

BURLEIGH DODDS SERIES IN AGRICULTURAL SCIENCE

Achieving sustainable production of sheep

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Introduction

Sheep farming, whether for meat, wool or milk, has long been an essential component in diversifying farming systems, particularly in exploiting land unsuitable for arable crops. It has been estimated that there are over 1 billion sheep around the globe, over 8 million tonnes of sheep meat consumed each year and over 2 million tonnes of wool produced. Overall demand for meat in particular is rising and could reach as much as 15 million tonnes by 2019 according to FAO estimates.

Sheep farming faces a range of challenges in meeting this demand. There is an ongoing threat both from endemic and more exotic diseases. Consumer expectations about nutritional and sensory quality have never been higher. There is also greater concern about the environmental impact of animal production and the need to minimise that impact. In addition, consumers are increasingly concerned about animal welfare issues. In recent years there has been a wealth of research to address these challenges, from the increasing use of genetics to improve breeding and predict meat quality to improving animal nutrition and disease management in flocks. This volume summarises key developments in research in these areas, whether to make farming more efficient, improve its environmental sustainability or promote animal welfare.

Part 1 Quality issues

The first part of the book looks at aspects of quality. Chapter 1 reviews research on factors affecting sheep carcass characteristics. Because of their relevance to on-farm production and profit, carcass traits are often used in breeding objectives with sires ranked and evaluated for carcass characteristics such as meat yield or fat depth. Understanding the on-farm and animal influences on meat yield and fat deposition in the carcasses of sheep has allowed the selection of sire rams and the management of the progeny to produce carcasses that yield more meat. The result has been a steady increase in lean meat yields over the last decade which has been matched by increases in carcass weights and dressing-out percentages.

This chapter starts by describing the characteristics of a sheep's carcass and explains the principles of carcass composition (the weight or proportion of muscle, fat and bone in the carcass). It then examines current research on the factors that influence a carcass's dressing-out percentage (the relative proportions of carcass and non-carcass components in an animal's body), carcass composition, distribution and partitioning of tissues within the carcass and carcass shape. As research shows, in each of these areas, type-of animal effects such as the weight or age, breed, genetic line and sex (including castration), have the greatest influence on carcass characteristics. How the animal is managed with respect to its nutrition and health, which influence its growth, also have an impact, as does the use of growth promotants. As an example, supplementation of lambs on pasture with proteins that escape rumen degradation has been shown to enhance lamb growth and decrease rates of fat deposition. However, as the review of research in Chapter 1 suggests, these factors have a less significant and more variable effect than type-of animal characteristics.

Chapter 1 is complemented by Chapter 2 which assesses animal and on-farm factors affecting sheep and lamb meat quality. Quality attributes valued by consumers include

appearance traits such as meat or fat colour and palatability characteristics such as tenderness, succulence and flavour. The chapter begins by summarising how quality characteristics may be defined and their chemical basis. Research suggests that differences in meat quality between different types of sheep, as well as between different nutritional regimens for sheep and lambs, can generally be explained by changes in the intrinsic determinants of meat quality such as pH, intramuscular fat content, collagen content and collagen solubility.

The chapter goes on to provide a comprehensive review of what we know about on-farm factors that affect meat quality, including lean meat and fat colour, tenderness, juiciness and flavour. In the case of each quality attribute, the chapter looks at the relative importance of age, breed and genetic factors, sex, diet and nutrition as well as how handling and transport affect meat quality. As an example, research shows that colour pigments in muscle increase in concentration as the sheep gets older. The most rapid changes in muscle myoglobin concentration appear to take place during the first few months of age and that, once lambs are older than 270 days of age (9 months), there is no further change in the colour or redness of the meat. Research also shows that meat from lambs fed on forage diets has been shown to be redder and to retain redness and colour saturation for longer when under retail display conditions, compared to meat from lambs on concentrate diets. Studies also highlight the significance of the 1-2 weeks prior to slaughter and the activities of the animals immediately prior to stunning and slaughter as well the importance of maximising growth rates of lambs to ensure an early slaughter age.

In addition to meat, sheep also produce wool. To maintain market share and remain competitive against other types of fibre, the wool industry requires increased efficiency and management of sheep. The focus of Chapter 3 is on the quality of Merino wool, the dominant wool type. The chapter discusses ways of improving the management of sheep in a number of key areas. These include: utilisation of breeding values to select better animals; improved welfare and management of diseases such as gastrointestinal parasites, blowfly strike, fleece rot and lice; optimising nutritional management of breeding ewes to deliver lifetime wool productivity of both the ewe and progeny; and adoption of precision sheep management to increase efficiency and profitability. This allows farmers to provide consumers with a high quality, ethically and sustainably produced product with marketable provenance.

Sheep have been milked for about ten thousand years, particularly for the manufacture of cheeses such as feta. There is increasing interest in sheep dairying in developing more diverse and sustainable livestock production systems. Chapter 4 provides an authoritative review of the sheep dairy industry, starting by analysing the advantages and disadvantages of different sheep breeds for production of sheep's milk of high quality. The chapter addresses in detail key issues in dairy farming of sheep, including frequency of milking, the nutritional needs of pregnant and lactating ewes, the weaning of lambs, as well as the role of photoperiod and season. The chapter also reviews the composition and quality of sheep milk, as well as examining the common problem of mastitis in ewes and possible management strategies and treatments for the condition. Finally, the chapter suggests future directions the sheep dairy industry may take.

Part 2 Genetics and breeding

The second part of the book reviews recent research on sheep genetics and breeding. The exploration of genomic variation is central to advances in animal genetic studies.

Understanding genetic variation and the way it relates to particular traits will both accelerate breeding and improve animal husbandry in such areas as optimisation of nutrition as well as preventing and managing disease. Chapter 5 summarises the important work of the International Sheep Genome Consortium (ISGC) in coordinating research to develop genomic resources for the ovine species. As the chapter points out, perhaps the most important ISGC achievement to date has been the construction of the sheep reference genome assembly, which currently contains whole genome sequences from over 450 sheep collected from around the world. A key recent development has been the launch of the Functional Annotation of Animal Genomes (FAANG) project which provides coordinated functional annotation of farmed animal genomes, linking phenotypes and genotypes. Association studies using the FAANG datasets will inform our understanding of biological processes underlying a phenotype by providing an estimate of the probability of a particular variation in the genome sequence affecting the phenotype of interest. This increased understanding of biological processes will also be used to improve the management of the animals so they can reach their genetic potential. As an example, a key target is understanding the complement of genes expressed in the gastrointestinal tract of sheep and their potential regulatory networks. This will increase our understanding of the development and function of the rumen and its role in nutrient acquisition, control of methane production and animal efficiency to facilitate more effective management of animals for optimal performance.

Building on Chapter 5, Chapter 6 reviews recent advances in sheep breeding. Focusing on wool and meat sheep breeding programmes, the chapter discusses the implementation and adoption of genetic evaluation systems, the development of breeding objectives, and the recent developments towards uptake of genomic selection. From a relatively informal, low-cost base, the last 25 years have seen a transition to more formal approaches in sheep breeding, with more objective multi-trait measurement, across-flock genetic evaluation and the development of breeding objectives based on more systematic economic analysis. As a result, sheep breeding programmes have become more sophisticated, with significant genetic improvements being made.

The chapter reviews the impact of advances in breeding technologies such as artificial insemination as well as embryo transfer techniques such as multiple ovulation and embryo transfer (MOET) and juvenile *in vitro* embryo production and transfer (JIVET). It also discusses developments in crossbreeding as a way of accelerating breed improvement, including its application in developing dual-purpose breeds suited to both wool and meat production. An important recent development is genomic selection based on genomic tests. The advantage of a genomic test is that the information is available early in life and for traits that are hard to measure on-farm. Genomic selection can thus help achieve higher rates of genetic improvement, especially for traits such as reproductive rate, lifetime wool productivity, lamb carcass and eating quality, disease resistance and feed efficiency. This has resulted, for example, in the development of estimated breeding values (EBV) incorporating traits such as intra-muscular fat percentage, along with EBVs for lean meat yield, based on genomic prediction.

As Chapter 7 points out, given constraints on land availability, it is essential to make sheep farming more efficient, with the same numbers of animals generating higher production. An obvious option is an increased reproduction rate. The chapter reviews the range of ways of improving the reproductive efficiency of sheep. Given that seasonal nutrient deficiencies may limit overall productivity, the chapter discusses ways of optimizing maternal nutrition, which has been reported to influence foetal development, lamb birth

weight and growth weights from birth to weaning. The chapter also discusses lactational feeding as well as the use of strategic nutritional flushing of ewes and rams. Using this practice, animals are fed an energy concentration (e.g. maize) for a period of 3-6 weeks at strategic times e.g. prior to mating or late pregnancy and peri-partum to limit lamb mortality.

The chapter also explores the importance of maintaining animal health through a comprehensive health programme, including strategic dipping (ecto parasites), dosing (endo parasites) and vaccinations. The chapter concludes by reviewing developments in reproductive technologies such as oestrous synchronization, artificial insemination, the use of exogenous hormones and pregnancy diagnosis, as well as the complex management challenges in controlled breeding programmes. The chapter concludes that, provided adequate nutrition is provided and a strict animal health and reproduction programme is adhered to with a breed adapted to the specific environment, a lambing rate of 130-150% is achievable.

Part 3 Animal nutrition and health

Chapter 2 discussed the role of diet in influencing meat quality, whilst Chapter 7 emphasised the importance of nutrition in animal health and reproductive performance. Chapter 8 opens Part 3 by suggesting new ways of optimising grazing to meet sheep nutritional requirements. It suggests that a more effective and sustainable approach is to minimise fluctuations in nutrient supply by using forage plants suited to the local environment. It then argues for managing inevitable fluctuations in feed quality and quantity by capitalising on the adaptive strategies of grazing herbivores. Optimising the diet of grazing sheep by providing diverse forages suited to the local environment, and by managing the experiences of animals so they learn to combine appropriate mixtures of plants, represents an opportunity to combine profitable animal production with broader goals associated with land stewardship and natural resource management.

Modern production systems are often characterised by a limited diversity of forage, which then has to be supplemented by feed, and management systems which make it hard for animals to learn about the functional attributes of different forages during their life cycle. The chapter explores how sheep continuously assess how well their nutrient requirements are being met and, given the opportunity, modify their selection of forages accordingly. The chapter shows, for example, how this behaviour can be reinforced by broadening the range of plants that animals are exposed to during early life, as well the value of introducing new forages into an existing diet to allow sheep to adapt accordingly. As an example, the author discusses the 'Enrich' project which incorporated native, perennial shrub species into grazing systems in southern Australia, assessing how well this programme filled existing feed gap deficiencies in the autumn, reduced reliance on supplementary feeding, enhanced animal gut function and health, improved natural resource management and overall farm profitability.

Whilst, as Chapter 8 points out, much can be done to optimise grazing, there remains an important role for formulated diets in sheep nutrition. Sheep farming is sustainable because the primary feeds for sheep are renewable and contain high concentrations of components not useful for human consumption. As an example, by-products of grains such as corn, barley, sorghum, wheat, soybeans or rapeseed can be fed strategically during

parts of the lifecycle of sheep. Chapter 9 provides a general overview of sheep nutrient requirements, discusses the measurable components of sheep feeds which supply those nutrients (including fermentable fiber), and suggests practical methods of combining feed ingredients to achieve functional supplements and diets. The chapter discusses nutrients in sheep feed, methods for formulating sheep feed as well as mixing, storage and delivery of feed.

The next group of chapters discuss aspects of animal health. As Chapter 10 points out, while animal health problems are not the only cause of low production and poor welfare, better planned sheep flock health management affords opportunities for more rapid improvement than genetic selection for production traits. The concept of flock health management extends beyond the diagnosis and treatment of particular diseases, taking into consideration wider issues of better surveillance and prevention, as well as factors such as nutrition, welfare, environmental impact and improved productivity.

As the chapter points out, the main components of an animal health programme are effective biosecurity, good nutrition, protection from infectious pathogens, and endemic disease management, for example by ensuring trace element sufficiency in the diet, appropriate vaccination programmes or sustainable parasite control measures. Such programmes require setting and measuring targets (such as body condition scoring), as well as good practice in surveillance and diagnosis, including on-farm post-mortem examination. Picking up on Chapters 8 and 9, the chapter emphasises the importance of good nutrition in maintaining healthy animals able to resist infection. Undernutrition, for example, can weaken host protective immune responses to infectious diseases such as helminth, arthropod and protozoal parasitism, or contagious viral diseases. The chapter highlights the need for better understanding of the nutritive value of herbage that is fed to small ruminants, the concept of a balanced ration, and of the effects of concentrate feeding on the efficiency of digestion of primary, natural nutrient resources. The chapter also highlights the importance of effective biosecurity measures and challenges in implementation for diseases with delayed and hard to diagnose symptoms. Good biosecurity includes appropriate risk assessment, proper sourcing of new animals, quarantine and isolation procedures. The chapter concludes with two case studies showing sheep flock health management in practice, both in achieving weaned lamb growth rates as well as parasitic nematode control in sheep.

Chapter 10 highlighted the importance of effective surveillance and early diagnosis in effective flock health management. Chapter 11 provides a helpful summary of the key bacterial and viral diseases affecting sheep with a particular focus on disease symptoms and methods of diagnosis. The chapter begins with an overview of diseases of the reproductive system such as enzootic abortion of ewes (EAE), Q fever (*Coxiella burnetii*), Brucellosis (*Brucella spp*), Contagious agalactia (*Mycoplasma agalactiae*), *Salmonellosis* (*Salmonella spp*) and *Campylobacteriosis* (*Campylobacter fetus* and *jejuni*). The chapter then provides summaries for key diseases of the nervous system, the respiratory and alimentary systems as well diseases of the skin and feet. It concludes by discussing multi-systemic diseases and other relevant infectious diseases.

Building on Chapter 10, Chapter 12 reviews sustainable control of gastrointestinal nematode parasites affecting sheep. The threat of anthelmintic resistance has loomed over attempts to control gastrointestinal nematodes (GIN) in sheep for several decades and in some regions is threatening the sustainability of sheep farming. This chapter describes the current state of options to achieve sustainable control of GIN in sheep, covering general principles of worm control and methods specific to controlling GIN,

including nematophagous fungi, condensed tannins, copper oxide wire particles (COWP) and vaccines.

Echoing Chapter 10, Chapter 13 suggests that prevention and control of infectious diseases of sheep can be achieved through measures such as disease screening programmes, implementation of biosecurity measures, chemotherapeutics and vaccination. Chemotherapeutics can be very effective for treating certain infectious diseases of sheep (principally bacterial and parasitic infections). As the chapter points out, our understanding of the mechanisms underlying immune responses in sheep is still relatively poor. The chapter reviews current progress in studying immunology in sheep, including techniques for investigating cell-mediated immunity in sheep. It then goes on to discuss the identification of immunological correlates and how these can be used in vaccine design. These issues are illustrated by a case study on ovine enzootic abortion (OEA) which looks at current vaccination strategies for controlling OEA, antibodies as an immune correlate of protection or infection for OEA, cell-mediated immunity and protection against OEA.

Parts 4 and 5 Animal welfare and sustainability issues

The final parts of the book discuss aspects of animal welfare and the environmental impact of sheep production. As Chapter 14 points out, under farm conditions, sheep are often maintained in single-sex groups of similar age or size, the main exceptions being male-female groups at mating and the mother-young dyad. Separating lambs from their mother at an early age and rearing them with artificial milk is also a frequent practice. However, the most prominent behavioural feature of sheep is their marked sociality together with the formation of a bond between mother and young. Sheep show a strong need to stay with their flock mates and become very distressed when isolated. Chapter 14 examines the importance of understanding sheep sociality and how this can be taken into account in improved husbandry. It looks specifically at natural behaviour in reproduction, as well as at maternal and infant behaviour. The chapter then discusses how animal management can best incorporate these behaviours to minimise stress and promote animal health and wellbeing, including reduced lamb mortality. The chapter also looks at environmental factors such as the importance of shelter, and concludes with a case study on improving the welfare of artificially-reared lambs, showing the value of positive human-lamb interactions and nutritional factors in improving the health status of artificially reared lambs.

Practical and validated indicators of both negative and positive experiences that influence sheep welfare are required to facilitate the identification, prevention and mitigation of negative welfare impacts and to enhance welfare wherever possible. Sheep have traditionally been managed extensively, and their greater behavioural freedom has led to perceptions of fewer or lesser risks to their welfare. However, extensively managed sheep are still vulnerable to welfare challenges such as thirst, hunger or thermal comfort. Chapter 15 reviews the principles of welfare indicators for sheep and addresses the question of how sheep welfare can be scientifically assessed in repeatable, reliable and practical ways. The chapter describes possible welfare risks in a variety of sheep production systems and includes a detailed case study on the use of body condition scoring as an indicator of hunger.

Building on both Chapters 14 and 15, Chapter 16 looks specifically at improving the welfare of ewes. Ewes are often grazed in large flocks in extensive pastoral production systems, and health or production problems may go unnoticed for some time. The chapter considers what we know about the major welfare considerations affecting ewes. These include longevity and mortality, undernutrition and body condition score, environment and housing, lambing management and dystocia, vaginal prolapse, lameness and footrot, ectoparasites and on-farm euthanasia. In each case, the chapter suggests ways of assessing and improving ewe health and wellbeing in these areas.

Chapter 16 is complemented by Chapter 17 which discusses improving the welfare of lambs. High lambing rates and maintaining high standards of lamb survival, health, nutrition and growth are essential for farm profitability. Chapter 17 examines the main issues affecting the welfare of lambs, including the handling and training of lambs from birth, causes of lamb mortality, techniques for marking lambs, and issues regarding the weaning of lambs and controlling infectious diseases in the lamb population.

Chapter 18 reviews the main welfare issues associated with management of sheep post-farm gate, including transport by road and by sea, as well as pen design to allow rest and recovery in lairage. It also assesses best practice in treatment of sheep in abattoirs, including handling and stunning. The chapter argues that welfare monitoring at each stage of the post-farm gate production process is essential, together with well-designed holding systems for transport, as well as proper training for staff on handling sheep.

The final two chapters in the book look at the environmental impact of sheep production. Sheep production can have a local impact on water, air and soil quality, as well as a global impact (such as contributing to greenhouse gas emissions). Sheep production can also impact biodiversity, human health via various pollutants, and community and cultural wellbeing. Chapter 19 examines how life cycle assessment (LCA) can be used as a tool to quantify multiple resource use and environmental impacts. Via a detailed comparative case study of lamb production in France and New Zealand, it examines how potentially harmful emissions can be assessed and measured at each stage in a sheep's lifecycle, so that the most damaging stages can be identified and steps taken to mitigate them. As an example, LCA of a housed system showed that it resulted in higher sheep productivity but was associated with relatively high greenhouse gas (GHG) and nitrogen (N) emissions per hectare and per-kg product, associated with crop-feed provision and manure management. Such analyses allow more informed decisions about improving sustainability.

Building on Chapter 19, Chapter 20 discusses nutritional strategies to minimise emissions from sheep. Agricultural production accounts for 10-12% of global annual greenhouse gas (GHG) emissions, with livestock production (including sheep) being the most important contributing factor within this sector. The largest single contributor to agricultural GHG emissions is methane produced during enteric fermentation. Chapter 20 describes the various approaches to minimising enteric emissions from sheep, including plant-based approaches such as high sugar grass sward or the addition of legumes such as clover. The chapter also looks at dietary components such as garlic, essential oils and saponins. It reviews the potential use of additives for grazing sheep such as ionophoric antibiotics, before examining host-driven effects on the rumen and what determines whether some animals segregate into 'low' or 'high' methane producers.

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