% of the average breed level. Producers, therefore, can expect to find considerable variation within breeds of beef cattle as well as between breeds. These differences within breeds may be as large as the differences between breeds, making selection of strain as important as selection of breed.

Strydom *et al.* (2000) evaluated several indigenous African (*Bos taurus africanus*) cattle breeds in relation to their meat quality traits.

Table 5.11. Comparison of average production values of breeds of bulls (from Kuehn and Thallman, 2020).

Breed	Birth wt (kg)	Weaning wt (kg)	Yearling wt (kg)	Maternal milk (kg)	Marbling score[a]	Ribeye area (cm^2)	Fat thickness (cm)	Carcass wt (kg)
Angus	38.80	254.22	477.50	247.80	5.78	88.56	1.73	426.88
Hereford	40.03	245.17	450.67	242.03	5.00	87.59	1.54	406.91
Red Angus	38.75	246.44	460.90	247.67	5.54	86.95	1.65	412.05
Shorthorn	40.94	238.07	448.39	246.85	5.14	88.95	1.39	406.96
South Devon	40.12	237.93	441.12	250.12	5.25	89.01	1.27	388.99
Beefmaster	40.25	249.71	450.85	244.94				
Brahman	43.44	260.36	451.94	247.94		86.82	1.31	400.82
Brangus	39.85	248.08	456.58	247.80				
Santa Gertrudis	40.57	249.35	453.85	246.26	4.77	86.37	1.48	406.50
Braunvieh	40.48	242.39	448.62	253.58	5.17	94.62	1.23	398.45
Charolais	41.21	256.58	469.64	244.62	5.02	94.62	1.22	421.42
Chiangus	40.16	241.53	449.30	245.21	5.02	90.69	1.28	406.05
Gelbvieh	39.71	252.13	465.86	251.17	5.03	94.04	1.37	416.28
Limousin	39.71	250.03	454.94	245.48	5.02	95.07	1.37	415.46
Maine-Anjou	39.85	236.16	431.02	243.07	4.80	93.40	1.15	396.68
Salers	39.03	244.94	452.62	248.58	5.53	92.75	1.28	399.77
Simmental	40.21	254.90	471.27	247.62	5.17	93.40	1.30	419.24
Tarentaise	39.57	245.44	439.39	246.94				

[a]400 = Slight degree of marbling = Select Quality Grade; 500 = Small degree of marbling = Choice Quality Grade.

The breeds included the Bonsmara, Afrikander and Nguni, which have been introduced to other continents because of their ability to adapt to harsh range conditions. The study found that they have high fertility, low inter-calf periods, ease of calving and resistance to ticks. It was also found that these breeds have an inherent capacity to produce meat of comparable eating quality to that of British and Continental breeds and of higher tenderness than that from *Bos indicus* breeds.

The creation of a National Organic Livestock Database (NOLD) in the UK is a very useful resource for organic cattle farmers (Van Diepen *et al*., 2007). The Soil Association's Producer Services established the database in 2001 in order to assist producers in sourcing organic replacement of specific breeds. Producers can post a request for livestock or offer livestock for sale on the database.

Table 5.12. Live weights (kg) of selected European cattle from birth to 365 days (from Jakubec *et al*., 2003).

	Weight (kg)		
Breed	Birth	210 days	365 days
Czech Pied	33.3	234.1	375.8
Angus	29.2	241.4	379.5
Blonde d'Aquitaine	35.1	275.1	424.4
Hereford	24.0	195.5	308.3
Charolais	35.8	272.0	415.6
Limousin	29.2	216.0	348.2
Piedmont	37.9	207.2	341.6
Simmental	28.3	260.7	418.5

Dual-purpose Breeds

As indicated previously, dual-purpose breeds are becoming the animals of choice for organic milk and meat production since they meet the organic ethic more closely than breeds developed specifically as milk or meat animals. Dual-purpose breeds probably fit better with the smaller organic farms than the specialized milk or beef breeds. These are breeds such as the French Montbéliard and French Normande, discussed in the Irish studies outlined earlier in this chapter. In these studies the Montbéliard gave a higher profitability, due to lower replacement costs, higher beef values and acceptable milk returns (Evans *et al*., 2004).

One reservation that some organic producers have about cross-bred animals relates to the feeding programme. All of the established requirements relate to pure breeds. Feeding programmes have, therefore, to be developed using existing information and recent research data.

Pyrenean Brown cattle have had an interesting evolution in Europe (Gibon and Revilla, 2003). At the beginning of the 20th century dual-purpose Pyrenean Brown cattle were introduced on both the French and the Spanish sides of the Pyrenees, to improve the local mountain breeds. On the Spanish side, they have become the prevailing breed since the 1950s and 1960s in systems utilizing both their meat and milk production potentials. Dairy production was intensified later, and subsequently abandoned following the entry of Spain into the European Community. The Brown breed is now used for meat production in Spain where it competes

Table 5.13. Daily weight gains (kg) of selected European cattle from birth to 365 days (from Jakubec *et al*., 2003).

	Daily gains (kg)		
Breed	Birth–210 days	Birth–365 days	210–365 days
Czech Pied	0.96	0.94	0.91
Angus	1.01	0.96	0.89
Blonde d'Aquitaine	1.14	1.09	1.03
Hereford	0.82	0.78	0.73
Charolais	1.13	1.04	0.93
Limousin	0.89	0.87	0.85
Piedmont	0.81	0.83	0.87
Simmental	1.11	1.07	1.02

successfully with other breeds. On the French side the Brown cattle were introduced with the aim of developing milk production for the butter and cheese industries. As a result they became the prevailing breed in dairy areas located in the foothills and some valleys, where they were used in systems associating veal and milk production. In most of the farms in the foothills, Brown cows were replaced by specialized dairy cows (Holstein). In contrast, Pyrenean Brown cattle remain as the main breed in use on the few dairy farms in mountain valleys where milk is mainly processed into homemade cheese. This study shows another aspect of the use of dual-purpose breeds: an adaptability to be developed into more specialized breeds and strains depending on environmental and economic influences.

A similar adaptability of dual-purpose breeds was demonstrated in Greece. Immediately after the Second World War, the Greek authorities and individual farmers and companies imported, on a large scale, dual-purpose breeds either as semen or as live animals. This was because of the climatic conditions, a lack of tradition in producing milk from cows and the need to meet the increased demands for cattle meat by the urban population. Later, an increasing demand for milk and dairy products motivated the import of dairy breeds, mainly Holstein-Friesian. The data cited by Gibon and Revilla (2003) showed a higher production capacity of the Holstein breed under the better husbandry conditions of recorded dairy farms. This has resulted in a prevalence of this breed over the existing Swiss Brown and Simmental breeds, especially in the lowlands. In the upland areas, however, the dual-purpose breeds showed milk yields comparable to those of pure-bred Holstein cows and they maintained a relatively high percentage of the cattle population until the beginning of the 1990s. From the end of the 1980s dairy cattle units concentrated more around the big cities of the country and in areas where feed production, especially maize silage as a second crop, is favourable. This concentration of the dairy cattle industry and the constraints of the quota system have given advantages to the Holstein animals in competition with dual-purpose breeds and explains their predominance in the dairy population. Nevertheless, there is a lack of reliable information regarding the characteristics of the breeds for longevity or reproduction traits under Greek conditions.

Dual-purpose or dairy-beef production systems can be found in all countries but are more predominant in developing countries. This is especially true of the tropical areas such as Latin America, India and some areas of Africa. In the temperate (mostly developed) countries, smallholder farmers also use this production system, and many excellent dual-purpose cattle breeds are available in Europe. A trend towards increasing numbers of these breeds is apparent in France, and in Germany and Austria with the Fleckvieh breed.

Dual-purpose breeds are especially important in Latin America where a mix of Zebu, Criollo and European breeds is used in meat and milk production. This region obtains 78% of its beef and 41% of its milk production from these breeds. In some countries of this region these breeds account for over 90% of the total milk produced. Production from specialized dairy breeds is decreasing because of high costs. The dual-purpose production systems are generally based on grazing and hand-milking of cows with the calf at foot. They vary in intensity, particularly with regard to the relative importance of natural and cultivated pastures, supplementary feeding with crop residues or concentrates, drinking-water supply, health control measures and overall management. Compared with specialized dairy production systems, the advantages of the dual-purpose system are: (i) reduced risk of fluctuation in milk and beef prices; (ii) lower incidence of mastitis because of suckling of calves; (iii) reduced need for capital investment; and (iv) lower requirements of technical support. Net annual income per cow has been shown to be highest on dual-purpose farms, whether or not the cost of family labour is taken into account.

Many organic producers prefer to use purebreds but it is desirable for beef animals to be cross-bred in order to obtain the full advantage of heterosis (hybrid vigour). In conventional production the cow is commonly a cross-bred (F1 generation) obtained from a crossing of selected animals of two pure breeds (e.g. Hereford × Angus). These cross-bred cows are then mated to selected bulls of a third breed such as Charolais or Limousin to impart further heterosis and desirable carcass characteristics in the progeny

(F2 generation) to be marketed as meat animals. The F2 animals do not enter the breeding herd.

Cross-breeding has been widely accepted by commercial beef producers in several countries as a method of increasing production efficiency. Approximately 70% of the conventional beef cattle marketed in the USA are cross-bred. Cross-breeding is more common in beef production than in milk production.

Advantages from cross-breeding can be maximized with a well-designed breeding programme that matches breeds to utilize complementarity in cows and their progeny. Near-maximum performance can be attained by using two-breed-cross dams and selected sire terminal lines (Dickerson, 1969). The Limousin breed has often been recommended (Fredeen *et al.*, 1982a,b) as a terminal sire breed due to its growth characteristics and superior ability to produce lean carcasses. Limousin-sired calves also have lower birthweights and result in less calving difficulty than other Continental breeds (Vissac *et al.*, 1982).

The main objectives of a cross-breeding policy are to maximize three traits: cow productivity, efficiency of gain in the calf (growth rate and feed conversion ratio) and suitability of the carcass for the selected market (weight, length, fat depth/quality, skin and meat and fat colour). It will be clear from this brief description of cross-breeding principles that only large organic units would be capable of producing such superior stock on a regular basis. A compromise would be to purchase bulls and cross-bred females as required, within the limits imposed by the local regulations.

Organic producers are encouraged to use traditional breeds, which may be more suited to local conditions than improved genotypes that may have to be imported to the region. Some governments provide financial incentives for use of traditional breeds. A large number of these breeds exist in several countries, though often in relatively low numbers. One disadvantage of using a pure breed on small farms is an inadequate size of the breeding herd, leading to the problem of inbreeding, which results in loss of productivity in the stock.

The local climate is an important factor influencing breed selection for outdoor-based organic production.

As stated above, beef production is frequently based on surplus animals from the dairy herd. For example, Nielsen and Thamsborg (2002) studied dairy bull calves as a resource for organic beef production in Denmark. Of all dairy bull calves born on organic dairy farms, 8% were killed, 66% were sold to conventional farms, 6% were sold to other organic farms and 20% remained on the farm of birth. However, 59% of the farmers who sold their bull calves would have preferred to keep them. The main problems in doing so were lack of stall capacity, expected low returns and shortage of on-farm feedstuffs. The main reason for keeping the bull calves on 29% of the farms was the desire for a holistic production system. Most of these farmers (66%) chose steer production because of high utilization of roughage, the capacity to graze marginal areas and their calm temperament. Marginal areas were utilized for beef production on 59% of the farms. It is concluded that the majority of the bull calves born on organic dairy farms are not reared on organic farms. This issue needs to be taken into account in any assessment of the sustainability of organic dairy farms.

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6

Integrating Feeding Programmes into Organic Production Systems

Dairy Cattle

It will be clear from the previous chapters that organic dairy farming has a different objective than conventional dairy farming. The aim is to optimize the available resources on the farm rather than to maximize the output of milk. This results in two main differences from conventional dairy farming. The first is a heavy reliance on forage in the diet of the animals, coupled with the use of home-grown feeds for supplementation. The second is a preference for dual-purpose rather than high-producing animals.

Pasture is the natural feed for dairy and beef cattle; therefore forages, either grazed or conserved, must comprise at least 60% in the diet of organic animals, as mandated by the organic regulations. Some organic producers feed even higher levels, in some cases providing forage as the sole feed. Such a level may be suitable for low-production stock, provided it is supplemented with necessary minerals and vitamins.

One of the leading countries in organic dairy production is Germany. As reported by Haas *et al.* (2007), organic dairy farms in that country are not yet at the stage of feeding the cows on all-forage diets, which may be related to farm size in Germany. Milk yield was found to be almost 7000 kg/ha on the organic farms. The researchers calculated that 0.96 ha/cow was needed to produce the feed requirement for that level of production, of which 0.85 ha was farmland and the production area for purchased feed was 0.11 ha. Their data showed that, on an energy basis (MJ NEL), 74% of the annual average milk yield of 6737 kg/cow was derived from forage, 23% from purchased concentrates and 3% from commercial processing by-products such as spent grains from the brewing industry.

A 2000–2001 Economic Farm Survey (Verkerk and Tervit, 2003) found that the dry matter (DM) intake of the average New Zealand dairy cow on conventional farms comprised a higher content of forage, being made up of 88.5% grazed pasture, 5.5% pasture silage, 3.0% maize silage, 2.0% purchased grazing and only 1.0% supplement.

These data confirm that, while forage is the main feed of organic cattle, supplementary feeding with grains and other feedstuffs is usually necessary in many countries, especially for dairy cows. Weller (2002) carried out a comparison between two systems of organic dairy farming, one with a high stocking density using purchased concentrates and the other a self-sufficient system. He found that the self-sufficient system had more problems in balancing the dietary energy, resulting in lower milk production, more post-calving health problems and a reduction in reproductive performance.

In countries with temperate climates, grazed forages are utilized in late spring, summer and early autumn, while some regions, such as Australia, New Zealand and South America, may

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support cattle production on year-round grazing of forages. At other times of the year conserved forages have to be fed. In some regions the forage may be deficient in certain trace elements, requiring that the deficiency be remedied by providing the necessary nutrients in the form of a supplement, feed blocks or mineral licks. For example, in parts of North America the soils and pastures are low in iodine. In this case the use of iodized salt is recommended.

Pasture is generally based on grasses (e.g. perennial ryegrass, *Lolium perenne*) with a legume such as white clover (*Trifolium repens*) included in the mix to fix atmospheric nitrogen and improve the nutritive quality of the forage. When young and lush, such forage is a feed of high nutritive value and may provide most of the requirements of a good dairy ration. Higher milk yields usually require supplementary feeding, especially when the pasture is of lower quality.

It is necessary for the forage, whether grazed or conserved, to be of high quality in order for acceptable milk yields to be achieved. In addition to the mix of plants forming the sward, forage quality is determined by its stage of development and by the soil and climatic conditions. Utilizing or harvesting the stand of forage at the correct stage of growth is an important first step in attaining high quality, using plant growth information of the type shown in Chapter 4.

As Kersbergen (2010) pointed out, nutritionists characterize quality forages as feeds that provide high levels of digestible nutrients and have the potential for high intakes by cattle, while maintaining ruminal health. Intake potential is a good barometer of quality in forages, since maximizing forage intake will result in healthy cows with good milk production. As plants become larger, cell contents (which are 100% digestible) decline, with an associated increase in cell wall content. As the cell walls become a larger proportion of the forage with increasing maturity, the percentage of lignin (100% indigestible) increases and the ability of the plant material to be digested by microorganisms in the rumen declines. As the plant continues to mature, the concentration of protein in the plant material declines as well. To add to the situation, as forages become more fibrous and less digestible, they also decrease the ability of animals to consume large amounts of feed, further reducing nutrients that are available for milk production. Maximizing intake from quality forages should be a priority for all dairy producers to maintain good production levels and body condition.

Research in Ireland (Dillon, 2010) showed that grass production is maximized by grazing to 3.5–4 cm residual height. With good-quality grass this should yield 1250 kg DM/ha. By keeping the pasture in a growing state, a higher quality of grass will be produced in a green leafy base. Pre-grazing height should be 8–9 cm (three leaves); if this is grazed down to 3.5–4 cm, then growth will be 16 t/ha. Allowing the grass to go to seed should be avoided. An electric fence can be used to allocate grass on a 12 h basis when all of the available grassland is being used. The research also showed that when cows are restricted to two 3 h periods of grazing, 97% of that time is spent grazing, and when cows are given 24 h access to grazing only 41% of the time is spent grazing. The target pre-grazing yield should be between 1200 and 1500 kg DM/ha.

Many organic producers hold the view that acceptable milk production can be obtained with forage alone. Therefore it is useful to review the results of experiments in which this issue was put to the test.

Data provided by Stockdale (1999) from Australia are relevant in this connection. The study in question involved three short-term experiments with Friesian cows provided with pasture only or a supplement of 5 kg DM/cow/day of pelleted cereal grain (75% barley, 25% wheat), pelleted mixed grains (50% lupin seed, 25% barley, 25% wheat) or hay. The hay used in experiment 1 was made from lucerne, while that used in experiments 2 and 3 was from irrigated annual and perennial pastures, respectively. Cows strip-grazed irrigated pasture at a herbage allowance of about 30 kg DM/cow/day in each experiment. Prior to each experiment the average milk yield of the cows was 30, 25.6 and 16.9 kg/day, respectively. Days in lactation were 105, 114 and 222, and the cows were 6, 6 and 7 years of age, respectively.

The main results are shown in Tables 6.1 and 6.2.

Supplementation was clearly beneficial, all supplements resulting in a significant increase in milk production. The lupin seed + cereal grain supplement gave the highest response and the hay the lowest response, both in terms of yield

Table 6.1. Effects of supplement type on the milk production of grazed cows (Stockdale, 1999).

	Supplement type			
Measure	None (pasture only)	Cereal grain	Lupin seed + cereal grain	Hay
Pasture allowance (kg DM/cow/day)	31	32	32	32
Post-grazing pasture height (cm)	3.7	4.2	4.1	4.1
Post-grazing pasture mass (t DM/ha)	2.21	2.44	2.40	2.41
Pasture intake (kg DM/cow/day)	14.0	12.5	12.8	12.7
Supplement intake (kg DM)				
Spring	0	4.6	4.9	2.8
Summer	0	4.9	5.0	4.8
Autumn	0	5.0	5.0	4.0
Total intake (kg DM/cow/day)	14.0	17.4	17.8	16.6
Milk production				
Yield (kg/cow/day)	18.2	22.9	24.0	20.1
Fat-corrected milk (kg/cow/day)	18.5	23.3	24.4	20.6
Milk fat content (%)	4.26	4.22	4.21	4.27
Milk protein content (%)	3.16	3.26	3.21	3.13
Fat + protein yield (kg/cow/day)	1.30	1.67	1.74	1.45
Condition score change (units)	–0.28a	0.17	0.15	–0.16
Live weight change (kg/day)	0.09	0.42	0.40	0.19

Table 6.2. Concentrations of nutrients consumed by grazed cows fed three different supplements (Stockdale, 1999).

	Experiment 1	Experiment 2	Experiment 3
Pasture only treatment			
Metabolizable energy (MJ/kg DM)	11.3	8.8	10.6
Crude protein (% DM)	21.9	17.1	16.4
Neutral-detergent fibre (% DM)	33.6	54.2	44.3
Cereal grain supplement			
Metabolizable energy (MJ/kg DM)	11.7	9.9	11.4
Crude protein (% DM)	19.3	15.6	14.7
Neutral-detergent fibre (% DM)	30.2	44.2	37.0
Lupin seed + cereal grain supplement			
Metabolizable energy (MJ/kg DM)	11.8	10.1	11.6
Crude protein (% DM)	21.7	18.1	18.0
Neutral-detergent fibre (% DM)	30.5	44.4	36.4
Hay supplement treatment			
Metabolizable energy (MJ/kg DM)	11.1	9.3	9.8
Crude protein (% DM)	21.7	16.6	14.8
Neutral-detergent fibre (% DM)	35.3	48.8	50.0

and the marginal return to additional total DM consumed (1.4, 1.7 and 0.9 kg of extra milk for each additional kg DM from each supplement, respectively).

Yield of milk solids responded similarly to milk yield. This was principally due to the fact that none of the supplements affected milk protein content significantly. Milk fat content was reduced with both cereal grain supplements, but the effects were small.

The cows lost body condition when allowed grazing only or when supplemented with hay, indicating that these diets were lacking in nutrients. No doubt these effects would have been magnified had the experiments continued over a complete lactation rather than for 5 weeks. It was clear from the grazing results that the cows allowed access only to grass increased their intake of pasture in an attempt to compensate for a lower concentration of nutrients in the diet.

Total feed intake was highest in cows given the supplement of lupin seed + cereal grains and the overall results suggested that this supplement was the best of the three to feed for milk production in grazed cows.

In interpreting the results, it may appear that the reason for the superiority of this supplement was its higher content of protein. However, Stockdale (1999) concluded that this supplement gave the best results principally because of its higher energy concentration, not because it contained more protein than the other supplements. He interpreted the data shown in Table 6.2 as indicating that the quantity of protein consumed by the cows in each treatment should have been adequate for their requirements. The energy concentrations (metabolizable energy, MJ/kg DM) of the cereal grain and cereal grain + lupin seed supplements were, however, quite similar and further analysis of the total intakes of energy and protein on the four treatments would have helped the interpretation of the findings. One relevant point made by Stockdale (1999) in defence of the energy explanation for the better production obtained with the cereal grain + lupin seed supplement was that this supplement provided energy in a different form from that of the cereal grain supplement. It had half as much starch and more acid-detergent fibre (ADF), which might have been beneficial in terms of rumen function.

The concentrations of metabolizable energy, crude protein (CP) and neutral-detergent fibre (NDF) in the four dietary treatments are shown in Table 6.2.

More information on whether forage alone can provide all the necessary nutrients for acceptable milk production can be obtained from the work of Kolver and Muller (1998). They fed high-producing dairy cows either on pasture alone or on a total mixed ration that contained concentrate. Cows fed the total mixed ration produced 40 l/cow/day and cows grazing only high-quality pasture (to appetite) achieved 30 l/cow/day. The lower milk yield of cows consuming pasture only was attributed mainly to a lower DM intake. It was concluded, therefore, that cows of high genetic merit cannot achieve their genetic milk potential on pasture alone. The reasons for this include a greater energy expenditure in a grazed pasture system and a lower intake capacity of the cows when fully fed on a bulky feed. Therefore, high-producing cows grazing pasture have to be supplemented with concentrates to achieve their genetic milk potential and to reduce the need to mobilize excessive amounts of body reserves in early lactation.

Mixed grazing

As pointed out above, a main objective of organic livestock farming is to maximize the resources of the farm in a sustainable and effective manner and in a way that is as natural as possible. One system that helps to achieve this objective is multi-species grazing, i.e. the practice of using two or more species of livestock together or separately on the same land in a specific growing season (Blair, 2016).

Different species of livestock prefer different forages and graze them to different heights. With an understanding of the different grazing behaviours of each species, various combinations of animals can be used to utilize the forages in a pasture more efficiently. Grazing cattle, sheep and goats together on a diverse pasture should result in all types of plant material available being consumed, resulting in a more efficient utilization of the forage and browse.

More research needs to be done on this topic so that organic producers have more specific guidelines for implementation on any particular farm. Currently it is necessary for producers to test out several systems until the most satisfactory system is identified. In general, research findings (Coffey, 2001; Pennington, 2019) indicate that multi-species grazing can yield a more efficient and uniform use of pastures, but that results will vary with the type of pasture, land type and climatic conditions. Land that includes grasses, forbs and browse is best utilized with multi-species grazing. If the terrain is steep and rough, goats and sheep are superior to cattle for grazing the land. They also eat more forbs and browse than cattle, as sheep and goats are well adapted to grazing rough borders around an otherwise relatively level pasture.

Varying terrain also lends itself to multi-species grazing. Cattle prefer to graze grass and prefer more gently sloping land. Land that is uniformly in grass may best be utilized by cattle.

Pigs do not pasture well in that they root in the soil and plough up the ground, making it unsuitable for grazing, unless nose-rings have been inserted. Also, sows with piglets at foot are liable to attack anything they consider a threat. Boars tend to be aggressive and are easier to manage when penned separately. Wooded areas which can be fenced off are well suited to outdoor pig production.

Poultry can be added to the mix of animals on pasture, making a much lower usage of plant material than ruminant animals but ingesting seeds, earthworms and insects, etc. not consumed by other stock and breaking up manure clumps to aid decomposition. The availability of a lake or pond on the farm would suggest the addition of waterfowl to the mix of species, as well as fish to utilize the resources presented by the water. Geese can also serve as 'watchdogs'.

Multi-species grazing can improve utilization of forages by around 5–20%, depending primarily on the type of vegetation, land type and the mix of animals used. It is the combination of grasses, forbs and browse that provides for the more efficient use of multiple species for grazing, sometimes increasing meat production per hectare by over 20%.

As explained by Pennington (2019), cattle tend to be intermediate grazers. They graze grasses and legumes and bite with their mouth and tongue. Cattle and horses tend to graze grasses better than small ruminants such as sheep and goats. Sheep and goats consume forbs (many of which are weeds) better than cattle or horses, although goats have a greater preference for browse than do sheep.

It has been shown that sheep graze near cattle manure deposits, which cattle avoid. This results in more even use of the pasture, also in carrying capacity and pasture productivity.

Improved brush and weed control is one noticeable benefit from multi-species grazing with cattle and small ruminants. Sheep and goats can be used to consume weeds and browse that cattle avoid. Some of these weeds are problematic in certain areas. For example, leafy spurge and larkspur if ingested by cattle are harmful, but can be consumed safely by sheep. Using sheep to control these weeds results in safer pastures for cattle and an overall better utilization of the available pasture.

The addition of goats to cattle pastures has been shown to benefit the cattle by reducing browse plants and broad-leaved weeds. This allows for better grass growth. Goats will control blackberry brambles, multiflora rose, honeysuckle and many other troublesome plants. This is a simple and cost-effective way of renovating pastures. The same principle holds for sheep. Although they are less likely to clean up woody plants, sheep are quite effective at controlling several weeds.

Another benefit of a multi-species grazing system is the effective control of internal parasites in sheep and goats. Worm infestations are a major concern with sheep and goats, especially under organic conditions which restrict or prohibit the use of chemical treatments. Worm eggs from affected animals are deposited on the pasture in the manure and the eggs hatch and larvae are consumed by grazing animals, resulting in reinfection and the cycle of infestation being repeated. If left untreated, the concentrations of parasites will increase. These parasites are mostly species-specific, i.e. cattle parasites affect cattle, but not sheep, while sheep parasites affect sheep, but not cattle. Thus cattle can be used on affected pastures, ingesting the sheep worm larvae and preventing them from affecting the sheep. This is most helpful when sheep and cattle follow each other in a grazing system. However, goats and sheep do share parasites and therefore grazing them together does not improve parasite control.

Because parasite eggs are deposited in the manure, and larvae only travel a short distance up grass blades, animals grazing taller forages (well above ground level) will not consume worm eggs or larvae. Therefore, goats that are given ample browse will be much less likely to become infested with parasites. If goats are forced to graze at ground level, however, the goats may acquire a serious parasite load.

Since gastrointestinal parasites affecting sheep and goats do not survive in the gut of cattle (and vice versa), multi-species grazing can be used to decrease internal parasite loads. It is recommended that fields infected with a high load of larvae from sheep and goat parasites should be grazed first with cattle to remove as many of the larvae of parasites, so that sheep and goats can then graze with less danger of parasite infestation. Producers may wish to seek veterinary advice on this important issue.

The identification of effective medication for parasitic control that is acceptable to the organic industry continues to be an urgent area of research. A related area is the breeding of sheep and goat types with increased resistance to parasites.

Wildlife existing in the area of the farm with several species of livestock may be carriers of several pathogens, which can be transmitted to the stock and possibly the farm staff. Veterinary advice may have to be obtained on this issue.

A potential problem with grazing of multiple species is the feeding of supplemental trace minerals. The mineral supplement that is adequate in copper for sheep is likely to be inadequate for cattle, and a mineral supplement that is best for cattle may be toxic to sheep. Therefore precautions should be taken to provide separate mineral supplements to sheep and cattle.

Supplementation

It is clear from the above that dairy cows on pasture or fed forage are likely to need supplementary feed, at least during some stages of their reproductive cycle. A main question is how to calculate the amount and composition of supplement needed. With pigs and poultry it is usually possible to use standard formulas for feed mixtures based on average nutrient content of feedstuffs. Appropriate feedstuffs, minerals and vitamins can then be purchased to supplement the home-grown grains. Similar standard formulas are available for use with dairy cows, but are not advised for general use because of variability in the nutritive quality of the forage. Examples are shown in Table 6.3.

Table 6.3. Suggested supplementary feed mixtures for dairy cows fed forage of high, medium or low protein content (Chiba, 2009).

	High protein		Medium protein		Low protein	
	Example 1	Example 2	Example 1	Example 2	Example 1	Example 2
Ingredient (g/kg, air-dry basis)						
Maize grain		700			500	
Ear maize, ground	920		740	780		610
Oats, ground or rolled		280				
Wheat bran					230	
Molasses, liquid						60
Soybean meal	60			200	240	300
Soybeans, cracked			240			
Dicalcium phosphate	10	10	10	10	10	10
Ground limestone					10	10
Trace mineral, salt and vitamin mix	10	10	10	10	10	10
Calculated analysis, as-fed basis						
Crude protein (g/kg)	99	95	152	152	189	187
TDN (g/kg)	714	742	735	717	716	705
NEL (MJ/kg)	1.65	1.72	1.70	1.65	1.66	1.63
Calcium (g/kg)	2.9	2.5	3.4	3.2	7.0	7.6
Phosphorus (g/kg)	4.5	4.8	5.1	5.1	7.6	5.5
Dry matter (g/kg)	869	881	881	874	886	871
Calculated analysis, dry-matter basis						
Crude protein (g/kg)	114	108	172	174	213	214
TDN (g/kg)	822	842	834	820	808	809
NEL (MJ/kg)	1.90	1.95	1.93	1.89	1.87	1.87
Calcium (g/kg)	3.3	2.8	3.8	3.7	7.9	8.7
Phosphorus (g/kg)	5.2	5.4	5.8	5.8	8.6	6.3

In order to formulate an exact supplementary feed mixture it is necessary to match the nutrients in the feed supply to the requirements of the cow. This cannot be done for each individual animal; therefore the cows should be managed in groups at the same stages of lactation and reproductive cycle.

In assessing the nutrients in the feed supply an important first step is to have the forage analysed for nutrient content. Forages and roughages vary greatly in nutrient content, as explained earlier, depending on factors such as forage species, agronomic conditions, maturity at harvest and storage procedures. This variation is too great to allow the use of standard feed mixtures, and since forages constitute a very high proportion of the diet any errors would be magnified. Hence the need for laboratory analysis of a representative sample of the forage prior to its use. This allows the nature and extent of supplementation to be calculated.

Important information provided by laboratory testing includes the fibre and protein values. Cherney *et al.* (2009) advised that NDF content is the most useful measure of quality. According to these authors there is a relatively small range in optimal NDF for lactating dairy cows but there is as yet no reliable method of estimating the fibre content of grass and lucerne–grass mixtures for use in timing harvesting operations. NDF has to be measured after the forage has been harvested and stored, prior to ration balancing. The optimum content of NDF appears to be 38% for lucerne and 50% for grass. These authors showed that milk production decreased linearly as dietary forage content increased from 50% to 80%. NDF intake remained constant as forage content increased from 50% to 80%, suggesting that, when forage source is constant, NDF intake is a reliable predictor of DM intake and milk production. Further information can be derived from NDF. Knowledge of the NDF and DM values allows the NEL and total digestible nutrients (TDN) contents to be predicted, using standard equations. NEG values can be calculated in a similar way for use in beef cattle feeding.

Kersbergen (2010) provided further information on the value of forage analysis reports. He advised that close attention should be paid to both ADF and NDF levels. ADF helps to predict the available energy of the forage and NDF helps to predict the intake potential. Forages should represent 60–100% of the cow's diet to maintain rumen health and function, conveniently the range mandated for organic cattle feeding. He advised that a cow can usually eat 0.8–1% of her body weight in NDF if the quality of the forage is poor, whereas she can eat up to 1.2% of her body weight in NDF if the forage is of high quality. On well-managed pastures, that percentage can go even higher (1.4% of body weight in NDF). Quality forages will allow dairy cows to consume the equivalent of 3.5–4% of their body weight on a DM basis.

Figure 6.1 shows an example of an organic forage analysis report, indicating some analytical parameters that producers can use as goals (R. Kersbergen, University of Maine Cooperative Extension, 2010, personal communication). These include CP at 232, NDF at 377 and ADF at 277 g/kg (DM basis).

As can be seen in the analysis report, the forage is of high quality. Based on the reported CP level, it contains some leguminous material. In addition to the analytical results the report also provides information on the predicted NEM, NEG and NEL values at various levels of production, these values being predicted from the NRC (2001) equations.

With that information, together with breed/age information, a complete ration can then be formulated. An example ration was formulated for a mature Jersey cow (R. Kersbergen, 2010, personal communication), using the following specifications: (i) animal type: lactating dairy cow; (ii) breed: Jersey; (iii) age: 37 months; (iv) empty body weight: 450 kg; (v) days pregnant: 15; (vi) condition score: 2.60; (vii) age at 1st calving: 22 months; (viii) calving interval: 13 months; (ix) milk production: 20 kg/day; (x) milk fat: 45 g/kg; (xi) milk true protein: 32 g/kg; and (xii) current temperature: 16°C. The diet formulated, based on these forage and animal specifications, is shown in Table 6.4.

The diet obtained, using the Cornell Net Carbohydrate and Protein System, is an acceptable feed mixture that could be fed as a total mixed ration. It contains almost 70% forage. The nutrients provided by the diet are shown in Table 6.5 and show a slight surplus of energy, metabolizable protein, methionine, lysine, calcium, phosphorus and potassium. A small safety margin in terms of nutrients is preferred to a deficiency, which would limit production or affect body condition.

Dairy One

FORAGE TESTING LABORATORY
DAIRY ONE, INC.
730 WARREN ROAD
ITHACA, NEW YORK 14850
607-257-1272 (fax 607-257-1350)

Sample Description	Farm	Code	Sample
MMG SILAGE		302	11850910

Sampled	Recvd	Printed	ST	CO
	11/15/07	11/19/07		

OG 2008 3RD G/A
UNIV OF MAINE CO-OP EXTENSION
EXTENSION CROPS TEAM
LIBBY HALL
ORONO, ME 04469

ENERGY TABLE - NRC 2001
BW = 1350 Fat% = 3.7 Tprot% = 3.1

Milk, Lb	NEL Mcal/Lb	NEL Mcal/Kg	Milk, Kg
Dry	0.72	1.59	Dry
40	0.69	1.52	18
60	0.66	1.46	27
80	0.63	1.39	36
100	0.59	1.31	45
120+	0.55	1.21	54+
NEM3X	0.70	1.53	
NEG3X	0.43	0.94	
ME1X	1.15	2.53	
DE1X	1.34	2.95	
TDN1X,%	63		

COMMENTS:
1.NRC ENERGIES - SMALL BREEDS - DO NOT USE ENERGIES BEYOND 80 LBS. MILK. LARGE BREEDS - USE 120 LB. ENERGY WITH EXTREME CAUTION.

Analysis Results

Components	As Fed	DM
% Dry Matter	46.9	
% Neutral Detergent Fiber	17.7	37.7
% Crude Protein	10.9	23.2
Soluble Protein % CP		62
ADICP % CP		4.8
% Crude Fat	2.0	4.3
% Ash	4.77	10.15
% Calcium	.57	1.22
% Phosphorus	.17	.35
% Magnesium	.14	.31
% Potassium	1.40	2.99
% Sulfur	.11	.24
% Sodium	.025	.054
PPM Iron	50	106
PPM Zinc	16	35
PPM Copper	4	8
PPM Manganese	11	23
% Acid Detergent Fiber	13.0	27.7
% ADICP	.5	1.1
% NFC	13.6	29.0
% TDN	30	63
NEL, Mcal/Lb	.32	.67
NEM, Mcal/Lb	.30	.64
NEG, Mcal/Lb	.18	.38
Relative Feed Value		166
% Moisture	53.1	
% Available Protein	10.3	22.0
% Adjusted Crude Protein	10.9	23.2
PPM Molybdenum	.9	1.9

Fig. 6.1. Example of organic forage analysis conducted by a forage testing laboratory in New York State, USA (R. Kersbergen, 2010, personal communication).

The DM intake predicted by the computer program was 15.1 kg/day, and the actual intake was 15.4 kg/day (Table 6.4). The energy and metabolizable protein provided by the ration would allow a milk yield up to 20.5–21.0 kg/day, slightly higher than the actual yield measured before the ration was formulated.

One important point about ration formulation is that the nutrient requirements of dairy cows are not static but vary with stage of lactation. The feed mixture to be used at any stage has to be based, therefore, on the nutrients required during that stage. At peak production the cow may require from three to ten times as much protein and energy as in late gestation. A complication is that the voluntary intake (appetite) of the cow at peak production may be less than the intake necessary to fulfil the requirements. Maximum DM intake is not reached until 12–15 weeks after calving. The requirement for protein increases greatly at the start of lactation because milk contains about 270 g protein/kg. In addition to being adequate in amount, the dietary protein should provide an optimal ratio of

Table 6.4. Formulated diet for a high-producing (Jersey) cow, based on values specified in the text.

	DM (kg/day)	As fed (kg/day)
MMG[a] silage	10.60	22.60
Barley grain, ground	3.03	3.44
Soybeans, roasted	1.51	1.68
Mineral/vitamin supplement	0.25	0.25

[a] MMG, mixed mostly grass.

Table 6.5. Nutrients provided by the diet formulated in Table 6.4.

Requirement	ME (Mcal/day)	MP (g/day)	Met (g/day)	Lys (g/day)	Ca (g/day)	P (g/day)	K (g/day)
Maintenance	13.86	569	11	35	0	0	0
Pregnancy	0.03	1	0	0	0	0	0
Lactation	24.35	985	17	59	29	20	30
Growth	0	0	0	0	0	0	0
Total required	38.24	1555	28	94	43	36	87
Total supplied	39.49	1578	30	110	162	50	305
Balance	1.25	23	2	16	119	14	218

ruminally degradable protein to ruminally undegradable (bypass) protein. The recommended ratio for high-producing cows is around 60:40 (in the Jersey diet in Table 6.4 it was 57:43).

It is also important that the diet of dairy cows provides sufficient calcium and phosphorus, because of the high content of these minerals in milk. In the case of a Jersey cow the recommended intakes are about 50–65 g (absorbable Ca)/day and 35–55 g (absorbable P)/day, respectively.

The reproductive cycle can be considered in various phases with differing nutrient requirements. The cows can then be fed appropriately for each phase.

The first phase is usually regarded as the first 6–10 weeks after calving. During this time intake is lower than optimal and peak milk production is reached. The cows respond by using body stores to make up for deficits in nutrient intake. The second phase is the period from 6 to 14 weeks after calving, when intake is optimal and nutrient needs are in balance with the supply. The third phase is the remainder of the lactation period, when intake exceeds requirements, the excess being used to build up body reserves for the next lactation.

Two main strategies are used by organic farmers to design an appropriate feeding plan for use during lactation: (i) challenge feeding; and (ii) phase feeding. Challenge feeding is introduced in phase one. This involves giving each cow, regardless of yield, an estimated allowance of the supplement formulated for the forage being used. The allowance is then adjusted up or down according to the production of each cow. The strategy is continued in the second phase, when each cow is fed to match her measured milk yield. This strategy means feeding each cow individually and is more difficult to implement in large herds unless automated equipment is available. However, it can result in feed savings and the risk of fat cows from overfeeding is reduced.

Phase feeding is the other approach that can be taken. In early lactation (phase one), high-quality supplement mixtures are fed. Later in phase two, these high-quality supplements are replaced by lower-quality supplements. Challenge feeding is probably the simpler procedure for organic farmers to adopt.

During the dry period the aim should be to ensure that each cow is in good condition for the next calving but not too fat. Good forage may provide all of the required nutrients during this phase, but a supplement may be required in the final 3–4 months of gestation.

Cows are designed to graze forage; therefore it is usually recommended that feed troughs be placed so that the cows eat in a body position similar to that when grazing on pasture. Cows eating with their heads down produce more saliva, which increases their ability to buffer the rumen from excess acidity. The general recommendation is that the feed trough should be 10–15 cm higher than the floor where the cows are standing.

Feeding during the dry period may require that feed be restricted to avoid the cows becoming too fat, resulting in metabolic disturbances during the early part of lactation. However, a gradual increase in supplement is generally recommended during the final 6–8 weeks before calving. This is to adapt the cows to a higher intake of feed at the start of lactation and minimize or avoid the negative energy balance that occurs at that time.

A similar approach is generally recommended for bred heifers, to allow for growth to mature size without the animal becoming too fat.

Bulls can be fed similarly to heifers except that they grow faster and consequently require more feed. Mature bulls can be maintained mainly on forage with minimal feeding of supplement.

Replacement stock

It is important, as explained above, that newborn calves be allowed to suckle their mothers and ingest colostrum, which provides a source of immunoglobulins to help fight infections until the calves develop active immunity. Consequently, in organic production the calves have a mandatory period of suckling and may remain with their mothers or nursing cows for a more extended period than in conventional production. According to the organic regulations, young bovine animals must be fed natural milk, preferably maternal milk, for a period of 3 months.

Research by Weary (2001) has provided valuable information for the organic dairy farmer on the correct rearing of calves. On most North American dairy farms, calves are separated from their mothers within 24 h of birth and then fed milk by bucket or bottle until 4–10 weeks of age. Separating cow and calf early is thought to allow for better control of colostrum, milk and solid feed intake and help prevent transmission of disease. However, his research showed that calves do very well when kept with the cows during the first few weeks after birth, gaining weight at up to three times the rate of conventionally reared calves (i.e. separated early and fed milk at 10% of body weight per day). He pointed out that under natural conditions cows leave their calves in groups from about 2 weeks of age and usually continue to nurse calves for more than 6 months. In a number of organic milk production systems, the heifers suckle the dam for 4 days (Denmark) to 8 weeks (Sweden). Producers report healthier and faster-growing calves and believe that this management system reduces the incidence of mastitis.

Another finding was that calves can easily consume at least 9 l of milk a day, compared with the 4 l they receive when fed conventionally. The increased milk intake greatly improves weight gains, with no detrimental effect on calf health or post-weaning intake of solid feed. The calves can be reared successfully in small groups without stimulating cross-sucking or increasing the incidence of disease. Weary (2001) also found that cows kept with calves yielded less milk at milking. However, this was probably due to a lack of milk ejection at milking and not to reduced milk synthesis. Consequently, yields rebounded after separation, such that total yield over the lactation period did not differ. Another important finding was that calves separated at 14 days of age took advantage of the extra milk by gaining 16.5 kg over this period, versus 4.5 kg for those separated early, and that the calves maintained this weight advantage after separation.

In another experiment, heifer calves were allowed to suckle the cow twice a day for 9 weeks. These heifers gained weight at twice the rate of calves fed conventionally (1 kg/day versus 0.5 kg/day). Again, calves maintained this weight advantage after weaning. Thus it was concluded that separating calves at later ages does increase their response to separation, but allows calves to grow much faster and remain healthier.

The research involved the way in which dairy calves are offered milk after separation from their dams and how this might affect their behaviour, growth and welfare. The most common system is to feed calves twice daily from buckets, typically with an amount equivalent to 10% of their body weight per day. Research findings reviewed by Weary (2001) showed that dramatically different weight gains could be achieved by feeding calves higher amounts of milk by bucket, three times per day. Thus feeding larger quantities by bucket would seem to have important advantages. He also reported that, instead of providing milk from a bucket, a teat allows calves to drink in a more natural manner. In addition, calves fed from an artificial teat tend not to suck on each other or on objects, unlike calves fed from a bucket. It was found that calves fed to appetite by nipple spent approximately 45 min/day drinking milk, compared with just a few minutes per day for bucket-fed calves. Weight gains during the first 2 weeks of life were less than 0.4 kg/day for the conventionally fed calves versus 0.85 kg/day for teat-fed calves. During the next 2 weeks, gains were 0.58 and 0.79 kg/day, respectively. Calves maintained this advantage in body weight after weaning.

Another issue investigated by Weary (2001) was the belief that calves should be encouraged to increase their consumption of starter feed at an early age. He found that, over the first 5 weeks of life, feeding calves less milk did increase starter consumption (0.17 versus 0.09 kg/day) but that this practice severely limited weight gains. Moreover, he found that calves fed milk to appetite quickly caught up with the conventionally fed calves in their intake of starter after weaning. Both groups consumed on average 1.9 kg/day during the 2 weeks after weaning.

Calves housed in small groups grew better than calves housed individually. During the week following weaning the weight gains of individually-penned calves declined to 0.5 kg/day, but pair-housed calves continued to gain weight at pre-weaning levels. No signs of disease were observed except diarrhoea, but incidence of this condition was low and did not differ between the housing treatments. These findings gave support to the recommendation by Weary (2001) that dairy producers should consider increasing the quantity of milk fed to calves and housing them in small groups prior to weaning. The higher quantity of milk would be very appropriate for veal production.

It is common for a milk replacer to be used instead of whole milk during the pre-weaning period. This is generally purchased as a powder for reconstitution with water prior to feeding. It is usually based on dried skimmed milk or dried whey but may contain other protein sources such as potato protein concentrate. Fat is also included as a source of energy, together with vitamins and minerals.

Examples of feed mixtures for use with calves from about 1 week of age are shown in Table 6.6. The feed should be introduced gradually to stimulate rumen development and allow continued live weight gain after weaning. Good-quality hay or forage should also be provided from about 10 days of age, although appreciable quantities will not be consumed until the calves are about 8–10 weeks of age.

Grower feed can be introduced to heifers at around 4 months of age (Table 6.7). Although these animals will be ruminating by this stage, it is likely that the rumen capacity is insufficient to allow all the required nutrients to be provided from pasture. In addition, pasture-reared heifers have to expend high levels of energy for maintenance due to their increased activity and exposure to climatic conditions, which are often less than ideal. As a result the amount of energy available for growth may be limiting and supplementation may be required.

The allowance of supplement is best based on the observed growth rate and condition of the heifers in relation to those of the breed and strain of the animal in question. The allowance can then be adjusted upwards or downwards accordingly. The aim is to have the heifers achieve adequate growth rates without becoming too fat.

All of the feedstuffs listed in the abovementioned tables should be drawn from the lists of approved organic feedstuffs detailed in Chapter 4 or otherwise meet organic standards.

Quality of Organic Milk

Composition

Milk composition is usually defined in terms of solids content, including fat and protein contents, fatty acid composition, protein components, mineral and vitamin contents, somatic cell counts (SCC) and the effect of these various attributes on the processing quality of the milk. SCC is an index of the occurrence of mastitis in the cow, both clinical and subclinical mastitis being major health problems that occur frequently in dairy herds. It is also used as an index of the keeping quality of the milk.

Table 6.6. Suggested feed mixtures for dairy calves (Chiba, 2009).[a]

	Mixture 1	Mixture 2	Mixture 3	Mixture 4	Mixture 5	Mixture 6
Ingredient (g/kg, air-dry basis)						
Maize grain, rolled	500	390	540	500	340	280
Ear maize, ground				140		
Oats, rolled	350		120	260	340	300
Barley, rolled		390				
Wheat bran		100	110			
Soybean meal expeller	130	100	80	170	160	150
Linseed meal			80			
Beet pulp						200
Molasses, liquid			50	50		50
Dicalcium phosphate	10	10	10	10	10	10
Trace mineral, salt and vitamin mix	10	10	10	10	10	10
Calculated analysis, as-fed basis						
Crude protein (g/kg)	145	140	145	154	147	148
TDN (g/kg)	731	730	725	729	682	705
NEM (MJ/kg)	7.66	7.37	7.54	7.66	7.03	7.33
NEG (MJ/kg)	5.23	4.98	5.11	5.23	4.65	4.98
Calcium (g/kg)	2.9	2.9	3.5	3.4	3.2	4.5
Phosphorus (g/kg)	5.4	6.1	6.4	5.4	5.2	4.9
Dry matter (g/kg)	885	884	878	878	889	885
Calculated analysis, dry-matter basis						
Crude protein (g/kg)	164	158	165	175	165	167
TDN (g/kg)	826	826	825	830	767	797
NEM (MJ/kg)	8.67	8.33	8.58	8.71	7.91	8.30
NEG (MJ/kg)	5.9	5.65	5.82	5.95	5.23	5.61
Calcium (g/kg)	3.3	3.3	4.0	3.9	3.6	5.1
Phosphorus (g/kg)	6.1	6.9	7.3	6.1	5.8	5.5

[a] Mixtures 1–4 are suggested for calves weaned after 4 weeks of age and receiving forage. Mixtures 5 and 6 are suggested for calves weaned after 4 weeks of age and not receiving forage.

The fatty acid composition of milk is an important factor that affects the physical properties during processing and has also been linked to health issue factors in humans (Weller and Bowling, 2007). Health benefits of milk have been associated with the n-3 series of polyunsaturated fatty acid (PUFA) and conjugated linoleic acid (CLA) contents, including the prevention of carcinogenesis, a reduced incidence of heart disease and benefits to the immune system.

Since both grasses and legumes contain significant levels of PUFAs, the feeding of high-forage diets has the potential to enhance the value of milk for human consumption (Weller and Bowling, 2007). Dewhurst *et al.* (2003) fed dairy cows either grass or legume silages and reported improved intakes and milk yields with the legume silages (lucerne, red clover, white clover), as well as higher concentration levels of PUFAs in milk, particularly α-linolenic acid. The highest concentrations were found in the milk from cows fed red clover silage.

Investigations cited by Weller and Bowling (2007) showed that changing the feed from conserved forages to fresh herbage increases the CLA concentration in the milk. Conserving crops as hay or silage results in a reduction in the CLA content. Forage maize has a higher CLA content than grass silage. As a result, the linoleic acid content of milk from cows fed maize silage is higher than that in milk from cows fed grass silage diets, with the total PUFA concentrations being similar. The CLA content of milk is also influenced by the breed of cow, with milk from Jersey cows

Table 6.7. Examples of feed mixtures for dairy heifers (Chiba, 2009).[a]

	Mixture 1	Mixture 2	Mixture 3	Mixture 4
Ingredient (g/kg air-dry basis)				
Maize grain, cracked	780			500
Ear maize, ground			760	
Oats, rolled	200	350		270
Barley, rolled		500		
Soybean meal expeller		80	170	200
Molasses, liquid		50	50	
Ground limestone				10
Dicalcium phosphate	10	10	10	10
Trace mineral, salt and vitamin mix	10	10	10	10
Calculated analysis, as-fed basis				
Crude protein (g/kg)	92	138	139	167
TDN (g/kg)	749	700	711	728
NEM (MJ/kg)	7.83	7.16	7.70	7.62
NEG (MJ/kg)	5.4	4.86	5.32	5.23
Calcium (g/kg)	2.5	3.3	3.5	6.8
Phosphorus (g/kg)	4.8	5.6	4.9	5.6
Dry matter (g/kg)	879	884	867	886
Calculated analysis, dry-matter basis				
Crude protein (g/kg)	105	156	160	188
TDN (g/kg)	852	792	820	822
NEM (MJ/kg)	8.92	8.08	8.88	8.58
NEG (MJ/kg)	6.15	5.48	6.11	5.9
Calcium (g/kg)	2.8	3.7	4.0	7.7
Phosphorus (g/kg)	5.5	6.3	5.6	6.3

[a] Mixture 1 is designed for feeding with legume hay; mixtures 2 and 3 are designed for feeding with legume–grass hay; and mixture 4 is designed for feeding with grass hay. As with other feed mixtures, alternative feedstuffs can be formulated into the feed mixture to provide a similar content of energy and nutrients.

having a lower concentration than milk from either Friesian or Holstein cows.

Several investigations have been carried out to test whether organic milk differs in composition and consumer acceptance quality from milk produced conventionally. This work is complicated by the fact that (as shown above) breed, in addition to feed composition and the lower production found on organic farms as a result of a lower usage of concentrate supplementation, can affect milk composition. Another factor is that feed composition during the year is more likely to fluctuate on organic farms than on conventional farms, due to seasonal changes in forage composition (Weller and Cooper, 2001). This factor may also influence the composition of the milk. A further factor is that organic milk may be pasteurized by ultra-high heat treatment (UHT) to allow it to be shipped to markets distant from the farm of origin, and allow it to be stored without refrigeration. UHT milk has a slight nutty taste that some consumers like and others dislike.

Investigations involving raw milk and conducted over an entire year are therefore more pertinent to the issue of possible compositional changes. One such study was conducted by Toledo *et al.* (2002), who investigated the composition of raw milk from sustainable production systems in Sweden. Raw milk samples from 31 organic dairy farms in Sweden were collected once a month for 1 year. The samples were analysed for gross composition, SCC, fatty acids, urea, iodine and selenium. As a reference, milk composition data from similar conventional farms were obtained. The results showed small or no differences in the investigated parameters between organic milk and the milk from the conventional farms or average values regarding gross composition of Swedish raw milk. The only significant differences found were in urea content and SCC, both of which were lower in organic milk. In addition, levels of selenium (but not iodine) were lower in organic milk, which is of nutritional importance since dairy products are significant dietary sources of selenium in Scandinavian diets.

Ellis *et al.* (2006) reported on a comparison of the fatty acid composition of organic and conventional milk based on samples taken from bulk collection tanks in the UK. The investigation lasted 12 months and involved 17 organic and 19 conventional dairy farms. All milk samples were analysed for fatty acid (FA) content and the effects of farm type, herd production level and nutritional factors affecting the FA composition were examined. Included in the FA analyses were saturated fatty acids, the ratio of PUFA to monounsaturated fatty acids, total n-3 FA, total n-6 FA, conjugated linoleic acid and vaccenic acid. The ratio of n-6:n-3 FA was also compared. The results showed that organic milk had a higher proportion of PUFA to monounsaturated fatty acids and of n-3 FA than conventional milk, and contained a consistently lower n-6:n-3 FA ratio compared with conventional milk. There was no difference between organic and conventional milk with respect to the contents of conjugated linoleic acid or vaccenic acid. A number of factors other than farm type were identified as affecting milk FA content, including month of year, herd-average milk yield, breed type, use of a total mixed ration and access to fresh grazing. It was concluded that organic dairy farms in the UK produce milk with a higher average content of PUFAs, particularly n-3 FA, throughout the year.

Hermansen *et al.* (2005) compared the contents of major and trace elements in organically or conventionally produced milk in Denmark over a 12-month period. Concentrations of aluminium, copper, iron, molybdenum, rubidium, selenium and zinc were within the range of published values. Concentrations of arsenic, cadmium, chromium, manganese and lead were lower, and concentrations of cobalt and strontium were higher than published ranges. Organic milk had a slightly lower content of calcium (1.16 versus 1.17 g/kg), phosphorus (1.06 versus 1.10 g/kg) and magnesium (1.06 versus 1.10 g/kg) but the differences were not significant statistically, Organic milk contained a significantly higher concentration of molybdenum (48 versus 37 ng/g) and a lower concentration of barium (43 versus 62 ng/g), europium (4 versus 7 ng/g), manganese (16 versus 20 ng/g) and zinc (4400 versus 5150 ng/g), respectively. The data included concentrations of the following trace elements in milk, for which no or very few data are available: Ba, Bi, Ce, Cs, Eu, Ga, Gd, In, La, Nb, Nd, Pd, Pr, Rh, Sb, Sm, Tb, Te, Th, Ti, Tl, U, V, Y and Zr.

Vicini *et al.* (2008) carried out a study to compare the composition of whole organic milk, milk labelled 'rbST-free' (i.e. free from recombinant bovine somatotropin) and regular milk purchased at the retail level. Samples (total 334, pasteurized) of all three types of milk were collected from all 48 contiguous states in the USA and tested for bacterial counts, antibiotics, fat, true protein, solids-non-fat and hormone content. The study found minimal differences among the three types of milk (Table 6.8). Conventional milk had a slightly lower bacterial count than organic or rbST-free and lower levels of oestradiol and progesterone than organic milk. There were no differences in the level of bovine somatotrophin (bST) in the three milks. Approximately 82% of the somatotrophin values were less than the limit of quantitation (0.033 ng/ml) and 72% were less than the limit of detection (0.010 ng/ml) for the assay. Levels of insulin-like growth factor-1 (IGF-1) were similar in conventional milk and rbST-free milk, and a little lower in organic milk. Organic milk had a 2.3% higher protein content than the other two types of milk, a statistically significant effect. The researchers speculated that this effect might be due to breed, Jerseys being more common than Holsteins on organic farms. However, this explanation is not supported by the similar fat contents of the milks. Jersey milk is usually much higher in fat content than Holstein milk. Another possible explanation put forward was that production is usually lower on organic dairy farms. Antibiotics were not detectable in any of the milk samples. As a result of the findings the researchers concluded that conventional, rbST-free and organic milk were similar in composition.

Table 6.8. Average concentrations of nutrients, hormones and bacterial counts in retail milk from conventional, rbST-free and organic dairy production systems (Vicini *et al.*, 2008).

	Production system		
	Conventional	rbST-free	Organic
Bacterial counts (1000 cfu/ml)	11	26	22
Composition			
Fat (g/kg)	33.0	33.8	33.8
Lactose (g/kg)	47.1	47.0	46.7
Protein (g/kg)	31.4	31.5	32.2
Total solids (g/kg)	120.7	121.6	122.0
Solids-not-fat (g/kg)	87.7	87.7	88.2
Hormone contents			
Bovine somatotrophin (ng/ml)	0.005	0.042	0.002
Insulin-like growth factor-1 (ng/ml)	3.12	3.04	2.73
Progesterone (ng/ml)	12.0	12.8	13.9
Oestradiol (pg/ml)	4.97	6.63	6.40

Średnicka-Tober *et al.* (2016) reported the results of meta-analyses based on 170 published European studies comparing the nutrient content of organic and conventional bovine milk. No significant differences in total saturated fatty acid (SFA) and monounsaturated fatty acid (MUFA) concentrations were found. However, statistical analyses showed higher concentrations of total PUFA and n-3 PUFA in organic milk, by an estimated 7% and 56%, respectively. Concentrations of α-linolenic acid (ALA), very long-chain n-3 fatty acids (EPA + DPA + DHA) and conjugated linoleic acid were also found to be higher in organic milk, by an estimated 69%, 57% and 41%, respectively. It was concluded that organic bovine milk has a more desirable FA composition than conventional milk. The analyses also showed that organic milk has significantly higher α-tocopherol and Fe, but lower I and Se concentrations. The differences in composition were considered to be due mainly to the higher grazing/conserved forage intakes in organic systems.

In an invited commentary Givens and Lovegrove (2016) reported several concerns over how the above data had been analysed and presented. A key concern was the use of mean percentage change as the principal measure of differences between the milk types, since this often implies a greater change than is nutritionally relevant. Moreover, the values reported for milk FA concentrations were in the milk fat fraction and were not reported in the whole milk, which can be misleading. They also considered it unfortunate that data on the actual concentrations of nutrients were only available in online supplementary tables and not in the main text. Presentation of the results in this manner had, in their opinion, led to considerable misinterpretation by the media.

The possible presence of contaminants and chemical residues in organic milk was investigated in an Italian study (Ghidini *et al.*, 2005). The study involved 12 (six conventional, six organic) farms, with one milk sample (1000 ml) taken per month from the farm tank. The researchers were careful to couple each organic farm with a conventional one within a range of 2 km in order to cover the same production area. All farms had between 80 and 150 lactating cows. Analyses were conducted for organochlorine pesticides, polychlorinated biphenyls (PCBs), lead, cadmium and mycotoxins in both organic and conventional milk. It was found that the concentrations of pesticide and PCB residues were lower than the legal limits in both organic and conventional milk and that concentrations of lead and cadmium residues were very low and did not differ between organic and conventional milks (1.85 versus 1.68 and 0.09 versus 0.16 μg/l, respectively). Concentration of the mycotoxin aflatoxin M1 was significantly higher in some samples of organic milk than in conventional milk, possibly due to factors other than organic production. A total of 49% of the organic samples had concentrations of aflatoxin M1 above the legal limit of

50 ng/l set by EU Regulation 466/2001. The average value for this mycotoxin in organic and conventional milk was found to be 35 and 21 ng/l, respectively.

The possibility that synthetic antioxidants added to feedstuffs to prevent rancidity can be transferred to milk was investigated by Pattono *et al*. (2009). In this investigation, samples of conventional ($n = 11$) and organic ($n = 81$) milk, both raw and heat-treated, were analysed for the presence of synthetic antioxidants (butylated hydroxytoluene, butylated hydroxyanisole, dodecyl gallate, propyl gallate and octyl gallate) to verify whether those labelled as 'organic' complied with EU regulations on the use of additives in such products. The analysis detected only the antioxidant BHT and its aldehyde BHT-CHO in all 11 conventional milk samples and in 18 of 81 organic milk samples. The investigation highlighted the importance of strict control of organic dairy production, since synthetic antioxidants added to feedstuffs to prevent rancidity can be transferred to milk.

All of the above studies indicate that small differences in composition occur between bovine milk produced organically and conventionally. These differences relate to the high intake of forage by the cows, which is a key component of organic dairy production. From a nutritional aspect the results on the differences in fat components will be of greatest relevance to consumers of high intakes of full-fat milk and high-fat milk products.

Any mineral deficiencies in the soil or forage will be reflected in the milk composition. As Schwendel *et al*. (2015) stated in an invited review on factors influencing milk composition, 'controlled studies investigating whether differences exist between organic and conventionally produced milk have so far been largely equivocal due principally to the complexity of the research question and the number of factors that can influence milk composition'. As they pointed out, the factors influencing milk composition (e.g. diet, breed and stage of lactation) have been studied individually, whereas interactions between multiple factors have been largely ignored.

Sensory attributes

The sensory attributes of organic milk have also been investigated in a few studies. Among the dietary factors known to have effects on the taste, flavour and aroma of milk are the presence of legumes in the feed. Organic diets are therefore likely to affect the sensory properties of milk. For example, Bertilsson *et al*. (2002) compared the effects of feeding red clover, white clover, lucerne and grass silages to dairy cows and reported that the presence of legumes in the diet, particularly red clover, had a negative effect on the organoleptic quality of milk. Al-Mabruk *et al*. (2004) found increased oxidative deterioration of milk produced from cows fed red clover silage. Mogensen *et al*. (2010) reported that milk from cows fed a diet containing toasted field beans and a high content of maize had a sour feed odour, a bitter taste and a reduced fatty mouth-feel. In comparison, milk from cows fed a high amount of maize and untreated field beans had a higher sugar-sweet taste and fatty mouth-feel and a lower astringent aftertaste and creamy flavour.

The sensory properties of milk are known also to be greatly influenced by the fat content of the milk; therefore the most meaningful tests are those conducted on whole milk in the raw (unpasteurized) state.

Flavour and taste

In a review of factors affecting milk composition, Schwendel *et al*. (2015) found that organic milk is associated not only with the image of being safe and environmentally friendly, but also with being more flavourful than conventional milk. The flavour of milk from cows fed different amounts of concentrate and pasture has been examined in several studies, with no difference in consumer acceptance reported. No detectable difference in taste was established between organic and conventional milk, but organic milk was found to be creamier and with a greater intensity of grassy flavour. Schwendel *et al*. (2015) also reported that the temperature at which the milk was tested (7 versus 15°C) affected the intensity of specific flavours, the explanation being the increased volatility of flavour compounds at higher temperatures. Among the other findings of the review were that a lower concentration of fat in organic milk in spring was related to a loss in flavour; that trained panellists were not able to differentiate between plain yogurts of different fat contents or milk varieties (organic versus conventional); and that consumers did not distinguish between odour and taste of yogurt produced from organic and conventional milks, but that the most-liked conventional yogurt scored higher when it was labelled as organic.

Consumer attitudes

Organic production is largely consumer driven; therefore it is important to take into account consumer attitudes when selecting the appropriate breeds and strains for organic beef and milk production.

One of the most striking consumer trends in recent years has been the increasing demand for natural and healthy foods where also ethical issues (animal welfare and health) are taken into consideration. Safety has also become a very important issue of concern in modern food production, prompted by concerns about hormones, bovine spongiform encephalopathy, antibiotics, dioxin contamination of feed, etc. A review by Yiridoe *et al*. (2005) found that food safety and nutritive value were rated as very important factors by 80% of consumers. Consumers who usually buy organic food tended to be more concerned about food safety and nutritive value than price.

The published literature on factors influencing consumer choice of organic milk is limited. Part of the reason for this may be that milk is a much more uniform product than beef. Milk has to be marketed to the public largely through milk boards, which ensure that the product is heat-treated to ensure its safety from microbial diseases for the human consumer. The process may also remove some of the fat.

Hill and Lynchehaun (2002) found that the main reasons stated for buying organic milk were health, better taste and because it was felt to be better for the environment. The health issue was more pronounced in families with children in the household. Consumers also perceived organic food to be more nutritious than conventional food. Price was the primary reason mentioned by consumers for not purchasing organic milk, as it was perceived to be quite expensive. The organic milk in that study was about 25% higher in price than standard milk. Mixed opinions were expressed about whether organic milk tasted different from conventional milk. Some organic consumers purchased organic milk because it tasted nicer. Others did not like the taste. Therefore lack of improved taste was identified as the second main reason after price for not buying organic food.

These researchers concluded that there was a lack of consistency among consumers about the taste of organic milk. In support of this conclusion they cited a report in *The Times* of London (Young, 2000, cited in Hill and Lynchehaun, 2002) on organic and non-organic milk:

> A blind triangle test was carried out on organic semi-skimmed milk and ordinary semi-skimmed milk. Confronted with two [*surely this should be three? – RB*] glasses, no one could confidently identify the odd one out.

In the USA many of the consumers who purchase organic milk do so to avoid milk from cows treated with recombinant bovine growth hormone (rBGH) (also called bovine somatotrophin, or bST) (Dhar and Foltz, 2005). For these consumers the other attributes are secondary. The product (bST) has been approved for use in some 20 countries, including the USA, Mexico, South Africa and some European countries, but not in Canada, most of Europe, Australia, New Zealand or Japan.

Consumer preference for organic milk has also been analysed in other studies. Wang and Sun (2003) analysed the purchase of organic milk and apples in Vermont (USA) and found that price and location were important determinants of purchasing decisions by consumers. Dhar and Foltz (2005) used the preferences of US consumers to study the consumer benefits from organically labelled and rbST-free milk. They found significant consumer preferences for organic milk and, to a lesser extent, rbST-free milk. Results from Japan indicated that public perceptions of safety of organic milk, better taste, an environmentally friendly production process, and health and comfort of the cows are important factors influencing purchasing decisions by consumers. Price was identified as a key inhibitor of consumer demand for organic milk, especially among older consumers (Managi *et al*., 2008).

Results of taste tests are not clear-cut in that some organic milk is subjected to ultra-high heat treatment (UHT). The UHT process involves heating the milk to 138°C for 2–4 s, killing all organisms. This can mask the taste of the initial product. Some consumers like the taste of UHT milk; others do not. It is not clear from the results of the Japanese study (or from other studies cited above) whether the organic milk was UHT or not.

One test, in which UHT treatment did not complicate the design or findings, found that the preference for organic milk was lower than for conventional milk (Valverde, 2007). The objectives of this study were to characterize the flavour profile and sensory attributes of whole (non-defatted) milk from organic, pasture-based and conventional production systems using laboratory methods and consumer preference and discrimination tests. Most of the cows were Holsteins. All samples were commercially homogenized, pasteurized and bottled in glass containers except for one sample of organic milk and one sample of conventional milk, which were purchased raw directly from the farmer. Results of the consumer preference test are shown in Table 6.9.

Organic milk was significantly different from conventional milk and milk from pasture-fed cows for the attributes of overall liking, overall flavour, overall mouth-feel and also from milk from pasture-fed cows, but not conventional milk, for overall appearance. From the results, the researchers concluded that panellists clearly differentiated organic milk from conventional milk and from milk from pasture-fed cows for their liking, whereas distinction between conventional milk and milk from pasture-fed cows was only achieved for appearance. Organic milk was the least liked among the samples, whereas conventional milk and milk from pasture-fed cows were rated similarly. One possible reason suggested for the low scores received by organic milk was the feed used.

A triangle test was also used to determine whether consumers could discriminate between samples of milk from the three production systems. A total of 30 untrained panellists evaluated the milk samples in three consecutive sets of triangle tests. The sample combinations in the triangle tests were: organic milk versus conventional milk; organic milk versus milk from pasture-fed cows; and conventional milk versus milk from pasture-fed cows. A significance level of $P = 0.01$ was chosen for this test. Based on using 30 panellists, more than 17 would have to select correctly the sample that was different to establish significance. The results are shown in Table 6.10.

According to the results shown in Table 6.10, consumers were able to discriminate significantly

Table 6.9. Average consumer assessment[a] of milk from cows fed organically, conventionally or on a pasture-based system (Valverde, 2007).

	Overall liking	Overall flavour	Overall appearance	Overall mouth-feel
Organic	4.67[b]	4.48[b]	5.34[b]	4.92[b]
Pasture-based	5.72[a]	5.71[a]	5.87[a]	5.91[a]
Conventional	5.84[a]	5.94[a]	5.67[b]	5.82[a]

[a]On a scale of 1–9: 1, dislike extremely to 9, like extremely.
ab Means within a column with different superscripts are significantly different at $P < 0.05$.

Table 6.10. Ability of consumers to discriminate between samples of milk produced by cows fed organically, conventionally or on a pasture-based system (Valverde, 2007).

	Tests		
Samples	Organic versus conventional	Organic versus pasture-based	Pasture-based versus conventional
Incorrect	10	12	17
Correct	20*	18*	13
Total	30	30	30

*significantly different at $P < 0.01$.

between organic and conventional milk, and between organic milk and milk from pasture-fed cows. They were not able to discriminate between conventional milk and milk from pasture-fed cows. These results were in accordance with the results of the taste test, indicating that organic milk was perceived as milk with lower consumer attributes than milk from pasture-fed cows and conventional milk. No explanation was provided for this finding. Conventional milk and milk from pasture-fed cows received similar scores. The results indicated that there were significant differences among milks from the three different production systems, based on analytical, sensory and discrimination studies. In assessing the value of these findings it should be noted that, although published in a graduate research thesis, the work has not yet been published in a peer-reviewed journal.

Croissant *et al.* (2007) compared the chemical properties and consumer perception of fluid milk from conventional and pasture-based production systems. Although not a study involving organic milk, it yielded useful information on the effects of a high intake of pasture by cows on the sensory properties of the milk. Fluid milk was collected throughout one growing season from Holstein and Jersey cows located in two herds, one fed a pasture-based diet and one fed a conventional total mixed diet. Milk was batch-pasteurized and homogenized. Instrumental and sensory analyses differentiated the two types of milks, related to a higher concentration of unsaturated fatty acids (including two common isomers of conjugated linoleic acid) in the milk from pasture-based cows. Trained consumer panellists reported a greater intensity of grass and cow/barn flavours in milk from pasture-based cows than in milk from cows fed the total mixed diet, when evaluated at 15°C. Volatile compound analysis by solid-phase micro-extraction and gas chromatography–mass spectrometry separated the two types of milk. However, analyses showed no compounds unique to either sample: all identified compounds were common to both samples. Consumer panellists were unable to differentiate consistently between the two types of milks when evaluated at 7°C, and cow diet had no effect on overall consumer acceptance. These results indicated distinct flavour and compositional differences between milk from cows fed a pasture-based diet and from those fed a conventional total mixed ration, but the differences were such that they did not affect consumer acceptance by consumer panellists.

The findings from the literature allow us to come to several conclusions. Some consumers are willing to pay higher price premiums for organic products. For example, Millock *et al.* (2002) reported that 59% of respondents in Denmark were willing to pay a price premium of 32% for organic milk, 41% indicated a willingness to pay 40% extra for organic potatoes, 51% were willing to pay a price premium of 23% for organic rye bread and 41% indicated they would pay 19% extra for minced organic meat. Also, the proportion of respondents willing to pay a price premium decreased as the premium level increased.

The overall conclusion of the above findings is that there is a definite consumer demand for organic milk; Some consumers like the taste of organic milk, others do not. The amount of heat used during the processing of organic milk is likely to be a factor influencing the preference for the taste. However, the sale of raw (unpasteurized) milk to the public is not advised unless produced under strict veterinary guidelines, because of the risk of bacterial contamination. Some countries ban the sale of unpasteurized milk to the public because of the disease risk. The higher cost of organic milk is a deterrent to some consumers.

The logical application of these findings by the organic dairy industry is to find ways of increasing the amount of organic milk available at a price closer to that of conventional milk, and to determine which components in the organic production system result in milk flavours that are unattractive to some consumers.

Beef Cattle

As in organic dairying, the aim of organic beef farming is to optimize the available resources on the farm rather than to maximize the output of meat. Forage is the main feed of beef cattle and much of the requirement for energy and protein can be provided by rangeland and pasture. Hay and silage can be used when weather conditions restrict grazing. The organic regulations require that at least 60% of the feed DM must be supplied by forage produced on the farm itself. Some organic producers feed even higher levels, in some cases providing forage as the sole feed. Such a level may be suitable for low-production stock provided it is supplemented with necessary minerals and vitamins.

In addition, the proportion of concentrates in the diet is restricted to 40% on a daily DM basis. Low-quality pastures can be used but, in view of their influence on methane production in the animals (see Environmental Aspects later in this chapter), the quality should be improved where possible.

The objective with breeding herds of organic beef animals is a high production of strong calves; therefore calving at the start of the forage growing season is the preferred system. The peak requirement for nutrients is then matched by the availability of high-quality forage.

Younie and Mackie (1996) showed that efficient beef production can be obtained in an organic system, provided the forage quality is good (Table 6.11).

Factors influencing the choice of breed include the size of the breeding herd and the length of the grazing season (Younie, 2001). For example, in small herds in northern Europe it is common to use a pure-bred dam such as Angus and to adopt a pure pedigree breeding policy. In this environment a cow of small to medium mature size is better able to maintain itself on grass alone and to cope with a relatively short grazing season. This fits with the organic philosophy of selecting breeds well adapted to the environmental conditions of the farm. Ease of calving, satisfactory temperament, proportionate milk production and the production of a premium beef animal are also significantly attractive traits, as is natural polling, particularly in a low-input labour situation. Other breeds may meet many or possibly all of these objectives, but the Angus has performed well in these conditions (Younie, 2001).

Cross-breeding gives advantages from hybrid vigour and allows greater biological efficiency by using a larger crossing sire on to the smaller Angus. However, this reduces the opportunity to increase herd size and achieve genetic progress, and potentially to sell breeding stock. Once the herd has achieved a target size of 200 cows, a terminal sire of another breed such as Hereford or Simmental may be selected for breeding to poorer females (Younie, 2001). Cross-bred cows benefit from hybrid vigour, particularly in enhanced milk production. In addition to its genetic suitability to a grass-based organic system, the Aberdeen-Angus breed has a high-quality image which complements the organic brand image.

On some farms in north-east Scotland a March–April calving programme has been adopted to take maximum advantage of the seasonal cycle. Calving in spring has several notable advantages for organic beef production (Younie, 2001), as follows.

- For a herd wintered outside, spring calving ensures that all animals carried into winter are approximately 6 months old at least and better able to withstand harsh weather.
- Cows approach calving at the period of the year when they are at their leanest, thus reducing dystocia problems.
- Incidence of excess milk production is reduced.
- Fly problems do not exist, reducing the incidence of mastitis.
- Calving can take place outdoors with reduced risk of severe weather (although with a greater risk than summer calving).

Table 6.11. Comparison of the growth performance of Hereford × Friesian steers in organic and conventional (intensive) 18-month beef systems (Younie and Mackie, 1996).

	Production system	
Output (animal basis)	Organic	Conventional
Daily live weight gain (kg)	0.84	0.86
Age at slaughter (months)	17.5	17.1
Weight at slaughter (kg)	499	497
Carcass weight (kg)	267	268
Stocking rate (number/ha)	3.42	4.46
Live weight gain (kg)	1481	1921

- Cows meet spring grass peak growth rates at their lowest body condition and an increasing demand for milk from the calf. This makes them very efficient biologically.
- A peak milk yield on grass alone is achieved at peak grass productivity, thus maximizing annual lactation yield.
- Fertility is maximized by a rising plane of nutrition.
- Calves begin grazing when grass productivity, quality and palatability are high.
- Cows can lay down significant body reserves during the latter part of the grazing season, assisting body heat insulation and reducing winter feed requirements.
- Weaning takes place around late December to late January. The date of weaning is related to fine-tuning of dam body condition, thus leaving an independent calf well able to cope with a forage diet.
- Weaned calves approach their second grazing season with good frames and moderate to thin body condition, again allowing maximum use to be made of grazed grass. This permits sale of finished animals to take place from grazed grass alone in September–November.

Establishing a good grass cover in spring and withholding stock from grazing until the sward is ahead of future demand will pay very large dividends. At one of the university farms described by Younie (2001), stock in that area were turned out directly on to their main summer grazing at a fairly high stocking rate of about 3.5 cows/ha in May/June. There was no spring grazing of silage fields and the first cut was taken in late June, followed by a second cut in mid-August. All cows and calves were housed in late October, when the cows started to receive silage and mineral supplements, plus straw. Calves received a daily creep feed of 500 g organic grain, mineral supplement and seaweed meal. After weaning, the feeding rate of grain supplement was increased to 1 kg/head/day. In their second (finishing) winter, cattle were fed silage to appetite plus 2–3 kg/day of organic grain plus a mineral supplement. For finishing heifers, grain feeding might be delayed or reduced in order to avoid finishing too early at light carcass weights or at high fat cover. No purchased protein feedstuffs were fed to either cow, calf or finishing animal. Total grain consumption per head was 120 kg for calves in their first winter and 325 kg for finishing animals.

Cow herd

It is convenient in planning a feeding regimen to divide the reproductive production cycle into four periods.

First trimester of pregnancy

Nutrients are needed for maintenance (and lactation if the cow has a calf). Factors influencing the requirements include breed, body weight, milk yield and milk composition. Body condition should be monitored and supplementary feed provided if required. The cow usually nurses a calf throughout this trimester. The trimester ends when the calf is weaned. Creep feeding is commonly practised with conventional production but is less common in organic production. It is advised if the cows are not producing enough milk and calf growth is inadequate. One benefit of creep feeding (apart from improved calf growth) is that the cows are more likely to rebreed more quickly and require less feed to rebuild body reserves. Another is that the calf crop is more likely to be uniform in weight and that post-weaning weight loss is more likely to be reduced following creep feeding. However, heifers that are to be kept as replacements are usually not creep fed. When practised, creep feeding usually starts when the calves are about 3 weeks old. The creep feeder should be located close to water, shade and salt box. Only a small amount of creep feed should be placed in the feeder until the calves start to eat. This is to ensure freshness.

In situations requiring it, grazing cattle should have access to a mineral supplement in the form of loose mineral or a block. A high level of salt or other substance can be included to limit consumption, if acceptable under the local organic regulations.

Second trimester

At this stage, the calf is weaned and lactation ends. This is the period of lowest nutrient needs. Body condition should continue to be monitored and supplementary feed provided if required.

This is the period when it is easier to make adjustments to the cow's body condition. Body condition scoring (BCS) is used to assess the amount of energy reserves in the form of fat and muscle of beef cows. The scores used in North America range from 1 to 9, with a score of 1 denoting an extremely thin animal and 9 denoting a very obese animal. Areas such as the back, tail head, pins, hooks, ribs and brisket of beef cattle can be used to determine BCS. Cows should calve with a BCS score between 5 and 7. Ideally, cows should achieve this score by the end of the second trimester and be managed to maintain it throughout the third trimester.

Third trimester

During this phase, nutrient needs are increasing rapidly due to fetal growth. Body condition has to be monitored to prevent cows becoming too fat or too thin. Failure to meet the cow's nutrient needs at this time may result in a reduced percentage calf crop: fewer of the brood cows will successfully produce a live and healthy calf. It may also result in a cow that has difficulty rebreeding. In a spring-calving programme, the third trimester coincides with the winter season. Cold weather will increase the energy needs and supplementary feeding of hay or silage may be required. First-calf heifers will be lower in dominance and will probably receive an inadequate amount of a hand-fed supplement unless fed separately from the cows. The third trimester ends at parturition.

Post-calving period

During this period, lactation needs are high and the reproductive system is recovering from parturition. Adequate forage supplies need to be available at this time. Peak milk production is around 5–12 kg/day, depending on breed, and the lactation period is around 175–200 days. Feed intake is 35–50% higher than in non-lactating animals. Good pasture together with a mineral supplement should provide all of the required nutrients. If pasture quality is poor a supplement of silage or hay is beneficial. Lucerne hay or silage is a good choice when the protein content of the forage is low.

It is important to achieve conception in cows by 80 days post-calving in order to maintain a 12-month calving interval. Cows calving with a BCS of less than 4 are likely to have a delay in onset of first oestrus following calving, increasing the time required for rebreeding. Cows, and particularly heifers, receiving an inadequate intake of nutrients during pregnancy have a poor reproductive performance overall. On the other hand, cows calving with a BCS over 7 are likely to have a reduced conception rate.

The forage should be managed so that it is of high quality. Mature forages and low-quality hays are likely to result in a protein deficiency and poor reproduction. The dietary crude protein should be more than 70 g/kg. An adequate water supply needs to be provided.

It follows from the above that the most important period in terms of nutrient needs is from 30 days before calving until 70 days after calving. Another important finding is that cows gaining weight just before and during the breeding season have a shorter period between calving and first oestrus and tend to have high conception rates.

In North America it is common to have either a spring (March–April) or autumn (September–October) calving. This avoids periods of very hot or very cold weather. The feeding programme can then be devised accordingly. Most producers favour spring calving, for the reasons outlined above by Younie (2001).

To achieve these goals, lactating beef cows need to receive sufficient nutrients in order to provide adequate milk to support calf growth. If the feed resources are inadequate, e.g. pasture quality is poor, the cow may be unable to produce sufficient milk for good calf growth. In this case, creep feed may be required for the calves. The composition could be similar to that described above by Younie (2001) or provided as hay, cracked grain or a mixed feed of 900 g grain/kg, 50 g molasses/kg and 50 g of a protein feedstuff/kg such as soybean meal.

Weaning of the calves from their dams generally takes place when the calves are 6–9 months of age.

Breeding herd replacements

Nutritional management of replacement beef heifers was reviewed by Bagley (1993). It is recommended that heifers to be kept as herd replacements be fed and managed separately from the cows. This is to ensure that they receive adequate amounts of feed and grow uniformly to reach puberty in time to breed at 13–15 months of age. Typically puberty is reached when the animals reach 60% of their mature body weight (dual-purpose breeds reach puberty slightly earlier, at 55% of their mature body weight). Calving is then at 22–25 months of age. In addition to the nutrient demands of pregnancy, heifers require nutrients for growth so that they attain 85% of mature body weight at calving. Where the forage is deficient in certain trace elements, the deficiency should be remedied by providing the necessary nutrients in the form of a supplement, feed blocks or mineral licks, as with dairy herds.

Research conducted at the Agriculture Canada Research Station, Lethbridge, indicated that the feeding of high- versus medium-energy diets to young British-type beef breed bulls (Hereford and Angus) is detrimental to their reproductive capacity (Coulter and Kozub, 1984). The high-energy diets consisted of 80% concentrate (barley, 60%; oats, 10%; beet pulp, 10%) and 20% forage (lucerne or lucerne–straw (70:30) cubes), while the medium-energy diet was forage alone. Bulls were fed either high- or medium-energy diets from weaning until slaughter at 12, 15 or 24 months of age. At slaughter, sperm production by the bulls was estimated by epididymal sperm reserves. In most cases, regardless of age, bulls fed high-energy diets had substantially reduced reproductive potential compared with bulls fed medium-energy diets. Along with a reduction in sperm reserves, quality of semen and the libido of bulls fed high-energy diets were reduced. In addition to the detrimental influence on reproductive traits, it would be expected that bulls fed high-energy diets would have a much greater probability of developing foot and leg problems and consequently a reduced longevity. Very little comparable research has been conducted on bulls of Continental breeds. Results of a study conducted at Kansas State University showed no effect, on either seminal characteristics or breeding capacity, of feeding three different levels of energy to Hereford and Simmental bulls from weaning for a period of 200 days followed by grazing for 38 days (Pruitt *et al.*, 1986). However, it should be noted that Hereford bulls in this study fed the lowest of three levels of energy had back-fat thicknesses similar to bulls of the same breed and comparable age fed the high-energy diet referred to earlier in the Lethbridge Research Station study.

A 3-year field trial conducted by the Lethbridge Research Station was designed to assess the effectiveness of different criteria used to evaluate the reproductive capacity of young beef bulls used for multiple-sire natural service under range conditions (Coulter and Kozub, 1989). Several measurements, including back-fat thickness, were taken immediately before the breeding season. A total of 277 bulls representing five composite 'breeds' of cross-bred bulls were included in the analysis. Bulls were composed of Brown Swiss, Charolais, Chianina, Gelbvieh, Limousin, Romagnola and Simmental breeds. Bull fertility was determined by blood-typing calves to determine their paternal parent. The mean back-fat thickness of all bulls was 1.5 + 0.07 mm (range 0–7 mm). There was a highly significant negative contribution of back-fat thickness to bull fertility, indicating that, as back-fat thickness increased, bull fertility decreased. As a result of this finding it is now recommended that cattle ranchers select bulls with minimum back-fat thickness, in order to optimize reproductive capacity.

Market animals

Weaned calves not kept as breeding herd replacements are grown to market weight as meat animals. The simplest system is to pasture the cattle during the grazing season and to feed them preserved forage during winter. Rotational grazing systems can be used to maximize grass production and minimize infection from internal parasites. After weaning it is common for organic cattle at this stage to receive some cereal grain such as oats or barley over the winter period (e.g. 0.5 increasing to 1 kg/head/day) in addition to silage or other preserved forage. In their second (finishing) winter, cattle which receive cereal grain and a mineral supplement in addition to silage fed to appetite are more likely to achieve high grades at slaughter than when forage-feeding only is allowed. In general, animals fed exclusively on forage have to be taken to a higher market weight to achieve good grades.

As stated previously, organic farms with the ability to manage several breeds can obtain the benefits of milk and meat production by the use of cross-breeding. This system takes advantage of heterosis (hybrid vigour). An example would be a Jersey cow mated to a Hereford bull. The female offspring would be mated to a third beef breed such as an Angus. All the offspring would be raised for meat.

Quality of Organic Beef

The feeding system has a main influence on beef quality, in addition to breed and age/weight at slaughter. In general, organic beef carcasses contain less fat and the composition of the beef lipids reflects the fatty acid composition of the diet.

Beef quality is assessed mainly in two ways: grade and eating quality. The payment grade of beef carcasses in North America is determined primarily by estimates of lean meat and fat contents. For example, beef graded as Prime by the US Department of Agriculture has more marbling (fat within the meat). However, it is higher in fat content. The qualitative traits of beef, such as colour, tenderness and flavour, are not taken into account in setting the payment grade. Inspection of slaughtered animals is mandatory in the USA, but grading is voluntary. The payment grade achieved by organic beef carcasses often underestimates their commercial value, because they contain a lower level of fat than conventionally raised beef animals.

A main effect of forage feeding on beef composition is to alter the fatty acid composition, influencing both the nutritive value of beef and the organoleptic properties, in particular flavour. Several investigations have been carried out to compare the quality of beef produced in a parallel manner to conventional beef but with organic cereal grains and other feedstuffs substituted for conventional feedstuffs. These studies are of less interest to organic producers who wish to maximize the use of forage in the production of beef animals.

Composition

French *et al.* (2001) conducted a study that covered the extremes of a diet based on forage alone, to one based on concentrate alone, and the effects on the growth rate and meat quality of steers. In this study, Limousin and Charolais cross-bred steers of 567 kg initial body weight were allotted to one of six dietary treatments: (i) 18 kg grass (DM basis); (ii) 18 kg grass (DM) and 2.5 kg concentrate; (iii) 18 kg grass (DM) and 5 kg concentrate; (iv) 6 kg grass (DM) and 5 kg concentrate; (v) 12 kg grass (DM) and 2.5 kg concentrate; or (vi) concentrates only. The grass allowances were achieved by varying the size of the grazing area. Animals were offered a fresh grass allowance daily and did not have access to the previous day's allowance. Grass intake was estimated by dosing the animals with gelatine capsules containing a marker and analysis of the faeces, which were collected twice daily. The grass contained DM 198, CP 225, ash 125, DM digestibility 738, crude fibre 287 and ether extract 29 g/kg DM. The corresponding values for the concentrate were 872, 143, 48, 843, 101 and 24 g/kg. Animals were slaughtered after an average of 95 days. Samples of the longissimus dorsi were collected at the eighth to ninth rib interface and subjected to sensory analysis by a taste panel and to other assessments of quality following 2, 7 or 14 days of ageing. The results are shown in Table 6.12.

The results showed that carcass weight gain was markedly affected by diet, averaging 360, 631, 727, 617, 551 and 809 g/day for treatments (i) to (vi), respectively. As a result the animals fed the all-grass diet weighed less and the animals fed the all-concentrate diet weighed more at the end of the 95-day period. Fat score and intramuscular fat content were significantly higher in the animals fed all-concentrate, but did not differ in the other treatment groups. Muscle moisture content was also significantly lower in the animals fed all-concentrate. No significant differences were found for the effects of dietary treatment on other measures of meat quality, these being affected mainly by ageing of the beef after slaughter. The authors concluded that high carcass growth can be achieved on an all-grass diet without affecting meat quality. Other researchers have reached a similar conclusion, with Razminowicz *et al.* (2006) reporting that the year-round feeding of forage products resulted in n-3 enriched beef which was at least as tender as conventional beef.

Table 6.12. Effect of diet on grass intake, carcass characteristics and meat quality of steers (French *et al*., 2001).

	Dietary allowances					
	18 kg grass (DM)	18 kg grass DM + 2.5 kg conc.	18 kg grass DM + 5 kg conc.	6 kg grass DM + 5 kg conc.	12 kg grass DM + 2.5 kg conc.	Conc. to appetite
Grass DM intake (kg/day)	10.67	7.72	7.78	4.49	6.78	0
Concentrate DM intake (kg/day)	0	2.25	4.50	4.50	2.25	13.3
Carcass weight (kg)	330	355	363	352	348	371
Carcass gain/day (g)	360	631	727	617	551	809
Fat score[a]	4.03	3.97	4.14	3.79	4.15	4.64
KCF[b] per carcass (g/kg)	24	26	28	25	22	29
Intramuscular fat (g/kg muscle)	23	24	29	23	25	44
Ash (g/kg muscle)	12	17	12	12	12	12
Moisture (g/kg muscle)	737	736	733	735	734	717
Protein (g/kg muscle)	225	227	224	226	228	226
Meat quality after 2 days' ageing						
Warner–Bratzler shear force	8.0	7.5	6.6	7.0	6.4	6.1
Cooking loss (%)	30.0	29.5	28.7	29.3	29.1	29.8
Tenderness[c]	3.5	4.2	4.5	4.0	4.8	4.4
Texture[d]	2.9	3.2	3.3	3.1	3.2	3.3
Flavour[e]	3.5	3.6	3.7	3.8	3.6	3.7
Juiciness[f]	4.8	5.2	5.3	5.2	4.7	5.2
Chewiness[g]	4.2	3.7	3.7	4.0	3.6	3.9
Acceptability[h]	3.2	3.1	3.4	2.8	3.2	3.3

conc. = concentrate.
[a] 1 = leanest, 5 = fattest; [b] KCF, kidney plus channel fat; [c] 1 = extremely tough, 8 = extremely tender; [d] 1 = very poor, 6 = very good; [e] 1 = very poor, 6 = very good; [f] 1 = extremely dry, 8 = extremely juicy; [g] 1 = not chewy, 6 = extremely chewy; [h] 1 = not acceptable, 6 = extremely acceptable.

However, it is clear from the results that animals fed grass alone take longer to reach market weight. Producers wishing to apply these findings would therefore have to carry out an economic analysis of the inputs and outputs in order to arrive at an acceptable feeding schedule.

Russo and Preziuso (2005) reviewed findings in the scientific literature on the qualitative characteristics of carcasses and beef from cattle raised organically. According to their findings, carcasses of organically raised beef cattle are characterized by poor muscular development and reduced fat content. They attributed this to the fact that the diets are mainly based on forage, with low energy contributions from concentrates. Native breeds are preferred with this type of production system and are often characterized by rather slow development. These facts were suggested to explain why the findings reviewed showed that organic beef had a lower intramuscular lipid content than that generally found in meat from cattle raised conventionally. Another conclusion was that other organoleptic characteristics of the meat do not appear to be influenced by the organic rearing system. These conclusions are in general agreement with the findings of Younie and Mackie (1996) above.

The marbling of muscle is also influenced by breed. Dairy breeds deposit more intramuscular fat in relation to total fat while producing a leaner carcass than more traditional beef breeds. For instance, Zembayashi *et al.* (1995) concluded that Japanese Black cattle have a genetic predisposition for producing carcass lipids containing higher concentrations of MUFAs than Holstein, Japanese Brown or Charolais cattle. Choi *et al.* (2000) reported that Welsh Black (a traditional beef breed) deposited higher proportions of C18:3 n-3 and its metabolic products C20:5 n-3 and C22:5 n-3 in muscle phospholipids and higher proportions of C18:3 n-3 in muscle neutral lipids and adipose tissue than Holstein-Friesians even after the dietary intakes of n-3 PUFA were increased by feeding linseed or fish oil. Dinh *et al.* (2010) reported significantly greater concentrations of SFAs (26.67 mg/g), MUFAs (26.50 mg/g) and PUFAs (2.37 mg/g) in longissimus muscle from Angus cattle than in Brahman or Romosinuano cattle. These findings indicate a genetic variability in fatty acid synthesis and deposition among breeds that influences both marbling and its composition.

The appropriate choice of breed is therefore important in seeking to achieve a desired content of marbling in the meat.

As noted above, a main effect of forage feeding on beef composition is to alter the relative contents of fatty acids, and in general the composition of the beef lipids reflects the fatty acid composition of the diet. For example, beef can be a relatively rich source of n-3 PUFAs due to the presence of C18:3 in grass. A switch from a concentrate-based diet to pasture has been shown to increase the content of conjugated linoleic acid (CLA) in beef. This fatty acid is produced by rumen microorganisms and is considered to be desirable in the human diet, with anti-cancerogenic, anti-diabetic and anti-atherogenic effects as well as beneficial effects on the immune system, bone metabolism and body composition.

French *et al.* (2000) reported increasing CLA contents in the intramuscular fat of steers (longissimus dorsi muscle) with increasing intakes of grass. Levels of 5.4, 6.6 and 10.8 mg CLA/g were detected in grazing steers with increasing grass intake compared with 3.7 mg/g in animals fed concentrate. Grass silage also positively influenced CLA content (4.7 mg/g) but not to the same extent.

Adding oilseeds to the diet has been proved to be an efficient method to increase the CLA content in the muscle lipids. However, not all oilseeds exert the same effect. Casutt *et al.* (2000) supplemented the concentrate feed of Brown Swiss bulls with either sunflower, rapeseed or linseed meal, increasing the dietary fat content by 3%. Compared with the concentration of the subcutaneous fat in the control group (5.6 mg/g), the CLA in fat of the sunflower group was significantly increased (7.8 mg/g) whereas no changes were observed with linseed meal (5.5 mg/g) and in the rapeseed group the CLA content decreased (4.6 mg/g). The effect of added sunflower seed was confirmed in another study (Santos-Silva *et al.*, 2003). The inclusion of linoleic acid-rich oilseeds, such as safflower or sunflower, in the diet of ruminants appears to be most effective for increasing CLA concentration.

Compared with the CLA increase in milk fat with sunflower seed or soybean supplementation (Schmid *et al.*, 2006) the increase in the CLA content in meat with these supplements is relatively low.

Research on the quality of organic and conventionally raised beef purchased at retail outlets has also been conducted, for example Turner *et al.* (2015). In this study beef ribeye steaks were purchased at 16 retail grocery stores in western Canada. The samples included: Canadian conventional beef, representing the majority of beef available to consumers, and from animals typically finished on diets containing 70–90% DM barley; and beef from animals grown under alternative production systems, i.e. Canadian certified organic grain-fed (in which diets containing up to 40% DM grain can be fed), forage-fed organic grass and natural grass beef production systems.

The results (Table 6.13) showed that beef from organic-grass and natural-grass production systems was leaner, with greater proportions of desirable n-3 PUFA, a lower n-6/n-3 ratio and greater proportions of potentially beneficial MUFAs. Beef from animals fed on the organic grain system was fairly similar to that from animals fed forage-only diets, suggesting a preferable compromise between pure grass-fed and grain-fed production systems to retain a desirable FA profile while improving production efficiency. Trim fat was similarly affected by production system, but having a greater proportion of potentially beneficial MUFAs.

Ribas-Agustí *et al.* (2019) reported that organic beef purchased at retail outlets in Spain contained 17% less cholesterol, 32% less fat, 16% less fatty acids, 24% less monounsaturated fatty acids, 170% more α-linolenic acid, 24% more α-tocopherol, 53% more β-carotene, 34%

Table 6.13. Fat content and fatty acid profile of subcutaneous fat and trimmed retail ribeye steaks from conventional and niche market beef production systems (from Turner *et al.*, 2015).

Fatty acid profile	Conventional	Organic grain	Organic grass	Natural grass	Statistical significance
Subcutaneous trim fat					
mg fat/g tissue	814	793	797	786	NS
Total PUFAs	2.74	2.38	2.38	2.7	NS
Total n-3 FAs	0.29b	0.79a	1.02a	1.05a	$P < 0.001$
Total t-MUFAs	3.59	4.32	5.55	4.56	NS
Total c-MUFAs	43.2a	39.5ab	36.5b	35.8b	$P < 0.001$
Total SFAs	46.9	49.1	49.7	51.2	NS
PUFA/SFA	0.06	0.05	0.05	0.05	NS
Trimmed steaks					
mg fat/g muscle					
Total PUFAs	4.67b	5.79ab	7.05a	6.96a	$P < 0.01$
Total n-3 FAs	0.58c	1.66b	2.49a	2.15ab	$P < 0.001$
Total t-MUFAs	2.39	2.96	3.45	2.97	NS
Total c-MUFAs	44.1a	41.2ab	39.2b	39.1b	$P < 0.05$
Total SFAs	46.8	47.3	47.1	47.7	NS
PUFA/SFA	0.10b	0.12ab	0.15a	0.15a	$P < 0.01$

a–d Means within a row without a common letter differ significantly ($P < 0.05$).
PUFAs = polyunsaturated fatty acids.
t-MUFAs = *trans*-monounsaturated fatty acids.
c-MUFAs = *cis*-monounsaturated fatty acids.
SFAs = saturated fatty acids.

more coenzyme Q10 and 72% more taurine than conventional beef (Table 6.14). The differences between organic and conventional samples were dependent on muscle type, the longissimus thoracis (ribeye) and supraspinatus (mock tender) muscles showing different patterns of compound accumulation of these compounds. The researchers concluded that retail organic beef had a higher nutritional value than retail conventional beef, as a result of its better-balanced lipid and bioactive compound content.

A concern has been expressed by some food scientists that a high content of PUFAs in meat might result in a shorter shelf life (due to lipid and myoglobin oxidation) and reduced flavour because of the instability of these fatty acids. However, it appears that only when concentrations of α-linolenic acid (18:3) approach 3% of neutral lipids or phospholipids are there any adverse effects on meat quality (Wood *et al.*, 2003). In addition, grazing increased the content of antioxidants in beef, including vitamin E and β-carotene, which maintain PUFA levels in meat and prevent quality deterioration during processing and display (Van Elswyk and McNeill, 2014).

Few differences in other nutrients in grass-fed beef have been reported (e.g. Van Elswyk and McNeill, 2014; Cintra *et al.*, 2018), which were inconsistent and attributed mainly to the mineral status of the soils on which the forages had been grown.

Although the above findings are supportive of the quality of organic beef, Sundrum (2010) concluded that there was substantial variation in the quality of organic meat entering the marketplace. This was in spite of the fact that, although defined by specific and basic guidelines, organic livestock production is characterized by largely heterogeneous farming conditions that allow for huge differences in the availability of nutrient resources, the implementation of feeding regimes and the use of different genotypes. As a result, the quality of organic beef (and pork) was inconsistent and often fell short of expectations, since it was often similar in quality to conventionally produced meat. In some cases the organic guidelines appeared to play only a minor role with respect to meat quality. Another point made was that the commercial value of carcasses is determined primarily by lean meat and lean cut

Table 6.14. Content of nutrients and bioactive compounds in retail beef muscle from conventional and organic beef production systems (Ribas-Agustí *et al*., 2019).

Compound	Conventional beef	Organic beef	Statistical significance of difference
Moisture (g/kg)	707.5	734.3	$P < 0.001$
Fat (g/kg)	46.9	31.8	$P < 0.001$
Protein (g/kg)	217.5	215.0	NS
Collagen (g/kg)	12.0	14.5	$P < 0.05$
Total FAs (mg/kg)	28.59	24.01	$P < 0.05$
Total SFAs (mg/kg)	11.63	10.66	NS
Total MUFAs (mg/kg)	14.4	10.94	$P < 0.01$
Total PUFAs (mg/kg)	2.58	2.41	NS
Cholesterol (mg/kg)	712.2	590.3	$P < 0.001$
α-Tocopherol (μg/kg)	2.19	2.73	$P < 0.001$
β-Carotene (μg/kg)	0.39	0.60	$P < 0.05$
Coenzyme Q10 (μg/kg)	10.48	14.01	$P < 0.05$
Taurine (μg/kg)	347.09	598.20	$P < 0.01$

SFAs = saturated fatty acids.
MUFAs = monounsaturated fatty acids.
PUFAs = polyunsaturated fatty acids.

composition, while qualitative traits of meat are not taken into account (as outlined above). Qualitative traits are not recorded and outstanding meat quality is not rewarded by higher prices. Of the various quality parameters that could be used, intramuscular fat content is highly correlated with palatability traits in both beef and pork and could be used to distinguish between different levels of eating quality. Despite the fact that many consumers express their wish for high-quality meats, the payment and marketing systems negate efforts to follow consumer demands and fail to include measures of meat palatability. Sundrum (2010) concluded that only a direct assessment of qualitative traits and a payment system that rewards meat quality grades that are above average are needed to improve the currently unsatisfactory situation.

Consumer attitudes

Organic production is largely consumer driven; therefore it is important to take into account consumer attitudes in selecting the appropriate breeds and feeding systems for organic beef production. The purchase of meat by the consumer appears to be governed by two main factors: (i) the initial perception and expectation of quality based on appearance, price, presentation and labelling, and possibly ethical and philosophical considerations such as freedom from chemical residues and how the animal was raised; and (ii) the actual quality experienced after cooking and eating. The response to the second factor greatly influences whether the consumer purchases the same meat on other occasions. European research indicates that the first factor is much more important than the second (e.g. Scholderer *et al*., 2004).

There is also evidence that nutritional quality is becoming more important to the consumer than safety concerns. Consumers expect substantially higher quality in meat produced in organic and pasture-based systems, which are perceived as being more 'natural'.

As Grunert (2006) pointed out, once a perception is firmly established in the mind of the consumer, the effects on quality perception can be quite dramatic. Both country of origin and organic production have been shown to have 'halo' effects with regard to quality perception. Consumers tend then to believe that an organically produced piece of meat is better not only in terms of its process characteristics, but also in terms of 'healthiness' and sensory quality. When the differences between the eating quality of the different meats are not too large, the quality inferences from the initial cues may be held even when the eating experience is disappointing.

Some consumer studies yield a great amount of detail, which can make generalizations difficult.

Corcoran *et al*. (2001) reported on consumer attitudes towards lamb and beef in Europe. The issues for analysis were: (i) trends in consumption of lamb and beef (in and out of the home); (ii) factors influencing lamb and beef consumption; (iii) quality issues and quality meat products; and (iv) sources of information. Focus group discussions were held in Edinburgh and Cirencester in the UK, Zaragoza in Spain, Reggio Emilia in Italy and Perpignan in France. Participants were randomly selected from people responsible for buying meat for the family. The type of meat that was generally purchased differed among the four countries. In the UK, beef was consumed more often at home and lamb was seen as an expensive product. The Spanish preferred local traditional lamb. In Italy, white meat was preferred to red meat, half of the participants consuming beef only two or three times a month. In France, participants liked variability in the type of meat. Participants with families with children consumed more meat and had a more diversified diet. Meat consumption was lower in families with older members. Older people cared more about meat quality and were quoted as stating that 'too much meat is not healthy for us'. In the UK, the trend was to buy everyday cuts from supermarkets, but special-occasion meat from the butcher, where quality is considered better and more consistent. In Spain and France, most participants bought all their meat from a traditional butcher because of trust. Conversely, Italian participants bought most of their meat in super/hypermarkets, where they felt meat was more hygienic, better packed, more convenient to buy, offered a better range and choice and was priced more competitively.

Qualitative factors influencing consumption had similarities in the four countries. These included taste, nutritional benefits, tradition and origin (especially in Scotland and Spain). A low fat content was important for Italian and younger UK consumers. Low price was an important factor for the Italians and the English, whereas Scots, Spanish and French participants suggested price was not a critical factor when choosing meat, as they bought 'less meat but of a higher quality'. 'Quality' was interpreted differently among locations.

In general, participants worried about health and security issues when consuming meat. The British admitted to be concerned after BSE and *E. coli* scares, particularly consumers with children. The Spanish and British admitted to worrying more about meat than other foods and were aware of genetically modified products. Italians trusted white meat more because they felt red meat (beef) 'could be more toxic'. French participants thought that hormones, antibiotics and other additives should be banned.

Sensory attributes

Factors that characterized meat quality were largely similar in all focus groups in the above study. Colour was the first factor, though colour preference differed between countries. In Scotland bright red was considered false, suggesting additives or a lack of maturation. A natural red was preferred for beef. In Spain, intense red or brown was not appreciated and consumers preferred a 'pinkish' colour. In Italy an intense red colour was preferred, but not brown. The latter was not considered fresh. A strong smell was disliked everywhere. British and French participants favoured a marbled appearance (fat) in beef for flavour. The Spanish preferred fresh rather than mature meat. They also refused 'cheap' meat and considered origin to be a very important quality attribute. Italian participants cared more about freshness, a low fat content and type of packaging. Ready-frozen meat was not appreciated by any of the participants in the five locations. Some UK participants were confused, ignorant and/or mistrusting of the number of current assurance schemes covering meat quality. They felt that an independent body or consumer group, not government, should control meat safety and quality. The Spanish felt that the government was responsible for guaranteeing safety and quality but they thought that farmers should also be responsible for delivering these. Italian participants put their trust in the public health services. All participants said they would pay more for a better level of assurance, quality and information relating to the beef and lamb meat and meat products that they purchased.

For Italian participants, price was a very important factor. A number of Italian participants suggested that, if animals are not fed with adulterated additives (in feed) and are reared in a natural way, then meat should be safe and quality meat products should not be needed. In general, participants complained about a lack of clear and consistent information on quality meat products. More information was sought by all participants: the British wanted information on 'eatability', production methods and animal welfare; the Spanish, days to market, farmer and origin; the Italians, more nutritional information and information on origin; and the French, information on production and processing, details of health implications and control of 'taste' quality.

The responses from this survey indicate large regional differences in consumer attitudes and taste, which would have to be taken into account in producing organic meat for the region in question.

Napolitano *et al*. (2010) conducted a study to assess the effect of information about organic production on the liking for beef and consumer willingness to pay. Mean scores of perceived liking were higher for organic beef than for conventional beef and consumers showed a willingness to pay more than the suggested price for organic beef.

It can be concluded, therefore, that extrinsic cues play a large role in the way in which consumers perceive meat quality. The origin of the meat and place of purchase have a strong influence on the perception of quality by consumers. Also, in situations where the physical differences between alternative products are small, the quality inferences made on the basis of these cues may be so strong that consumers stay with their choice regardless of other information. Although there is a strong demand for organic meat, there is evidence that it has to be produced economically. A survey in Scotland found that organic meat was perceived as being expensive, especially when consumers did not perceive a positive difference in quality (McEachern and Schröder, 2002; Andersen *et al*., 2005). This resulted in some consumers being more interested in conventional meats with added-value features (e.g. animal welfare) rather than organic meat. A Canadian study confirmed the price aspect. Anders and Moeser (2008) estimated the consumer demand for organic and conventional fresh beef products in the Canadian retail market and found that demand for organic beef was highly dependent on price and expenditures.

Some US grass/forage-feeding studies, but not all, report steaks from grass/forage-fed beef to be less tender than steaks from grain-finished beef but most have found grass/forage- and grain-fed beef to be of similar juiciness, according to a review by Van Elswyk and McNeill (2014). These effects may be dependent, at least in part, on type of pasture and muscle type. The review also reported a significant increase in yellowness of external fat with grass/forage feeding in some studies, probably a result of the 1.5–10 times increase in adipose β-carotene deposition due to grass/forage feeding.

They concluded that flavour acceptability may be related to individual preference or cultural norms, US consumers appearing to prefer the flavour of grain-finished beef while consumers in other countries preferred the flavour of beef from grass/forage-fed cattle. Members of a US consumer panel described the flavour of ground beef from grass/forage-fed cattle as lacking beef flavour with an intense dairy-milky flavour often accompanied by a soured dairy flavour and/or other off-flavours, although the fat content was the same in each treatment and thus not responsible for flavour difference. Other conclusions reached by Van Elswyk and McNeill (2014) were that flavour varies according to the type and maturity of forage, cattle breed, fat content and marbling score, making it difficult to compare the flavour of beef from grass/forage-fed and grain-finished cattle. However, they pointed out that much of the US research in question had been conducted in the 1970s and 1980s and more current research was needed to determine if US acceptance of the flavour quality of grass/forage-fed beef had changed. In this connection they reported that trained sensory panellists in the USA found beef from grass-finished cattle to lack beef flavour and with more off-flavours than beef from grain-finished cattle (Duckett *et al*., 2013)

The above studies suggest several important conclusions. First, organic beef should be produced in such a way that it meets the expectations of consumers. Second, the willingness of consumers to pay a premium for organic beef is not unlimited. These conclusions indicate that organic producers need to strive to produce a high-quality product as economically as possible.

Overall, most studies report that consumers purchase organic foods because of a perception that such products are safer, healthier and more environmentally friendly than conventionally produced alternatives. Some studies reported health and food safety as the number one quality attribute considered by organic produce buyers, followed by concern for the environment, suggesting that such consumers might rank private or personal benefits higher than the social benefits of organic agriculture.

Given that most of the studies relate to particular geographical areas and conditions, the extent to which the findings from such studies can be generalized is limited. A review of the available findings also shows little consistency across countries, in terms of consumer perceptions about organic product attributes. The findings from some studies provide useful background information for future consumer and policy research.

A recent review by Stampa *et al.* (2020) provided an international perspective on further information and recommendations regarding consumer perceptions, preference and behaviour regarding pasture-raised beef. In addition to reiterating points raised above, the authors stressed the importance of having a well-informed consumer. They noted that the terms 'pasture-raised', 'meadow-grazed', 'grass-finished' or 'grass-fed', when referring to milk or beef, are not defined at the legislative level, either in the USA or in the EU. While this issue is likely to be difficult to address legislatively, it does reflect a lack of knowledge about pasture-based and conventional production practices among the majority of consumers. It is also likely to result in judgements based on false assumptions or associations. This is important in that it can affect intentions to purchase pasture-raised milk and beef. Having good informational support is necessary for the acquisition of new customers, but to encourage consumers to make repeat purchases, taste must comply with consumer expectations. Stampa *et al.* (2020) found that many consumers believed in the higher sensory quality of pasture-raised products, an attraction especially for consumers with higher incomes and those with animal welfare concerns. Among consumer groups women reacted more positively than men to descriptions such as 'animal welfare', 'local product' and 'raised on a family farm'. Furthermore, addressing personal values by providing health and nutritional information, such as benefits of omega-3 fatty acids and their higher contents in pasture-raised beef, induced higher preferences and a greater likelihood to purchase grass-finished beef.

Younger US consumers also had a more positive attitude towards pasture-raised products, based on environmental and animal welfare concerns. However, their lower income prevented a corresponding buying behaviour.

One concern that some consumers express about organic meat from animals raised outdoors is the possibility of bacterial contamination. Some information on this topic was provided by Reinstein *et al.* (2009), who studied the prevalence of *Escherichia coli* O157:H7 in beef cattle that had been raised organically and conventionally. In organically raised cattle, the average prevalence of *E. coli* O157:H7 in faecal samples was 9.3% (range 0–24.4%). The average prevalence in rectal samples was 8.7% (range 0–30.9%). The average faecal prevalence of *E. coli* O157:H7 in conventionally raised animals was 6.5% and in faecal samples was 7.1%. No major difference in antibiotic susceptibility patterns among the isolates was observed.

Another related finding was that, when cattle that were naturally infected with *E. coli* O157:H7 were abruptly changed from a high-grain (maize) diet to a forage diet, generic *E. coli* populations in faeces declined 1000-fold within 5 days and the ability of the faecal generic *E. coli* population to survive an acid shock similar to the human gastric stomach decreased (Callaway *et al.*, 2003). The suggested explanation was that, when cattle are fed high-grain diets, some starch escapes ruminal microbial degradation and passes to the hind gut, where it is fermented. Enterohaemorrhagic *E. coli* are capable of fermenting sugars released from starch breakdown in the colon, resulting in higher populations of *E. coli* in the gut and increased shedding of *E. coli* O157:H7. An all-forage diet reduces these populations in the gut by changing the pattern of digestion in the gut. Callaway *et al.* (2003) observed that other researchers have shown that a switch from a high-grain to a hay-based diet results in a smaller decrease in *E. coli* populations, and without the effect on gastric shock survivability.

Animal Health Issues Related to Diet

One of the aims of organic production is to maximize the health of cattle by promoting the development of natural immunity by feeding and management practices. It is interesting, therefore, to review the extent to which this aim has been achieved and to identify any disease issues that relate particularly to organic feeding. There was interest in this topic in Europe following the introduction in 2008 of EU regulation No. 889/2008 that required the feed to be 100% organic and restricted the types of dietary supplements that could be used.

Surprisingly, little published information on the topic is available in peer-reviewed journals and it relates mainly to dairy cattle. It shows that health status is fairly similar in both conventional and organic systems, provided the organic cattle are fed nutritionally adequate diets, are maintained in good body condition and allowed access to well-managed pasture/pasture products and a safe and adequate supply of drinking water. Limited slaughter data show that the high intake of dietary roughage mandated by the organic regulations is beneficial in that it predisposes cattle to improved ruminal health and results in a reduced incidence of liver abscesses and of organ condemnations at slaughter.

The possibility that the organic diet might not satisfy the high energy demands of early-lactation dairy cows was investigated by Blanco-Penedo *et al.* (2012a). Energy balance was measured in Swedish organic dairy herds, based on blood levels of β-hydroxybutyrate (BHBA), non-esterified fatty acid (NEFA) and insulin, and on the occurrence of clinical ketosis. The metabolic status of the same herds under the previous rules was available for comparison. The BHBA, NEFA and insulin levels were different before and after the change in legislation, but the effects were similar in organic and conventional cows. The incidence of clinical ketosis was not associated with herd type or the change of legislation. It was therefore concluded that the change did not appear to have had any detrimental effects on the metabolic profiles of organic cows in early lactation and there was no evidence that organic cows were metabolically more challenged or had a severe negative energy balance.

Blanco-Penedo *et al.* (2014) investigated the blood levels of essential minerals (Cu, Co, Se, Zn, Mn, Mo, I and Fe) in organic and conventional dairy herds in relation to milk yield and the occurrence of mastitis. No significant differences between organic and conventional herds were found and no severely deficient concentrations of essential minerals were observed in organic herds, either before or after the change in regulation. Cows with low serum concentrations of Se had lower SCCs, an unexpected finding. Daily milk yield was significantly reduced by deficient concentrations of Cu. Low levels of some elements (Se, I) in the diet were associated with a reduced risk of mastitis; other elements appeared to have a protective effect against mastitis.

Details of the dietary regime or feed composition were not provided in the two reports published by these researchers, which would have helped to establish whether the findings were applicable to other organic farms. The most likely conclusion to be taken from their findings is that there is no difference in the feed-related health status of organic dairy cows provided they are given diets containing all essential nutrients at appropriate levels.

There is no clear evidence that organic dairy cows are less susceptible to mastitis than conventional cows (Sutherland *et al.*, 2013). A main reason for the lack of clarity on this issue is that conventional dairy farmers make greater use of veterinary services than organic farmers, who are more likely to deal with health issues without veterinary help and less likely to report such issues (Richert *et al.*, 2013; Stiglbauer *et al.*, 2013). Any difference found in incidence may therefore be attributed mainly to a lower level of reporting of cases in organic production.

Other researchers have found a similar difference in health incident reporting. For instance, Valle *et al.* (2007), using records of veterinary calls, found several apparent and large differences in herd health parameters between organic and conventional dairy herds in Norway. However, in analysing the records they found that organic farmers called for veterinary service less frequently (2/10 cases), except for milk fever, than did conventional farmers (4.7/10 cases). When the data were adjusted to correct for this practice, no differences in health status were found, except for acute mastitis (15/136 versus 22/147). This difference disappeared when a further adjustment for production level (lower in the organic group) was made. It was therefore concluded by the researchers that the explanation for the apparent difference in health status between the two groups could be attributed to management practices.

Stiglbauer *et al.* (2013) found that organic dairy farmers in the USA used veterinary help less frequently and had a lower usage of vaccinations. These researchers also pointed out that the conventional dairy farms on average had a higher percentage of first-lactation heifers, a factor that would need to be taken into account in an assessment of animal health between organic and conventional herds. A study conducted in Canada (Levison *et al.*, 2016) provided comparative data on the incidence rate of producer-reported clinical mastitis in both conventional and organic dairy farms. It showed that the rate was higher on conventional than on organic farms (23.7 versus 13.2 cases per 100 cow-years) and was not associated with housing type (loose or tie-stall), pasture access, or herd-average milk yield. The authors suggested that reduced rates of producer-identified clinical mastitis for certain pathogens may be related to the organic management system and that further investigation was needed to identify the specific management factors involved.

It is clear that more controlled studies are required to clarify whether mastitis is more or less likely to be problematic on organic than on conventional dairy farms, and the explanation for any difference needs to be found.

Organic certification requires that the feed contains a relatively high level of roughage and usually a lower level of supplement compared with that used in conventional production. This raises the possibility of an increased risk of metabolic diseases such as milk fever and ketosis in organic cattle, particularly during high lactation periods.

According to the review by Sutherland *et al.* (2013) the incidence of milk fever, related to a low serum Ca level, did not differ between organic and non-organic herds in Sweden, and the incidence was lower on organic farms in Norway. According to these researchers the risk of milk fever rises by 5% with each kilogram increase in peak daily milk production; therefore, the relatively lower level of milk production from organic herds is a probable explanation for the reduced incidence of milk fever.

Ketosis is associated with a rapid mobilization of energy from bodily fat stores when the dietary energy intake is inadequate and there is a high glucose demand for milk production. As a result there is an accumulation of large quantities of ketone bodies in blood and tissue, leading to metabolic acidosis. When the incidence of ketosis was compared between organic and non-organic farms in Sweden, no difference was observed (Sutherland *et al.*, 2013). On the other hand, cows required veterinary treatment for ketosis less regularly on organic than on non-organic farms in Norway. The researchers also reported a tendency for more cows on organic farms in the UK to have subclinical ketosis than on conventional farms. As with milk fever, these authors concluded that a possible explanation for a lower incidence of ketosis on organic farms is a relatively lower milk production.

Infertility was another issue covered in the review of Sutherland *et al.* (2013). This is a major issue on conventional and organic farms, since it results in reduced productivity and accelerated culling of animals. A variety of conditions contribute to infertility, including placental retention, endometritis and abortion. The incidence of retained placenta was reported as being lower on organic than non-organic farms (Sutherland *et al.*, 2013). Over an 8-year period, veterinary treatment for retained placenta was higher in conventional than in organic herds. However, reproductive efficiency of organic herds was lower than in conventional herds when milk yield, breeding season, service and parity were taken into account, due possibly to their energy requirements not being fully met during winter.

The overall conclusion based on the available evidence that the health status of dairy cattle raised organically and conventionally is similar probably applies also to beef animals. The available data are inadequate to allow a more definite conclusion to be drawn and some data suggest that the rate of organ condemnations at slaughter may be lower in organic animals. Blanco-Penedo *et al.* (2012b) used farm and slaughterhouse data to compare the effects of organic and conventional production on herd health and on the quality and safety of the meat. In general, incidence of clinical disease was lower on organic farms but the differences did not achieve statistical significance, except for reproductive disorders. Mortality rate of calves and cows was similar, although the incidence of diarrhoea was higher in calves on conventional farms. Annual data from a slaughterhouse in Spain involving 244 cattle from organic farms and 3021 cattle from conventional farms were analysed for the rate of carcass condemnations. Overall, 26% of all animals were found to have at least one category of pathological defect. Condemnations of the liver (including those with parasite infection), lung and kidney were significantly higher in animals from conventional than from organic farms, while condemnations of the digestive tract were significantly lower in animals from conventional farms. The differences were attributed mainly to differences in housing, feeding and management practices in the two systems. No condemnations due to drug residues were recorded in either organic or conventional animals.

Environmental Aspects

One aspect of the production of animals that is receiving scrutiny at present is its contribution to greenhouse gas production. This analysis indicates that organic cattle production is not as benign as it appears initially.

As outlined in Chapter 3, a common perception is that traditional pasture-based, low-input dairy systems are more in keeping with environmental stewardship than modern milk production systems. To test this theory, Capper *et al.* (2009) compared the environmental impact of US dairy production in 1944 and 2007. They calculated that the carbon 'footprint' per billion kilograms of milk produced in 2007 was 37% of that for equivalent milk production in 1944.

Farming methods have also been compared internationally from an environmental aspect. The situation was shown dramatically in a comparison of a dairy farm in Wisconsin with one in New Zealand (Johnson *et al.*, 2002). Using total farm emissions/kg milk produced as a parameter, the researchers showed that production of methane from belching was higher in the New Zealand farm, while carbon dioxide production was higher in the Wisconsin farm. Output of nitrous oxide, a gas with an estimated global warming potential 310 times that of carbon dioxide, was also higher in the New Zealand farm. Methane from manure handling was similar in the two types of farm.

The environmental impact of animal farming (conventional and organic) is therefore an issue that is currently being reviewed by scientists. One response to the issue is that the European Common Agricultural Policy has been revised to add supplementary measures that include the environmental role of agriculture. The revision includes the adoption of a life-cycle assessment to estimate emissions/kg of CO_2 equivalent/kg live weight leaving the farm gate per annum and per hectare. It is possible that in certain countries such legislation will place restrictions on ruminant production, including organic farms.

One particular aspect of the environmental issue that is being studied is the influence of organic cattle production on greenhouse gas emissions, particularly methane. This gas is considered to have 21 times the global warming potential of CO_2. As outlined in Chapter 3, it has been estimated that beef production worldwide accounts for about 62% of total livestock methane emissions, milk 19%, sheep 12%, pigs 5% and poultry 1%. Estimates suggest that livestock in Asia and the Pacific produce 33% of total livestock methane emissions, Latin America 23%, Europe 14%, Africa 14%, North America 11% and Oceania 5%.

Various researchers have addressed this important issue. As explained in Chapter 3, as the pattern of ruminal fermentation in cattle alters from acetate to mainly propionate, both hydrogen and methane production are reduced. This relationship between methane production and the ratio of the various VFAs has been well documented. It explains why the feeding of fibrous diets results in more methane than less fibrous diets: the fibrous diets promote a higher production of acetate in the rumen, resulting in more hydrogen and more methane. Methane is formed as a result of the need to remove hydrogen from the rumen. Diets that are more highly digestible promote a higher production of propionate, which results in less methane in the rumen. There is also an economic aspect to methane reduction in cattle. Methane represents a significant loss of dietary energy; thus reducing methane production in the gut may also improve feed efficiency. This aspect is therefore being researched actively and several recommendations have been made, some of which are relevant to organic production methods.

It should be clear from the foregoing that, logically, the first option available to organic farmers is to avoid low-quality pastures and forages, which are the feeds associated with higher methane emissions. Where possible the low-quality pastures should be improved and only high-quality forages should be produced. An added benefit is that use of these feeds will result in improved growth and milk production, which should lead to increased profits. Other feed changes can then be considered.

Moe and Tyrrell (1979) reported that for every gram of cellulose digested, methane emissions are nearly three times that from hemicellulose and five times that from the soluble residue. However, there has been little work to compare methane production on different concentrates. This could be of value as there is a large selection of concentrate ingredients available, ranging from cereals (low in fibre, high in starch) to cereal by-products (high in fibre, low in starch), pulps (high fibre), molasses (high sugar) and oilseed meals (high in protein, variable in fibre). Johnson and Johnson (1995) noted that soluble sugars have a higher methanogenic potential than starch. Moe and Tyrrell (1979) had recommended that research was required to establish if concentrates can be formulated to bring about significant reductions in methane production.

Use of improved pastures and improved forage quality is an obvious consideration as a means of reducing methane production. This has been investigated by several researchers, but the conclusions reached are influenced by how the results are interpreted. For example, Hart *et al.* (2009) fed Charolais-cross heifers and Aberdeen Angus-cross steers on swards managed to produce high-digestibility pasture (high DMD) or pasture with lower digestibility (low DMD). Both types of forage were fed to appetite, all animals being zero-grazed and offered the freshly cut herbage twice daily. Dry-matter digestibility (DMD) values for the high and low DMD swards were 816 and 706 g/kg, respectively. Heifers offered the high DMD grass had a higher daily intake (7.66 kg DM) than those offered the lower DMD grass (5.38 kg DM), and had a higher daily production of methane (193 g) than those offered the lower DMD grass (138 g). However, when corrected for total or digestible DM intake or ingested gross energy, there was no difference in methane production between dietary treatments. For steers, daily intake tended to be greater with the high DMD grass (5.56 versus 4.27 kg DM), but rumen protozoa number (4.95×10^4/ml), rumen ammonia concentration (34 mg nitrogen/l), ruminal total VFA (103 μmol) and rumen pH (6.8) did not differ between treatments. There was no difference in total number of bacteria or in other ruminal parameters. Results of the study were taken to demonstrate that there was no difference in methane production when corrected for intake or rumen fermentation variables of beef cattle offered a high- or low-digestibility sward. When calculated on an annual basis, it was estimated that cattle grazing the low and high DMD swards would produce 50.4 and 70.4 kg methane/year, respectively, assuming that intakes and sward quality remained unchanged over the grazing season. However, these estimates do not take into account the faster growth of cattle fed forages of higher digestibility. As a result, methane production per unit of beef produced would be lower with a higher-quality diet. This point was exemplified by Boadi *et al.* (2004), who reported that cattle receiving a diet with a high grain:forage (89.5:11.5 DM basis) ratio had similar methane emissions to cattle receiving a diet with a lower grain:forage (58.2:41.8 DM basis) ratio when corrected for DM intake. When corrected for daily live weight gain, cattle on the high grain:forage diet produced significantly less methane.

Beauchemin *et al.* (2008) reviewed various nutritional management strategies that reduce methane production in cattle. These included strategies such as increasing the level of grain in the diet, inclusion of lipids in the diet and supplementation with ionophores. Unfortunately, implementation of some of these particular strategies would move organic production closer to conventional production in an unacceptable way. These authors agreed that improved pasture management, replacing grass silage with maize silage and using legumes hold some promise for methane mitigation but as yet their impact is not sufficiently documented. Several new strategies, including dietary supplementation with saponins and tannins, selection of yeast cultures and use of fibre-digesting enzymes, may mitigate methane but these still require extensive research. Most of the studies on reductions in methane from ruminants due to diet management are short-term and focus only on changes in enteric emissions. These authors concluded that further research was needed to examine the long-term sustainability of reductions in methane production and impacts on the entire farm greenhouse gas budget.

Crops such as maize and whole-crop small grain silages are cultivated, conserved and fed because they typically provide high yields of DM, are readily digestible and increase animal intake and performance. There are three ways by which these alternative forages can reduce methane emissions: (i) the starch within the grain silages favours the production of propionate rather than acetate in the rumen; (ii) by increasing voluntary intake, these alternative forage crops can reduce the ruminal residence time of feeds, hence restricting ruminal fermentation and promoting post-ruminal digestion; and (iii) when maize silage replaces grass silage, the increase in voluntary intake combined with the increase in the energetically more efficient post-ruminal digestion (relative to ruminal microbial fermentation) improves animal performance, thereby lowering methane emissions per unit of animal product (O'Mara *et al.*, 1998).

According to Chase (2008) and other researchers such as O'Mara *et al.* (2008), there is a large number of potential approaches that could be used to decrease total methane emissions from dairy cattle and to lower the methane emitted/kg of milk produced. The main approaches that could be undertaken by organic farmers include the following.

1. Improving animal productivity. The information in Table 6.15 shows the relationship between daily milk production and methane emissions in dairy cattle fed the same diet. It can be seen that as milk production increases the methane produced per cow per day increases. This is logical, since the animal is consuming and processing larger quantities of feed to produce an increased yield of milk. However, the amount of methane generated per unit of milk produced decreases as milk production increases. The net effect is that fewer animals would be needed to produce a specific quantity of milk, resulting in less total methane being generated. Chase (2008) pointed out that factors such as genetics, feed quality, ration formulation and daily nutrition management can all assist in increasing animal productivity.

2. Feeding high-quality forages. Higher-quality forages help to decrease methane emissions due to their higher efficiency of use in the animal. For example, one trial compared lactating beef cows fed a lucerne–grass pasture (13% CP, 53% NDF) or a grass pasture (9% CP, 73% NDF). Methane production was about 9% higher for cows on the lower-quality grass pasture. Legumes generally result in higher intakes and digestibility than grass swards and thus give rise to higher productivity. This should reduce methane emissions as discussed above. In addition it has been shown that legumes result in reduced methane emissions when fed at comparable intake levels to grass sward. This could be due to a modified ruminal fermentation pattern combined with higher passage rates.

3. Including higher levels of grain or soluble carbohydrate in the diet. Using a modelling approach, it was reported that replacing beet pulp with barley in diets for beef animals decreased methane emissions by 22%. Using the same approach, a 17.5% reduction in methane emissions was reported when maize grain replaced barley in the diet. This is the reason that finishing beef steers in feedlots have low methane emissions compared with dairy cattle. However, there are a number of rumen and animal health concerns that limit the quantity of grain that can be fed to dairy cattle. This limits the potential decreases in methane emissions that can be attained in dairy cattle by feeding higher grain diets.

Table 6.15. Relationship between level of milk production and methane emissions in dairy cattle (Chase, 2008).

Milk (kg/day)	DM intake (kg/day)	Methane produced (l/day)	Methane produced (l/kg milk)
20	16.8	518	26.0
30	19.5	580	19.4
40	23.6	652	16.3
50	28.2	725	14.5
60	33.2	793	13.2

4. Adding fat to the diet. This could be done by including full-fat oilseeds in the feed mixture. For example, in a Canadian study Beauchemin *et al.* (2009) found that supplementation with crushed canola seed was a convenient method of adding fat to the diet and mitigating methane production without negatively affecting diet digestibility or milk production. Not all seeds gave the same effect. Including crushed sunflower seed or flaxseed to provide a similar level of fat addition (about 40 g/kg diet) lowered digestible DM intake by 16% and 9%, respectively, because of lowered digestibility. Beauchemin *et al.* (2008) reviewed the effect of level of dietary lipid on methane emissions in over 17 studies and reported that, with beef cattle, dairy cows and lambs, there was a proportional reduction in methane (g/kg DM intake) of 5.6% for each 10 g addition of supplemental fat/kg DM.

5. Using additives to alter rumen fermentation. A logical approach would be to add compounds to the feed that could alter rumen fermentation and decrease methane production. A large number of compounds have been screened for methane emissions in laboratory situations. Many of these appeared promising but had not been tested adequately in animal trials or had been considered acceptable in organic rations. Among these were an extract of *Yucca schidigera* or *Quillaja saponaria*, which gave a reduction in methane production of up to 60%. Methane production was decreased by 49–75% in growing lambs when an encapsulated fumaric acid product was used, and the addition of sarsaponin (a yucca extract) to a laboratory rumen system decreased methane production by up to 60%.

As Chase (2008) pointed out, reducing methane emissions on farms is a practical and realistic goal. However, there must be some economic return to producers if they are expected to adopt practices that decrease methane production. The practices used must also be practical and fit within the herd management system. Practices that improve animal production and efficiency usually provide a positive economic return to the producer. Those suggested could be implemented on most farms, especially dairy farms. A report by Mayen *et al.* (2010) suggested that, although the organic dairy technology in the USA is approximately 13% less productive than conventional technology, there is little difference in technical efficiency between organic and conventional farms. This finding suggests that organic dairy farmers in the USA, at least, have the technical knowhow to implement the above suggestions.

As recommended by O'Mara *et al.* (2008), when animal performance is improved through better nutrition, energy for maintenance is reduced as a proportion of total energy requirement, and methane associated with maintenance is reduced. Thus methane emissions/kg milk or meat are reduced. Similarly, if improved animal performance leads to animals reaching target slaughter weight at a younger age, then total lifetime methane emissions per animal are reduced.

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7

Conclusions and Recommendations for the Future

Of all the livestock industries, the ruminant sector is the one most readily converted to an organic system, because of the heavy reliance of cattle on forage which can be grown on-farm. Pigs and poultry require a much higher content of concentrates in the feed, making these industries more difficult to integrate into sustainable organic systems.

The production of organic milk and beef continues to increase, in response to consumer demand for these products, although there is some evidence of a substantial variation in the quality of organic meat entering the marketplace in some countries (e.g. Sundrum, 2010).

An important factor related to the consumer demand for organic milk and (especially) beef is an altered profile of the fat in these products from grass-fed cattle, which is more favourable than from conventionally fed cattle in terms of human health. The evidence is now quite conclusive, making beef from grass-fed cattle more attractive than conventional beef to the knowledgeable consumer. While taste and cost are important factors in food purchasing decisions by consumers, it is clear that there is now a distinct shift towards healthy food choices. For instance, according to the 2020 Food & Health Survey (International Food Information Council, 2020), 54% of American consumers and 63% of those aged 50+ cared more about the healthfulness of their choices than they did in 2010. The shift to healthfulness was found to be the biggest mover in food purchasing decisions. Another interesting statistic from the survey was that in 2010 only 23% of consumers reported that they knew at least a fair amount about the US Dietary Guidelines; in 2020 that figure had risen to 41%.

The altered fat profile, with a higher content of polyunsaturated fatty acids (PUFAs) and other bioactive compounds from grass should theoretically make organic milk and meat more susceptible to rancidity and have a lower shelf life than conventional products, but to date there is no evidence of any problem in this regard.

Environmental consciousness and ethical concerns related to animal welfare are other factors that make food products from pasture-raised animals more attractive to an increasing number of consumers (e.g. Stampa *et al.*, 2020). These concerns are being addressed in active research programmes worldwide. For instance, one analysis showed that improved dairy practices in 2007 required considerably fewer resources than dairying in 1944, with 21% of animals, 23% of feedstuffs, 35% of the water and only 10% of the land required to produce the same 1 billion kg of milk (Capper *et al.*, 2009). Waste outputs were similarly reduced, with modern dairy systems producing 24% of the manure, 43% methane and 56% nitrous oxide per billion kg of milk compared with equivalent milk production in the earlier period. The carbon ‘footprint’ per billion kg of milk produced in 2007 was 37% that of equivalent milk production in 1944.

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Organic milk production inherently increases methane emission because of the feeding system used unless the forage is of high quality, emphasizing the importance of forage quality in controlling greenhouse gas production. Continued research on forage types and on rapid methods of timing harvesting to ensure optimum quality will help greatly in achieving the objective of quality forage production.

The main characteristics of an ideal dairy system identified in a survey of consumers were related to animal welfare from two perspectives: (i) consideration for the quality of life of the animals, based on ethical arguments; and (ii) the consequences of animal care on the quality of milk (Cardosa *et al.*, 2016). Preferences for organic systems and smaller family size were expressed. The study suggested that providing assurances that animals are well treated, developing methods to incorporate pasture access and ensuring healthy products without relying on antibiotics or hormones will improve the social sustainability of the dairy industry.

Organic milk and meat cost more at the retail level than conventional products, due mainly to a more extended life cycle of organic animals and a restricted supply of acceptable supplementary feedstuffs. For example, Thomassen *et al.* (2008) found that in the Netherlands the feed mixture of cows on organic dairy farms contained ingredients from Malaysia, Australia, France, Germany and Brazil. In addition, not all of the ingredients were organic (allowed for under derogation). The provision for derogations in the organic production standards used in some countries is understandable, due to shortages of organic feedstuffs, but is unfortunate in that some consumers may be being sold organic foods that are not purely organic in origin. It is logical, therefore, to suggest that the production of organic feed crops be encouraged, especially those that can be produced on-farm. Chapter 4 of this book provides relevant examples for consideration. However, it has to be recognized that a limitation in implementing this recommendation is the size of farm involved and its ability to produce sufficient feed crops in addition to forage. In keeping with an increase in the production and supply of organic feedstuffs, it would be helpful for a database of nutrient contents of organic feedstuffs to be established.

A greater availability of high-quality forage should be beneficial in providing an increased supply of the nutrients required on organic farms, allowing milk and meat to be produced more economically and increasing the sustainability of the farm unit. A key to efficient production of organic milk and meat is, therefore, the availability of an adequate supply of high-quality forage on-farm.

A second key factor is the application of up-to-date technical knowledge so that the optimum utilization of the forage and other farm-produced feeds can be achieved. Many organic farmers have this capability. The applications include:

- planting the most appropriate forage mixture;
- the use of field instruments to predict the optimal stage for grazing or for harvesting;
- the use of rotational and other advanced grazing management systems; and
- the use of laboratory testing of fresh and conserved forages prior to their use in feeding programmes.

Accurate knowledge of the nutrient content of the feeds available allows a feed mixture to be formulated that meets the requirements of the herd more exactly and helps to prevent unnecessary excesses that can contribute to runoff and environmental pollution. The standards for organic milk production require that the need for mineral and trace element supplementation be assessed before supplementation is allowed. This assessment requires, at least, a laboratory analysis of the forage. Various software programs are available to the organic farmer that are designed to produce optimal rationing systems. It is clear that the nutritional requirements of organic cattle are no different from those of conventional cattle; therefore these programs are applicable on organic units. Farmers unable to formulate the rations themselves should be able to obtain the necessary help from feed supply companies or possibly from cooperatives.

A third key to successful and efficient production of organic milk and meat is the use of dual-purpose breeds and strains that are suited to the farm and geographical location in question. Research is undoubtedly required in several regions to identify those most suitable.

A current debate relates to the question of whether organic cattle contribute more or less to greenhouse gas production. As outlined in Chapter 3, a common perception is that traditional pasture-based, low-input dairy systems are more in keeping with environmental stewardship than modern milk production systems. Unfortunately, that perception is not completely valid. The importance of this issue is that some commentators consider that eventually restrictions may be placed on livestock production in some countries or regions, with decisions having to be made on whether organic production should suffer more or fewer cuts than conventional production. This is a very important issue, with facets that are beyond analysis in this publication. Some researchers have attempted to analyse the situation, their results being influenced greatly by the assumptions made and how the findings are interpreted. This point was exemplified by Boadi *et al*. (2004), who reported that cattle receiving a ration with a high grain:forage ratio had a similar methane emission to cattle receiving a feed mixture with a lower grain:forage ratio, when corrected for dry-matter intake. However, when corrected for daily live weight gain, cattle on the high grain:forage ration produced significantly less methane.

Some facts are indisputable. Livestock have been identified as a major source of global methane emission, derived primarily from enteric fermentation and respiration and to a lesser extent from manure. As stated above, a recent estimate is that beef production worldwide accounts for about 62% of total livestock methane emissions, milk 19%, sheep 12%, pigs 5% and poultry 1%. Ways of reducing methane are therefore being actively researched, with the aim of reducing greenhouse gas production from livestock. One method is by including a supplement of a fat source such as crushed oilseed in the feed, as described in Chapter 4. There is also an economic aspect to methane reduction in cattle. Methane represents a significant loss of dietary energy; thus, reducing methane production in the gut may also improve the efficiency of conversion of feed to milk or meat.

It follows, as outlined previously in this book, that organic farmers should avoid the use of low-quality pastures and forages, which are associated with higher methane emissions. Where possible, low-quality pastures should be improved and only high-quality forages should be produced. An added benefit is that use of these feeds will result in improved growth and milk production, which should lead to increased profits. Other feed changes can then be considered. It may be tempting to delay the harvesting of forage in order to produce a larger yield, but the resultant crop is likely to be of lower nutritive value and one that results in a higher production of methane as well as lower productivity in the animals. This is another, important, reason for the need to ensure that the forage used on organic farms is of high quality.

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