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Achieving sustainable production of milk

Volume 2: Safety, quality and sustainability

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Contents

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Introduction

Milk and associated dairy products constitute the world's most important agricultural commodity by value, particularly if dairy ingredients in other food products are taken into account. The dairy sector provides livelihoods for 1 billion people and is key to enriching diets for over six billion people, although global consumption of dairy still falls short of national dietary guidelines. At the same time, dairy production is also a significant user of land and other resources, and is responsible for 2.7% of total anthropogenic greenhouse gas (GHG) emissions. There is therefore an urgent need to improve the efficiency of dairy production so that it can meet the nutritional needs of a growing population in a more environmentally sustainable way. These challenges are explored in more detail in Chapter 15 in this volume which provides an authoritative review of the global importance of the dairy sector and some of the key issues it faces.

The two volumes of *Achieving sustainable production of milk* summarize a huge array of research addressing the challenges dairy farming faces. This volume (Volume 2) reviews ways of ensuring the safety and quality of milk on the dairy farm. It also assesses ways of improving the sustainability of dairy farming, as well as ways of improving milk production in the developing world. The companion Volume 1 complements Volume 2 by summarizing current research on the composition of milk as well as the role of genetics and breeding in improving milk production.

Part 1 Ensuring the safety and quality of milk on the farm

The first group of chapters review safety issues. Chapter 1 provides a detailed review of what we know about pathogens affecting raw milk and dairy products made from raw milk, including *Escherichia coli, Yersinia, Staphylococcus aureus, Clostridium botulinum, Bacillus cereus, Listeria* and *Campylobacter* as well as other hazards such as tick-borne encephalitis virus. The chapter summarizes sources of contamination, whether direct contamination of the milk from blood or the udder, or indirect contamination from sources such as faecal shedding or the broader farm environment. As an example, the chapter describes the way some pathogens such as *Listeria monocytogenes* can circulate in the blood of the animals, localize in the mammary gland or associated lymph nodes, and then pass into milk.

The chapter also summarizes current research on the growth of bacteria in raw milk, highlighting the ways psychrotrophic organisms such as *Pseudomonas* spp., *Listeria* spp. or *Yersinia* spp. are able to proliferate at low temperatures. It discusses antimicrobial systems in raw milk, including the use of lactoperoxidase to enhance antibacterial, antiviral and antifungal activity, as well as heat treatment and other techniques such as centrifugation and microfiltration to prevent bacterial contamination. As it points out, pasteurization may not always inactivate thermo-resistant spores of *Clostridium botulinum* and *Bacillus cereus*. Finally, given the increasing popularity of such products, the authors review current evidence on the occurrence of pathogenic microorganisms in raw milk and cheese made from raw milk, as well as outbreaks related to these products from pathogens such as *Salmonella*, *Campylobacter* spp. and pathogenic *E. coli*

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As the chapter points out, complete control of microbiological hazards is challenging, if not impossible in the dairy farm environment, because many of these organisms have multiple reservoirs and may not produce clinical disease in cattle. Dairy product safety, however, can be enhanced by implementing appropriate hygienic standards and practices for housing and milking centres as well as cow cleanliness. This theme is picked up in Chapter 5 and particularly in Chapter 7.

An essential first step in pathogen control is effective detection. Chapter 2 discusses testing for pathogens in milk on dairy farms. The limited use of on-farm pathogen detection can be attributed in part to the challenges of operating in farm environments as well as the lack of sufficiently specific, sensitive, practicable and affordable microbiological tests (an issue that is also picked up in Chapter 3). The chapter reviews the available tests, starting with direct detection techniques such as on-farm culture techniques and milk ring tests. It then considers indirect test methods that can proxy for pathogens by measuring other parameters which change due to the presence of pathogens. These tests include organoleptic characteristics (such as taste, smell and appearance), measuring acidity, somatic cell count (SCC) tests and conductance tests.

The chapter includes two case studies addressing the challenges of testing on dairy farms in developing countries. The first from Tanzania highlights the challenges presented by widespread consumption of raw milk, lack of quality testing and high levels of pathogens in on-farm milk which cause serious disease in both people and animals. The second case study from India shows how these challenges can be addressed through effective training and the use of simple indirect on-farm tests of milk quality, including observation of smell, colour, visible foreign bodies and assessment of added water (a potential source of contamination) using a lactometer. This study shows that simple interventions along the value chain, including indirect on-farm pathogen tests, have long-term benefits in terms of increased food safety and productivity. Challenges in the effective detection of biological and other types of contaminant are also discussed in Chapter 5.

Chapter 3 builds on Chapter 2 by looking in more detail at SCC and other tests as indicators of mastitis and in measuring milk quality more generally. As it points out, the most widely recognized method for mastitis monitoring is by measuring the cells present in milk, that is, determining its SCC. The SCC can be measured in bulk tank milk (BMSCC), at cow level with composite samples of all four quarters (CSSCC) and at quarter level (QMSCC). Whilst BMSCC can provide reliable indications at the herd level, measuring CSSCC or QMSCC is essential in monitoring the incidence of mastitis precisely and keeping subclinical mastitis under control. Somatic cells can be assessed with cow-side methods such as the California Mastitis Test (CMT). The CMT is cost-effective and practical in allowing dairy farmers to take appropriate action, including sampling for subsequent culture analysis, veterinary treatment, segregation of milk, dry-off periods or culling infected animals. However, due to its qualitative nature, the CMT is significantly dependent on user ability and experience and has a low sensitivity. Other tests include milk colour determination or electrical conductivity but these are not sufficiently reliable or sensitive for a conclusive diagnosis.

To improve the quality of detection, biosensors and immuno-biosensors have been developed for detecting protein markers of mastitis as well as other, non-protein, mastitis-associated molecules. The ability to monitor more reliable mastitis markers on line with a biosensor during milking has great potential for the earlier detection of mastitis. Researchers are developing point-of-care techniques or rapid diagnostic tests, mostly

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based on antibody-based techniques such as agglutination, enzyme immunoassays and lateral flow immunochromatography, to make this improvement in detection possible.

Chapter 3 also looks at the broader impact of mastitis on milk production and quality. Mastitis is one of the most economically important diseases in dairy production. The economic impact of mastitis includes costs of treatment and culling as well as decreased milk production and quality. The chapter reviews current research on the impact of the disease on the properties of milk. These include an increase in total proteins and a decrease in caseins, modifications in the amount and composition of fats, a decrease in lactose and changes in many milk ions. These changes impact on milk yield and result in quality issues such as off-flavours and reduced shelf life in milk as well as quality problems in dairy products such as yoghurt and cheese.

Chapter 4 addresses another potential safety issue in milk production, the risk of chemical rather than microbiological contamination. Chemical contamination of milk can occur from a number of sources, including application of agrochemicals to fields, inappropriate use of veterinary products, contaminants or natural toxins present in feed or forage, or from cleaning and disinfection products used during milk production, processing and packaging. There have been increasing reports of residues being detected in milk, attributed in part to improvements in analytical instrumentation which allow more sensitive detection of a wider range of residues, some of which were not previously detectable. These techniques include high-resolution mass spectrometry (MS), high-performance liquid chromatography (LC) and electrochemical detection techniques.

Improvements in detection create new challenges to identify current levels of residues in milk, sources and potential health effects, safe limits and recommendations to reduce contamination. The problem can be exacerbated by processing, which can lead to higher concentrations of residues in products such as milk powder, and by the development of products such as infant formula targeted at groups with greater potential vulnerability to the presence of even small traces of residues.

Chapter 4 explores these challenges through case studies which focus on three key sources of contamination: animal diet, veterinary medicines and disinfection products. The first case study looks at iodine residues in milk. These are caused by iodine supplementation of feed to lactating cows to improve fertility and udder health, as well as by disinfection of cow teats with iodine-containing products, particularly for mastitis control. The case study summarizes research to assess current iodine levels and sources as well as appropriate limits in milk.

The second case study focuses on the use of flukicides to combat liver fluke parasites that can lead to loss of productivity, fertility problems and reduced weight gain in dairy cows. The development of analytical methods such as high-performance LC coupled to electrochemical detection (HPLC-ECD) have allowed detection of flukicide residues in milk at very low concentrations. The case study reviews research on the ways residues can survive processing as well as improving best practice in treatment, including the use of withdrawal periods. The use of antibiotics in dairy farming is also discussed in Chapter 6 in the context of antimicrobial resistance.

The final case study looks at chlorine residues in milk. While chlorine is an effective disinfectant, inappropriate use in disinfection processes in dairy production and processing can cause contamination. Reactions between chlorine and organic matter produce a wide range of potentially harmful halogenated and non-halogenated compounds, collectively known as disinfection by-products. These include trichloromethane (TCM) and chlorate residues. The chapter reviews research on mechanisms of formation of these compounds,

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levels detected, toxicity and safe limits as well as recommendations for good disinfection practice, including the importance of rinsing. As the chapter suggests, future research in the area of chemical contaminants in milk and dairy products should focus, firstly, on the development, accuracy, precision and efficiency of analytical capabilities; secondly, on efficient and comprehensive strategies to detect the source of such residues; and thirdly, on addressing ways to eliminate or reduce the problem to acceptable levels. The challenges of dealing with contaminants are also discussed in Chapter 5.

As Chapter 5 indicates, contamination of dairy feed compromises the safety of milk and can affect animal health. Animal feeds include roughage, fresh and dried forages such as grass, silage or hay. Feeds also include concentrates, feeds with a high density of nutrients and typically low fibre. They may be fed as individual feeds or blended and formulated into balanced rations (compound feed). Concentrates include products such as maize, sorghum or soybean, and by-products such as brans or fishmeal. Concentrates may be grown or produced on the dairy farm or purchased in the form of products, by-products, or compounded feed from feed manufacturers. Evidence suggests that the main types of contaminant in dairy feed are microbiological hazards (such as *Salmonella* and *Brucella*), persistent organic pollutants (such as dioxins and organochlorines), veterinary drug residues and heavy metals (such as lead, cadmium and arsenic). Dairy feeds have been associated with major food and feed safety incidents involving hazards such as aflatoxins and dioxins.

Global governance of the livestock sector is provided by the World Animal Health Organisation (OIE), the Food and Agriculture Organization (FAO) and the World Health Organization (WHO). The *OIE Terrestrial Animal Health Code* covers hazards of human and animal health importance that can be present in animal feed. It provides guidance on regulatory standards, risk analysis, good agricultural and manufacturing practices, traceability and quality assurance. The OIE-FAO Guide to Good Farming Practices contains a section on animal feeding. The FAO/WHO Codex Alimentarius Commission (CAC) has also approved a *Code of Practice on Good Animal Feeding* and, based on this, the FAO has developed a manual on good practices for the feed industry. These and similar guidelines (e.g. the FAO-International Dairy Federation (IDF) Guide to good dairy farming practice) are useful for the feed industry in high-income countries. However, they are less appropriate for low-income countries where most dairy feed is produced on-farm or obtained from small, informal sector mills, and where relatively high levels of miscellaneous feed such as food waste are used.

The rest of the chapter reviews issues in identification, diagnosis and prevention of a range of hazards such as aflatoxins, *Salmonella*, dioxins, veterinary drug residues and heavy metals. The chapter includes an assessment of the health and economic impact of each hazard as well as sources of contamination. The chapter highlights the continuing challenges in managing these hazards. There are, for example, a number of established diagnostic technologies for detecting aflatoxins such as enzyme-linked immunosorbent assay and LC-MS techniques. However, current methods have disadvantages ranging from cost, low throughput, low sensitivity and specificity in some cases, to lack of portability for use in the field. There is ongoing research to develop techniques such as electrochemical biosensors, electronic noses to detect fungal volatiles and immunoassay-based dipstick techniques to address these problems. There are also challenges in areas such as effective sampling of hazards such as aflatoxins or *Salmonella* which may be present in low concentrations and unevenly distributed in feed.

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Many good agricultural practices have also been developed to minimize aflatoxins in feed ingredients. These include the use of resilient/resistant crop varieties, appropriate cultivation practices to prevent fungal growth, use of fungicides, biological control using atoxigenic fungus, proper harvesting, drying and storage. There are also established procedures for the treatment, destruction or safe alternative use of contaminated feed. Treatments include physical sorting and blending, extrusion and heating, binding and other chemical treatments. However, as noted earlier, these procedures can be difficult to implement in developing countries where sources and production of feed are much more fragmented and where appropriate training and resources are limited.

Dioxins are a group of 210 polychlorinated aromatic chemical compounds. They arise mainly from industrial processes or other sources such as the incineration of municipal waste. For cattle, roughages are the most important single route of dioxin exposure, with fishmeal as the most heavily contaminated feed material. Contaminated soil may also drastically increase the exposure of grazing cattle to dioxins. Dioxins are usually detected using gas chromatography/high-resolution mass spectroscopy or ion trap mass spectroscopy. However, analysis costs are high and biological (cell- or antibody-based) screening methods are being developed and validated.

As suggested in Chapter 4, therapeutic use of antimicrobials in dairy cows has the potential to affect human health by increasing the risk of exposure to antimicrobial residues in foodstuffs or by influencing selection of resistant pathogens. Chapter 6 focuses on antibiotic use on dairy farms which is mainly for the treatment of mastitis. As the chapter points out, the evolution and maintenance of resistant mastitis pathogens in dairy cows or dairy farm environments has not been well described. The chapter provides an authoritative review of the current evidence. Studies show that greater exposure to some commonly used antimicrobials has been linked to a greater proportion of resistant organisms, but these studies have reported little evidence of a systematic increase in resistance associated with drugs used for treatment and prevention of mastitis.

However, while there is no compelling evidence that use of antimicrobials for treatment of mastitis has resulted in increased prevalence of resistant pathogens, ensuring continued efficacy of antimicrobials is a public health priority. The chapter therefore describes a wide range of studies identifying best practice in targeted use of antibiotics for prevention and appropriate treatment of mastitis. Principles for appropriate use include accurate, rapid and consistent detection and diagnostic protocols, good recording systems, initial assessment of a cow's medical history to determine likely benefit before treatment, an assessment of whether a bacterial infection can be effectively treated with available antibiotics, selection of an antibiotic appropriate for the aetiology of the disease with narrow-spectrum drugs preferred as the first choice and treatment for as short a period as possible. As the chapter shows, there is sufficient research evidence to help develop mastitis treatment protocols that vary depending on animal characteristics and the history of subclinical disease. Determination of aetiology is one of the most important steps in justifying antibiotic treatment.

Chapter 7 builds on themes identified in Chapters 2, 4 and 5 about the importance of appropriate safety management systems on dairy farms. It is written by experts from Canada, the United States and France which have market-leading safety management programmes in the dairy industry. The chapter looks first at international guidelines such as the CAC *Code of Hygienic Practice for Milk and Milk Products* and the FAO and IDF *Guide to Good Dairy Farming Practice* which provide a framework of best practice. These guidelines cover animal health, milking hygiene, nutrition, animal welfare, environment

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and management. The main objective is to ensure that, 'Safe, quality milk is produced from healthy animals using management practices that are sustainable from an animal welfare, social, economic and environmental perspective'. The FAO/IDF Guide has been the inspiration for developing numerous national programmes integrating all aspects of dairy production.

The chapter then reviews on-farm safety programmes in Canada as an example of a leading national programme. Canadian on-farm food safety programmes are based on hazard analysis and critical control points (HACCP) principles widely used in the food processing sector as a whole. The National Dairy Code is the Canadian technical reference that provides guidance to all food safety aspects of dairy production and processing. This informs the Canadian Quality Milk programme which requires dairy farmers to implement critical control points (CCPs) relating to milking animals treated with veterinary drugs, cooling and storage of milk, and, finally, movement of animals.

These CCPs are underpinned by a reference manual describing a series of best management practices (BMP) to help prevent occurrence of on-farm food safety problems. The BMPs are the foundation of any HACCP programme. The eight BMPs deal with (1) dairy facilities, pesticides and nutrient management; (2) feed; (3) animal health; (4) medicines and chemicals used on livestock; (5) milking management; (6) facility and equipment sanitation; (7) use of water for cleaning milk contact surfaces; and (8) staff training and communication. A second key supporting document is a workbook to assist producers in developing standard operating procedures used on the farm in such areas as milking operations and hygiene. Once producers have complied with the programmes for a period of three months, a third-party validator assesses the conformity of the dairy operation with the on-farm food safety programme and provides appropriate certification. Third-party certification is important not just for verification purposes. By demonstrating quality assurance, it allows better market access for farmers. Farmers need to be convinced that the cost of running an on-farm food safety results in added value to their operations. On-farm food safety is also dependent on effective systems in related areas such as biosecurity and traceability. In recognition of the importance of a holistic approach, Canadian dairy producers have recently launched proAction. This initiative consists of a number of on-farm programmes integrating all aspects of dairying. These programmes cover milk quality and safety, animal welfare, animal health and biosecurity, traceability and environmental performance.

The chapter then includes summaries from leading national experts reviewing the scope and design of on-farm safety management programmes in the United States, France and Australia. A good example is the Australian Dairy Industry Sustainability Framework which includes 11 key targets with 36 measures. These focus on profitability, community resilience, occupational health and safety, operator training, product safety and quality, nutrition, animal care and environmental impact. The framework emphasizes the importance of regular review and improvement.

Part 2 Sustainability

Chapter 8 provides an introduction to and overview of sustainability in dairy farming. It provides a context for the following chapters. As the chapter points out, there is no area of human activity more basic to society than a sustainable agricultural sector. Agriculture

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faces the daunting challenge of meeting the needs of a growing world population of approximately 9–10 billion people in 2050 with the need to provide about 60–70% more food than is currently being produced. Farming must achieve this within the constraints of climate change whilst reducing its environmental impact in such areas as GHG emissions, water and energy use. As noted earlier, the FAO has estimated that global milk production, processing and transportation contributes 2.7% of total anthropogenic GHG emissions. At about 52% of the total, methane emissions from livestock contributes most to the global warming impact of milk production. The chapter reviews different ways of measuring the environmental impact of milk production together with problems in measurement and interpretation. As an example, the amount of water required to produce milk ranges from as little as 1 L/kg of milk to as much as 1000 L/kg of milk depending on the metric used, volumetric water footprints or water footprints based on life cycle assessment (LCA), the respective production system (grazing, mixed or industrial) and local water scarcity. These issues are addressed in Chapter 9.

Sustainability has been defined as 'meeting the needs of the present without compromising the ability of future generations to meet their own needs'. The Sustainable Agriculture Initiative Platform Dairy Working Group has set out principles and practices for sustainable dairy farming based on a collaboration with the IDF, the FAO of the United Nations and with the Global Dairy Agenda for Action which includes the Dairy Sustainable Framework (DSF). The DSF is also discussed in Chapter 15. The DSF is focused on 11 key sustainability criteria relevant to the global dairy sector. These cover GHG emissions, soil health and nutrition, waste and water management, biodiversity, product safety and quality, animal welfare, market development, rural economies and working conditions. Other elements that may be added in the future include pollution, breeding and energy use. This broad concept of sustainability encompasses the need to:

- Ensure agricultural production continues to meet food and other needs;
- Enhance environmental quality and the resource base;
- Sustain the economic viability of agriculture; and
- Enhance the quality of life for farmers, farm workers and society as a whole.

As the chapter shows, different dairy systems face different challenges:

- *Smallholder mixed farming systems* face limited access to resources, markets and services; variable resource efficiency and big yield gaps; and have little capacity to adapt to a global economy.
- *Pastoral systems* must cope with conflicts for land and water, economic and political exclusion, social (including gender) inequity, poor animal health and high risks of zoonotic diseases.
- *Commercial grazing systems* face degradation of the natural grasslands they depend upon, conflicts with other sectors over land and resource use, poor conditions for workers and, in some cases, technical inefficiencies.
- *Intensive livestock systems* face environmental challenges resulting from intensification (land and water use, water, soil and air pollution); the potential harm to human and animal health created by antimicrobial resistance, the social consequences of intensification (rural abandonment, poor working conditions, low wages, vulnerability of migrant labour, occupational hazards); and economic risks

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in the form of dependence on external inputs, including feed and energy, market concentration, price volatility and inequitable distribution of value added.

Established by the UN World Committee on Food Security, the High Level Panel of Experts on Food Security and Nutrition (HLPE) has highlighted a number of priorities in improving the sustainability of dairy production, including the need to:

- Recognize the importance of smallholder mixed farming systems for food security and nutrition
- Recognize and support the unique role of pastoral systems
- Promote the sustainability of commercial grazing systems
- Address the specific challenges of intensive livestock systems

The chapter concludes with some practical examples of ways of improving sustainability. These include using anaerobic digestion of dairy manure to produce electricity on farms and for local electric grids, using anaerobic digestion to produce ethanol as a biofuel, recycling manure nutrients to reduce the amount of commercial fertilizer needed for crops, as well as separation of manure into liquid and solid components, with solids used as a bedding material and the liquid for fertigation of field crops.

Reducing the environmental impact of dairy farming requires an understanding of where the problem lies and setting targets for improvement. As Chapter 8 suggests, establishing targets for environmental performance can be challenging. This challenge is addressed in Chapter 9. Dairy farming is extremely diverse evolving in a very different geographical context which makes assessing the environmental impact extremely complex. The second challenge is that different methods and tools can be used in the assessment, giving very different results.

To address the first challenge, the FAO has developed a global typology of dairy production systems. This is based on two major feed-base system types, mixed- and grass-based, classified into three major agro-ecological zones: temperate regions, arid and semi-arid tropics, and sub-humid and humid tropics. This typology is used by the FAO to evaluate the environmental impact of dairy farming globally using the model it has developed: GLEAM (Global Livestock Environmental Assessment Model).

In addressing the second challenge, LCA has become the internationally agreed method to address the complexity of interlinked and multiple impacts in food production. LCA helps identify effective approaches to reduce environmental burdens and evaluate the effect that changes within a production process may have on the overall life cycle balance of environmental burdens. This enables the identification and exclusion of measures that simply shift environmental problems from one phase of the life cycle to another. The International Standards Organization (ISO) has set out guidelines for the use of LCA. Chapter 9 summarizes key concepts in LCA methodology such as system boundaries, reference and functional units.

LCA still presents significant challenges and limits when applied to agriculture. First, the method is data-intensive which is a problem with biological systems (e.g. soil or climate) where data are difficult to collect. A second difficulty lies in the fact that methodological choices are still possible when following the ISO guidelines, such as defining the system boundary, functional units and method of allocation, which can make a big difference to the results, even with the same initial data. To help resolve these methodological issues, in 2012 the FAO launched the Livestock Environmental Assessment and Performance

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(LEAP) initiative. LEAP provides a platform for the harmonization of metrics and methods to monitor the environmental performance of the livestock supply chains. The partnership develops broadly recognized sector-specific guidelines and metrics for assessing and monitoring the environmental performance of the livestock sector. LEAP has published a number of LCA guides covering, for example, large ruminant products (milk and beef), feed supply chains and biodiversity assessment.

A key measure of environmental impact within LCA methodology is a product's carbon footprint. This measures the GHG emissions of a product throughout its life cycle in relation to a defined functional unit. The IDF has established a commonly accepted methodology for calculating carbon footprints in dairy farming. Comparing a large number of dairy farms using this harmonized method allowed dairy stakeholders to identify a 20% potential reduction in emissions if dairy farmers adopted practices used on the best-performing farms in such areas as type and quantity of feed and other aspects of herd management. The FAO has also published a comprehensive global assessment of emissions from the ruminant sector, based on a common methodology, which has identified key emission pathways and hot spots. This analysis suggested that a 30% reduction of GHG emission would be possible if producers in a given system, region and climate adopted the practices used by the 10% of producers with the lowest emissions.

The work of the FAO and IDF has allowed national dairy sectors to undertake their own initiatives. As an example, the French Livestock Institute has developed a tool, CAP'2ER, based on the harmonized LCA method, that can measure GHG emissions at the dairy farm level and identify areas for improvement. In 2015 the French dairy sector launched an ambitious carbon road map, 'the low carbon dairy farm'. Farm advisers were trained to use the CAP'2ER tool and went to visit more than 5000 volunteer dairy farmers to help them build an action plan to reduce emissions on their farms. The ambition of the French dairy sector is to reduce the carbon footprint of French milk by 20% in 2025. A similar approach has been developed by the Innovation Center for US Dairy using its 'Farm Smart' model.

Although impressive progress has been made, there remain many challenges in measuring environmental performance. Unlike carbon footprinting, which is now a straightforward documented procedure based on computing global warming potentials within the LCA, a range of methods for estimating water consumption have been developed which, as shown in Chapter 8, can give widely varying results. In 2016 both the FAO and IDF have launched initiatives to agree and implement a common methodology. Other areas for development include the assessment of biodiversity, carbon storage and, more broadly, ecosystem services in dairy farming.

Chapters 8 and 9 highlight the various different types of dairy farming system. Chapter 10 focuses specifically on forage-based dairy farming systems and their environmental impact. Current LCA research indicates that the global warming potential of forage-based farms is often about the same as intensive high concentrate-based dairy farms, because the decrease in carbon dioxide (CO2) and nitrous oxide (N2O) is nullified by an increase in enteric methane (CH4). Feeding a dairy cow a diet high in concentrates increases digestibility, but is associated with higher inputs from growing and storing crops for feed, potential pollution issues from fertilizer runoff and the indirect costs of housing cattle in intensive systems. However, as the chapter shows, improvements in grazing systems using high-quality forage can result in similar enteric emissions as a higher-concentrate/confinement diet. This means that forage-based systems can represent a way to achieve low CH4, N2O and indirect CO2 emissions with the result of a lower overall carbon

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footprint. As well as requiring fewer inputs, perennial forages can also be good for soil health and biodiversity.

Extensive pasture systems are often associated with relatively poor forage quality, which reduces milk yield and cow health, increases enteric methane (CH4) emissions and damages soil health. These problems can be addressed by improved pasture systems such as management-intensive [rotational] grazing (MIG). This is a system involving a high density of cows for a short period of time on a given paddock. The recovery period for the paddock is long enough to optimize forage yield and quality before cows are allowed to graze it again.

Chapter 10 looks at ways to optimize MIG systems to decrease enteric methane emissions, reduce nitrogen and phosphorus losses from grasslands as well as optimize soil health and biodiversity. As the chapter shows, maintaining high-quality pasture can reduce enteric emissions because of improved digestibility. Maintaining a highly digestible sward depends on factors such as choice of forage species and cultivar, including both grasses and legumes in the mix, timing and frequency of grazing initiation. The chapter looks at different species and mixes, including C4 grasses and warm-season legumes able to adapt to the likely impact of climate change. The chapter also reviews research on issues such as extending the grazing season and improving the evenness of forage production to optimize land use. It concludes by discussing case studies from Canada, Australia and New Zealand which demonstrate how managed pasture systems affect milk yield, profitability, emissions, soil health and biodiversity. These case studies suggest MIG is a lower-input system that can match milk yields while decreasing concentrate intake and maintaining enteric methane emissions to equivalent levels when compared to a typical confinement system. More research is needed in such areas as the best species, cultivars and mixtures to use, and best practices for pasture renovation. These issues are also discussed in Chapter 13 on organic dairy farming.

Chapters 8 and 9 highlight the issues of water and energy. Chapter 11 discusses improved energy and water management to minimize the environmental impact of dairy farming. As the chapter notes, direct energy uses are those where the energy is consumed on the farm. Examples are the use of electricity for lighting or milking and oil or diesel for crop cultivation. Indirect energy uses are those where the direct energy use occurs outside the farm boundaries. The energy use, therefore, is then embodied in the products used on the farm. Examples are energy used during the manufacture and transport of fertilizers or feed.

The chapter provides a detailed assessment of current studies quantifying direct and indirect energy use (i.e. energy use up to the farm-gate or along the entire life cycle) of production of dairy milk. As well as identifying the relative importance of different types of energy use, studies suggest savings of up to 40% or more by adopting best practices in energy management. The chapter also assesses the strengths and weaknesses of models such as DairyWise, FarmGHG, FarmSim and the Moorepark Dairy Systems Model in analysing energy use.

The chapter then discusses a case study assessing two main strategies to reduce electricity consumption in dairy milking facilities. 'Cost strategies' focus on measures to save on-farm electricity costs, such as moving to a new electricity tariff or moving energy-intensive processes such as water heating to off-peak periods when electricity price is lower. 'Energy strategies' aim to reduce electricity consumption, associated costs and GHG emissions. Possible 'energy strategies' are the use of pre-cooling of milk and solar thermal technologies to provide hot water for washing of milking equipment. Research

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suggests, for example, that milking earlier in the morning and later in the evening could reduce electricity costs by 30% or more. The use of energy-efficient technologies such as a direct expansion or ice bank milk cooling system, together with solar panel technology, could reduce electricity costs by around 40%. Investment in technologies such as pre-cooling coupled with direct expansion milk cooling systems is attractive in both reducing costs and GHG emissions.

Given increasing concern about pressures on water resources, the chapter also looks at quantifying the water footprint of dairy farming, whether the consumption of soil moisture due to evapotranspiration (known as green water) or the consumption of groundwater and surface water (known as blue water). The chapter reviews the range of studies of farm water use as well as the role of measures such as the water stress index which measures water consumption impacts in relation to water scarcity. Studies show, for example, that around 25% of livestock drinking water on pasture-based dairy farms is wasted through leakage, as well as the benefits of improving water use monitoring and water recycling technologies.

A number of chapters such as Chapters 9 and 10 have highlighted the importance of biodiversity as a key aspect of sustainability. On dairy farms, biodiversity can include soil biodiversity, grass or pasture species, native vegetation, and other flora and fauna in the agricultural landscape matrix. Dairy farming can also affect aquatic, downstream estuarine and coastal biodiversity because of the nutrients, pesticides and sediments transported away from the farm through surface runoff and groundwater. As the chapter points out, the key to enhancing biological diversity within dairying landscapes is to increase heterogeneity at multiple scales – within the farm, between farms, from subcatchment to catchment scales and ultimately across whole landscapes.

High-intensity farming is often associated with more homogenous monoculture cropping systems that results in greater ecological disturbance and biodiversity loss. Impacts of dairy farming on biodiversity can include modifying the structure and species composition of ground cover and understorey vegetation; promoting exotic plant species invasions; reducing the regeneration of shade trees and increasing the mortality of remaining trees; reductions in populations of a broad range of mammals, birds, reptiles, amphibians, fish and invertebrates due to habitat degradation; and the compacting and degrading of soils which increases runoff, erosion, and the transportation of sediments and nutrients, which can ultimately change the morphology of streams. In addition, the runoff of faeces and urine in and near streams can cause contamination by a range of viruses, bacteria and parasitic protozoa and have a significant negative impact on water quality and stream biota. The consequences of these changes include localized degradation of many critical ecosystem services including nitrogen fixation, pollination, soil enrichment, facilitation of nutrient uptake by plants, pest and disease dynamics, and water purification.

Improving biodiversity involves balancing a range of economic, ecological and other factors. The chapter discusses the use of models such as the Integrated Valuation of Ecosystem Services and Tradeoffs model. It is used to predict changes in ecosystem services, biodiversity conservation and commodity production levels. In improving biodiversity, it is important to restore or introduce elements that increase habitat heterogeneity in the farms in a region. These elements may include semi-natural habitat features such as hedgerows, shelterbelts, ditches, woodlots, restored native forest, agroforestry blocks, wetlands and riparian planting of stream, river and other water body margins with native vegetation to provide ecological corridors. A key element is to connect these elements to allow for

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better migration and dispersal with the wider agricultural matrix. Habitat improvements may also include the addition of flowering field margins suitable for pollinators and butterflies, dikes and reed beds for waterfowl, suitable pasture mowing regimes to attract field birds and cropland for foraging birds such as pheasants.

At the level of the individual dairy farm, it is possible to employ the concept of 'functional agrobiodiversity' which addresses both above- and below-ground biodiversity in dairy ecosystems by encouraging such services as nutrient cycling, disease control, pollination and water regulation. The measures to enhance functional agrobiodiversity focus on improving soil health and improving the cycles of nutrients, water and energy on the farm. Direct measures to support this may include outdoor grazing, protein-rich crops, herb-rich grassland, the establishment of permanent pasture, reductions in the use of agricultural chemicals and the use of green manure.

One of the most significant challenges to improving biodiversity is developing effective methods not just to convince individual farmers of the value of biodiversity but to convince them to work together to solve these landscape-level problems. The chapter looks at the main barriers to achieving commitment and collaboration amongst dairy farmers. The chapter concludes with a series of case studies illustrating both the challenges and the opportunities in improving biodiversity in the United States, Ireland and New Zealand. As an example, they show the impact of organic farming on biodiversity as well as the impact of riparian enhancement and other methods for biodiversity enhancement in New Zealand. These have both enhanced biodiversity and improved the farms themselves by reducing soil erosion, increasing shelter for stock and increasing pasture growth. The final case describes the results of a study identifying factors that affect dairy farmers' motivations to engage in conservation behaviour in New Zealand. As the chapter indicates, an ongoing challenge in assessing biodiversity initiatives is the limited amount of ecological monitoring data available across species and taxa.

Chapter 12 mentions the role of organic dairy farming in enhancing biodiversity. Chapter 13 looks more broadly at the environmental impact of organic dairy farming, picking up themes discussed in Chapter 10 on grassland management. Ruminants play a particularly important role in integrated organic systems, since they can efficiently utilize grassland resources, legume forages from crop rotations and crop residues, and provide valuable manure for the soil. Whilst not excluding the use of concentrates, organic standards prioritize the use of pasture and define minimum proportions of roughage in organic dairy cattle diets. However, as discussed in Chapter 10, the digestion of fibre is the most prominent source of enteric methane production in ruminants. This results in the apparent dilemma that the more a ruminant production system is based on roughages and avoids concentrates, the higher the methane emission is per unit of product. Ruminal methane production is thus the main factor which challenges the environmental sustainability of roughage-based ruminant production. Chapter 13 addresses this problem first by reviewing the range of studies comparing the effects of roughage and concentrate diets on outcomes such as milk yield and emissions.

The chapter then discusses the differing types of solution available to organic dairy farming. These solutions are to realize an efficient roughage-based production, which requires significantly less inputs from arable land than conventional systems; to enhance dairy cows' health and welfare, particularly their longevity; and to develop the right matches between local conditions (in particular available feed sources) and cow genotypes, in order to achieve functioning systems with the lowest possible need for external nutrient sources.

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One way of improving the efficiency of organic dairy farming is to extend the productive life of cows. The productive lifespan of dairy cows in conventional dairy farming has considerably decreased over the past decades and has currently reached levels as low as 2.5 lactations in many industrialized countries. This reduced lifespan results in lower overall feed efficiency and higher relative emissions if calculated for the whole lifespan of the cow. In addition to increasing overall feed efficiency, a further advantage of a prolonged productive lifespan is that it provides the opportunity to produce more calves for fattening systems out of the dairy production. It has been shown that combined dairy and beef production systems have clear advantages when it comes to GHG emissions per unit of product, mainly because the GHG emission for beef can be reduced if calves originate from dairy systems. Improving longevity requires developing more robust breeds and improvements in herd management. Increased longevity is related to better overall animal health and welfare. Studies have shown that a holistic herd management approach, which integrates husbandry, breeding and nutrition, can improve overall animal health in organic farming.

A second area of research is in increasing roughage-sourced nutrient efficiency through better management of different forage qualities. This includes offering forages with nutrient compositions and at volumes better adjusted to the changing intake needs and digestive processes of ruminants at different times of the day. Studies have shown, for example, that sequential feeding of forages improved feed efficiency. Another approach is the targeted use of herbal feedstuffs which contain high amounts of plant secondary compounds able to influence ruminal fermentation processes. The chapter summarizes research on several individual tannin-rich plant species and their effects on ruminant protein metabolism. It also includes a case study from the Research Institute of Organic Agriculture (FiBL) in Switzerland, the 'Feed-no-Food' project, which demonstrated the feasibility of a primarily roughage-based feeding regime for some organic production systems.

A third way of improving the environmental impact of dairy farming is in breeding. Organic breeding emphasizes the importance of a particular combination of functional traits, aiming at healthy, fertile, long-lived cows, able to cope with local conditions while maintaining consistent milk production with little change in body condition throughout lactation. Another objective is dual-purpose breeds that combine good levels of milk yield with beef quality. On this basis, some countries have developed specific organic selection indices for breeding. The development of genomic breeding tools offers new opportunities to investigate functional traits relevant to the organic sector. The chapter includes a case study summarizing the EU 'LowInputBreeds' which aimed at developing integrated livestock breeding and management strategies to improve animal health, product quality and performance in European organic milk production systems. The project results showed that there is considerable potential in the exploitation of innovative breeding tools for the organic dairy sector.

Building on the broader concept of sustainability discussed in Chapter 8, the final two chapters in Part 2 look more widely at the impact of dairy farming. As noted earlier, dairy production provides livelihoods for approximately 1 billion people and serves over 6 billion consumers. As Chapter 14 points out, global bovine milk production is 600 million tonnes with the top ten producing countries accounting for just over 56% of world production. The chapter looks at various indicators of production, consumption, price fluctuations and global trade in dairy products. As with overall production and consumption, a general expansion in trade of dairy products is expected with increased exports from the countries/regions such as the United States, EU, Australia and New Zealand which is the

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world's largest exporter of dairy commodities, representing approximately one-third of international dairy trade each year.

The chapter then looks in more detail at trends in milk production in the EU, the United Kingdom and New Zealand. The chapter concludes that it is evident that dairy farming is now a globally integrated industry. It is influenced by climate which can reduce feed availability and thus increase feed prices but can also lead to global oversupply affecting the prices that farmers can realize for their dairy products. This level of global integration is one reason why the viability of dairy farming has dropped and led to the number of dairy farms falling in many countries, whilst others have seen some increase primarily to meet increasing domestic demand for liquid milk as well as for the increasing trade in value-added products such as cheese and milk powders. The number of cows for the highest producing countries has tended to rise, more so recently, with those entering the market also demonstrating some increase. In other areas cow numbers have fallen. Average herd size is also increasing as farmers build on the need for some economies of scale in order to survive. Fluctuations in production levels have occurred, but are generally increasing. For the future, dairy production will remain profitable for many, there may be fewer producers better equipped to compete in a global market. Three key areas for these more successful producers will be closer working relationships within the industry, continued technical improvement, and product innovation.

Building on Chapter 14 and the opening paragraph of the Introduction, Chapter 15 seeks to assess the overall impact of the dairy sector in such areas as its economic impact, its role in nutrition and its effects on the environment. Given its scope, it covers many topics which are addressed in both Parts 2 and 3. As it points out, the Introduction to the 2016 Global Food Policy Report by the International Food Policy Research Institute notes that a food system that promotes the well-being of both people and the planet should be:

- Efficient
- Inclusive
- Climate-smart
- Sustainable
- Nutrition- and health-driven
- Business-friendly

The chapter explores the degree to which the dairy sector meets these criteria.

As it points out, analysis undertaken by the International Farm Comparisons Network and published by the FAO has determined that 750–900 million people live on approximately 150 million dairy farms. Many of these are smallholder farmers living in developing nations where dairy is indispensable to their livelihoods. As noted earlier, latest estimates are that 240 million people are either employed directly or indirectly in the dairy sector, whilst up to 1 billion people derive a significant proportion of their livelihoods from dairy if employment throughout the whole of the dairy chain is included.

In addition to providing a livelihood for approximately one-seventh of the world's population, dairy production provides an important source of nutrition for over six billion people. Milk makes a significant contribution to meeting the body's needs for a variety of macro and micro nutrients including protein, calcium, magnesium, selenium, riboflavin, and vitamins B5 and B12. In addition to providing a wide range of micronutrients, global milk production contributes on an average per capita/per day basis: 134 kcal of energy,

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8.3 g of protein, and 7.6 g fat; or 5%, 10% and 9% of global food energy, protein and fat, respectively.

Dairy consumption can also deliver substantial positive health outcomes through improved metabolic health, lower insulin resistance and improved muscular skeletal health, by reducing dental caries and by reducing the incidence of cardiovascular disease, hypertension and type 2 diabetes. The possible association of dairy consumption with certain cancers, with type 1 diabetes and (for whole fat dairy products) with heart disease all look unlikely given the findings from recent meta-analysis and the balance of scientific evidence. The nutritional value of milk means that dairy consumption could translate into substantial reductions in national health care costs. As an example, a study in the United States concluded that consumption of 3–4 servings of dairy per day could translate into cumulative five-year savings of over US$200 billion. In less developed countries, milk and dairy products can reduce micronutrient deficiency, malnutrition and stunting or low height-for-age.

As these figures make clear, the dairy sector has a huge impact on livelihoods and nutrition around the world. This can also be seen in the current scale of production and likely future demand. In 2015 global milk production reached approximately 800 billion litres. Dairy (including cow and buffalo milk) is the world's number one traded agricultural food by value. The FAO predicts that demand for milk could grow to approximately 1.1 trillion litres by 2050. If demand for milk matched current dietary recommendations by 2050 then 9.6 billion people will require over 1.7 trillion litres of milk/year or more than double the current production.

A key issue is the environmental impact and sustainability of increasing milk production. As Chapter 15 points out, dairy farming utilizes 1 billion hectares (ha) or 7% of the world's land to feed the major milking species (cows, buffaloes, goats and sheep). Of the 1 billion ha, 85% or 850 million ha is either pastures or rangeland, with 150 million ha of arable land also used to produce feed for dairy animals. Dairy cows consume 2.5 billion tons of dry matter or approximately 40% of the global livestock feed intake. As noted, dairy also generates 2.7% of total anthropogenic GHG emissions or on average 2.4 kg CO2 equivalent per kg of milk produced.

Dairy farming has made some impressive improvements in productivity through advances in breeding and feeding of dairy cows together with improved management of dairy farms. As an example, in the United States over the past sixty years, milk yield has increased more than fourfold while using 90% less land, 65% less water, producing 75% less manure and at 63% less GHG per unit of milk. Based on such advances, it has been estimated that it is possible to produce over one trillion litres of milk with fewer cows and at average GHG emissions that are 40% lower than today, though this may involve reducing the number of smallholders involved in dairy production. As the chapter indicates, globally 85% of the land used for dairying is pasture or rangeland and 77% of the feed consumed by dairy animals is from pasture and straws. This creates a solid platform from which to make improvements to dairy farming systems to reduce GHG emission per unit of milk production.

Recognizing the complexity of the challenge and the need for common global frameworks to be locally relevant and applicable, the dairy sector has developed a comprehensive DSF, previously discussed in Chapter 8. The DSF is composed of eleven sustainability criteria covering socio-economic and ecological aspects of the dairy chain. The DSF provides a common way for the dairy sector to make and measure progress towards more sustainable food systems. So far the DSF is being used to assist hundreds of dairy organizations to

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implement around two hundred sustainability-related initiatives. Participation in the DSF is growing rapidly with 27% of global milk production already operating under the DSF covering over 30 million cows, 658,000 farms and 3,700 processing plants worldwide. As Chapter 15 concludes, calls by some to limit dairy production and consumption on environmental or nutritional grounds do not look valid given the balance of current knowledge. The way forward is in initiatives such as the DSF as well as the kind of research on ways of improving milk production summarized in the other chapters in Part 2.

Part 3 Improving quality, safety and sustainability in developing countries

As Chapter 16 makes clear, much dairy production is still undertaken by smallholders in developing countries. The chapter looks at ways of helping smallholder dairy (SHD) farmers in Asia. The Asia-Pacific region has seen the world's highest growth in demand for milk and dairy products. The consumption of milk and dairy products in Asia has doubled over the last 30 years, now contributing to more than 60% of the total increases in global consumption. Even though Asia has increased its milk output (as a percentage of global production) from 15% in 1981 to 37% in 2011, it still accounts for over 40% of the world's total dairy imports. Most Asian countries still rely heavily on imported dairy products.

In Asia, as in the rest of the developing world, 80% of milk is produced by SHD farmers. Smallholder farms generally yield low outputs of milk per animal. Typical milk yields per cow per day still range between 8 and 10 kg as compared to average yields of 20 to 30 kg in developed countries. General factors limiting smallholder production include:

- Institutional factors, such as dairy cooperatives, suppliers of credit, training and extension services
- Government policies, such as development programmes, milk promotion and dairy boards
- Socio-economic factors, such as farmer education, off-farm jobs and traditional beliefs
- Technical factors, which can be further categorized into feeding, breeding and health
- Post-farm-gate factors, such as milk processing, marketing and consumption

Specific on-farm issues and areas for improvement include:

- *Low cow productivity*: improve management of feeding, reproductive management and milk harvesting
- *Low milk prices*: reduce costs of production, improve milk quality, mediate on milk pricing and find alternative markets
- *Poor milk quality*: improve milking hygiene at both farm and post-farm-gate, improve milk composition through better feeding management
- *Poor feed quality and availability*: identify better forage species (e.g. legumes), better quality control of concentrate supplies and utilize marginal land for forages

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- *Cooperative management*: reduce management structure and merge small cooperatives, improve post-harvest technology and improve calf and heifer rearing practices

The chapter concludes by reviewing various ways to help smallholders improve their performance as well as key performance indicators to measure success. The chapter concludes with a case study of investment in 'cow colonies', large dairy sheds holding 50 or more cows that are owned by a number of smallholder farmers. As the chapter shows, this attempt to help smallholders pool resources more efficiently has had mixed results. The problems associated with cow colonies show the need to take a holistic view which accounts for each step in the dairy value chain.

Mirroring the situation in Asia, an estimated 80% of the milk produced in Africa is from smallholder farming systems where producers rear less than ten head of cattle on land sizes that vary from 0.2 to 4 hectares. Issues such as breeding management, cattle feed resources, water, animal health and animal limit the potential productivity achievable. Low nutrient availability and environmental factors such as diseases, high ambient temperatures and the housing environment for high-yielding cows significantly impact their milk production and reproductive performance. However, advances in agricultural technologies, better production practices, suitably adapted cattle breeding programmes, innovation platforms and organized farmer support groups present new opportunities for realizing significant productivity gains in SHD farming systems.

A key area for improvement is breeding. Smallholder farmers rear a mosaic of genotypes comprising combinations of exotic and indigenous breeds. Most countries lack national programmes for selective breeding, livestock performance monitoring or systematic crossbreeding of their populations. One of the greatest technical challenges in optimizing utilization of breed resources in smallholder production systems is how to match livestock genotypes to local production conditions. There is an increasing amount of information available at country level on the diversity, characteristics and use of different cattle breeds in Africa through web-based electronic resources. These include the Domestic Animal Genetic Resources Information Systems available through the International Livestock Research Institute (and the Domestic Animal Diversity Information System available through the FAO). The potential of these resources can be seen, for example, in a recent study of indigenous breeds crossbred with exotic *Bos taurus* breeds of dairy cattle. The resulting crossbreeds demonstrated higher milk yields, increased lactation lengths, shorter calving intervals and a lower age at first calving compared with the local breeds.

Advances in high-density single-nucleotide polymorphism (SNP) technology, which enables genotyping of an individual at low cost, present an opportunity for revolutionary changes in the genetic analysis of populations and genetic improvement programmes. SNP technology offers an opportunity to reconstruct pedigrees of crossbred animals, increase the accuracies of breeding value estimations, lower rates of inbreeding, and reduce generation intervals in dairy cattle breeding. Other improved breeding techniques also include assortative and non-assortative mating, oestrus synchronization in combination with artificial insemination (AI) using sexed semen as well as embryo transfer. Community-based breeding programmes also offer opportunities for making better use of available genetic resources using crossbreeding as a first stepping stone, and AI to disseminate improved genetic material amongst farmers.

Availability and quality of animal feed has been identified as one of the greatest constraints to improving dairy productivity within smallholder farming systems of

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sub-Saharan Africa. Development of fodder banks, improved pasture species, planted legumes and feed supplementation with crop by-products would result in better-quality diets for dairy cattle (a theme echoed in Chapters 10 and 13). Novel livestock feeds based on crop species more suited to conditions in sub-Saharan Africa are being used as an alternative sources of carbohydrates and proteins for animals. These include cassava roots and by-products, dual-purpose sorghum varieties (for grain and fodder) and use of sweet potato vines and roots. Several manuals have been developed with country- and region-specific information on good feeding and management practices for dairy cattle.

Vector-borne diseases, notably East coast fever spread by ticks, trypanosomiasis spread by tsetse flies and anaemia caused by worm infestations, limit dairy productivity in many areas of sub-Saharan Africa. Parasitic diseases in particular cause serious losses in dairy productivity through both mortality and morbidity of animals in smallholder farming systems. Diseases related to production and management of animals such as mastitis, foot-and-leg problems, and reproduction and feed associated-disorders are also a challenge in many smallholder farms. The development of community-led animal health strategies such as vaccination programmes led by farmer groups, and implemented by veterinarians and community animal health workers, together with community-based disease and vector control (e.g. community dip tanks and community-coordinated rotational grazing) could greatly benefit SHD farmers in Africa. Building on the theme of cooperation, the chapter looks at the role of groups such as dairy cooperatives and dairy hubs as well as ways of strengthening SHD value chains.

The final chapter in the book, Chapter 18, combines issues of sustainability and development, picking up and developing themes identified in both Chapters 13 and 17. In African countries, organic farming is practised on almost 1.3 million ha or about 0.1% of the total agricultural area of the continent. The chapter reviews the challenges and opportunities for developing organic dairy farming in Africa in areas such as breeds and breeding techniques such as AI; fertility and reproduction; housing, grazing and feed; disease prevention and management; and milking techniques, milk collection and storage.

Summary

The chapters in this book highlight the ongoing challenges dairy farming faces from pathogens and other hazards such as chemical contaminants. They show the need for better on-farm detection techniques as well as adaption of best practices in dairy farm safety management to the conditions faced by smallholder farmers in the developing world. They also show the huge challenge of improving the sustainability of milk production as production increases to match demand, for example, in optimizing pasture-based systems to reduce methane emissions. The volume shows the progress the sector is making in setting appropriate environmental standards and implementing improvements as well as developing particular ways of dealing with emissions, energy and water use.

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