Principles of Cattle Production

3rd Edition

Clive J.C. Phillips

CABI

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Preface to the 3rd Edition

It is now approximately 20 years since the first edition of this book was written, and the cattle production industry is facing very different challenges and opportunities to the original ones I wrote about in the 1990s. The intensification and expansion of cattle production systems are still causing major concern on a number of counts but now there are alternatives to cattle products that are becoming popular. This new edition describes existing cattle production systems in detail, as before, but it also examines many of the concerns, the difficulties in changing existing systems and how they can become more sustainable.

Cattle production systems are being increasingly challenged, for their pollution of the atmosphere and environment, their inefficiency and wasteful use of resources, especially water and energy, the adverse effects of consuming cattle products on human health and the poor welfare of many cattle in intensive production systems. Governments, consumers and activist groups are all concerned about the impact that cattle production systems are having in the world today. I described many of these challenges in the second edition of this book, nearly 10 years ago. The difference now is that many alternatives to cattle products have become available – cheap poultry meat, fake (vegetable-based) meat and leather, and milks and milk products based on soya, almond, coconut and other non-animal alternatives. Next on the horizon are cultured meats (otherwise known as *in vitro* meat), already able to be grown under laboratory conditions but not yet produced on an industrial scale. The major investment in these alternatives, including by companies with strong interests in the cattle industries, and the rapid growth in consumption suggests that the cattle industry will have to adapt dramatically to maintain its market share.

Despite this rapidly changing market, new opportunities exist for cattle farmers, mainly relating to the fast-growing demand for cattle products in developing Asian regions. This stems from the growing affluence in these countries, their desire to emulate a Western diet and continued expansion of the population. However, consumers in these regions are also those who are more likely to change their diet in response to concerns about the cattle industries. Currently there is significant growth in the cattle production enterprises in the most prosperous regions of Asia, especially China, but we should not assume that this growth will continue indefinitely. Imports of live and deadstock are also increasing, the former leading to concerns about the welfare of cattle exported long distances. Demand for dairy cow products is also growing in India, which has the largest cow herd in the world, but expansion of the national herd is resulting in overcrowded cow shelters, as cattle slaughter is banned in most of the country. Africa has similar potential to Asia to grow its demand for cattle products but continued poverty is preventing the cattle production systems from modernizing and expanding in the way that they are in Asia.

The book has expanded in key areas of concern. There is a new chapter on cattle welfare, which provides important detail on the major welfare threats and challenges. Classroom exercises are included to aid discussion as a means to encourage readers to develop skills in resolving ethical dilemmas in the industry. Photographs are included to illustrate the cattle and systems of production in colour. New threats are considered in the chapter on diseases, especially the growing evidence for antibiotic resistance. New opportunities and requirements are described, such as better techniques for animal identification. The book addresses cattle production from a global perspective, with consideration of all cattle production systems from beef cattle on extensive rangeland to dairy cows that are permanently housed.

The cattle industry of the future will eventually be vastly different to what we have today, even though current production systems are growing at a rate that is demonstrably unsustainable. Cattle farmers are by nature conservative and reluctant to change their systems, but they will be faced with competition from within, as well as outside, the industry. Pressure on cattle farmers to produce more from fewer inputs is increasing continually, in response to growing competition between supermarket chains and retail outlets. Resources will at the same time diminish as the human population continues to grow and unrenewable supplies become exhausted, such as phosphorus fertilizer and fossil fuels. At the same time consumers are awakening to the need to purchase products that are produced sustainably in an ethical manner. This is driving change in production systems in some of the most responsible sales markets. Eventually the cattle industries will change and this will be led by entrepreneurs, the young, highly educated visionaries who can see a future for sustainable, ethical production systems.

The final chapter takes a new and objective view of where the cattle industry is heading over the next 50 years or so. Although some of the changes anticipated are similar to those considered in previous editions – more emphasis on limiting environmental pollution, better welfare systems, healthier products for humans – the developments in the past 10 years in producing alternatives to cattle products raise an entirely new scenario that has to be carefully considered. The cattle production enterprises will face major competition that does not exist today, and which may relegate cattle products to a niche market in some areas. Competition for land may force production to be concentrated into areas that cannot be easily used for other more efficient forms of agricultural production, the hills and uplands in particular. This may seem strange at a time when demand is increasing but the scope for sudden change in a fickle market should not be underestimated. Consider the photograph developing industry, which was wiped out almost overnight by digital cameras; telephone switchboard and telegraph operators have suffered a similar fate, and before them rag-and-bone men, elevator operators and street sweepers. In the developed world cattle farmers may be relegated to the history books in future unless their systems of production are seen by consumers as relevant, necessary and responsible. Diet is also changing fast, becoming more international, and is likely to continue to develop as healthy foods are increasingly demanded to allow people to live to their potential age with the assistance of modern medicine.

In many developing countries cattle are still an essential part of the fabric of society, and the book emphasizes that there are environmental benefits to cattle farming: the use of cow dung for fuel and in buildings prevents deforestation; and traction and transport by cattle avoids the use of machinery that relies on fossil fuels and spare parts from developed countries. Although cattle production systems in developing countries are not without their share of problems – including overgrazing, or competition with crop growers – abrupt changes to combat climate change, for example, would be socially undesirable and economically unwise.

Establishing new systems for producing cattle takes time, skill and money, so cattle producers need to be planning now for the future. This new edition describes many ways in which farmers can improve their systems over time to meet new demands. Silvopastoral systems potentially provide better welfare for the cattle and improve the efficiency of production of trees and cattle, including water use, but they take time and skill to establish. Alternatives to antibiotic use when cows are dried off requires farmers to learn the skills of teat sealant injection and removal; improving biosecurity on the farm needs much careful consideration and testing of different strategies, and so on. This book will stimulate cattle producers and students of cattle production to reflect on the systems, how well they are meeting the challenges of today and whether they are prepared, or preparing, to meet the challenges of tomorrow.

Clive Phillips
2018

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The Development of the World's Cattle Production Systems

Prehistoric Development

The climate change that caused the extinction of the dinosaurs about 65 million years ago led to the replacement of gymnosperms (mostly conifers and ferns) by angiosperms, including grasses, herbs and broadleaved trees. Primeval ruminants first appeared in the Indian subcontinent about 40 million years ago, adapted to browse the trees of the tropical forests. About 25 million years ago the savannahs and grasslands of the world developed, and ruminants evolved with the necessary hypsodont teeth to consume grass and an enlarged forestomach, or rumen, to digest it with the aid of microorganisms.

About 2 million years ago the first members of the grazing *Bos* genus began to appear in northern India. They spread to other parts of Asia, northern Africa and Europe after the Ice Ages, between 250,000 and 750,000 years ago in the Pleistocene period. Three distinct subtypes of *Bos* cattle developed: the humped *Bos primigenius namadicus*, the forebear of the zebu cattle, which predominated in the Indian subcontinent and became commonly known as *Bos indicus*; *Bos primigenius primigenius*, which had no hump and gave rise to modern European cattle, commonly known as *Bos taurus* (or taurine cattle); and *Bos primigenius africanus*, which lived in the woodland and shrubland of North Africa. Related animals in the Bovini tribe that developed at this time include the bison (*Bison bison*) of North America, the European bison (*Bison bonasus*), the gaur (*Bos gaurus*), banteng (*Bos javanicus*) and kouprey (*Bos sauveli*) of South and East Asia, the yak (*Poephagus mutus*) of central Asia, the African buffalo (*Syncerus caffer*) and the wild water buffalo (*Bubalus arnee*) of South-east Asia and the Indian subcontinent, the likely ancestor of domesticated water buffalo (*Bubalus bubalis*).

Within the Bovini tribe, the wild cattle, or aurochs (*Bos primigenius*), were most closely related to the gaur (Fig. 1.1) and banteng cattle. They were large animals with big horns and powerful forequarters compared with today's domesticated cattle, and they inhabited both the temperate and subtropical zones, together with bison and yak, and the hotter regions, inhabited by buffalo. They were most prominent in central and western Europe, the Mediterranean coastal regions of North Africa, West Asia, the Indian subcontinent and central East Asia. The bulls were usually dark brown to black, and the cows, which were much smaller than the bulls, were red-brown.

As early as 38,000 years ago, prehistoric humans had a close association with cattle. Cave paintings in Europe show the aurochs both running wild on grassland and being preyed upon by men with arrows and spears. Their carcasses provided not only meat but also valuable hides for tents, boats and clothing and bones for fishhooks and spears. The extinction of the aurochs was largely due to human predation, since they were a popular target of hunting activities. Competition for feed with domesticated cattle and transmission of diseases between the two populations may also have contributed to their demise. This was the first documented anthropogenic extinction, and it began in England in about 1300 BC and ended when the last aurochs cow died in a hunting reserve in Poland in AD 1627.

Domestication

Cattle were first domesticated from wild *Bos primigenius* cattle in the Middle East about 8000–10,000 years ago. *Bos indicus* cattle were developed primarily in the Indian subcontinent from the diverse range of wild cattle that existed there, and a less diverse new breed type, the European taurine cattle, emerged from sequential limited migrations from west Asia. The resulting genetic diversity is at least as great as humans,

Fig. 1.1. A family group of gaur cattle (*Bos gaurus*) in Malaysia: (from left to right) calves, a cow and a bull.

and considerably greater than the dog. The domesticated cattle were earlier maturing, with smaller brains and less acute senses than the aurochs, but possessed larger udders. They were less sexually dimorphic, i.e. males and females were more similar in size, and they were more variable in coat colour and horn shape, as well as more likely to be polled (without horns), which was a disadvantage for aurochs but not for domesticated cattle. The aurochs were seasonal breeders, with offspring produced in late spring, whereas the breeding period for domesticated cattle shows little seasonality. The diet of aurochs and domesticated cattle was similar, mostly grasses but with tree foliage during winter. The aurochs lived in harmony with their varied environment: grasslands, forests and wetlands. Domesticated cattle survived in increasingly large numbers in deforested areas where the land had been converted to grassland.

The milking of cows for the production of human food was already well developed at the time of the first written records in Mesopotamia in 6000 BC; it is likely to have originated soon after the domestication of cattle, which had occurred at some time up to 2000 years beforehand. Studies of Neolithic cows and the human diet in Europe and Africa in approximately 4000–5000 BC have shown that dairying was commonplace at this time, and that calves were weaned early, at some time between 2 and 9 months of age. This may have been due to their lactation being shortened as a result of limited feed resources, but it may be that the herders separated cow and calf at this time because they wanted to extract milk for themselves as soon as the calf could feed on solid feed (Balasse and Tresset, 2002). In North Africa, climatic conditions were getting drier at this time, and the Neolithic herders began to replace cattle with sheep and goats that have lower nutritional requirements and cope with drought better.

Domesticated cattle were therefore probably used for the production of milk and meat and for draught power from the start of their symbiotic relationship with humans, but even as early as the Stone Age cattle also had a dominant role in religion. This mainly related to their power–fertility symbolism, which derives from their strength, aggression and the ability of bulls to serve large numbers of cows. The bull came to dominate the religions of the Middle East and North Africa in particular. The ancient Egyptians worshipped the bull god, Apis, which was embodied in bulls that were selected from local herds. These bulls were ritually slaughtered at the end of each year, after which they were embalmed and ceremoniously placed in a tomb in Saqqarah. The ancient Egyptians also worshipped cow goddesses, which represented fertility and nurture. Significantly, in Hebrew culture, as the people changed from being warriors to farmers, the image of the bull changed from aggression to virility.

Cattle Farming in Eurasia

The spread of cattle farming across Asia and Europe was caused as much by the invasions of nomadic herdsman from the Eurasian steppes as by the Middle Eastern influence. These invasions started as long ago as 4000 BC, when the European Neolithic farmers were conquered by the herdsmen on horseback who brought traditions of raising cattle on the steppes. These farmers had been settled agriculturists, growing cereals and keeping small numbers of livestock. Security was provided by investing in the land, returning nutrients to build up fertility and trading peacefully between small communities.

Cattle had a crucial role in both religion – principally for sacrifice – and as a tradable commodity. In many European countries the word for 'cattle' is synonymous with 'capital'. The resistance of the people of the southern part of the Italian peninsula to encroachment from Rome was fought under a banner of their cattle culture: the name Italia, originally referring to the south, is popularly suggested to have meant '(land of) young cattle'. When the people from the Asian steppes invaded Europe they brought few cultural advances but a new warrior-like attitude, in which security was valued as well as the ability to move fast (on horseback), with little allegiance to any particular place. Warriors were expected to expropriate cattle, often for sacrifice to appease the gods. The influence of these warriors was particularly pronounced in the west of Europe, where the Celtic descendants of the Eurasian herdsman developed a powerful cattle-based culture. Some historians believe this fuelled the colonizing tendencies of the Iberian and British peoples.

The warriors from the Asian steppes also migrated into India, where the cow acquired a unique significance in the Hindu religion. A ritualistic and sacrificial role of cattle was recognized in the Vedic literature as long ago as 1500 BC. At the time the human population density was low and large areas were forested before domesticated cattle were widely kept. As the population grew, an increase in crop production became inextricably linked with the use of cattle for tillage. It became impossible for everybody to consume beef, as the animals were required for draught purposes, and the cows were required to produce offspring to till the soil. The consumption of beef became restricted to the upper classes, in particular the Brahmin sect, and a strict class system evolved. When increased population further restricted the use of cattle for beef consumption, strict regulations were introduced that prevented beef consumption altogether. With the prohibition of cattle consumption, shelters, or *gaushalas*, were established to care for unwanted animals or those that had become unproductive. In the period of British occupation cow protection became a source of national pride for Indian people. The first major revolt against the British, in 1857, was due to a rumour that they were using beef tallow to grease cartridges used by Hindu soldiers. Cow protection movements evolved from this time onward, including by Mahatma Gandhi. Even today cattle protection remains a political issue, with most states banning cattle trading and slaughter. There are about 3000 *gaushalas* now, all around the country, looking after cattle that have mostly been abandoned. Conditions are sometimes poor and cows are often overcrowded (Fig. 1.2) and dependent on philanthropic donations, including of food for the cattle (Fig. 1.3).

Nowhere exemplifies the problems facing cattle production systems in developing countries better than India. With one of the highest cattle populations per capita in the world, this vast country has had to cope with increased human population pressure and the requirement to maintain inefficient cattle production systems for religious reasons. Nowadays, many of the abandoned cattle in India have assumed the role of scavengers and they compete only little with humans for food resources, as less than 20% of their feed is suitable for humans. Most is either a by-product of the

Fig. 1.2. A heavily stocked cow house in India, containing Gir (brown) and Kankrej (grey) breeds in a *gaushala* (cow sanctuary). The cows are kept in this yard for 19 hours per day.

Fig. 1.3. Cattle kept in an Indian *gaushala* after they have reached the end of their working life.

human food industry or is grown on land that cannot be used to produce human food. They have become an essential and valuable part of the agrarian economy, but two problems remain. Firstly, the inability to slaughter cows requires the maintenance of sick and ailing animals, although some are sold to Muslims, for whom slaughter is not against their religious beliefs. Large numbers of cattle are also smuggled across the borders to neighbouring countries for slaughter. Scavenging in the streets around communities with no refuse collection, many Indian cattle consume significant quantities of indigestible and potentially toxic materials, especially plastic, in their search for food residues. Secondly, the increased livestock population has led to overgrazing of many grassland areas, which were first created when India's extensive forests were felled. The cultivable land area has been declining by over 1%/year and, at the same time, the livestock population increased by more than 50% in the second half of the 20th century. Some of the grazing areas used for cattle could be used for the production of human food but, because of the high social status accorded to those with large herds, the increasingly affluent Indians are turning to grassland improvement to support their expanded herds. Water retention properties of the land are improved by contour ploughing and trenching. Nitrogen and phosphorus fertilizer are used in greater quantities. In some areas sustainable use of grassland resources is encouraged by the incorporation of legumes into the sward, which can contribute substantial quantities of nitrogen. Intercropping is often used to improve water and mineral resource use.

Over the course of history, the fencing of grazing land has been an important measure to control the movement and nutrition of cattle. Land enclosure began in England in the 12th century AD and accelerated in the 18th century due to the demands of an expanding population. Enclosing land is no guarantee against overgrazing and it does not create any extra land, but it is an effective management tool to allow farmers to use available feed resources most efficiently. The controlled burning of trees and weeds has been another management tool to allow productive grass species to be introduced. In mediaeval times, periodically leaving the land fallow to create fodder banks allowed soil reserves to accumulate and fodder supplies to match ruminant numbers. However, with increasing population this is now rare, and worldwide there has often been insufficient control over cattle numbers, with grazing resources overused and deterioration of grass production potential.

Colonial Expansion

In Spain the ideological significance of cattle is deeply rooted in the culture brought by the Celtic invasion initially and later by the Romans. The bullfight signifies the trial of strength between humans and one of nature's most fearsome beasts. The consumption of beef reared on the Spanish plains has always been popular but, for a long time, the warm climate meant that spices had to be added to meat because it spoiled rapidly. When Christopher Columbus set off to find a quick route to the East for spices, he found something of much greater significance for the cattle industry. The virgin territory of the New World provided cattle pastures of superior quality to the arid interior of Spain and paved the way for the colonization of most of the Americas. With no natural predators, the Spanish Longhorn cattle multiplied rapidly, and by 1870 there were over 13 million cattle on the Argentinian pampas alone. The principal South American exports at the time were salted beef and cattle hides. In the late 19th century refrigerated transport enabled carcasses to be sent to Europe to fulfil the rising demand for beef. Most of the production was, and in places still is, on large ranches or haciendas, so that the production system and the profits were in the control of a few families. This oligopoly of agricultural production in the Iberian Peninsula and in its colonies prompted regular revolts by the peasants that are typical of those that have occurred in Europe since the Middle Ages, and most recently in Portugal in the 1970s. The most recent South American revolution emanated at least in part from poverty of the farm workers, or *campesinos*, in Chile in the 1970s.

Another large-scale colonization with beef cattle, that of North America, began with the industrial revolution providing wealth for a new British middle class, who came to be able to afford to eat beef on a regular basis. The English aristocracy had in the Middle Ages gained a reputation for excessive feasting on a variety of meats, with beef being the most favoured. The nouveau riche of the 19th century required choice joints to feed their families, and English breeders selected smaller, better-formed cattle than the Spanish Longhorn that was by this time common in South America. Breeds such as the Hereford were developed, which could be fattened in two grazing seasons, whereas the larger animals might require up to 3 years. A key figure in the development of British breeds was Robert Bakewell, who first selected cattle for meat production rather than for the dual purposes of meat and milk production.

In the late 19th century British and American pioneers began to search for new cattle pastures to provide for the growing demand for beef in Europe. The western ranges that covered much of the interior of the USA were home to about 4 million bison that had roamed free for about 15,000 years. In a 10-year period, from 1865 to 1875, the Americans and several European 'game hunters' systematically slaughtered the bison, mainly for their hides, which were more highly prized than cattle hides because of their greater elasticity. Coincidentally, perhaps, the slaughter of the bison greatly assisted in the subjugation of the indigenous Indians, who, deprived of their livelihood, became dependent on the colonizers. Many assisted in the bison slaughter and then turned to subsistence farming in the reservations. A rangeland management system that had been sustained by the Indians for several thousand years had been destroyed almost overnight.

The system that replaced it was funded by investment from abroad, especially from Britain, which supported the purchase of cattle, the expansion of the railways and later the development of refrigerated transport. The occupation of rangeland by cattle ranchers was facilitated by a simple invention, barbed wire, which could be used by the 'cowboys' to stake a claim to as much land as each felt able to manage. Publicly owned rangeland in the USA was, and still is, leased for a sum well below the market value. There was a similar spread of cattle over much of northern Australia, though this largely occurred during the 20th century, when farming methods for the tropics and subtropics had been developed and sheep had been found to be unviable in these areas. Decimated by disease and enforced subjugation, many aboriginal people found work on the large cattle stations. When the government forced station managers to pay the workers a wage in 1968, there was an exodus from the stations, which were unable or unwilling to pay for labour that had previously been provided in return for just the provision of food, clothing and accommodation.

The USA grew in stature as a world power as Britain declined, and with the increase in American affluence came the demand for well-fattened beef for home consumption. Then, instead of the cattle being finished on the range, they began to be transported for fattening on cereal-based diets in feedlots of the southern one-time Confederate states.

The Growth of Dairy Production Systems

For most of the second millennium AD, milk was produced for home consumption in villages, and cows were kept in the cities to produce milk for the urban populations. A rapid expansion of dairy farming in industrialized regions can be traced back to the advent of the railway. In Britain, for example, it meant that milk could be transported from the wet west of the country to the big cities, especially London, Bristol and the urban centres in the north. Nowadays, transporting milk and milk products is largely by road vehicles, but the centres of dairying remain in the west, where the rainfall is high and there is a plentiful supply of grass for much of the year.

In many developing countries such a ready supply of milk and milk products in the cities is not always available. With a continued migration from rural to urban areas, many rural migrants in the cities have inadequate access to high-quality dairy products because of their high cost. Often milk is diluted, or there is spoilage after being brought in from the countryside. Milk and dairy products provide an important source of minerals, particularly calcium, vitamins (especially vitamin A) and a highly digestible supply of energy and protein. In sub-Saharan Africa, rapid deterioration of milk and dairy products in the warm conditions prevailing necessitates the establishment of small urban and peri-urban farms, for which feed and other supplies have to be brought in from surrounding rural areas. Securing adequate forage resources can be difficult as the cities expand and distances to rural areas are often too long for the import of large quantities of fresh fodder. Conserved fodder may be scarce in supply, as well as being expensive and bulky to transport. In the rural areas there is sometimes conflict for land access between the settled agriculturists producing fodder and other crops and migrant pastoralists. Where land is limited in supply, the rural poor usually have to feed their cattle on waste products, including crop residues, or graze them on land that could not easily be used for other purposes. Rarely do they utilize grain, which can be used to feed humans. Of increasing interest is the use of by-products, such as paper and vegetable wastes, in the suburban dairy production systems. These non-conventional by-products are increasingly used with benefits to the environment and the efficiency of land use.

Cities are not just centres of human population but also of industrial development, and the continued growth of urban and peri-urban industry has left the problem of waste disposal. Some wastes, e.g. from the food and drink industry, can be used without modification for cattle production. They are characterized by variable nutritional value and poor hygienic quality and are more suited to feeding to ruminants than to monogastric animals because of their ability to ferment low-quality feeds. Brewers' and distillers' grains are particularly valued industrial by-products. Many other wastes do not have an established outlet and their safe disposal can be expensive; alternatively they may create a public health hazard if they are disposed of carelessly. Some can be utilized for cattle feed but others contain toxic agents, such as arsenicals in waste newspaper, or a variety of transmissible diseases. Zoonoses are of particular concern, especially since the transmission of a spongiform encephalopathy occurred from animal carcasses to cattle and thence to humans in the UK. Many feel that such recycling practices risk the emergence of novel pathogens, but it must be remembered that recycling predominates in nature and is in the interests of the development of an efficient industry. It is therefore not surprising that international bodies such as the Food and Agriculture Organization of the United Nations (FAO) and the World Bank have identified peri-urban dairying as showing the highest potential for meeting the growing nutrient need of urban consumers.

Cattle in the World Today

The world's cattle population is currently approximately 1.4 billion (Robinson *et al.*, 2014), or one for every five people, distributed across every continent except Antarctica (Fig. 1.4). Given that the biomass of cattle is almost ten times that of people, the biomass of cattle in the world is almost twice that of people and the largest of any animal on earth. It is increasingly recognized that the dominance of livestock systems in use of the world's land and water resources must be re-evaluated in the light of today's sustainability goals: poverty reduction, food and nutritional security, ecosystem protection, mitigation of greenhouse gases, and adaptation to climate change (Herrero *et al.*, 2013).

Just over a quarter of the cattle are dairy cows. Their density is determined by climate, topography, political considerations and religion (Fig 1.4). Nearly 30% reside in India, more than in any other country in the world. Here they are strongly connected with the country's religion, Hinduism. As sacred animals, they are not usually slaughtered for meat, but are used for production of milk, milk products and faeces. Elsewhere cattle are concentrated into parts of the world in which grass is more easily grown than crops: the savannah regions of Africa – both north and south of the equator – and Australia, the prairies of North America, the pampas of South America and the steppes of central and Eastern Europe. An exception is north-west Europe, where mixed farming systems integrate cattle and agricultural crop production.

Cattle production systems are often criticized for their environmental, welfare and nutritional impacts. In addition, protein production from beef cattle is one of the least efficient ways of producing protein for human consumption (Table 1.1), in part because of the high cost of maintaining cows to produce a relatively small number of calves. However, if it uses land that could not otherwise be used for human food production directly from crops it may augment the total food protein produced for human consumption. Protein in the milk of dairy cows is produced as efficiently as the non-ruminant protein sources – pigs, fish and poultry (see also Chapter 5 for discussion of processing efficiency).

Cattle are an integral part of the lives of many of the world's poorest people. In Africa, the savannah belt has many cattle farmers (Fig. 1.5), especially in Nigeria, Ethiopia, Uganda, Burundi, Rwanda and Malawi (FAO, 2002). In India, Pakistan and Bangladesh and much of South America, all of which are major cattle-rearing regions (Fig. 1.4), a high proportion of people earning less than US$2/day manage their cattle in mixed farming systems (compare Figs 1.4 and 1.6). Cattle make a significant contribution to wealth, and any attempts to restrict cattle numbers because of their environmental impact will need to take into account their widespread use by the world's poorest people. In many of the poorest parts of Africa, where only a small proportion of the population has access to electricity or clean cooking fuels, cattle dung is dried and used as a fuel for cooking. Sometimes it is mixed with straw. Its use in this way has been an important means of cooking food to improve its value for humans for thousands of years. Temperatures of several hundred degrees Celsius can be reached in a few minutes and sustained for a sufficient period of time for cooking. Using dung for fuel replaces the use of firewood (which has resulted in deforestation), but it prevents the dung being used as a valuable fertilizer on the land and may lead to increased use of artificial fertilizer.

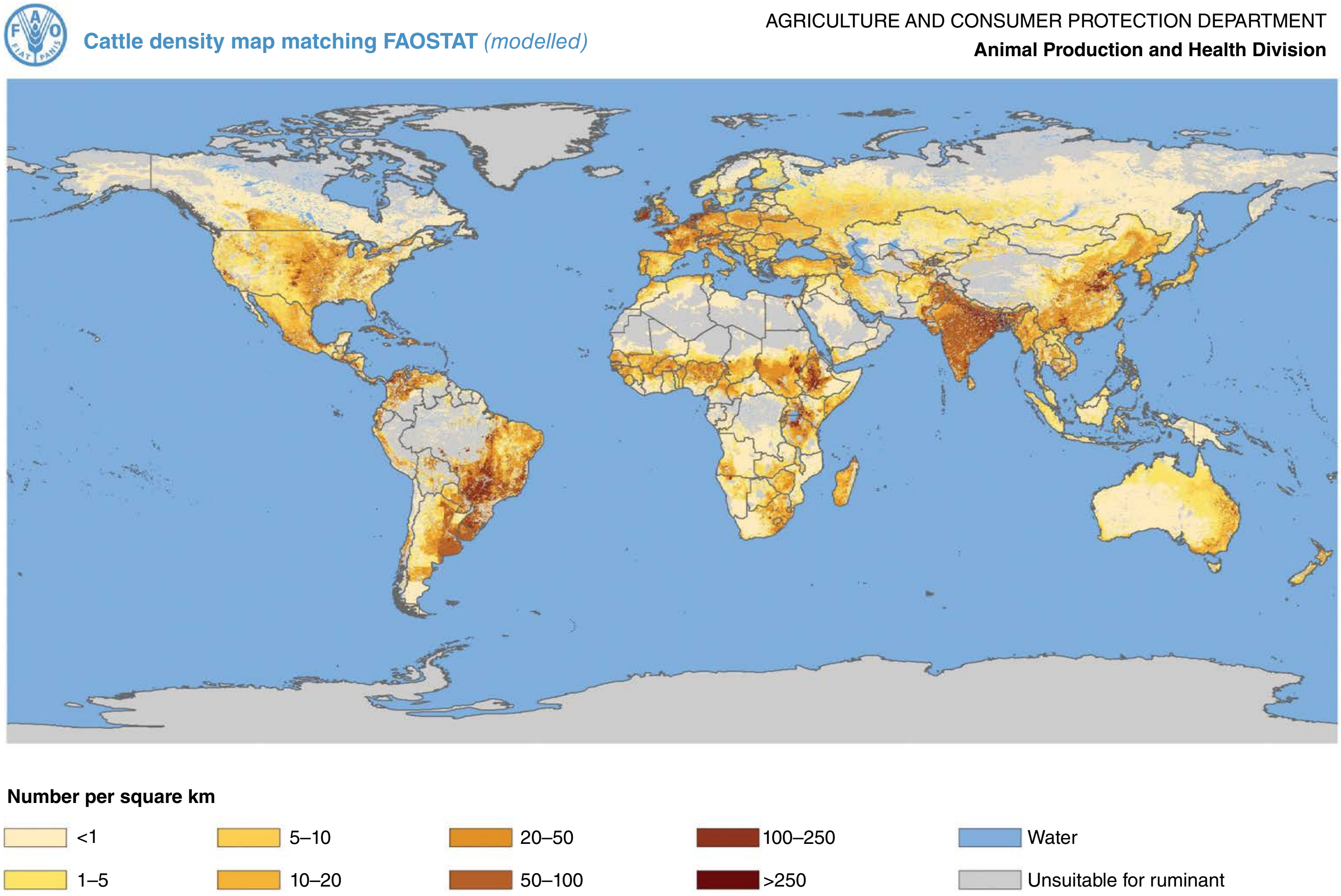

Fig. 1.4. World map of cattle density (from FAO, 2008a).

Table 1.1. Protein production efficiency of major animals used for human foods (adapted from Tilman and Clark, 2014).

Human food	Protein production efficiency (edible animal protein produced/feed protein used)
Beef	0.05
Mutton and goat	0.07
Pork	0.17
Poultry	0.20
Milk	0.25
Trout	0.25

Using dung directly for cooking pollutes the atmosphere and may cause respiratory problems in humans. Turning it into biogas, which is mainly methane (50%) and carbon dioxide (30%), requires some resources but it is a much more efficient and less polluting fuel for household use. Cattle dung is sometimes used for other purposes, for example in India where it is spread on the floor of houses because it has some sterilizing properties.

In the long term, cattle production systems cannot usually be justified only by their role in feeding and providing fuel for the rural poor, though this argument has been made to justify livestock exports from Australia to Asia and intensification of livestock production in countries, like South Africa, where there are rich and poor living in close contact. The reality is usually that the poor cannot afford to buy the cattle products as they are too expensive per unit of all of the major nutrients, and they have to be sold to generate income to buy staple foods. In the USA, even though cattle production has been intensified to reduce costs, meat products still cost over 40 cents per 100 kcal, and grains, beans, legumes, nuts and seeds only 10–20c/100 kcal (Drewnowski, 2010). Furthermore, the cost of meat is not the full cost, which should include the environmental pollution that animal farms cause, and the cost of their contribution to ill health, and eventually the cost of finding alternatives to the antibiotics that are being rendered ineffective because of their overuse in intensive livestock production. The high cost is principally due to the high level of resources that is required for cattle production. This includes large quantities of grain crops for intensive and semi-intensive feeding of cattle. The grain used for all animal feed, which accounts for 40% of all arable land worldwide, could feed 3.5 billion people (Niamir-Fuller, 2016).

Cattle Production Systems and Climate

Cattle are now kept in all the major climatic regions, which demonstrates the importance that they have assumed as the major species domesticated for the provision of food. Because of the large amount of heat produced by the microbial fermentation of coarse grasses, and their large size, they thrive better than most other domesticated animals in cold climates. The provision of a naturally ventilated shelter enables cattle to be kept for milk production in extreme cold, such as in Canada, even if ambient winter temperatures approach the lower end of their comfort zone. Feed intakes are increased to generate more internal heat but their survival is not threatened. Breeds of cattle that thrive under such conditions are usually of the more endomorphic type, such as the Hereford. At the opposite end of the climatic spectrum, cattle are able to survive in some of the hottest environments of the planet, especially if they are protected from the sun's radiant heat by provision of adequate shade. More crucial than the temperature in these environments is a regular supply of potable water.

Despite their successful integration into farming systems in extreme climates, cattle are best kept in moist, temperate environments with a regular rainfall that enables grass to grow for much of the year. In some parts of the southern hemisphere, such as New Zealand and southern Chile, and southern Ireland in the northern hemisphere, grass will grow for the entire year and grazing systems predominate. In more extreme latitudes colder conditions in winter mean that most cattle are housed for about 6 months of the year. Mediterranean climates are often too dry for cattle and the keeping of sheep and goats is traditional. Because of their low feed intake requirements sheep and goats survive on sparse vegetation more easily than cattle, and sheep in particular can survive with less water, producing a faecal pellet that is harder and drier. Mediterranean cattle production systems are therefore more likely to rely on forage crops such as maize rather than on grazing, as in the Po valley of Italy.

At high temperatures cattle reduce their production levels unless they are given shade, cooling and a highly concentrated diet to minimize the heat increment of digestion. Their morphology adapts to make their coat short-haired and shiny, to reflect the sun's rays, so that they absorb less heat and lose it more readily. Cattle have become well adapted to a hot

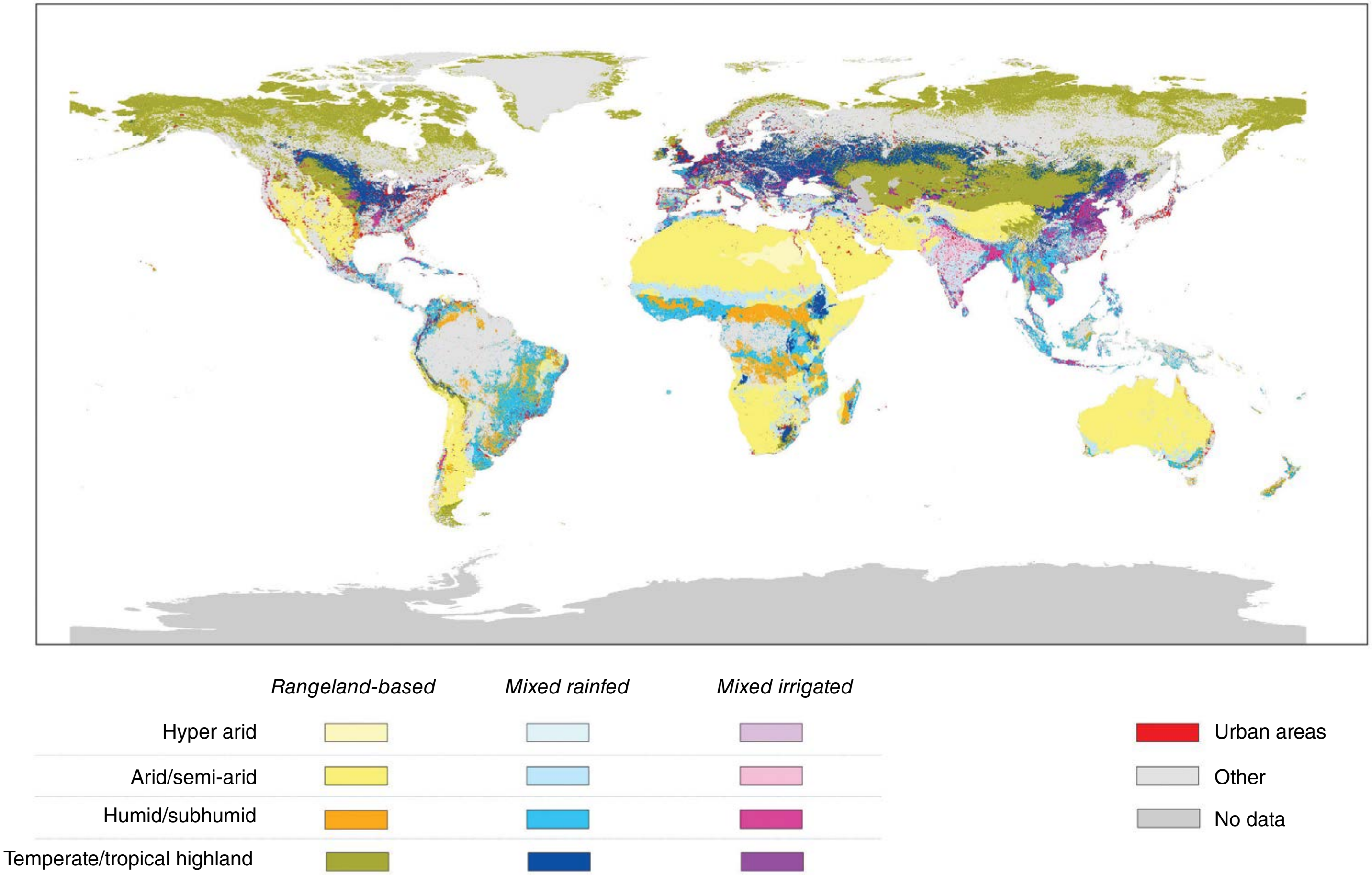

Fig. 1.5. Land utilization systems for livestock production in different climatic zones (from FAO, 2008b).

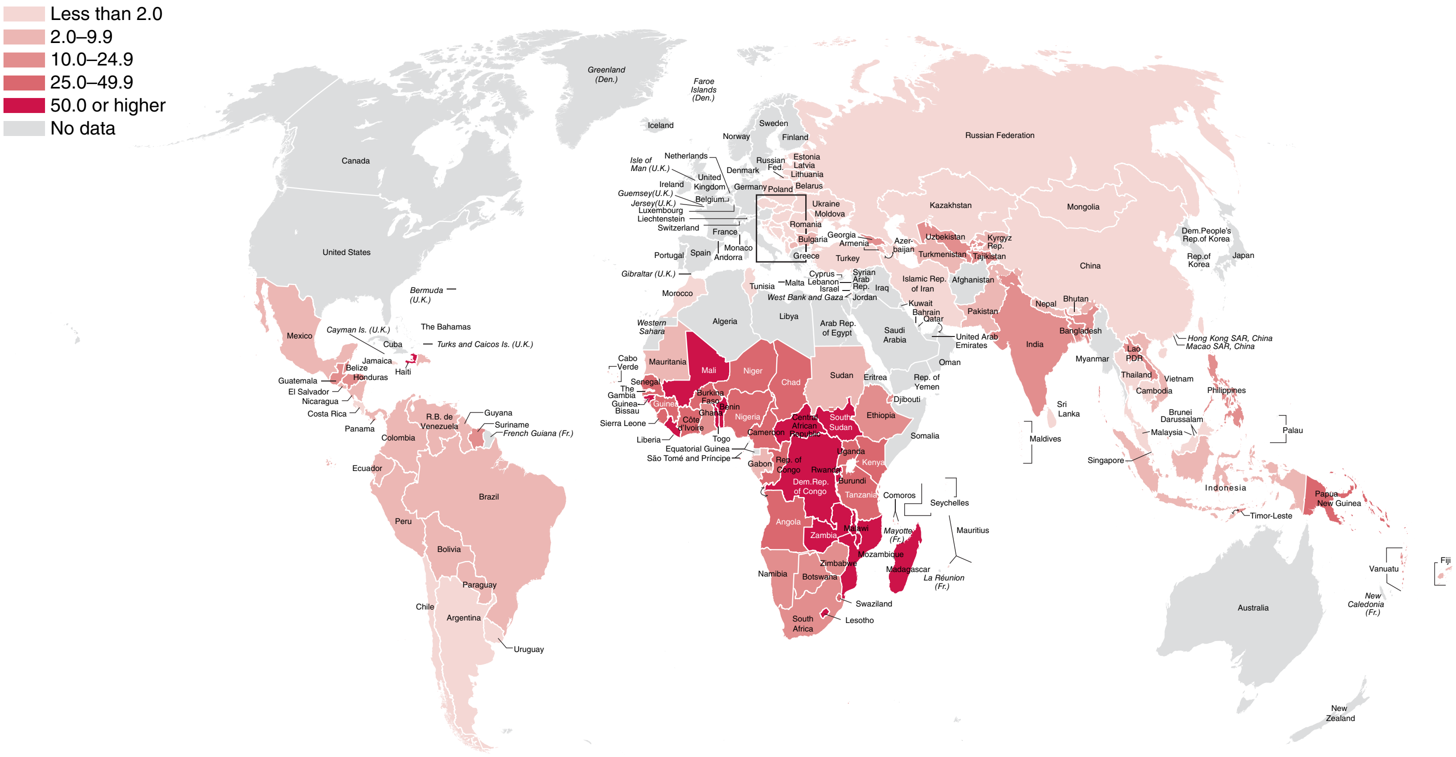

Fig. 1.6. World poverty map: the percentage of the population in countries below the poverty line (US$1.90/day in 2013) (from World Bank, 2017).

environment in the savannah regions of Africa, Australia and South America. Trees often provide the necessary shade, whilst allowing a flow of air to the cattle (Fig. 1.7). The cost of modifying the environment is high, for example in the feedlots of North America and Australia, but small-scale cattle herding is used as a reliable form of subsistence agriculture in the developing country environments of Africa and South America. In such systems, cattle provide not only human nutrition in the form of meat and offal, milk and occasionally blood, but also clothing from leather, dung for fuel and fertilizer and to increase moisture-holding capacity in the soil, and a means of tilling the land.

In some traditional societies, such as the Nuer of South Sudan, cattle adopt an even more central role in the culture. Status is indicated by the size of a cattle herd, cattle are used as a form of currency for major transactions, e.g. marriage dowry, and bulls are a major fertility symbol. Cattle provide an insurance against the costs of major life expenses, including medical expenses and school fees, and against adverse climatic conditions, drought and crop disease outbreaks. Most of the meat and milk output is sold, enabling herders to buy staple crops. But some is retained and provides high-quality nutrients to improve the well-being of the rural poor, especially that of the children. Most of the approximately 1 billion people in the world living in poverty are in rural areas of Asia and Africa, particularly Bangladesh, India, Pakistan and Nigeria. Cattle play a major role in feeding the rural poor in all of these countries. The majority keep or want to keep livestock. The land is mostly tilled by cattle and the income from traction and manure can exceed that from milk and meat production.

Fig. 1.7. Trees on savannah provide essential shade to cope with hot conditions and allow a flow of air to cool the cattle.

In many parts of the world cattle production systems have been intensifying since the middle of the last century. Between 1990 and 2003, Brazil's cattle herd increased from 27 million to 64 million head, as Amazonian forest was destroyed to make way for cattle pastures (Fig. 1.8). Average herd sizes generally increase by a process of amalgamation of small units and an increase in purchased feed use. Only dramatic political changes, such as in Eastern Europe in the 1990s, disrupt the agricultural intensification, reversing the expansion of herd sizes. In the former communist countries of Eastern Europe, land was returned to the many smallholders that had owned it before it was seized early in the 20th century. However, the economies of scale encouraged larger herd sizes, especially since the descendants of former owners often did not have the skills to profitably farm the small land areas returned to them. The intensification process has culminated in the development of feedlots for beef cattle and year-round housing for dairy cows, with several thousand animals in a unit and the feeding of conserved and processed feeds.

Modern Trends

The end of the second millennium AD brought an increased concern by the public about cattle farming practices, which are now increasingly required to produce food that is safe to eat, cheap, humane to the animals and not damaging to the local, or global, environment. This is partly in response to the suspicions of the intensification of modern farming methods, encouraged by the move to company ownership of farms and the introduction of new technologies that are directed at increasing the profitability of cattle farming. It has enabled milk yield to approximately double over the past 50 years; for example, annual milk yield per cow in the UK increased from 3750 l in 1970 to 7271 l in 2017. At the same time in the UK the mean herd size increased from 30 to 115 cows, and the annual milk sales per producer increased from 112,500 l to approximately 840,000 l.

The issues of concern stem partly from the industrialization of the farming process and the public's lack of understanding and involvement in the process. Increasing prosperity has enabled more people to eat outside the

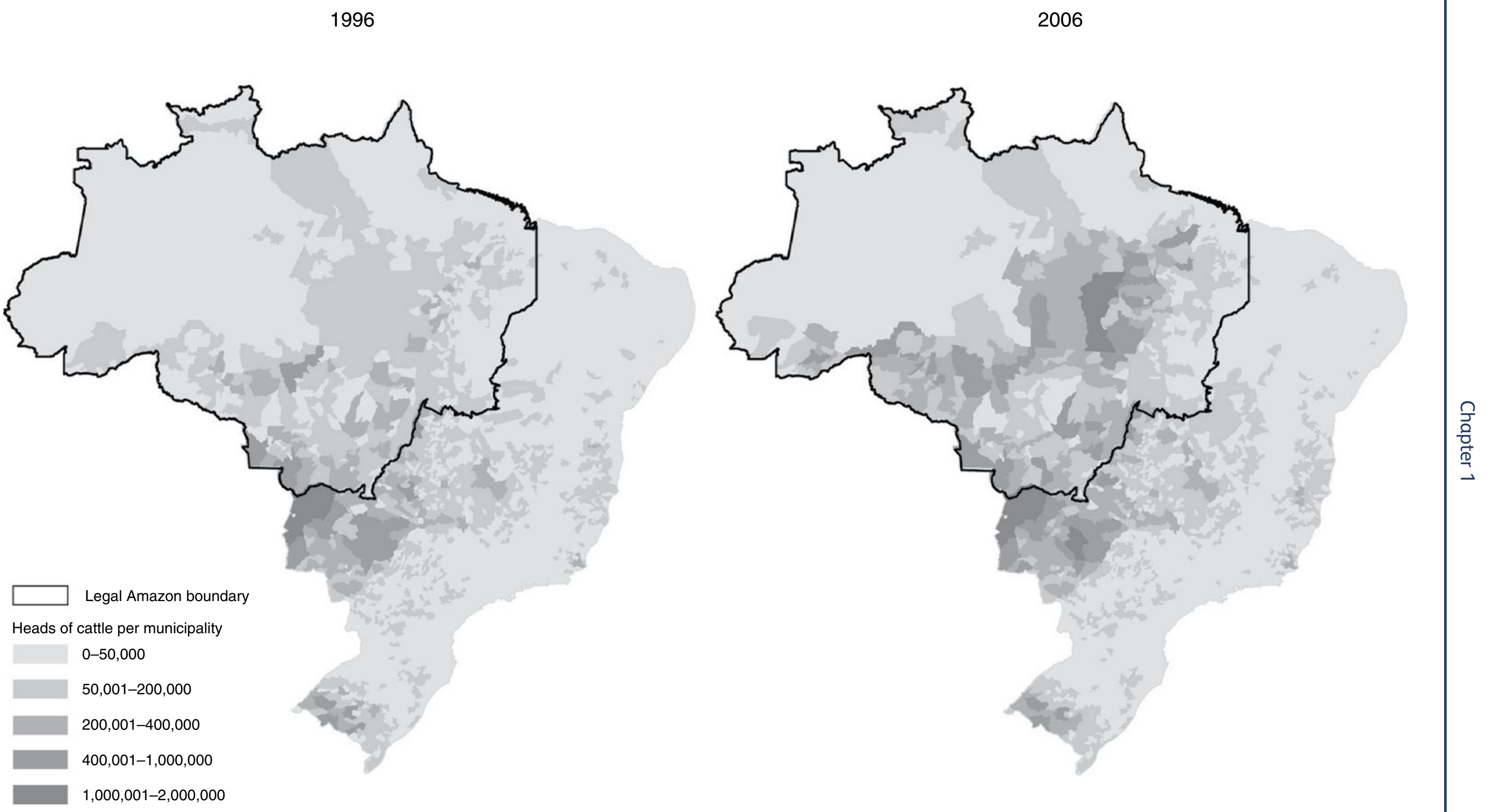

Fig. 1.8. Increase in cattle population in and around the Amazon region of Brazil between 1996 and 2006. During this period the area of cattle pastures in the Brazilian Amazon grew by approximately 10 million hectares (Greenpeace, 2009).

home, and more are buying processed food, as demanded by their busy life schedules. The intensification process has sometimes recycled animal and human waste products unwisely, and embraced a suite of animal and crop production enhancers, including growth promoters, pesticides, herbicides and fertilizers. Some have adverse or unknown consequences; cattle products have been found with high levels of persistent organic pollutants, especially dioxin, and there is concern about high levels of antibiotic use and the risk of transmission of zoonotic diseases (Niamir-Fuller, 2016). Nowhere are the modern trends exemplified more than in China. Traditionally beef was not a major food source for the majority of the population, yet the recent rapid development of animal agriculture, often of an intensive nature, elevated it to the rank of the third largest producer in the world by 2014. Widespread lactose intolerance in East Asians traditionally meant that milk from cows was not a major part of the diet. However, the promotion of children’s milk consumption by the national government has resulted in a rapid growth of the dairy industry. Intensive animal production is seen as a means of climbing out of poverty for many Chinese rural regions (Li, 2017).

These concerns and others have led to many consumers opting to buy food products from farmers who can demonstrate more long-term responsibility in their production systems. The 21st century has seen a growth in certification schemes, as well as much debate about what and how much the consumer should be told on the labels of the food they purchase. Perhaps the most successful scheme that farmers can join to demonstrate this attention to sustainability is the organic farming movement, otherwise known as biological or ecological farming. This movement is characterized by the systems for producing cattle being environmentally and socially sustainable and using a minimum of artificial inputs. As much as possible, organic farming fosters the use of crop rotations, crop residues, animal manure, legumes, green manure, off-farm organic wastes to supply crop nutrients and biological control of pests and diseases. Farmers in developed regions were the first to devise the legislation required for organic production, but many farmers in developing regions, where agriculture was often less intensive anyway, are now seeing an opportunity to increase their profit margin at little extra cost. In the European Union, the land devoted to organic farming practices has grown rapidly since the mid-1980s, reaching approximately 4% of agricultural land by 2016. The regulations for organic cattle farming are strict: for example, modern farming practices of zero-grazing cattle and embryo transfer are forbidden, as are the more contentious reproductive management practices such as genetic engineering. However, in the absence of accurate knowledge of the precise risks, the precautionary approach provides the best possible assurance to consumers that the production of the food they purchase has not harmed the environment or the animals and will not harm themselves. Critics argue that without the benefit of animal and crop production enhancers, such as growth promoters and fertilizers, farmers could not grow enough food to feed the world’s growing population.

Conclusions

Since the domestication of cattle 8000–10,000 years ago, different systems of management have been introduced to many different parts of the globe. With their easy herding characteristics, herbivorous diet, high reproductive rate and docility, cattle provided an easy way of using land for the production of meat, milk and other goods. In particular, they were introduced into many areas during periods of colonization. Now that their presence has spread to nearly all parts of the globe, it is necessary to examine the relationship between humans and cattle and decide whether it is the best way to feed the human population, while at the same time maintaining a high-quality environment and regional culture. Some systems of cattle production that have been developed are ecologically unsustainable and lead to deterioration of the environment. Others offend certain people’s moral or religious beliefs, but many of today’s systems make an important contribution to the nutrition of the human population by using land in a sustainable and worthwhile manner. The future will bring greater control of cattle production, preserving those systems that benefit society and restricting, controlling and even outlawing those that have detrimental effects.

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2

Today's Cattle Production Systems

Cattle production systems are diverse and allow the species to be kept for production of meat and milk all around the world. The systems have evolved over thousands of years and generally are designed so that the output is most efficiently achieved, in terms of utilizing local resources and providing for the specific needs of the region. They can be classified as rangeland based (land with fewer than 20 people/km^2), mixed grass and crop (rainfed or irrigated systems) (see Chapter 1, Fig. 1.5), and landless systems, in which cattle are fed on crops imported on to the 'farm'. Landless systems predominate in urban and peri-urban settings. Systems are considered irrigated if more than 10% of the land is under irrigation. Of the world's 1.4 billion cattle, approximately 42% are in rainfed mixed systems, 29% in irrigated mixed systems, 27% in grazing systems and 2% in landless systems. Dairy cattle are more concentrated into mixed systems than beef cattle, with an output of 522 billion litres/year, compared with only 72 billion litres/year from grazing systems. Beef cattle are still mainly produced from mixed systems (32 million tonnes/year), with lesser amounts from grazing systems (15 million tonnes/year) and landless systems (4 million tonnes/year).

Beef Production Systems

Rangeland cattle production

Rangelands are extensive, mostly unimproved lands, with most vegetation being native grasses, forbs and shrubs. Geographically, these include natural grasslands and savannahs, deserts, tundra, some alpine regions and coastal marshes. The land is usually arid or semi-arid, is often characterized by high rainfall variability and is usually unsuited to cultivation.

Rangeland farms generally occupy large areas, with little or no housing for cattle, and they utilize land that is either too mountainous, remote or climatically challenged to be used for agricultural crop production. Northern Australia has some of the largest rangeland farms, a mixture of family properties and private companies. The average size of cattle farms in the Northern Territories is 3122 km^2, usually with 2000–5000 head of cattle. The largest has 62,000 cattle. Employment of indigenous labour is important across much of northern Australia, with about 70,000 cattle in an indigenous land corporation established by the Australian government to facilitate indigenous ownership and management of land. On the most extensive farms, cattle are only mustered (gathered together) once a year, but on other farms there are usually two musters. The calves, of up to 12 months of age, are dehorned, branded, castrated and given any necessary vaccinations (for example, to protect against botulism or *Vibrio* infections), mineral supplements, probiotics, lousicide dips or hormonal treatments to maximize growth (hormone growth promoters). Cattle production is typically much lower than in other beef production systems because of undernutrition of the cows, reproductive problems, predation and heat stress. Cattle are typically of *Bos indicus* breeds, which have resistance to heat stress and tropical diseases, such as tick-borne fever. At mustering, younger calves are returned to the fields with their mothers, but older calves, known as weaners, are separated or drafted from their mothers at about 125 kg and retained in their sex groups as steers (castrated males, otherwise known as bullocks) or heifers (females). At 18–24 months most are sent to feedlots, where they are fattened on a pelleted diet, but the weaker ones will be returned for further growth. The number of calves weaned per cow mated is typically about 0.75/year, with a range from about 0.50–0.90.

Mustering cattle is usually done with the aid of small aircraft, helicopters, or both on the more extensive properties, especially where there are many trees that would make it difficult for a vehicle to round up the cattle (Fig. 2.1). Sometimes a light aircraft does initial sweeps across the paddock, moving the cattle away from the trees and roughly in the direction of the handling yards. Then a helicopter may take over and drive them more directly towards the yards. It is important that they are not hurried, especially when they approach the yards, otherwise they arrive in a state of stress and prone to heat overload. On the ground, teams of people on horses, motorbikes or in cars usually muster the cattle close to the yards (Fig. 2.2). Teams also go out into the paddocks at regular intervals to draft cattle. Skills in mustering and directing calf movements by horsemen and women are much prized and tested in rodeos and camp drafts (see Chapter 10) (Fig. 2.3). It is important to let the cattle settle, perhaps overnight, before putting them through the handling races. Gentle handling, with minimal or no use of electronic goads, will lead to cattle quite willingly and calmly entering the handling races; but if they are regularly hurried or given electric shocks when going through the handling race, they become frightened on approaching it and difficult to handle. Sometimes cattle can be 'self-mustered', walking to the handling facility to take water, with a gate that can be closed on them when handling is required.

Adequate training should be given to all staff handling cattle, ensuring that they have the time to do the job properly without stressing the cattle. Cattle sometimes avoid being mustered – usually males – and these may cause problems with other cattle. These 'scrub bulls' are often shot in the field, but a determined effort to collect them can pay off. They are often highly stressed by capture and have a tendency to produce dark, firm, dry (DFD) meat (see Chapter 10) unless they are handled carefully. Hitting cattle with vehicles during the muster in an attempt to teach them to respect the mustering crew and move with the other animals can cause broken legs or other injuries and should not be allowed on any farm.

Management of rangeland farms has been improved recently by splitting up the farms into smaller paddocks and putting in more watering points. As well as providing the opportunity for managing the feed supply for the cattle better, it also provides the opportunity for

Fig. 2.1. Mustering cattle by helicopter in northern Australian rangelands. Note the vehicle at top, accompanying the helicopter.

Fig. 2.2. Mustering cattle with a truck in Western Australia.

reproductive management, enabling bulls to be introduced to paddocks so that a tight calving pattern can be maintained. Cattle can then be mustered when all the calves are of a similar age, leading to better marketing possibilities and reduced problems caused by procedures like dehorning when they are too old. Mustering is easier in small paddocks, allowing cattle to be pregnancy tested and those that have not conceived to be sold. Service is normally by natural mating, though artificial insemination is increasingly used in more intensive units. Better control of pasture allows heifers to be grown to an adequate weight before they are served, and they are then more likely to conceive and produce a viable calf.

Ensuring that cattle have to walk no more than about 5 km to water allows the pasture to be evenly consumed around the paddock rather than being overgrazed near the watering points, which brings the risk of soil erosion and deterioration of the pasture composition. Providing more watering points has been facilitated by the introduction of better pumps and polythene tanks and pipe. Pumping water out of dams into tanks will prevent cattle getting into the dams and soiling the water with their treading activity and excreta (Fig. 2.4).

Grazing management on rangelands is often assisted by the use of fire, which when carefully used will remove the rank, low-quality pasture and allow younger, green shoots to grow, thus supporting good cattle growth. Burning usually takes place once a year, either just before the rainy season to allow rapid, lush growth when the rains come, or at the end of it to get rid of mature pasture that has accumulated in the good growing conditions. Fire is also used to control encroachment of trees on to the pastures, but for this purpose it must be a strong fire, not the cool type of burn that is usually used to control excess pasture growth.

Trees have mixed value on rangelands (Fig. 2.5). Excessive tree cover hinders mustering and reduces pasture growth, except in very poor-quality land, where the ability of trees to harvest water and provide shade (see Chapter 1, Fig. 1.7) can stimulate grass growth around the trunk in land otherwise unsuitable for grazing. Trees are also useful to prevent erosion of the banks of rivers and creeks by cattle and they can reduce salinity

Fig. 2.3. Camp draft in Northern Territories, Australia; a test of horsemanship and cattle handling skills.

by lowering the water table. In drought periods browse material from trees can be useful for the cattle if the pasture becomes bare. Trees also provide habitat for native fauna, increase floral diversity on the land and provide a carbon sink. Even though fire is a natural method of controlling excessive plant growth, there is concern nowadays that burning of cattle pastures contributes significantly to the release of carbon dioxide into the atmosphere and global warming. Fire is much less frequent when created by lightning strikes than by humans; nevertheless, natural fire strikes burn out about one-quarter of the land farmed in the Northern Territories of Australia each year, and they are more likely if farmers are not using fire to control excessive pasture growth.

Controlled rotation of cattle around the paddocks of the farm, or cell grazing, has been facilitated by the progressive subdivision of many rangeland farms into small paddocks. Usually at least 12–15 cells are present on the farm, with 30–90-day rotations. A rotational grazing system can force cattle to eat the less palatable plant species in the paddock, whereas in a continuous grazing system they may deplete the pasture of preferred species by concentrating their grazing in areas dominated by these species. Faeces and urine are more evenly spread around cells in rotational grazing, and those using it claim that the increased animal traffic helps in nutrient cycling and allows better water infiltration into the pasture. Better control of plant availability should be achieved, and introduced forage legumes, such as leucaena (*Leucaena leucocephala*), will be less likely to need cutting to keep foliage young and within reach of the cattle. Cell grazing is not possible in regions where parts of the farm become inundated in the wet season, nor is it possible if there is only limited labour on the farm, as cattle have to be moved on a regular basis. Movement is facilitated by the use of electric fences, now often powered by solar energy. A single wire 75 cm off the ground, or two at 40 cm and 80 cm, should be sufficient to restrain cattle. Electric fencing is not possible in areas with excessive pasture or tree growth or in inundated areas. Virtual fencing, by fitting cattle with electronic collars that give them a shock when they stray out of the required grazing area, is being commercialized.

Fig. 2.4. Cattle obtaining their water from a dam in the Northern Territories, Australia.

Fig. 2.5. Cattle amongst the trees on rangelands in northern Australia.

Rangeland farms, by definition, are often on more marginal land that is deficient in certain elements, or has high variation in pasture growth from year to year, or within a year. Supplementation is therefore often necessary to rectify nutrient deficiencies, especially nitrogen, sodium, phosphorus, selenium, copper and zinc. Sodium is usually already provided in the form of salt, both because it is commonly deficient in inland farms, far from the influence of sea air, and also because it can be used to limit the intake of supplementary feeds, as cattle have a specific requirement for sodium. Addition of salt to the supplement is not recommended if brackish bore water is offered to the cattle. Phosphorus is also commonly deficient and, if supplements are not provided, may result in cattle eating the bones of other cattle that die in the fields, from which they can acquire a bacterial infection, botulism. The supplements may be offered in the form of a feed block, including straw, molasses and sometimes cereals, which can be easily distributed to the paddocks. Blocks are usually weather resistant and should be fed on high ground to prevent soil damage in the vicinity. Alternatively, a loose mix, or 'lick', can be made up on the farm. These are usually fed in troughs, which are vulnerable to wetting unless a cover is added. They are better sited away from watering points to increase pasture utilization. Supplementation in water is also possible but only if there is no standing water on the farm. Urea is commonly added to rectify nitrogen deficiency caused by low-protein grasses. Supplementation in water requires a knowledge of cattle water intakes, otherwise there may be a risk of urea toxicity if cattle drink too much.

Apart from using fire to control pasture excesses and supplements to control shortfalls, the other major alternative for coping with variable quality and quantity of pasture is to move cattle. Cattle may be sent away on agistment (taken in for payment) to other farms and this is easiest if the farms are part of a chain run by single company. They are then in the hands of another manager, whose skills are probably more important than the land quality. Cattle are often challenged when sent away on agistment, in terms of new disease risks or possible weed species, and extra care is required to keep them in good health. When returning they should be quarantined for a week to prevent spreading weed seeds. Cattle can also be sent to a feedlot, but this is usually a costly option as feed costs increase during a drought.

Alternatively the cattle may be sold and in the initial stages of a drought this may just mean selling them 1–2 months early. Selling breeding cows from a herd that the farmer has taken pride in developing is always hard, but necessary in times of severe drought to achieve a progressive reduction in the herd (Fig. 2.6). It is important to consider feed costs, should the drought continue, and the risk of death, especially in primiparous and older cows (Fig. 2.7). Usually male cattle and older cows are sold first, to enable the herd to restock quickly after the drought. However, selling cows also brings the opportunity to restock with genetically improved cattle. Coping with drought puts a strain on the herd, the people looking after the cattle and those supporting them. Doing nothing may be the most stressful option and farmers must be aware of animal legislation, which in some jurisdictions makes it illegal to underfeed cattle to the extent that their health is reduced. Weaned calves are particularly at risk as they need feed to grow as well as to live; minimum daily growth rates of 400 g, 200 g a 100 g are recommended for weaners of less than 100 kg, 100–150 kg and more than 150 kg, respectively.

Availability of good-quality labour to work on rangeland properties may be restricted. Whereas in the

Fig. 2.6. Thin cattle sent to market during a drought in Australia.

Fig. 2.7. Cattle die during droughts as a result of insufficient food and water, frequently exacerbated by hot conditions.

past operations were essentially an annual harvest of the older calves, nowadays the level of management required to get good productivity and run a profitable farm is considerably greater, requiring skilled labour. However, skilled workers are often reluctant to live in remote regions, and better job opportunities in cities and in other industries have discouraged people from pursuing cattle production as a career. Knowledge about cattle farming in a particular region used to be passed from one generation to the next, but today there are many opportunities to change career even within one generation, let alone ensuring that there is succession by the following generation. Indigenous labour has been important in Australian rangeland farms, though there were fewer indigenous Australians employed in the latter part of the 20th century than previously, largely due to government intervention to ensure equitable wages for indigenous and white workers. Training packages have been developed to help indigenous Australians return to cattle stations. In Australia and the Americas land is being returned to indigenous people, who are learning to manage their own cattle farms. In Australia, government still exerts some control over pastoral production in the rangelands. Leases are issued by state governments and can be rescinded if the land is not well managed. The short-term nature of some leases, 15–20 years, while retaining a degree of control for government, acts as a disincentive to long-term investment in soil quality, infrastructure and stock.

High utilization rates of rangeland pasture growth are only achievable if the land is rested periodically to allow recovery. As an approximate guide, if 50% utilization is the target some rest will be required at the start of each growing season. If fields are rested only at the start of the season every other year, utilization should not exceed 35%. High utilization rates will render cattle susceptible to poisoning, if they become short of pasture grasses and are forced to eat poisonous plants. Cattle learn not to consume toxic plants, such as pimelea in south Australia or ragwort in the UK, if they are introduced to them slowly. However, if present in hay or soil, toxins may be ingested without the cattle realizing, as they only learn to recognize the smell or sight of the whole plant.

As well as pasture weeds, rangeland producers also have to contend with wild animals that predate on their cattle. In Australia, most common attacks on cattle are by wild and feral dogs and by crocodiles. Wild dogs are particularly active in drought conditions. In addition, feral pigs are a significant problem as they destroy pasture land, and kangaroos and wallabies compete with cattle for grazing. Electronic watering points may be available that allow cattle access because they have an electronic collar that opens a gate but exclude other animals like kangaroos. Snakes also attack cattle in many regions, but deaths are rare. In the USA, coyotes and wolves will occasionally attack cattle.

Pastoral nomadism

In rangeland systems the variation in feed availability encourages humans to move animals from place to place. In developed countries, such as Australia, this may be by moving cattle between properties owned by big pastoral companies or, in the case of smaller pastoralists, selling stock for someone to buy who has feed available elsewhere. The prevalence of nomadic systems in Africa is largely a result of the prevailing geographical conditions in tropical and subtropical areas. In the equatorial region cattle farming is rare, since the luxuriant plant growth there makes it difficult for grass to compete with taller, more profitable 'cash' crops; tropical diseases, such as those borne by the tsetse fly, also make the keeping of cattle difficult. An additional problem is the difficulty of preserving meat and milk products in warm, humid conditions. Many native African people have an intolerance to milk lactose, which makes milk and milk products difficult to digest. Nevertheless, some nomadic systems of keeping cattle have been maintained in Africa for cultural reasons, even if they are unprofitable and politically difficult to sustain.

North and south of the equatorial belt in Africa there exists a savannah grassland area of less intensive agriculture, mainly because of the low rainfall. Traditionally inhabited by indigenous African game, which are well adapted to the conditions but not as suitable for domestication, this region has for several hundred years (and in some areas thousands of years) been the preserve of nomadic cattle keepers, such as the Maasai of the Great Rift Valley of Kenya and Tanzania. Parts of Zimbabwe were developed in the first millennium AD as a cattle herders' highland refuge from the tsetse fly, which infested the more northern lands. The availability of grazing varies with region and season and hence nomadic systems evolved, with cattle herders moving their stock to find pasture land that would support their animals. Being nomadic, the herders have few possessions, and cattle, like other property, are communally managed in the tribal groups. The balance between feed availability and stock numbers has traditionally been managed by village councils, whose prime consideration is to maintain the animals in a healthy, productive state. They do this by attempting to prevent any shortage of grazing, which would result in the animals declining in productivity. In extreme cases it has led to tribal wars, involving the slaughter of many cattle and some humans, thus restoring the population balance. Nowadays, the village councils are often dismissed by national governments, in attempts to introduce a market-led economy, and the subsequent exhaustion of the grazing resources leads in the long term to reduced productivity.

For many farmers in Africa cattle act as the prime source of security. They provide meat, milk and blood for food, dung (which is dried and burned for fuel) and hides and other parts of the body for a variety of uses. Those who do not own cattle can usually share in the benefits from those belonging to others in the tribe. The cattle have additional value as a store of wealth by virtue of their being mobile and naturally able to regenerate, which means that the population can expand and contract according to the prevailing conditions. Money is of much less value. Such a delicate balance between nature, humans and domesticated animals survived for many centuries, but is now increasingly under threat from the forces of change that are bringing Africa into line with modern standards set by the developed world. The ideology of self-advancement espoused by capitalism stands in marked contrast to the communal ownership of cattle by the nomadic tribesmen. Colonial forces that assumed ownership of the land often did not understand the system and attempted to confine the nomads to specific areas, to prevent tribal warfare and to introduce Western farming methods. When overgrazing resulted, they attempted to artificially match stock numbers to land availability and encouraged the nomads to settle and grow crops. However, the greatest damage done by the colonizers was to instil materialistic desires in the hearts of the African people and to believe that their own living standards could be attained in Africa by pursuing European farming and managerial techniques. As with the bison in North America, a system in perfect balance was destroyed, not quite as rapidly and not as completely, but the consequences for the continent may yet prove catastrophic.

More recently, the increase in the populations of both humans and domestic animals has increased pressure for the best land to be used for cropping rather than grazing. Land is also increasingly taken for urban development. Pastoral nomads are encouraged to settle, even though it is their mobility that is key to effective management of changing levels of feed resources. Growing climate variability is adding to the problems faced by graziers who already have to contend with low and variable rainfall. Such uncertainty has intensified overgrazing problems and further marginalized the nomads. South of the equatorial belt there has been more emphasis on introducing cattle 'ranches', with some success. However, this and other semi-intensive stock-raising methods rely on producing a saleable product, mostly to the world market because of the inability of the local people to pay for a commodity that is relatively expensive to produce. Many developed countries have erected barriers to meat imports to protect their own markets, and sometimes to protect themselves against the introduction of, in particular, foot-and-mouth disease. As soon as more intensive methods are used to produce meat for the world market, the cost of inputs, many of which are taken for granted in the West, increases out of proportion. Concentrate feeds, veterinary medicines, managers trained in intensive cattle farming, all of which are much more expensive in Africa relative to meat price than in developed countries, necessitate that the products are sold on the world market rather than locally.

Similar nomadic systems have evolved elsewhere in the world in marginal areas, but not on the scale of those in Africa. Where land is fertile and has good rainfall, settled farming has over the past 2000 years or so replaced nomadism but small migrations still persist. These may even operate within a farm. In mountainous regions of Europe, such as the Alps and regions of

North Wales, farmers may own a lowland region for winter grazing and have grazing rights in the mountains for the summer. Formerly cattle were moved on foot between the two, but nowadays motorized transport is usually employed.

Suckled calf production

Producing calves for beef whilst still suckling their mother is potentially inefficient in its use of land because of the high maintenance cost of keeping the cow just to suckle a calf. In contrast, calves from a dairy herd are usually considered a by-product of the milk production industry, and the maintenance of the dairy cow is covered by the milk output of the cow. Hence, in most parts of the world, suckler cows are confined to land that cannot easily be used for other agricultural operations. The fact that suckler cow systems survive is as a result of their ability to use low-grade land and the high quality of the end product, which meets a need for tender, high-quality beef. In areas where the land used is of low fertility and remote, or the climate is hostile, as in much of Australia, or the terrain is too hilly for cultivation on a large scale, as in the uplands of the British Isles, suckler cows can be kept in relatively low-input systems to produce 'store calves' – young cattle that can be transported to more favourable regions for rearing to finishing weight on better-quality diets. This can be achieved on lowland pastures in the British Isles or, in the Americas and Australia, in feedlots that contain up to 75,000 cattle each.

Mountainous regions often have too little forage production potential for efficient suckled calf production, and the high nutritive requirements of a cow are much greater than those of a sheep or goat. Hence, in the UK suckler cows are more likely to be kept in the uplands than in the hill areas, which are mostly grazed by sheep. Similarly, the mountainous regions of the Mediterranean, where the climate and terrain do not support the production of large quantities of forage, are largely utilized for sheep production. A small number of cattle may nevertheless be beneficial on hill sheep farms, as their unselective grazing habit will keep coarse, unproductive grasses in check, whereas sheep will select only young grass tillers and allow these grasses to grow unhindered in summer. A harsh climate does not in itself prevent suckler cows being kept, and cattle are agile enough to cope with foraging on steep slopes, but they must have adequate pasture to provide for their maintenance requirements.

As cattle show little seasonality in their reproductive cycle, farmers can keep suckler herds that calve at any time of year. The most favoured calving period for herds kept in the harshest hill conditions in the British Isles is in spring, as peak nutrient requirements for cow and calf coincide with good availability of grass in summer. On lower slopes with better pasture, cows are more likely to calve in the autumn. In the hill and upland regions there are often annual calf sales in autumn, and an autumn-born calf aged 10–12 months will be larger and attract a higher price in the sales than a spring-born calf, sold at 4–6 months of age. However, winter feed requirements are much greater for an autumn-calving cow.

Underfed cows will not produce sufficient milk to sustain rapid growth in their calves and they will be difficult to get back in calf. The cow usually replenishes weight lost during winter when she is at pasture in the summer, but calf growth will suffer during periods of inadequate feeding in winter. Typically, a medium-sized suckler cow will have an energy requirement of about 100 megajoules (MJ) of metabolizable energy per day during winter. This translates into about 8 t of silage for the whole winter for an autumn-calving cow, whereas the requirements of a spring-calving cow are likely to only be about 5–6 t. This means that more land must be reserved for forage conservation for autumn-calving cows, perhaps 60% of the total grassland area for two cuts, compared with perhaps just 40% for a spring-calving herd. In many hill farms, setting such a high proportion of land aside for conservation, when the grass-growing season is short anyway, is not possible because of constraints of the terrain and the need for grazing. The introduction of baled silage-making and bale-handling machinery has assisted many farms in the transition from haymaking, which is inherently difficult in wet climates, to conserving fodder as silage.

A major constraint to efficient suckler cow management is the difficulty in getting cows pregnant. The acyclic period after calving is often 50–60 days, compared with only about 25 days in dairy cattle. This is mainly due to suckling of the cow by the calf and, in particular, the psychological inhibition of luteinizing hormone secretion when the calf is near the cow. One cause of lactational anoestrus in spring-calving cows is the increasing photoperiod at the time at which they would normally be bred. Cows, although not strongly seasonal in their reproductive cycle, show longer anoestrus in late spring/early summer, because if they conceived at this time the calf would be born in mid- to late winter when there was traditionally little feed available.

Table 2.1. Target condition scores on a 1–5 scale for autumn- and spring-calving cows (courtesy of the British Society of Animal Science).

	Serving	Mid-pregnancy	Calving
Autumn-calver	2.5	2.0	3.0
Spring-calver	2.5	3.0	2.5

Typically, only 50–60% of suckler cows that have been served by a bull or artificially inseminated conceive. This low conception rate is partly because of thin body condition at service, particularly in autumn-calving cows. Because of the difficulties in providing adequate forage for suckler cows in winter, target body condition scores are usually lower in late winter/early spring for autumn-calving cows than for spring calvers in autumn that are at the same stage in the pregnancy cycle (Table 2.1). An autumn-calving cow should calve in better condition to allow for this. Most spring-calving cows meet their targets, but many autumn-calving cows are in inadequate condition at mating and mid-pregnancy.

Cows that are served when they are too fat (body condition score of over 2.5 on a 1–5 scale) are likely to experience a high incidence of calving difficulty. This may occur with summer-calving cows that have plenty of grass before and after calving. However, summer calving in productive upland or lowland farms fits in well with a mixed cattle and sheep production system, as the cows have their greatest nutrient demand when the lambs are being weaned and removed from the farm in mid- to late summer.

The objective when rearing suckled calves is usually to produce a single weaned calf per year. In rangelands this is rarely achieved. In some more intensive operations, particularly those on lowland farms, additional calves may be purchased and given to the cow to suckle. If suckler cows are of high-yielding breeds, such as those with some Friesian genetics, this allows the cow to suckle more than one calf but increases her nutrient requirements.

The breeds used for suckled calf production are many and breed diversity has been preserved better than in the dairy industry. The traditional British beef breeds, such as the Hereford, Aberdeen Angus and Beef Shorthorn, are still popular worldwide, though there has recently been increased popularity of breeds from continental Europe, such as the Charolais and Limousin. The British breeds were developed in the 19th century with small, endomorphic carcasses that suited the conditions on the Isles. Recently, there have been efforts to increase the size to meet modern demands for a large carcass, particularly in the Hereford. In the hills of Scotland and Wales breeds were developed that are particularly hardy, notably the Highland, Galloway, Belted Galloway, Welsh Black (a former dual-purpose breed) and Luing. The latter was produced as Beef Shorthorn × Highland cattle on the Western Isles of Scotland. In the British Isles, a continental breed, such as the Charolais, or a classic beef breed, usually Hereford or Aberdeen Angus, are often crossed with a Friesian, which ensures a high milk yield for rearing good calves and allows the overheads of one-half of the cross to be covered by the dairy herd. Also the benefits of hybrid vigour arising from breed complementarity are realized. The Charolais cross has increased maintenance requirements because of the large size of the cow compared with the traditional breeds, which may reduce the efficiency of lean meat production.

Some improvement in efficiency can be achieved if high-yielding cows suckle two or more calves, brought to the cows and removed after suckling. With an average suckler herd size in the UK of about 39 cows, compared with about 143 for dairy herds, it may be feasible using existing farm labour on beef farms. Each calf will require about 5 l of milk daily in two feeds, if performance is not to suffer. Alternatively, the cows and calves can be grazed together, if the cows each allow more than one calf to suckle.

Instead of giving cows some surplus calves, usually from the dairy industry, the cows can be hormonally induced to have twins. There is a natural incidence of twinning of about 2%, but this is not sufficient for selecting a herd of twin-bearing cows in a reasonable time frame. The disadvantages of twinning are the small size of the calves (about 75% of the weight of a single), with the possibility of permanently stunting the growth of the calves, an increased calf mortality (up to 10%), a risk of freemartins[1] and increased nutrient requirements of the cow. These disadvantages explain why twins are not welcomed by most suckler cow producers, who aim to produce one calf from each cow. A better alternative for the farm to increase the profit from its operations is to rear the calves to slaughter weight, rather than sending them to another farm for finishing. This entails having several groups of cattle on the farm, but the producer can then produce high-quality cattle for the premium market. They may also be able to utilize one of the several quality assurance schemes that are increasingly popular.

A premium has always been available to producers of suckled calves, as such calves are recognized by purchasers as having better health and having grown faster on the milk-and-grass combination that is nutritionally well balanced. This produces a 'suckler bloom' in the calf: a shiny coat and bright eyes as a result of good nutrition.

An alternative to suckling cows that has often been promoted on the grounds of efficiency, but is not popular with farmers, is to breed a heifer once and then kill her for meat. In theory, this is an efficient way to increase the production of beef and not dairy products, when the latter are in surplus. However, farmers are reluctant to slaughter heifers that they have put much effort into rearing, and the meat is not of the quality demanded by the industry. The short lifespan of dairy cows in many intensive systems, often only two to three lactations, is nevertheless tending towards this type of production system.

Finishing store cattle

As previously described, store cattle are usually transported from extensive farms to be finished on more productive farms, for example in northern Europe from the hill and upland regions to the lowland farms, or in Australia from rangelands to feedlots. There is usually a large range of cattle of different ages and weights available, so farmers have to be able to adjust their systems to fit the type of cattle. The change of location and the transport can stress the cattle, which have low immunity to novel pathogens. Enzootic pneumonia (bovine respiratory disease complex or 'transit/shipping fever') is common. Affected cattle must be rapidly treated with a broad-spectrum antibiotic. Probiotics and respiratory vaccines are also used, preferably about 2 weeks before transport, and treatment may include non-steroidal anti-inflammatory drugs and oral antibiotics.

Store cattle can be fed a variety of diets but any change in diet should be introduced gradually. High-quality feeds, such as maize silage, root crops and cereals, are often included in the ration but waste products from the vegetable industry, such as stock feed potatoes, can be included and reduce the cost of the ration. The skill of the farmer in buying low-cost feeds, and cattle, plays a major part in the profitability of the store cattle finishing enterprise.

Store cattle can be finished indoors, in which case they are usually fed good-quality forage and a limited amount of concentrates (perhaps 2–3 kg/head/day). Alternatively, they can be finished at pasture or in a feedlot. If the cattle are purchased in early or midwinter and housed before finishing at pasture, they should not be fed too much expensive concentrate feed inside as they will not then produce economic gains at pasture. Silage or straw with a small amount of concentrates (a maximum of 1.5 kg/head/day) would be appropriate for the indoor feeding period. They may only grow at about 0.5 kg/day during winter but they will compensate when they are at pasture. The grazing cattle can be sold when they have reached an adequate fat cover or, in an emergency, if grass availability is very low. However, grass supply will influence the price of cattle and it is generally best to follow guidelines for good management of grazing (see Chapter 6) and finish the cattle at the target weight, rather than selling them early.

In the Americas and Australia, the main system of finishing cattle is though feedlots, which are confined to areas in which cattle are fed mechanically, or occasionally by hand, in their final stages of growth before slaughter for meat. There store cattle grow intensively over a 2–6-month period, depending on their growth potential and market requirements. Because the time is short, ownership of the cattle often remains with the farmer sending them, or it is shared. The feedlot manager charges for feed and usually space in the feedlot. A throughput of 150,000 animals/year is possible from a large feedlot. The cattle are kept in penned groups of about 400; the pens are usually sloped to allow the liquids to run off into an evaporation pond. Twice a year the pens are cleared out and the manure is spread on neighbouring land. Some exchange of cattle excreta for straw may be arranged with local arable farmers.

Such an intensity of operation raises environmental concerns, similar to those caused by high livestock densities in parts of the Netherlands (see Chapter 11). Local arable farmers may be contracted to produce suitable feeds for the final fattening period, such as whole-crop barley silage, hay or straw, and suitably processed cereals, such as rolled barley. Most feedlots include an ionophore, or rumen modifier, in the ration to increase feed conversion efficiency. Some use a coccidiostat as well, where it is legal. Feedlot finishing of cattle is less profitable when cereals and other high-quality feeds increase in price, for example when there are world grain shortages. The operation is more likely to be profitable if cattle are well matched for weight, age, breed and previous nutritional management, since an optimum strategy for feeding can be developed for the entire group. A mixed group of weaners may need to be split up and only the heavy animals sent to the feedlot, with the smaller animals prepared ('backgrounded') before going to the feedlot.

British breeds are not ideal for use in feedlots because they do not have the growth capacity of the continental European breeds. In the USA and Australia, where approximately one-third of cattle are finished in feedlots, there is emphasis on using cattle with good intramuscular fat, or marbling, characteristics.

The welfare of cattle in feedlots is often poor compared with that of grazing cattle. The conserved feeds offered are eaten rapidly, compared with pasture grass. This, coupled with the high stocking density, encourages the cattle to engage in deleterious behaviours, such as riding each other, tongue rolling and feed tossing. Excessive riding can exhaust the animal being mounted, known as a buller steer, and prompt recognition of the problem and removal of the affected animal to a hospital pen is essential. Buller steers can be identified from swellings on their rump and hair loss, weight loss, increased susceptibility to disease and occasionally broken bones. About 2–4% of animals in feedlots are affected. Contributing factors include use of anabolic agents, large group sizes, high stocking density and mixing of cattle. Some cattle are particularly attractive to be mounted, which may relate to pheromone production or steroid hormone levels. Another welfare problem in feedlots is muddy conditions following rainfall, leading to mud collecting on the coats of the cattle and potentially transmitting disease.

As a general rule, feedlot cattle should be checked several times a day for the first month, after which once a day is sufficient. Some of the welfare problems can be averted by bringing in cattle that have been suitably prepared, including castrating male calves and dehorning all cattle (rather than doing this at the feedlot), treating for internal and external parasites, getting the cattle accustomed to eating feeds out of bunks and weaning at least 4 weeks before transport. Good preparation will help to reduce the stress of close confinement, often within a new social group.

Feedlots can pollute both groundwater and the aerial environment, which may have an impact both on the cattle and on any people nearby. At high stocking densities, odours such as ammonia from the faeces, urine and feeds can be a problem, while at low stocking densities dust is created in the surrounding air, causing respiratory distress. Provision of shade in hot climates is important (Fig. 2.8) and is facilitated by a north–south orientation of the pens. Cattle welfare should be supported by good handling systems, with lanes that are

Fig. 2.8. Feedlots contain large numbers of cattle in a small area. Shade provision is important in hot conditions.

wide enough (approximately 5 m) to allow smooth flow of cattle. Tight turns should be avoided and solid-sided races provided to encourage cattle to move confidently.

Finishing dairy cows

Dairy cows have to leave the herd (termed culling) for many reasons, some of which (e.g. injury, disease) require their immediate slaughter, but at other times they can be removed to be fattened before slaughter (e.g. due to low milk yield or failure to conceive). Cows that are unable to walk (downer cows) cannot be slaughtered for human consumption in most developed countries, and welfare legislation requires that only cattle that are fit and able to walk on and off a vehicle are taken to slaughter. In underdeveloped countries human survival may necessitate using such animals for human consumption. If a farm is buying culled dairy cows to fatten, care must be taken that they do not pose a disease risk to other stock. Sometimes they will need special care and attention; for example, lame cows will quickly lose condition if they are required to walk long distances to pasture. Some cull cows may turn out to be pregnant, even if certified empty at sale, and require special attention.

Cull cows are available from both dairy and beef suckler herds, but the cows from the former will usually be more valuable as they are younger. The exception to this is cows from the Channel Island breeds (Jersey, Guernsey), which are difficult to fatten sufficiently to meet market requirements for a well-marbled carcass. Many cows are slaughtered at the end of lactation, which for autumn-calving cows is in the late summer. Others become available after a negative result to pregnancy checking in mid- to late lactation. Large numbers culled at these times will reduce their value, giving a considerable seasonal variation in price. In good grass-growing regions, cull cows purchased in spring and fattened until the following autumn will often realize a reduced price per unit weight in autumn, reflecting the cheap cost of feeding in summer. Culls purchased in spring should therefore be fattened quickly, though if they are coming off a forage-based diet it will take time for the rumen to adapt to lush pasture. The growth of cull dairy cows can be faster than that of steers, but they are relatively inefficient feed converters and therefore large amounts of concentrate are required. Those purchased in autumn can be kept for several months on a lower-quality diet and will generally achieve a good price in the spring, reflecting the high cost of feeding during the winter months. A concentrate diet will give the carcass a white fat, whereas a grass-based diet gives it a yellow fat, which is often less attractive to consumers.

Farmers sometimes organize themselves into cull cow-buying syndicates, which leads to better marketing as the syndicate can match supply to market requirements. Flexibility is the key to successful cull cow fattening and farmers must evaluate a number of different feeding strategies over different time periods. Freight charges are a more significant proportion of the cost than for cattle putting on more weight over a longer time period, and therefore have to be carefully evaluated. In some countries dairy culls may be implanted with hormone analogues, principally synthetic androgens and oestrogens, both of which increase lean tissue deposition and weight gain, but these must not be implanted until after lactation has ended, otherwise there may be dangerously high residue levels in the milk. Holstein-Friesian dairy cows do not convert feed efficiently into lean muscle tissue. Their maintenance requirements are high in cold weather because they have little subcutaneous fat.

Mixed indoor/outdoor systems of beef cattle rearing

In extreme latitudes the climate is too harsh for cattle to continue growing adequately if they are outside during winter, so they are brought inside and fed conserved feed. Calves are usually purchased after weaning and, in the case of autumn-born, early-maturing breeds, they are reared over an 18-month period. The cattle of later-maturing breeds, particularly those of continental European origin, such as the Charolais and Limousin, take longer to reach an adequate fat class and are usually reared for approximately 24 months, which involves a second summer at pasture for autumn-born calves. In countries in which the dairy and beef industries are closely connected, such as the British Isles, the most common cattle used for beef production are beef × dairy steers. Many dairy farmers run both a dairy and beef fattening unit. Dairy cattle, such as the Holstein-Friesian and Channel Island breeds, are different from most of the beef breeds, in that they put on more intermuscular and less subcutaneous fat. This may be desirable for cooking, but it means that if cattle are selected for slaughter on the basis of a fixed subcutaneous fat score, Holstein-Friesians or their crosses will have a greater total fat content. Among the beef breeds, there is little evidence for a positive relationship between growth rate and efficiency of production, so a faster-growing animal is not necessarily more efficient, just bigger at maturity. The main consideration is for farmers to use a breed that suits their situation.

When finishing cattle over an 18-month period, target growth rates are about 0.8 kg/day for beef × dairy steers. These might be reduced by about 0.1 kg/day for the first 6 months, as the young animal is not capable of growing so fast without a highly concentrated diet. If growth is less than 0.7 kg/day over the first 6 months, they will compensate when they are at pasture, but the final weight will still be less than in cattle that have grown rapidly throughout. Most farmers manage to achieve adequate performance in the cattle when they are housed but growth rates when the cattle are at pasture are often disappointing. Effective pasture and grazing management is made difficult by unpredictable effects of the weather. High growth rates in housed cattle are best achieved by offering high-quality forage *ad libitum*. If this is not available, whatever forage is obtainable should be supplemented with a cereal, such as rolled barley, the quantity depending on the quality of forage fed (see Table 5.4 in Chapter 5).

Farmers should avoid planning to finish the cattle at 18 months and then finding that growth rate is insufficient after utilizing expensive feed during the winter months and deciding to turn the cattle out to finish them during a second grazing season. This will prolong the finishing period considerably, because of the time to adapt to pasture after an indoor ration, and may make other cattle short of pasture and the enterprise unprofitable. Sufficient concentrate feed should be offered to allow the cattle to finish indoors, if this is what was planned. If insufficient concentrate is fed on a daily basis early on in the winter, farmers may actually feed more concentrates in total, because they cannot start marketing cattle in the midwinter period. Successful operators know how fast their cattle are growing and feed supplements accordingly, enabling them to market their cattle at the right time and plan for the next season's cattle. Regular weighing will allow growth rates to be monitored and is an important discipline in cattle finishing.

If cattle are reared over a longer period, such as over 24 months, which is suitable for finishing autumn-born cattle at pasture in their second summer, care must be taken not to offer too much concentrate feed during winter. Growth rates should be reduced to about 0.5 kg/day during the second winter and the cattle will then compensate when they are at pasture, growing at up to 1 kg/day. If they grow faster than this during their second winter, their performance at pasture is likely to be disappointing. The system can be run with a mixture of early- and late-maturing cattle, with the early-maturing cattle being marketed in the middle of their second summer at 20 months of age, leaving the remaining cattle more pasture so that they can grow adequately to finish in the late summer period. A leader–follower grazing system can also be utilized for this system, with the first-year cattle grazing ahead of the second-year cattle, which is not as easy for an 18-month rearing system. Gross margins are usually less than for 18-month finishing, as the financial outlays for cattle, buildings and other resources are over a longer period.

Intensive indoor rearing of beef cattle

In some situations it may be profitable to feed cattle indoors throughout their life, generally on a cereal-based or conserved forage diet. This usually occurs in high-rainfall districts, and the cattle would cause significant damage to pasture or would be difficult to keep in a feedlot. In highly populated regions bulls can only safely be kept corralled into a feedlot or barn. Here, their faster growth and high potential to put on lean meat tissue can be exploited, enabling the feeding period to be reduced to below 1 year, allowing an annual turnover of stock. Late-maturing breeds of cattle, however, can be difficult to finish within 1 year unless high-quality forage is fed and concentrate supplements are given. With most breeds of medium- to late-maturing bulls, growth rates in excess of 1.1 kg/day should be expected. The main disadvantage of the indoor 12-month system is the high working capital requirement, in buildings and machinery (Table 2.2). However, the working capital requirement is more evenly spread throughout the year, as only one group of cattle is on the farm at one time, compared with two groups for most less intensive systems.

An advantage of silage-based over pasture finishing is that the stocking rate on the farm can be increased, because the grass grown is usually more effectively utilized when conserved as silage than grazed. Losses of 20% are possible for ensiled grass but are commonly more than 30% when grass is grazed. Grass and maize silages have been commonly used, or

Table 2.2. Performance and capital requirements of cattle on 12- and 18-month feeding systems.

	18-month feeding	12-month feeding
Live weight gain (kg/day)	0.77	1.02
Time to finishing from 12 weeks of age (days)	466	355
Concentrate requirements (kg)	809	846
Stocking rate (animals/ha)	3.4	6.2
Utilized metabolizable energy (GJ/ha)	67	99
Relative gross margin (18 months = 100)	100	163
Relative working capital (annual mean/head 18 months = 100)		
Annual mean/head	100	88
Annual mean/ha	300	528
Peak/ha	416	528

a mixture of the two, since the high protein concentration in grass will complement the high energy content of maize. Both require significant fertilizer application and mechanization of crop sowing and harvesting. In future there may be a progression towards more sustainable crops, such as legumes that are able to fix their own nitrogen for growth through their symbiotic relationship with bacteria in rhizobia associated with the roots. Root crops themselves can be fed, but not usually at more than one-third of the diet. Calves do not adapt to a silage-based diet easily, so they are usually initially reared on hay and transferred at 8–10 weeks. Protein supplements can be kept at a constant level, so that as the cattle grow they consume more silage and the protein content of the ration is reduced, to match their reduced requirements as growth rates slow.

Bulls can be difficult to handle and may engage in damaging behaviours, such as riding each other. Excessive riding can only be overcome by removing the animal that is being bullied in this way (see section ‘Finishing store cattle’, above). It is a form of redirected aggression and does not necessarily have a sexual function. To avoid this problem, bulls should be kept in groups of fewer than 20 and they should not be mixed when they are older than 6 months. Problems with aggressive animals may be exacerbated by keeping cattle on slats, because high stocking densities are required for the faeces to pass through the slats as a result of treading activity by the cattle. Slats also cause more lameness in cattle. Hot conditions in the buildings increase aggression levels and care must be taken that bulls are kept quiet and not mixed when going to slaughter, to avoid dark cutting. Immediate slaughter on arrival is usually preferred, as a period of rest in lairage may only upset them.

Silage feeding in hot climates in summer can be difficult because of spoilage due to secondary aerobic fermentation of exposed material. Farmers should use a long, narrow clamp for summer feeding and preferably extract silage blocks with a cutter that will leave a tidy face. If the silage is teased out of the clamp, air enters and secondary fermentation occurs. Pits may need to be open at both ends, so that one end can be filled while silage is being fed out from the other end. With so much reliance on silage quality, the best techniques need to be used and an additive included to accelerate the fermentation, especially if there are inadequate sugar levels in the grass.

Feeding a predominantly cereal diet is not common, except where the two main inputs, cereals and calves, are inexpensive relative to the finished product. More efficient feed conversion to meat is obtained by feeding cereals to poultry or pigs and there is less risk of digestive disturbances. However, some farmers feed cattle on cereals if forage is expensive to produce and of low quality. The main advantages are the high throughput and rapid fattening of bulls, compared with offering forages that contain fewer nutrients. Heifers do not put on sufficient weight on this system, because they become fat too early. Metabolic disorders are common on cereal diets and include:

- ruminal acidosis, caused by rapid degradation of cereals by bacteria, for example if feeders get blocked and cattle then overeat when access is resumed;
- bloat, particularly on ground rations and also when cattle overeat, often caused by offering the feed in limited quantities twice a day rather than *ad libitum*;
- laminitis, also caused by excessive acidity in the rumen, leading to separation of the laminae of the hoof, haemorrhaging in the heel bulb and a severe and painful lameness; and
- liver abscesses, caused by damage to the ruminal wall, allowing bacteria to enter the bloodstream – in chronic cases this causes liver damage and condemnation in the abattoir, while in acute cases it may cause death.

Milk Production Systems

Dairy cow systems

Dairy cows have high nutrient requirements during lactation, as detailed in Chapter 4. In developed countries they are therefore usually kept in intensive systems based on good-quality forage. This may require year-round housing in regions best suited to growing maize or other crops that are harvested before feeding, but in regions in which grass grows all year round, such as western Ireland, southern Chile and the North Island of New Zealand, grazing systems predominate. Concentrate feeds are often added to the ration to increase nutrient intake if milk prices are sufficiently high. In developing countries, cows are often kept in small numbers by subsistence farmers as part of a mixed farming system. Yields are low, often just a few litres each day, and the systems are multi-purpose, with the dried faeces also being an important product for burning, building or cleansing around houses, as well as the output of calves and working the fields.

Cattle are often integrated with other forms of smallholder agriculture, crop, sheep and goat production. Greater reliance is placed on crop residues or scavenging for feed (especially in India), ensuring that the cattle do not compete with humans for food supplies. Such systems not only sustain a greater number of farmers than in developed countries, they are also more sustainable themselves, with little reliance on pesticides, antibiotics, land that could be used for human food production, inputs of fertilizer and purchased concentrate feed. Recently, many developing countries have been adopting the 'Western model' of dairy production, in an attempt to increase output and hence profitability. In former communist countries, large collective dairy farms have been replaced by smaller units suitable for individual families, whereas in Western countries dairy units have been increasing in size and output, replacing the family-run farm with an industrial process. Large outputs are required to justify the investment in machinery, which is financially possible in times of increasing world demand for dairy products.

Combined dairy and beef production in restricted suckling systems

Restriction of the suckling of cows to once or, at most, twice daily allows milk to be taken for sale. Such a restriction allows ovulation to proceed naturally, unlike continuous suckling, but is impractical for many farms in developed countries. It is widely practised in developing countries, especially where disease-resistant *Bos indicusj* cows are used, which require the presence of the calf to let down their milk for extraction by machine. Calves are allowed to suckle their mothers for about 20 min at each milking and the residual milk, which has a high fat content, is then collected for human consumption. Alternatively, with taurine cows, calves can be allowed to suckle after milk for human consumption has been taken. This has the advantage that, by bunting the udder, the calf is able to extract milk that could not easily be extracted by machine, thereby increasing total milk yield (calf + saleable milk). However, residual milk has a high fat content that may cause scouring. Also, the herdsperson may take too much milk for sale, not allowing enough for the calves. The increase in total milk yield by this technique increases the nutrient demands of the cow, which if not met will make it unlikely that she can be rebred, even if lactational anoestrus is prevented by restricting suckling to once or twice daily.

Dairy heifer rearing

Heifer calves born on a dairy farm are mostly reared for potential cow replacements rather than for meat. The extent to which heifers are used for replacements depends to a large extent on the culling rate of the cows, but on an average farm 25–40% of the cows will be culled annually and must be replaced by a heifer, or young cow. If the culling rate is 33%, cows last for only three lactations on average in the herd, which, added to the 2–3 years for their rearing, means that they die at about 5 or 6 years of age, substantially below the potential longevity for cattle species, which can often live to 25–30 years of age in the wild. Such premature mortality is normal because of the high expectations of cow productivity, and the inability of cows to resist disease and to rebreed on an annual basis.

The point may have been reached where increases in cow milk production are counterproductive as culling rates are increased. This problem is being addressed by cattle breeders through including lifetime milk production, rather than milk yield in one lactation, into the breeding indices (see Chapter 7). There are also ethical concerns about dairy cows having such short lives, which is similar to humans being euthanized at an average age of 20. One situation in which farmers accept a high culling rate is when persistent diseases, such as *Staphylococcus aureus* mastitis or Johne's disease, are common, particularly if they want to keep a pedigree herd in high productivity to demonstrate their herd's potential and to change the genotype rapidly by selective breeding.

As well as the culling rate, the length of the rearing period determines the number of replacement heifers that are required annually. On many farms this has intensified from 3 years to 2 years, mainly due to better feeding. Calving at 3 years of age requires about 75% more land than 2-year calving and 30–40% more working capital, with higher fixed costs and interest payments. Cows calving for the first time at 3 years of age give more milk in their first lactation, but not on a lifetime basis. Any further intensification is likely to be counterproductive: although Holstein-Friesian heifers can be reared to have their first calf at 18 months, the heifers are too small to be mixed with adult cows in the milking herd, and the competition for nutrients between growth and lactation in the first few lactations results in disappointing yields. The length of the rearing period must depend on the farmer's available feed resources. Good-quality grazing and systems for offering conserved feed during winter or dry seasons will allow first calving at 2 years of age. However, if only low-quality grazing is available for most of the year, first calving at 3 years is more achievable. Whatever age they calve, if heifers are too fat there will be calving difficulties, especially if calving heifers have a small pelvis, hindering calf expulsion.

It is not essential that dairy farmers rear their own replacements; indeed large numbers of heifers are being imported from New Zealand, Chile and Australia into Asia, especially China, to build up the dairy herds. Heifers that are in calf can often be purchased, and this method can be used to increase the herd size or average milk yield if the heifers are of good genetic stock. Well-grown stock that are at target weights for calving should be purchased. In winter housing areas, purchasing of replacements releases buildings for other operations. However, care must be taken that diseases are not introduced on to the farm by purchased cattle. Most farmers like the security of rearing their own livestock and they take a pride in the quality of the replacement cattle reared.

Heifers that are being reared for replacements follow a similar system to beef cattle for the first few weeks of life. At birth, the herdsperson should ensure that the calf breathes normally and that it suckles soon after. The navel should be dressed with an antiseptic if the calf is born indoors, but some farmers leave it to dry up naturally if the calf is born outdoors and the weather is dry and sunny. After 1–3 weeks, calves of naturally horned breeds should be dehorned (disbudded) by a hot iron, knife or scoop (see Chapter 10 for welfare implications). By 4 weeks of age, any surplus teats should have been removed and the calf identified by means of an ear tag or other mark, such as a brand. Target growth rates are less than for steers or bulls: 0.6–0.7 kg/day for the first 6 months if they are indoors, 0.6 kg/day for their first summer, 0.5 kg/day for their second winter and finally 0.7 kg/day for their second summer at pasture.

The success of the first summer growing period depends largely on adequate prevention of stomach worm infestation. However, whereas the aim with male calves is usually to prevent the animal being exposed to gastrointestinal worms, heifers have to build up immunity by the time they are adult, so gradual, careful exposure is necessary. At 15 months, the heifers should be served if they are to calve at 2 years of age. There is no difficulty in getting them to conceive at a light weight – they reach puberty at only 45% of their mature body weight, i.e. about 10–12 months for a Holstein-Friesian. However, a traditional small Friesian should be at least 350 kg at service to reach 520 kg pre-calving, 470 kg post-calving. For the large Holstein-Friesian cows that are favoured in many intensive dairy herds, these weights are increased by up to 20%. Small heifers will not thrive in a herd of large adult cows.

When close to calving, heifers need to be accustomed to entering the milking parlour and, if appropriate, being fed there. If relevant, they should have been taught to lie in cubicles in their early years and, before calving, they should be gradually introduced to concentrates to accustom their ruminal flora to the new feed.

Conclusions

Cattle management requires the skill and dedication of a good stockperson. The rewards are considerable but intangible, in the satisfaction of regular contact with healthy animals and the production of high-quality food products, meat or milk. The quality of interactions that stockpeople have with cattle influences behaviour (Bertenshaw *et al.*, 2008) and the ease with which they can be managed. The increasing demands of consumers for both high-quality produce and a high quality of life for the cattle make excellent management more and more essential. At the same time, the need for efficiency has never been greater: with an ever-growing world population to feed, the creation of a good foundation stock for meat and milk production and efficient utilization of land resources that would otherwise be wasted are essential requirements for a sustainable cattle industry.

Note

[1] An infertile female with masculinized behaviour and non-functioning gonads, which occurs only in the female of mixed-sex twins in the womb.

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3

Growth and Milk Production

Introduction

Cattle productivity is usually measured by the output of saleable products – meat and milk in most cases. Cattle are also kept for work; and as by-products of their being kept for other purposes, their hides, heads and internal organs are of varying value. Cattle have an important religious significance in some regions, and also as a status symbol and means of securing capital in an asset of long-term value in others. In many parts of the world, cattle production is woven deeply into the fabric of society. The different products are of varying value regionally and the extent to which they are incorporated into each production system is hugely variable. For example, meat and milk production is integrated into one unified system of production in most of Europe, but only rarely in the Americas and Australia, where separate industries are maintained for each. This has the advantage that breeds can be developed specifically for efficient output of each product, but the disadvantage that male calves born within the dairy industry are of little value.

Growth

One of the founding fathers of animal science, Sir John Hammond, defined animal growth as 'an increase in live weight until mature size'. Although this is a useful definition, it could equally well apply to a cancerous tumour as to muscle growth. Scientists have defined growth as 'cell enlargement and multiplication' and philosophers as 'an irreversible change over time in a measured dimension', but these are not particularly useful for cattle farmers, who are principally interested in 'an increase in saleable live weight until mature size'. At a more fundamental level, cattle farmers are primarily focused on the potential of their livestock to generate profits through sale of offspring and cattle products. From the point of view of producing a profit from rearing cattle for consumption, the critical statistic is the yield of lean meat, comprising carcass muscle and offal and containing 75% water, 18% protein, 3% non-protein nitrogen, 3% fat and 1% ash.

An overriding principle of the growth of mammals is that their form is related to their function. Cattle were domesticated because of their suitable diet and reproduction, their ability to produce milk for human consumption and perhaps their temperament, but not necessarily their conformation. To enable them to digest coarse grasses, cattle have a large, muscular abdomen containing the rumen. In addition, reflecting sexual dimorphism that results from their polygynous breeding habits, males have a large muscular neck and shoulders to assist in competition for access to the females. They are not built for rapid movement and mountainous conditions and hence they do not have well-developed limb and spinal muscles, unlike sheep and goats. Cattle therefore do not have the ideal muscle distribution for a meat producer that would favour large hind limbs, but they are well adapted to living off poor-quality grasses. Recent breeding developments have gone some way to redress the balance, with double-muscled cattle having big, muscular hind limbs that are suitable for the efficient production of high-priced cuts of meat, albeit at a risk to the welfare of the animals, for example during parturition.

The growth of cattle demonstrates a focus on different tissues as maturation proceeds, with nervous tissue first, then bone, muscle and finally fat tissue. The initial stage of nervous tissue growth is essential for most bodily functions, then bone, necessary for supporting muscle tissue, which matures next, and finally fat tissue, which provides a store of energy that will be useful in periods of undernutrition, as well as having specific functions relating to fat-soluble compounds. These stages of growth can be concentrated into a shorter time frame by initially feeding cattle on a high plane of nutrition, accelerating their passage to the final stage of fat growth. Thus, animals on a high plane of nutrition throughout their life end up with a high fat content at a given live weight because they enter the fat growth stage early. The ratio of bone to muscle is not affected by the plane of nutrition and is largely determined by the animal's physiological age. The final stage of growth, fat tissue accumulation, is particularly important for cattle that experience variation in feed quality between seasons. Adipose tissue acts, among other things, as a store of energy reserves that can be mobilized when little feed is available. It also restricts heat loss from the body, so in temperate breeds is situated more subcutaneously than in tropical breeds, where it is often concentrated into a hump on the animal's back. Adipose tissue has additional roles in immune response and inflammation, vasculature and neuron development.

Growth waves are evident in the relative proportions of the different body parts. Calves have relatively large heads because of the high content of nervous tissue. As the animal matures, the hindquarters become proportionately more significant, until finally the abdomen matures, providing a large rumen for microbial digestion of coarse grasses. This reduction in the proportion of the body accounted for by the head and skin can be seen as the dressing or killing-out percentage[1] increases as the animal grows (Table 3.1). Because the growth slows down as the animal reaches mature weight, the feed conversion ratio increases as cattle become older (Fig. 3.1). It actually increases exponentially, making it important to slaughter cattle at an early age to achieve an efficient use of feed resources.

Early growth

The growth of cattle usually follows a sigmoidal, or S-shaped, curve, with the initial constraint being the development of the fetus, which cannot be allowed to grow so big that the mother has difficulty in giving birth. The causes of calving difficulty, or dystocia, are many, but genotype plays an important part. For example, the proportion of Holstein-Friesian heifers with calving difficulties increases from about 2% when the sire is from a small breed, such as the Aberdeen Angus or Hereford, to an unacceptable 8–10% when the sire is one of the large continental European types, such as Limousin, Simmental or Charolais. The extent of dystocia problems decreases with age, and within breeds there is large variation between individual bulls, which

Table 3.1. Changes in carcass weight and composition with increases in the live weight of steers.

Live weight (kg) (A)	307	386	466	545
Slaughter weight (kg) (B)	167	217	268	322
Dressing (%) (B/A)	55	56	57	59
Bone (%)	18	16	15	14
Lean meat (%)	65	64	61	58
Fat (%)	14	18	24	29

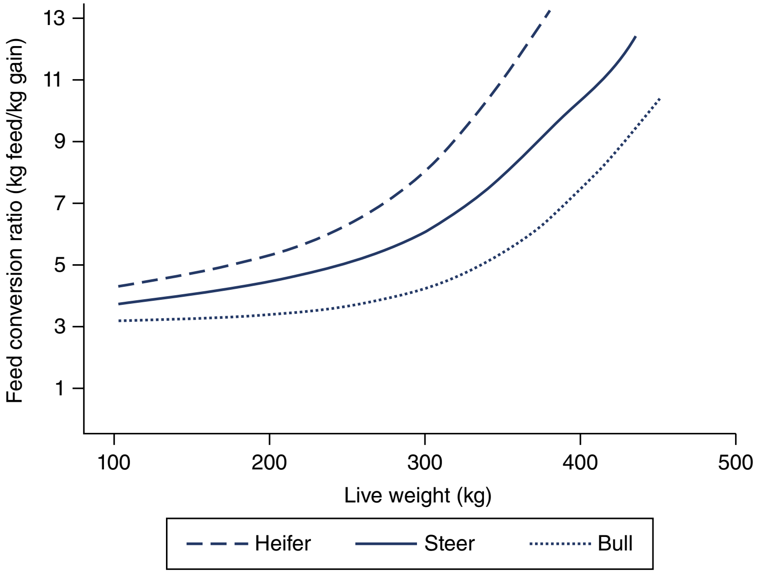


Fig. 3.1. The feed conversion ratio of steers, heifers and bulls at different live weights.

does not relate just to their body size. The shape and size of the head is particularly important, as this is often the most difficult part for the cow to expel.

Because of the risk of dystocia, it is not advisable to use a large breed of sire to produce a calf from a small cow. However, for most efficient use of feed reserves, the maintenance cost of the dam should be minimized by her having a small size in relation to the sire, but if taken to extremes this can lead to an unacceptable level of dystocia.

Post-natal growth

After birth, the calf enters an exponential phase of growth, provided that it is offered a high-quality diet. The main factors determining growth from this period to slaughter weight are:

- sex;
- growth-regulating hormones and hormone analogues;
- nutrition;
- genotype;
- climate; and
- health.

The next sections consider the effects of sex and hormones; the remaining factors are considered in other chapters.

Sex effects on growth and cattle management

Sex differences in growth rates are mainly explained by differences in mature size of the three main sex types: bulls (entire males), castrated males (otherwise known as steers or bullocks) and cows (known as heifers before or up to the end of their first lactation). Thus at any one stage in their growth cycle, bulls grow faster than steers, which in turn grow faster than heifers. Apart from this, bulls have a relatively low dressing or killing-out percentage, because they have large heads compared with the rest of their bodies (for fighting). They also have big, strong shoulders, also for fighting, as a result of which they have a greater proportion of fore- than hindquarter compared with other sex types (Table 3.2).

Bulls mature at a higher weight than castrated males or females, so at any given slaughter weight a bull of a particular breed will be a smaller proportion of their final weight than a steer and even less than a heifer.

Table 3.2. Carcass composition (percentage) of bulls, steers and heifers at 450 kg slaughter weight.

	Bulls	Steers	Heifers
Dressing	56	58	58
Hindquarter	47	50	50
Forequarter	53	50	50
Bone	16	15	13
Lean meat	68	58	54
Expensive muscle	53	54	56
Fat	13	25	31

As a result, at a common slaughter weight, bulls have the highest proportion of bone and muscle and the lowest proportion of fat, followed by steers and then heifers. In practice bulls are usually slaughtered at a heavier weight than steers and heifers because of their heavier mature weight. A slaughter weight of 450 kg would not normally be considered sufficient for bulls, but would be adequate for heifers.

Cattle-rearing methods are often similar for males and females but the purpose may be different, because a much larger proportion of females must be retained for breeding compared with the males. Bulls are, therefore, mostly reared for meat. Castration is usually performed on the young calf by: (i) surgical removal of the testes; (ii) applying a rubber ring around the scrotum so that blood supply to the testes is cut off; or (iii) crushing the spermatic cord with a Burdizzo instrument.

Castration is used mainly because it reduces the male animal's fighting urge, making it safer to handle, and it reduces the time that it takes to reach a certain level of fatness, which can be beneficial if there are seasonal reductions in feed supply. It also prevents breeding, enabling only progeny-tested bulls to be used, so that the offspring can be bred with selected sires' desirable characteristics. It affects meat quality, increasing fat content at a given weight; and because the stock are less likely to fight when stressed before slaughter, they are not prone to dark cutting, which is caused by inadequate glycogen stores at slaughter, leading to a high ultimate pH in the meat, usually over 6. This leads to rapid deterioration and, although the meat is tender, the flavour is unpleasant. It is not confined to bulls but is more common in these because of their excitability before slaughter, especially double-muscled bulls that are particularly stress-susceptible. The frequency of dark cutting is typically about 3% for steers and heifers, 7%

for cows and 12% for bulls, though it can be up to 20% in certain herds. The *M. longissimus dorsi* is the muscle most affected, but effects are observed throughout the carcass, the value of which will be reduced by at least 25%.

The disadvantages of castrating bulls are: (i) a decrease in feed conversion efficiency, mainly because of a reduced growth rate, which increases the maintenance requirement as a proportion of total energy requirements; (ii) increased fat content at a given carcass weight, which may need to be trimmed off before sale as meat; and (iii) the inability to grow cattle to a heavy weight to dilute the high cost of the calf in relation to its weight.

Castration is common where marbling (intramuscular fat) is preferred in the meat, such as in the USA and Australia. In the UK, marbling is not required as much but, because cattle are usually grazed for at least one-half of the year and many of the fields contain public rights of way, castration is often performed for safety reasons, usually at approximately 3 months of age. If a field is likely to be visited by groups of walkers with dogs, children on day trips or lone walkers, all of whom might attract the attention of bulls, or even a group of young heifers, caution dictates that bulls are not grazed there. If there are young calves with their mothers, this will encourage defensive action by the cows. Farmers with a right of way through their fields may wish to fence it off to protect the public from possible attack by the cattle. If bulls are kept in fields, farmers should ensure that the fences, gates, etc. are in good condition and that paths are clearly marked and signs erected warning members of the public that there is a bull in the field. When bulls are handled by farm workers there is a risk of injury, against which precautions should be taken. A ring 5 cm in diameter may be inserted in the nose when a bull reaches 10 months of age to enable him to be led safely. The bull should learn to associate human contact with pleasurable events, such as feeding. At least two people should be present whenever a bull is handled and they should work from a mobile sanctuary, such as a farm vehicle, whenever a bull is handled in a field.

Female cattle may be reared for replacement dairy cows, replacement beef (suckler) cows or for meat. They start to put on fat tissue earlier than castrates or bulls. Heifers grow to a smaller mature size than steers, which are in turn smaller than bulls. They also mature earlier, which means that they must be slaughtered for meat at a younger and lighter age than steers, which in turn must be younger and lighter than bulls if a similar level of fatness is required in the carcass. Because heifers lay down tissue with a greater fat content than steers or bulls at a given live weight, their feed conversion efficiency is less (see Fig. 3.1).

Hormones and hormone analogues that modify growth and lactation

The sex effects on growth are driven by the hormone complement of the sexes. Most potent are the androgens, principally testosterone, produced predominantly in the testes, and important in increasing the efficiency of growth by increasing the nitrogen incorporation into muscles. Androgens also cause epiphyseal plate fusion in bones, and exogenously administered androgens can reduce skeletal size. Exogenous androgens such as trenbolone acetate, if permitted, have their greatest effect in heifers or cull cows, because of the low level of natural male steroids in the female.

Growth stimulants are either naturally occurring hormones, such as oestrogens, or synthetic versions of these hormones, such as trenbolone acetate or zeranol. Oestrogens are also potent growth stimulators in young steers. They increase production of growth hormone, leading to increased muscle production, decreased fat production and reduced losses of urinary nitrogen. In the older animal, oestrogens cause epiphyseal plate fusion in bones in the same way as androgens. Both synthetic oestrogen-mimicking agents, such as diethylstilboestrol and zeranol, and naturally occurring female steroids, principally oestradiol, are most effective in steers, though combined-action trenbolone acetate and oestradiol implants are effective in stimulating growth in bulls, steers and calves. The growth benefits of synthetic steroid use are much greater in cattle than in sheep, which in turn are greater than in pigs. If oestrogenic or androgenic hormones or hormone-mimicking agents are used, it is often necessary to supply extra rumen-undegradable protein to implanted animals because of increased protein requirements through the stimulation of muscle growth.

In the European Union (EU), use of both synthetic and naturally occurring growth-promoting hormones (oestradiol 17β, testosterone, progesterone, zeranol, trenbolone acetate and melengestrol acetate) has been banned since 1988, as well as imports of meat from cattle implanted with the growth-promoting hormones. Many other countries have banned the use of these growth promoters, though notably not the USA. A low risk of carcinogenicity in consumers is evident for oestradiol at least, and since no maximum intake levels can be determined for any carcinogen, any additional intake could theoretically trigger tumour formation. However, human intakes of oestrogens from treated cattle are very low compared with endogenous production by humans, especially pregnant females, and are well below levels that have been observed to have carcinogenetic effects in experimental animals. There are concerns about the effects on immunocompetence, reproduction, genotoxicity and neurobiology of the growth-promoting hormones. While the risk is primarily assessed in relation to human consumers, it is acknowledged that there may also be risks to the environment.

Other hormone mediators of growth include β-agonists, which are synthetic analogues of adrenalin and noradrenalin, such as clenbuterol and cimaterol. These reduce intramuscular fat by up to 30%, with a corresponding increase in protein deposition of 10–15%. As a result, the feed conversion efficiency is often increased by about 10%. The effects on weight gain and feed intake are variable, depending on the relative impacts on fat and protein deposition. Cattle treated with β-agonists are more susceptible to dark cutting, and the low level of muscle glycogen and carcass fat can give rise to cold shortening (cross-bonding between actin and myosin fibres) if the carcass is rapidly chilled post-mortem to 10–15°C. The increase in carcass yield may be accompanied by smaller non-carcass components. The action of β-agonists is not sex-specific, but all animals are susceptible to tachycardia (elevated heart rate) and increased basal metabolic rate, which may be perceived as reducing their welfare especially if there are concurrent stressors, such as heat stress. The risk of residues is low because the β-agonists are rapidly metabolized and, after withdrawal of the substance from the feed, the animal's nitrogen metabolism rapidly reverts to normal.

The growth hormone complex can be moderated to influence milk production as well as body growth. Bovine somatotrophin (bST) increases milk production in cattle by up to 25%. This effect was first reported for growth hormone administered to cows in the early part of the 20th century, but the technology remained dormant until the growth hormone analogue bST was capable of being mass-produced by recombinant DNA techniques in the second half of the century. The galactopoietic effect, and in particular the increase in milk fat and lactose production, is caused by lipolysis. However, despite the obvious increases in milk production efficiency in cows injected with bST, there remains public and scientific concern that its use is unjustified. This derives from possible adverse effects on the welfare of the cows and effects on the health of humans consuming milk from treated cows.

The welfare impact of bST is often negative and, as a result, its use is banned in the EU and many other regions. It can be legally used in the USA, where despite companies in many states being unable to label their milk as produced without bST, retailers often have this as a stated policy. The major concern is that bST increases the prevalence of diseases associated with high milk yields, especially mastitis, lameness and reproductive failure. Cows are more likely to get mastitis when bST is administered, but the greater risk is only as much as would be predicted by the increase in milk yield, and perhaps less if the increase in insulin-like growth factor 1 (IGF-1) that accompanies bST administration has immunological benefit. Some of the potential effects of bST administration are not realized if cows cannot increase their nutrient intake to support additional milk production. The cow's homeostatic mechanisms still function, so that if a cow is injected with bST and no additional feed is available, the increase in milk yield is negligible or very small, depending on the level of body reserves. For this reason, bST has little role in most situations in developing countries, because of the low quality and sometimes quantity of feed available for cows.

Economical and effective use of bST is only possible if the farmer's management is good. Some potentially negative effects can be avoided by good management: for example, bST administration after calving can be delayed until a cow is pregnant, avoiding the difficulty in achieving conception. Another potentially serious problem with bST is that the fortnightly injections into the rump of the cow can cause localized reactions (which are caused by the injectate itself rather than the injection). However, the resultant abscesses quickly regress and subcutaneous injection rather than intramuscular is recommended to minimize the local impact of the chemical.

Another potential impact of bST is disproportionate effects on growth, in particular increases in skeletal growth. In just the same way that certain growth promoters do not affect all parts of the body equally, so bST administration increases spleen growth and glomerular hypertrophy in the kidney. The latter could have implications for the risk of kidney failure, though sufficient evidence is yet to be accumulated. In relation to the possible effects on human consumers, the increase in IGF-1 content of milk from cows to which bST has been administered is of concern, as this moderates a range of processes in humans (and cows) and causes intestinal cell proliferation – in rodents at least. However, it is unclear whether the oral consumption of milk with high concentrations of IGF-1 will result in increased circulating IGF-1 in humans.

Surprisingly, the administration of growth hormone to growing cattle does not result in large increases in muscle growth, perhaps because of the lack of additional receptors. However, immunization against the agonist of bST, somatostatin, can increase growth, but this tends to increase carcass fatness. Somatostatin also inhibits other hormones, such as insulin and the thyroid hormones, which may explain its action.

Other dietary growth promoters

Antimicrobial compounds were for many years routinely used in some cattle production systems to modify the ruminal microflora. Most are now banned, except for the maintenance of animal health, in many jurisdictions, including the EU and the USA, but not in two major cattle farming nations: China and India. The bans have followed growing evidence of antibiotic resistance developing and the possible transfer of resistant genes from animal bacteria to human pathogens. The transmission is potentially either via direct contact with the animals or by eating contaminated meat or milk. For example, *Staphylococcus aureus* infections in cattle are one of the most common forms of mastitis (see Chapter 8) and new antibiotic-resistant strains are becoming widespread, with likely transmission to humans.

The most commonly used has been monensin sodium, a class of antibiotic known as an ionophore because they work through ion transfer across cell membranes. Monensin is still licensed for improving growth and milk production efficiency in cattle in the USA under the direction of a veterinarian, but not for veal calves because of the risk of residues. Its use was banned in the EU for fattening cattle in 2006 (see Chapter 5), but it is still registered for control of ketosis in dairy cows. It was originally developed as a coccidiostat for poultry. In the rumen of cattle it is active in reducing the population of acetate- and hydrogen-producing bacteria, such as *Ruminococcus* species and *Butyrivibrio fibrisolvens*, allowing propionate producers such as *Selenomonas ruminantium* to flourish. This increases the efficiency of growth by about 5%, partly because acetate production is accompanied by methane loss via eructation. As a result of its mode of action, there are no effects of such growth promoters on carcass composition. The widespread use of monensin sodium was not possible until it could be incorporated into feed blocks that could be offered to the cattle when they were out at pasture. If cattle are offered feeds with added monensin sodium indoors and then turned out to pasture with no supplement, there is a considerable check to growth as the ruminal microflora adapt.

Currently, within the EU, animal feed additives are allowed only if there is no known adverse effect on human or animal health or on the environment. The scale of concern about antibiotic resistance is evidenced by the fact that, of the ten originally licensed antimicrobial growth promoters, four (bacitracin zinc, spiramycin, tylosin phosphate and virginiamycin) were withdrawn in 1999. Then a further two antibiotics (olaquindox and carbadox) were banned because of possible risks to human health during the manufacturing process, leaving only four that could legally be used (monensin sodium, salinomycin sodium, avilamycin and flavophospholipol), which were finally banned for use as growth promoters in cattle diets in 2006.

Many feed additives based on plant oils and spice acids have antimicrobial properties. Unsaturated fats reduce the action of fibre-digesting bacteria in the rumen, which are associated with wasteful and environmentally damaging methane output, but this can reduce intake and growth rates. Hence there may be no beneficial effect on methane output per unit of animal product. Unsaturated fats have other potentially beneficial effects, including an alternative method of using surplus hydrogen in reducing carbon dioxide to methane and reducing the numbers of protozoans in the rumen that digest methanogenic bacteria. Fumaric acid appears to offer beneficial effects on surplus hydrogen in the rumen, with some evidence of reduced methane output. In the long term, rumen modification techniques may utilize bacteria from the gastrointestinal tract of herbivores like kangaroos, which effectively digest coarse fibre without any associated methane production.

Probiotics are an alternative to antibiotics when they are used therapeutically to control development of disease and promote health, but they do not act directly as an alternative growth promoter. They have potential for use in adult cattle to prevent common infections such as mastitis and urogenital infections, and work by producing hydrogen peroxide, organic acids or bacteriocins to prevent the growth of pathogenic bacteria. They also promote colonization of the gut by benign bacteria, such as lactobacilli, thereby excluding pathogenic bacteria by reducing nutrient availability or, in the case of lactobacilli, acidifying the gut contents with lactic acid. Their use in the gastrointestinal tract is currently restricted to the pre-ruminant calf, where they may prevent *Escherichia coli* from colonizing the gut and causing scours (diarrhoea). Live yeast preparations containing *Saccharomyces cerevisiae* are increasingly added to the diet of adult cattle as they are believed to play a role in stabilizing rumen pH, preventing an accumulation of lactic acid. They are particularly beneficial when added to the diet of cattle whose diet has been changed suddenly, or the diet is rich in concentrates, such as in early lactation. Prebiotics are indigestible plant compounds, such as oligosaccharides, that may be added to the diet of cattle to stimulate the growth of benign bacteria in the gastrointestinal tract. When combined with probiotics, there may be synergistic effects, the combined additive being known as a synbiotic.

Manipulating growth through photoperiod

Apart from dietary additives, the environmental conditions that cattle are exposed to can modulate growth patterns. Most prominent of the conditions is the photoperiod, and this probably derives from the fact that the progenitors of modern cattle, *Bos primigenius*, were seasonal breeders, with growth of calves regulated by photoperiod. Mating took place in late summer/early autumn, with calves born the following spring. These cattle had high appetites in autumn to fatten up so that they could survive harsh winters without much feed. Many wild herbivores utilize body fat stores in winter: for example, the bison, a close relative of cattle, catabolizes considerable amounts of fat tissue through its winter on the American plains.

Similarly, growing cattle today use the declining day length in autumn as a cue to divert nutrients from muscle to fat deposition. This gives them a store of nutrients that can sustain them through the winter, even though nowadays adequate conserved feed is usually made available to prevent cattle losing weight in winter. Calves in long days reach puberty earlier, which is probably related to the seasonal breeding of *Bos primigenius*, in autumn. Earlier attainment of puberty in long days would have increased the chance of breeding that autumn, rapidly becoming an adaptive trait. In intensive rearing of cattle, feed is available in similar quantity and quality throughout the year, but cattle still use the cue of declining photoperiod to start diverting more nutrients to fat deposition in autumn. By artificially extending the photoperiod in autumn to 16 h of light daily, cattle metabolism can be altered to deposit more lean tissue, as if the animals were still in summer. This could be useful if they are to be slaughtered midwinter, as they will put on more valuable muscle and less fat tissue, which might need to be trimmed off the carcass before sale. If, however, they are being kept until the spring, photoperiodic manipulation will have less benefit, as cattle in natural photoperiod start to divert nutrients away from fat deposition to muscle growth in spring. Photoperiodic manipulation of cattle growth can therefore achieve desirable changes in carcass composition, and it can improve feed intake and weight gain of growing cattle.

Lactating cows are also affected by day length. Artificially maintaining a long day length during the short days of winter can increase milk yield, which appears to be caused by increased leptin and prolactin secretion. As feeding is concentrated into daylight hours, increasing day length allows feeding periods to be distributed over a longer period of light. The cows also spend less time sleeping on long days. There are management benefits to increasing day length artificially in the housed environment, allowing oestrus to be detected more easily during the hours of darkness and potentially improving the cows' well-being in a stressful environment. Thus photoperiod manipulation can provide a method of manipulating the production and behaviour of dairy and beef cattle that is more acceptable to the public than the feed additives described.

Compensatory growth

Cattle whose growth has been retarded on a low plane of nutrition will exhibit, when returned to a high plane of nutrition, a faster growth than would normally be expected. This phenomenon has been of benefit to beef cattle farmers in many regions of the world in which fodder supply declines substantially in the winter or dry seasons. It enables cattle to catch up on growth later and allows farmers to use feed resources optimally, taking into account fluctuations in availability and the price of different feed resources. The expensive alternative is for farmers to store high-quality fodder and allow cattle to reach a mature weight more rapidly on a continual high plane of nutrition.

Cattle that undergo a period of growth retardation, followed by compensatory growth, experience some delay in reaching maturity (Fig. 3.2), particularly if the restriction is severe and imposed for a long time. If the restriction is imposed at a very early age or *in utero*, full

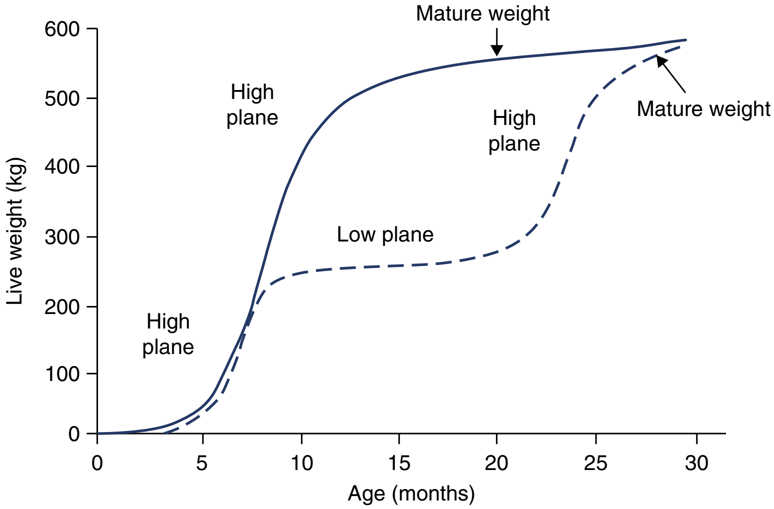


Fig. 3.2. The comparative growth of two animals, one reared on a high plane of nutrition throughout (——), the other transferred from a high plane to a low plane and then returned to a high plane (– –), demonstrating differences in the time at which maturity is reached.

compensation may never occur and the animals become runts. Generally, the greater the restriction has been, the faster cattle will compensate. Periods of restriction are characterized by a reduction in maintenance requirements, partly because of reduced size and activity of some vital organs, principally the liver and gastrointestinal tract, and perhaps partly because of reduced activity (though searching for feed may increase).

The compensation period is characterized by increased voluntary feed intake, leading to a rapid increase in weight gain, though some of the initial weight gain may be caused by increased gut fill and restoration of vital organ weight. Adequate feed availability is essential for cattle to compensate. If they are deprived of sufficient nutrients in winter or during a dry season, beef cattle can catch up later only if there is suitable pasture herbage available for high intakes. Pasture used for realimentation should preferably be about 8–10 cm tall and of high quality. Hence low-quality straw will not allow cattle to catch up if they have been restricted.

During the restriction period, the growth of the tissue that is most actively maturing at the time is most reduced. Less fat is deposited around the gastrointestinal tract, allowing feed intake to increase rapidly when adequate high-quality feed becomes available. If young animals are restricted, they show delayed bone maturation until feed is more plentiful. During realimentation, the rapid protein turnover can increase turnover of protein in some muscle groups, which can increase carcass tenderness.

High growth rates during realimentation, relative to body size, increase feed conversion efficiency at this time, compared with animals of the same chronological age that have been well fed throughout. This can be used to good effect by farmers buying cattle that have been underfed (store cattle), particularly after winter or a dry season. Farmers know that store cattle will grow rapidly and efficiently when grazed on good pasture. For this reason, the price of store cattle often increases just before the new season's grass growth. However, over their entire lifetime cattle that have been restricted and then realimentated will have a reduced feed conversion efficiency compared with cattle that have been on a high plane of nutrition throughout.

Measuring Cattle Production

Growth

An efficient cattle-rearing industry cannot exist without accurate measures of growth, as the animals should ideally be slaughtered at the optimum time in relation to their weight and composition and with due regard to feed availability and cost. Regular monitoring of growth throughout the rearing period will enable feeding schedules to be adjusted so that growth targets can be met. The methods used by farmers to determine when to alter their feeding regime and when to send the animals to slaughter are often simple rules derived from experience, though more sophisticated and objective methods may bring improved profitability.

An important prerequisite for monitoring cattle production is to be able to identify all animals accurately. This is easier in a dairy herd, in which cows are brought into a parlour daily, than in a beef herd in which cattle are only mustered annually. Individual identification can be by ear tags (though these are prone to being torn out), ankle straps (which get dirty and are difficult to read), neck collars or subcutaneous electronic implants. Ankle straps and neck collars may contain electronic chips to relay information automatically to a receiver, which can send the information to a central computer for processing. There are welfare implications of inserting identification tags in cattle that are described in Chapter 10.

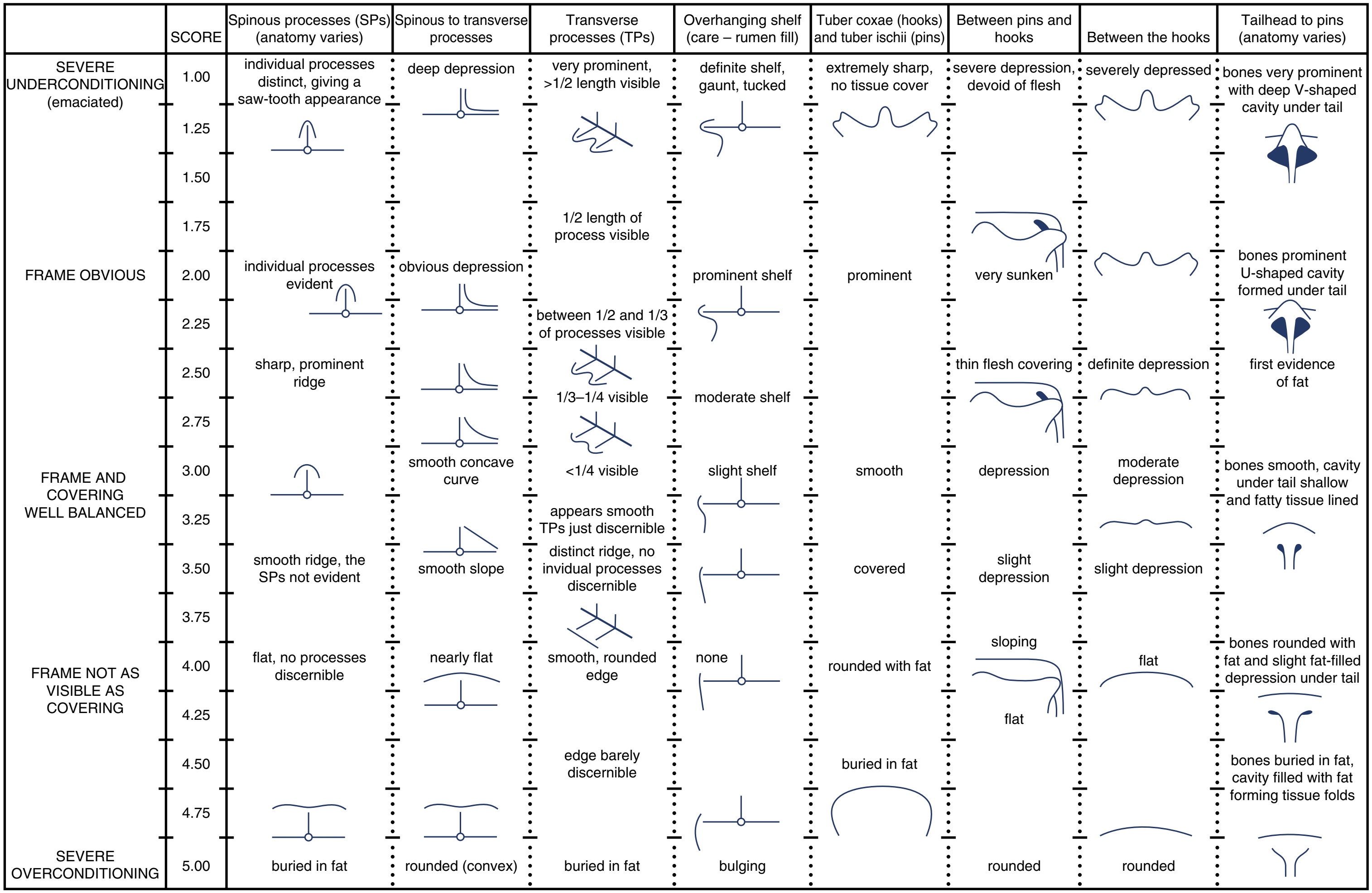
Increasingly, the movement of cattle is monitored throughout their lives in many jurisdictions. One of the more beneficial outcomes of the bovine spongiform encephalopathy (BSE) disease outbreak that started in the UK was that a cattle passport system was established within the EU to allow traceability of all cattle. Passports are issued shortly after birth on application and accompany an animal whenever it is sold or goes to slaughter. Movement labels with bar codes allow animals to be tracked quickly, and low-frequency radio signal emitters allow the weight of animals to be tracked from birth to their final destination, i.e. the retailer. Subsequently, identification schemes to allow cattle to be traced to their farm of origin at all stages of the production cycle have been introduced in most of the advanced cattle production nations of the world, including the USA, Canada and Australia. The Australian system uses machine-readable devices to identify cattle, in the form of an ear tag or rumen bolus/ear tag combination. The animal's residency and all animals with which it has interacted are recorded.

Measuring growth by weighing cattle is the simplest method of determining growth, but it will give limited information, because of fluctuations in gut fill, which comprises up to 25% of total weight in the adult animal. The rapid passage of feed through the gastrointestinal tract is accompanied by a reduction in the animal's live weight, sometimes by up to 40 kg when a mature animal is turned out to pasture in spring. Automatic electronic weighing scales take mean readings of repeated measurements from load cells under the floor of the crate containing the animal. Scales based on a lever connected to a spring balance are prone to error because of animal movement in the crate. Some handling facilities are fitted with electronic scales that record each animal's weight automatically as it walks down a race. In milking parlours, this can alert the herdsperson if there is a change in the weight of an individual animal or in the herd's mean weight.

Body composition

Visual assessment is used to estimate body muscle and fat cover in both the dairy and beef industries. The measurement of the body condition of cattle was first described in 1917, when it was used to estimate the ratio of fat to non-fat composition, but it was not widely used until Lowman *et al.* (1976) proposed a 5-point scoring method based on palpation of the spinous processes and the tailhead of cattle, using principles that had already been successfully developed for sheep. At this time, intensification of the dairy industry necessitated better assessment and regulation of body fat reserves. Today, most dairy herd managers regularly check the 'body condition' of their cows by either a visual assessment from behind each cow or a visual assessment together with palpation of the spinal cord and the tuber coxae/tuber ischii region if possible (Fig. 3.3).

Assigning scores of 1 to 5, depending on fat and, to a lesser extent, on muscle cover, enables the herdsperson to assess a cow's body condition scores in the context of optimum scores at certain stages of the lactation cycle that have been experimentally determined. On the 5-point scale commonly used for dairy cows in Europe and North America, these are generally accepted to be scores of 3.5 to 4.0 at calving, declining to 2.0 to 3.0 by 1 month post-partum and then gradually returning to 3.5 to 4.0 by the end of the lactation. Any cows with scores of 1.0 to 2.0 or more than 4.0 need attention, as reproductive performance is likely to be impaired. For beef cattle, scoring should be at weaning and calving for all cows. Different scales have been developed around the world: 9 points in the USA, 5 points in Canada, 8 points in Australia and 10 points in New Zealand. The 5-point scales often include half points. In today's global market for cattle, harmonization of condition-scoring systems is desirable. Condition scores are subjective measurements and differences in an animal's frame size and shape can lead to different body condition scores being attributed to animals with similar levels of fat/muscle cover. Nevertheless, it is possible to attain a reasonable degree of uniformity between different people scoring the cattle, which enables the system to be used for advisory and research purposes.



	SCORE	Spinous processes (SPs) (anatomy varies)	Spinous to transverse processes	Transverse processes (TPs)	Overhanging shelf (care – rumen fill)	Tuber coxae (hooks) and tuber ischii (pins)	Between pins and hooks	Between the hooks	Tailhead to pins (anatomy varies)
SEVERE UNDERCONDITIONING (emaciated)	1.00	individual processes distinct, giving a saw-tooth appearance	deep depression	very prominent, >1/2 length visible	definite shelf, gaunt, tucked	extremely sharp, no tissue cover	severe depression, devoid of flesh	severely depressed	bones very prominent with deep V-shaped cavity under tail
	1.25								
	1.50								
	1.75			1/2 length of process visible					
FRAME OBVIOUS	2.00	individual processes evident	obvious depression		prominent shelf	prominent	very sunken		bones prominent U-shaped cavity formed under tail
	2.25			between 1/2 and 1/3 of processes visible					
	2.50	sharp, prominent ridge					thin flesh covering	definite depression	first evidence of fat
	2.75			1/3–1/4 visible	moderate shelf				
FRAME AND COVERING WELL BALANCED	3.00		smooth concave curve	<1/4 visible	slight shelf	smooth	depression	moderate depression	bones smooth, cavity under tail shallow and fatty tissue lined
	3.25			appears smooth TPs just discernible					
	3.50	smooth ridge, the SPs not evident	smooth slope	distinct ridge, no invidual processes discernible		covered	slight depression	slight depression	
	3.75								
FRAME NOT AS VISIBLE AS COVERING	4.00	flat, no processes discernible	nearly flat	smooth, rounded edge	none	rounded with fat	sloping	flat	bones rounded with fat and slight fat-filled depression under tail
	4.25						flat		
	4.50			edge barely discernible		buried in fat			bones buried in fat, cavity filled with fat forming tissue folds
	4.75								
SEVERE OVERCONDITIONING	5.00	buried in fat	rounded (convex)	buried in fat	bulging		rounded	rounded	

Fig. 3.3. Body condition score chart for dairy cows (from Edmondson *et al.*, 1989, courtesy of *Journal of Dairy Science*).

Beef cattle are also subject to visual appraisal post-mortem. In Europe cattle are graded for conformation, which is a visual assessment of the shape of a carcass, in particular whether it is endomorphic or ectomorphic. This mainly reflects the muscle and fat cover. Carcasses are also specifically graded on a visual appraisal of fat cover.

The most important indicators of the saleable beef content of a carcass that are recorded in an abattoir are the weight, fat cover, conformation and breed, in that order. The dressing or killing-out percentage is also important and is influenced by the animal's age, sex and breed. The grades awarded in an abattoir influence the price paid for the carcass and enable retailers to specify the type of carcass that they wish to purchase, according to the market that they supply. Although grading is determined visually, ultrasonic probes are available for a more objective appraisal. In the live animal, the use of ultrasonic scanning to determine the optimum time of slaughter is possible with a mobile scanning service. Measurements are usually made over the 12th and 13th ribs for rib-eye area and rib-fat thickness, and between the hook and pin bones for rump-fat thickness. Intramuscular fat proportion derived from rib-fat thickness can then be used to predict a marbling score and grades at slaughter, if the assessment is conducted at about 1 year of age. Marbling is the term used for flecks of fat in the longissimus muscle and it is considered a desirable trait in some countries, such as the USA, because it improves the flavour of the meat and consumers pay a premium for marbled meat. In the USA many producers feed their cattle well and to a heavy weight to ensure well-marbled meat, which reduces the efficiency of feed conversion because growth rate slows as the animal matures and feed is used for maintenance of the animal and the production of fat tissue, rather than for growth of muscle and bone. An accurate assessment of fat cover should enable cattle to be marketed at the correct time. The system of carcass grading in the USA emphasizes marbling, whereas that in the EU emphasizes subcutaneous fat, reflecting a greater desire for marbling by consumers in the USA. Video image analysis is now facilitating the prediction of beef carcass red meat yield. The use of colour differences could improve prediction of tenderness characteristics of the meat, which is a common criticism of the American and European grading systems. Video image analysis can also predict marbling, lean and fat colour of the meat.

Milk Production

Milk has been the lifeblood of human history, revered over the centuries for its life-giving properties. Forever associated with the more feminine side of human nature, the milk-giving properties of the dairy cow have been increasingly valued for their capacity to provide a basic human food, whether as liquid milk, or stored as yoghurt or cheese. This section considers the basic properties of milk production by the cow.

Commencement of milk production coincides with the parturition of the calf and will continue for a year or more if not curtailed by drying the cow off in preparation for a subsequent calf. Cows of the *Bos taurus* genetic subtype usually produce milk without the presence of their calf, whereas those of the *Bos indicus* subtype require their calf to be present. This limits the scope of intensification of milking systems for *Bos indicus* cows, whereas for taurine cows ever more labour-saving and efficient methods have been devised for extracting the milk, culminating in robotic milking units that are fully automated. There is growing popularity of milk and dairy products, partly due to the increased sales of pizza as a fast food, but also in developing countries because of the popularity of the Western diet and growing affluence. However, in Western society at least, concerns about the sustainability of large-scale intensive dairy farms are driving an increasing popularity of alternative vegetarian-based milks. The concerns focus on cow emissions, the removal of the calf from the cow at a few days of age, the slaughter of male calves, and cow health and its link to genetic selection for cows with ever-increasing milk yields.

Measuring milk production

Genetic selection for milk production has required accurate and easily obtained records of individual cow yields. These are usually easier to obtain than for cattle growth, because cows are being handled daily for milking. Disease conditions, oestrus and adverse treatment of cows all result in reduced milk yield and can be identified from changes in daily recorded milk yields. Computerized recording of individual cows allows early identification of disease and helps in oestrus detection. Alternatively, in some countries dairy herds still rely on a regular, usually monthly, visiting service to record the yield of each cow and take samples for composition analysis.

Milk records should ideally be included in selection of cows for breeding. Only a few records from each cow per lactation are required. Regular recording of milk composition is more difficult, since samples must be taken and sent for analysis to a laboratory. Fat, protein, non-protein nitrogen, lactose, somatic cell numbers, conductivity and the presence of antibiotics can be determined. Samples for bacterial analysis have to be collected manually, using aseptic techniques. Bulk tank samples may be taken to indicate herd average values, but individual cow samples taken from the milk line are now being used in major dairies to provide more useful data.

Milk composition

The milk that is first produced by the cow for its calf, the colostrum or beestings, has an unusually high concentration of antibodies, to protect the calf until it has developed its own immunity. This is usually reserved for the calf. Milk produced after the first few days usually contains about 3–4% fat, 3% protein, 5% lactose and 0.7% minerals, but this varies with breed, feed type, lactation stage and other factors. The mineral and vitamin content of milk is of significant value for human nutrition, with vitamins A, B, C and D and calcium, iron and zinc being the most important. Milk also contains somatic cells, sloughed off from the mammary gland or secreted into the milk.

Milk fat is present in milk as a suspension of globules, about 10^{10}/ml. Its concentration varies considerably between breeds of cattle, being high in Channel Island breeds and *Bos indicus* cows (usually 4–5%) and low in Holstein-Friesians (3–4%). Milk fat is naturally palatable to consumers, but it contributes to the human health problems of atherosclerosis and heart disease. Nearly all milk fat is in the form of triglycerides. About two-thirds of milk fat is composed of saturated fatty acids, with the remainder mostly mono-unsaturated fatty acids and only a small amount of polyunsaturated fatty acids (about 2%, depending on the diet of the cow). Since long-chain, mainly unsaturated, fatty acids can be absorbed in some quantities directly into the milk, as opposed to the approximately 50% of milk fats by weight that are short-chain saturated fatty acids which are synthesized de novo by the cow, it is possible to increase the content of unsaturated fats by including them in the cow's diet. Some of this happens naturally when cows are grazed on fresh pasture. It is also possible to breed cows with high monounsaturated fatty acid content, as it is moderately heritable. However, unsaturated fats become rancid more quickly than saturated fats, reducing the shelf-life of milk, making this enhancement of unsaturated fats undesirable. Instead consumers, especially those with sedentary lifestyles, have switched to consumption of milk that has had either most (skimmed milk) or some (semi-skimmed milk) of the fat removed. This does little to reduce the palatability of the milk, but the colour of whole milk is more yellow than skimmed or semi-skimmed because of the increased concentration of carotene and its derivatives in the fat. Farmers are usually paid less for milk fat than protein, because of oversupply due to the popularity of skimmed milks. In some countries there is a quota on milk fat production, so there is little benefit in producing milk with very high fat concentrations. However, the potential to modify milk fat content by genetics and nutrition to improve its fatty acid composition is greater than for other constituents.

Milk protein is about 70% casein, with the remaining 30% comprising β-lactoglobulin, α-lactalbumin and immunoglobulins. The casein precipitates in mild acid and is therefore of particular value for clotting cheese and yoghurt. For human consumption, milk protein has a naturally high content of lysine, which complements cereal protein well. A small proportion of people are allergic to milk protein, but the effects are transitory and diminish with age. Although protein is present in milk at lower concentrations than either fat or lactose, it is often the most valuable constituent because of its use for the production of cheese and yoghurt. The natural variation in milk protein content is less than for fat, so the opportunity to select cattle with increased milk protein is limited. In addition, if cows are bred for high milk protein content, milk yield declines, and hence genetic progress in increasing milk protein yield is slow.

Milk lactose is a disaccharide comprising two simple sugars: glucose and galactose. It is synthesized in the Golgi apparatus and secreted into milk along with protein. It is the major osmotic regulator in milk, though chloride, sodium and potassium also play a part. As a result, when mastitis damages the junctions between the alveolar cells, more sodium (the main extracellular osmotic regulator) is released into milk and the lactose content of the milk is reduced in compensation by about 2 g/kg. Lactose content in milk may also decline by 1–2 g/kg when cows are underfed in late lactation. Milk lactose is of little value to the processor. Lactose content is similar in different dairy cow breeds and, as a result, dairy cow breeds with relatively low yields of milk with high fat and protein contents – such as those from the Channel Islands – use less energy on lactose output than breeds with high yields of low fat and protein content, such as the Holstein. Nevertheless, it is one of the constituents of liquid milk that is highly valued by most consumers, as sweetness is one of the main determinants of milk acceptability. However, lactose can be absorbed only after separation into glucose and galactose by the enzyme lactase. Some people are deficient in lactase and are therefore lactose intolerant, with the lactose eventually being fermented in the colon, leading to problems of bloating. There are genetic influences on the incidence of lactose intolerance and it is most rare in people of northern European descent.

Effects of stage of lactation on milk composition

Changes in milk composition over the cow's lactation reflect the changes in milk yield, energy balance and feeding level. In the first few weeks, milk fat content declines rapidly as yield increases (Fig. 3.4). After 4 weeks, milk fat content gradually increases for the rest of the lactation. Milk protein content declines gradually over the first 12 weeks of lactation, as the cow mobilizes body tissue to sustain lactation. Thereafter it increases again, until by the end of lactation it is back to approximately the concentration at the start of lactation. Milk lactose content initially increases as colostrum is replaced by milk. Thereafter it changes very little over the lactation, except that it may decline towards the end, particularly if the cows are underfed at this time.

It is difficult to distinguish the true effects of stage of lactation from the changes that take place in milk yield, appetite and body condition that occur as the lactation progresses. Changes in two of the major milk constituents, fat and protein, over the course of lactation mirror the change in milk yield that occurs at this time, and hence changes in the yield of these constituents are less than in the concentration. The absence of variation in milk lactose concentration over the lactation reflects its role as an osmotic regulator.

Conclusions

The physiological processes that produce meat and milk in cattle have been exploited by humans to create high output systems of production that can meet the growing demand for cattle products. Growth is not of

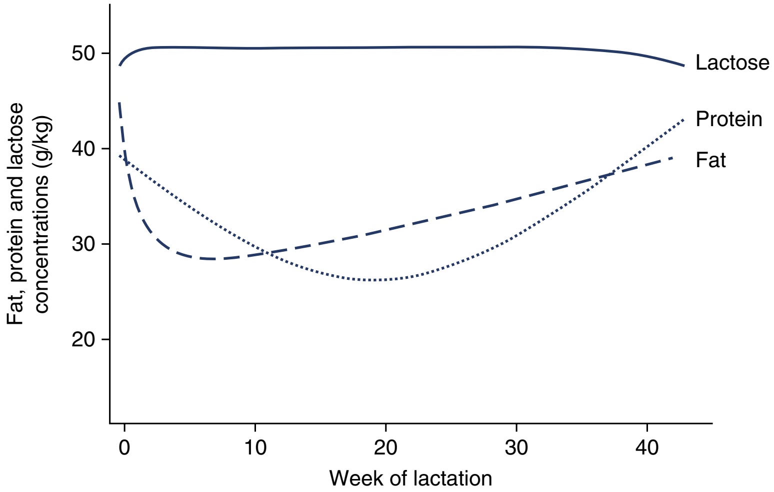


Fig. 3.4. The changes in milk fat, protein and lactose concentrations over the lactation of a dairy cow.

ideal conformation for producing high-price cuts of meat, but that is partly related to the digestive processes in cattle, based around a large muscular rumen. Similarly, milk composition is not ideal for human health, comprising largely saturated fats. Both of these factors can be manipulated by a number of methods but this alters the fundamental characteristics of the product. In the face of growing demand for milk products as part of a Western-style diet in Asia at least, and increasing demand worldwide for cheese in fast-food outlets, it is unlikely that dramatic steps will be taken to improve the quality of the products in the near future.

Note

[1] Carcass weight as a proportion of total weight.

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4

Nutrient Requirements and Metabolic Diseases

Introduction

An accurate knowledge of the nutrient requirements of cattle can aid in optimizing output, reducing emissions to the environment, improving profitability and avoiding those metabolic disorders that can lead to low productivity and, ultimately, disease. Without this knowledge rationing cattle is difficult and likely to lead to wastage of nutrients. The major nutrients for which rationing systems have been devised are energy and protein, but simple models have also been created for major mineral nutrients.

Rationing Cattle

Determining the nutrient requirements of cattle to enable them to be effectively rationed has been a focus of attention for nutrition scientists for approximately 200 years. As genetic selection has increased the potential productivity of cattle, particularly dairy cows, so their nutrient intake has had to increase. If intake does not meet the requirements for production, cattle may lose weight and eventually normal bodily functions become compromised. A long-term nutrient deficit creates a significant stress for cattle. It leads to an adventurous appetite, or pica, as the animal searches for new sources of nutrients but, in the case of energy deficits, may also cause lethargy as the animal attempts to conserve its energy. Any prolonged nutrient deficit may cause eventual collapse and death. Such long-term deficiencies in the diet are more likely to occur in rangeland beef cattle, particularly in marginal areas prone to the extremes of weather and drought. A short-term discrepancy between requirements and nutrient supply leads to either a reduction in production levels or, if of significant magnitude, metabolic breakdown.

A nutrient deficit often occurs during the first few weeks of lactation in the dairy cow, because breeders have selected for high milk yields in their cows, which is usually achieved by a rapid increase in milk production over the first few weeks of lactation. This can overload the ability of the digestive system to supply adequate nutrients, resulting in metabolic breakdown. In future, breeders may select for cattle with more persistent lactations, rather than those with a rapid increase to high milk yields at the start of lactation. More persistent lactations could help to lengthen the production cycle, preventing the output of unwanted calves in regions where the demand for milk is high relative to the demand for beef. In the long term, it may be possible to regulate the apoptosis of mammary gland cells, perhaps leading to cows that are permanently lactating after their first calf. Since many of the welfare and disease problems associated with lactation arise as a result of imbalances in nutrient intake and output at the start of the lactation, a persistent, steady-state lactation, in which nutrient intake and output are in balance, could be better for the cow.

Dairy cow managers must provide feeds that enable high-yielding cows to increase intake as rapidly as possible after calving. These should be highly digestible feeds and offered in a form that is conducive to high nutrient intakes. Total mixed rations (otherwise known as complete diets), in which the animal's entire diet is offered in a well-mixed feed, are one of the best ways to achieve this. For very high-yielding cows, self-feed silage and highly stocked grazing systems are probably best avoided, as they are unlikely to provide adequate fibrous feed. Diets can now be accurately constructed to enable cattle to grow or lactate at various levels, largely as a result of the extensive research efforts in the latter part of the 20th century. Efficient rationing is particularly important in regions where output is restricted, for example by milk quotas. It can also be beneficial in regions where there is strong competition between milk producers for market share or where large farms prevail, creating the economies of scale to allow the purchase of sophisticated equipment for feeding and rationing the animals. In such situations, accurate rationing will enable farmers to adjust milk output and quality according to the market conditions. In developing countries, the shortage and variable quality of feed resources for cattle feeding make effective rationing difficult but potentially important, though the research effort into managing cattle nutrition in such conditions has not yet been as extensive as for high-productivity situations. Rationing systems are almost always focused on productivity, whereas a focus on animal welfare would bring separate but significant dividends.

Least-cost rations, where diet ingredients are compared in terms of the nutrients that they supply and their cost, can be rapidly formulated with the aid of a computer, which solves a series of simultaneous equations to arrive at the optimum diet. Such methods are already essential in devising rations for pigs and poultry but are necessarily confined to feeds that can be purchased, or attributed a cost, i.e. mainly conserved feeds, rather than grazed grass. A cost can be introduced for forage, which is saleable, but if it is home-produced the opportunity cost of the land must be a prime consideration. This should include fertilizer and water application costs in the case of intensive dairy farming. In least-cost rations, maximum and minimum inclusion rates can be included for certain ingredients to take into account particular constraints, such as the bulk density of the feed, its palatability or subtle aspects of its digestion or utilization, such as the presence of anti-nutritive agents, which may not be accounted for in the rationing system. In the large intensive dairy farms in Israel, complete diets are often mixed centrally and transported to farms within a driving distance of 2–3 h. The mixing factory can take advantage of low-cost feeds, bulk purchase of ingredients and centralized nutritional expertise to formulate rations for the farms.

Cattle-farming systems in which the animals spend part of the year at pasture and are given conserved feeds for the rest of the year, and possibly as a pasture supplement, benefit if forage stocks are assessed well before the end of the grazing period. Quantities of hay are easily calculated, and silage volume can be calculated from knowledge of clamp, tower or bale dimensions and converted to a mass using known densities of silages of different dry matter (DM) concentrations. In clamped silage the DM content can be most reliably estimated by taking cores through the silage mass at regular intervals. As silage DM content varies considerably at different points in the clamp, it is not sufficient to sample just at the edge of the clamp. Tabulated values of silage density can then be consulted. For example, grass silage at 220 g DM/kg fresh weight contains approximately 700 kg fresh matter and 155 kg DM/m^3. At 300 g DM/kg fresh weight, grass silage contains approximately 650 kg fresh matter but 195 kg DM/m^3. Maize silage tends to have lower densities than grass silage. Silage in towers has a greater density than clamped or baled silage, because the mass of silage in the tall stack squeezes air out of the lower layers. The DM density is most important for calculating rations, but the fresh (or wet) matter density is also necessary for weighing out the rations.

In addition to a knowledge of silage DM and fresh matter consumption by cattle, silage quality should be chemically analysed to obtain information concerning its nutrient value. As with determinations of DM concentration, it is most important to use the proper sampling techniques. The silage analysis should provide the concentrations of DM, crude protein, digestible organic matter (DOM), available energy (often measured as metabolizable energy (ME)), pH, ammonia-nitrogen as a proportion of total nitrogen, and ash. To determine the available protein rather than just the crude protein contribution, the metabolizable protein (MP) is calculated using predictions of the concentration of fermentable ME, effective rumen-degradable protein and digestible rumen undegradable protein.

From a knowledge of silage quality and quantity, farmers can approximately predict the performance of their cattle, given a certain level of supplement, or they can estimate how much supplement to feed in order to achieve a certain production level. This has been made possible by the transition from rationing systems that estimated cattle nutrient ‘requirements’ into prediction systems where responses to additional nutrients are determined. Cattle can only be said to have a ‘requirement’ for a certain nutrient if they respond up to a certain point and then no more, whereupon another nutrient becomes limiting. This is analogous to the control of photosynthetic rate in plants by temperature, CO_2 concentration or irradiance. In this case only one resource will limit output at any time, which can be increased in a stepwise fashion by providing more of each of the resources in turn above its limiting threshold.

In animals, this response pattern to a series of different nutrients rarely occurs, and it is even an oversimplification of plant responses. Because cattle can store most of the major nutrients in preparation for future restrictions, the instantaneous response is often quite different from the long-term response. Also, nutrients interact with each other; for example, minerals that are similar in their chemical and physical structures often compete with each other for absorption or adsorption sites. In addition, nutrients may not always be used for the same purpose, as for example protein, which can be used to satisfy either the nitrogen or energy demands of the animal.

Rationing grazing cattle presents particular problems, as it is difficult to know how much they are eating, even under research conditions. Sampling the herbage grazed by cattle to understand its chemical composition is also more difficult than sampling conserved forage, as cattle select certain pasture species and plants of different age and height, compared with more homogeneous conserved forages.

Production responses will depend on the genotype of cattle, which influences energy maintenance requirements, the extent of nitrogen recycling, the partitioning of nutrients and feed and water intake. Most modern feeding standards make some allowance for the effects of breed on at least maintenance ME requirement and feed intake, but fairly inexactly. Protein and energy response systems are now well developed, and both are important in determining the output and profitability of cattle production units. Ideally, a rationing system should predict responses to changes in nutrient intake, in terms of both the quantity of output – usually milk or growth – and the quality, in particular the chemical composition of milk. As well as production responses, nutrient response systems should take account of the impact on the welfare of the animals; in this respect minimum requirements for survival are not well defined, even though they are important in drought conditions.

Future developments in rationing systems may include prediction of the changes in meat fatty acid (FA) composition in response to dietary constituents. Rationing schemes are progressing from estimating feed requirements for given levels of output to determining responses in quality and quantity of output in response to varying nutrient intake, or the reverse. Currently, only milk (not meat) composition can be used to determine the energy balance of cattle, as it can easily be determined on a regular basis.

Energy Rationing

Energy is usually the first limiting nutrient in a diet for cattle. Because cattle respond to changes in energy intake even when a high-energy diet is fed, it is not possible to determine an energy ‘requirement’, nor even an allowance, that is independent of the production level. However, dose–response relationships allow production to be predicted when energy intake is known, or energy requirements to be determined for a specific production level. For example, milk yield can be predicted for cows in a dairy herd, either as a group or individually, using the intended diet and the cows’ appetite to predict energy intake. After the energy requirements for maintenance, weight changes and pregnancy (if applicable) have been deducted, the residual energy can be assumed to be that available for milk production. As long as milk composition is known or can be predicted, and therefore the energy requirement per litre of production estimated, yield can be predicted. If the actual yield is then monitored regularly, any deviations from predicted yield can be investigated. On an individual basis, major reductions in yield may indicate ill health; and on a group basis, the energy-rationing system can be used to predict how feed energy supply should be altered to bring the actual yields back in line with required yields. This is especially important for farmers operating under a milk production quota.

Comparative analysis of agricultural feeds to promote the fattening of cattle was instigated by the German agricultural scientist Oscar Kellner (1851–1911) at the end of the 19th century (Breirem, 1952). He produced ‘starch equivalent’ values, which related the fattening ability of different feeds to that of pure starch. These values were used to ration cattle for much of the 20th century.

Metabolizable energy (ME)

In 1975 the British Ministry of Agriculture, Fisheries and Food (MAFF) published an energy-rationing system based on ME, which has been adopted in many countries and remains in use today (MAFF, 1975). The ME content of a feed was defined as the energy content remaining after faecal, urinary and methane energy have been subtracted (Table 4.1 and Equations 4.1–4.3).

$$\text{Digestible energy content} = \frac{350-135}{18} = 11.9\ \text{MJ/kg DM} \qquad \text{Equation 4.1}$$

Table 4.1. The intake and distribution of energy (in megajoules (MJ)) in a typical feed for dairy cows and the determination of digestible, metabolizable and net energy concentrations of the feed.

Dry matter intake (kg/day)	18
Gross energy intake (MJ/day)	350
Faecal energy (MJ/day)	135
Urinary energy (MJ/day)	12
Methane energy (MJ/day)	24
Heat increment (MJ/day)	70

$$\text{Metabolizable energy content} = \frac{350-(135+12+24)}{18} = 9.9 \text{ MJ/kg DM} \qquad \text{Equation 4.2}$$

$$\text{Net energy content} = \frac{350-(135+12+24+70)}{18} = 6.0 \text{ MJ/kg DM} \qquad \text{Equation 4.3}$$

The net energy (Equation 4.3) is that which is directly used to maintain the animal for lactation, body growth and pregnancy; however, in most rationing systems for cattle the ME fraction (Equation 4.2) is used because of the difficulty in measuring the heat increment. The main energy source in cattle feed is structural carbohydrate. Protein and fat have greater energy concentrations, but the former is used largely to supply the protein requirements, and the latter cannot be included in high concentrations (more than about 7%) in the diet of cattle because of adverse effects on ruminal bacteria.

In energy rationing, it is important to realize that energy intake, from feed (e.g. pasture, forages or concentrate) and body tissue mobilization, is equivalent to energy output in milk, maintenance, pregnancy and live weight change. Within the system energy can neither be lost nor created, if heat exchange to the environment is included.

However, the factorial addition of energy contributions from different sources in this way is not entirely accurate. As energy intake increases, the utilization of the energy becomes less complete, partly because more rapid passage through the gastrointestinal tract reduces the extent of feed digestion. Thus, an additional 1 kg of concentrate will provide less energy if it is added to the diet of a high-producing cow that is consuming large quantities of an energy-dense diet than if it is added to the diet of a non-lactating cow consuming smaller quantities of low-energy feed, as a result of faster passage through the former. Furthermore, the concentrate will replace more silage in the high-producing cow, which will additionally reduce its value to the animal.

Another problem with the factorial energy-rationing system is that it is not possible to predict the destination of additional energy consumption. It may contribute to increased milk production, but it may also contribute to lipogenesis. Much depends on the source of the energy, and in particular whether it provides lipogenic or glucogenic precursors, and on the production level of the cattle. The animal's physiological state will also determine the partitioning of energy: in early lactation it may be used for milk production, but in late lactation towards body tissue gain and milk fat content. However, despite these constraints the ME system has been used successfully for rationing cattle since the 1970s and appears to be reasonably accurate. By contrast, protein-rationing systems have fundamentally changed over this period.

The factorial estimation of energy input and output is determined as follows. The feed energy requirement to maintain cattle without gain or loss of weight (maintenance energy requirement) is determined from estimates of energy utilization during fasting, adjusted for the weight of the animal and an activity increment, then divided by the efficiency of utilization of ingested ME for maintenance. Fasting energy utilization is assumed to be greater for bulls than for other cattle, in part because of their reduced level of subcutaneous fat. It includes an activity increment, which is greater for grazing than for housed cattle because they walk further, eat for longer and may be required to walk up and down a gradient on inclined land.

The activity increment can vary between individual animals within the same farming system by 8–10%, depending on their behaviour and physiology. The energy costs of different activities – getting up, walking, lying down, etc. – are known with reasonable accuracy and the maintenance requirements could be adjusted for different activity schedules, if necessary. Dynamic models could potentially predict the response of cattle to changing environmental conditions, but their complexity requires considerable computer processing capabilities. In future, some recognition may be given for the increase in maintenance requirements as lactation progresses and for increased maintenance requirements for dairy cattle compared with beef cattle. However, for now, fasting energy requirements can be predicted as follows:

$$\text{Energy utilized during fasting (MJ/day)} = \text{C1}\ [0.53(\text{W}/1.08)^{0.67}] \quad \text{Equation 4.4}$$

in which C1 is a constant of 1.15 for bulls and 1.0 for other cattle, and W is weight (kg).

The activity increment is based on the animal's weight and is estimated as follows:

$$\text{Activity increment (MJ/day)} = 0.0095 \times \text{weight (kg) for lactating cows, and } 0.0071 \times \text{weight (kg) for other cattle}$$

Equation 4.5

The efficiency of energy utilization for maintenance is dependent on the metabolizability of the diet, i.e. the concentration of ME in the dietary DM. The energy requirements for milk production are well established for milk of different compositions. They can be calculated by multiplying milk yield by the energy value of the milk, which can be determined from milk composition as follows:

$$\text{Energy value of milk (MJ/kg)} = 0.038\ \text{F} + 0.022\ \text{P} + 0.020\ \text{L} - 0.11$$

Equation 4.6

in which F, P and L are the fat, crude protein and lactose concentrations (g/kg), respectively, in milk.

For lactating cows, the energy required for weight change will depend on the composition of the gain. A late-lactation cow that is replenishing body fat stores will require more feed energy per kilogram live weight gain than a heifer that is still growing during her first lactation, since the late-lactation cow will be laying down fat tissue whereas the heifer will be depositing other tissues, particularly muscle, which have a lower energy and higher water content. Such complexities are hard to estimate for different types of weight change in lactating cows, and a common value of 19 MJ/kg live weight change is usual. If body tissue is mobilized, it will be used with an efficiency of approximately 84%, thus contributing 19 × 0.84 = 16 MJ/day of feed energy equivalent.

The energy required for the growth of beef cattle is also dependent on the composition of the gain and can be predicted from the rate of gain, with a correction for the class and breed of cattle (Table 4.2). Bulls produce leaner growth than steers at a particular weight, which in turn produce leaner growth than heifers, and lean tissue deposition requires less feed energy than fat tissue. In this analysis, Aberdeen Angus and North Devon are classified as early maturing, Hereford, Lincoln Red and Sussex as medium maturing and Charolais, Limousin, Simmental, Holstein-Friesian and South Devon as late maturing. The equation for predicting the energy value of live weight gain is as follows:

$$\begin{matrix}\text{Energy}\\ \text{value}\\ \text{(MJ/kg)}\end{matrix} = \frac{\text{C1}\left(4.1 + 0.0332\ \text{W} - 0.000009\ \text{W}^2\right)}{\left(1 - \text{C2}^{*}0.148\Delta \text{W}\right)}$$

Equation 4.7

where C1 is the correction factor from Table 4.2 and C2 = 1 if the plane of nutrition is sufficient to provide for at least maintenance, otherwise it is 0. W is the weight (kg).

The energy requirement for gestation is small in the early stages, but significant in the last trimester. It is partly determined by the potential for growth of the fetus, as prescribed by the breed. It can be estimated from the following exponential equation:

$$\log_{10} \text{energy requirement} = 151.665 - 151.64e^{-0.0000576t} \quad \text{Equation 4.8}$$

where e is the exponential constant, 2.718, and t is time (days from conception).

These summated energy requirements can be compared with energy supply, which is determined from feed intake and the energy concentrations of the feeds. If the diet is hypothetical but offered *ad libitum* and intakes are unknown, equations that estimate how much they are likely to eat should be used that utilize

Table 4.2. Correction factors for the energy content of weight gain by beef cattle of varying gender and maturity.

Maturity classification	Bulls	Steers	Heifers
Early	1.00	1.15	1.30
Medium	0.85	1.00	1.15
Late	0.70	0.85	1.00

various cow and feed factors. The simplest equations use the milk yield of cows and their weight to predict intake, but more complicated equations exist that introduce feed factors. The following equation gives a good estimate of grass silage DM intake under temperate conditions:

$$\text{Silage DM intake (kg/day)} = -3.74 - 0.387C + 1.486\ (F + P) + 0.0066W + 0.0136\ \text{DOMD} \quad \text{Equation 4.9}$$

where C is concentrate DM intake (kg/day), F + P is the daily yield of fat and protein in milk (kg/day), W is the cow's weight (kg) and DOMD is the digestible organic matter in the DM (g/kg DM).

If the proposed ration is unlikely to be able to be consumed in sufficient quantities by the cows, then the energy concentration must be increased to achieve the required energy intake or the productivity of the cows will decline. The ration must be offered in such a way as to maximize DM intake in early lactation.

Net energy rationing

The net energy is the energy retained in the animal and subsequently lost after having been used for maintenance. This can be calculated from the ME minus the heat energy produced by the animal. The net energy contents of feeds are usually calculated from ME concentrations, adjusted for the partial efficiency of energy utilization for maintenance, lactation or growth. The efficiency of use of net energy for maintenance appears to be lower than originally assumed. Net energy systems are often used to ration beef cattle, because the heat increment is less than for dairy cattle.

Nitrogen Response Systems

Effective management of nitrogen inputs to the dairy cow is important because of the high cost of proteinaceous feeds, the relationship between protein intake and several metabolic diseases – notably reproductive disorders – and the cost to the environment of high nitrogen emissions from cattle, especially dairy cows (Abbasi *et al.*, 2018).

For much of the 20th century, protein rationing was based on estimates of digestible crude protein requirements, obtained from empirical data of cattle producing different quantities of milk or growing at different rates when fed varying levels of digestible crude protein. However, this was unsatisfactory for high-yielding dairy cows in particular, because the extent to which the consumed protein is degraded in the rumen partly determines the amino acid supply to the animal. If feed protein is extensively degraded, the capacity of the ruminal microbes to utilize all the nitrogenous compounds is exceeded, and the surplus is absorbed as ammonia and converted by the liver to urea for recycling into the gastrointestinal tract for excretion. This has a substantial energy cost. However, if some of the protein escapes degradation in the rumen, this will pass into the small intestine where most of it is digested to amino acids and these are absorbed. These then contribute directly to the animal's amino acid requirements, in addition to the microbial protein that is made available to the animal when the microbes are digested by enzymes and the nitrogen breakdown products – principally amino acids and nucleic acids – absorbed.

Nitrogen response systems available for use on farms improved considerably when, in 1980, the UK Agricultural Research Council (ARC, 1980) published a system that first recognized the importance of independently quantifying the contributions to amino acid requirements from microbial and directly absorbed (rumen-undegraded) sources.

These systems can now be used in the field with reasonable success. The essential features of protein-rationing systems are that microbial protein production can be predicted from the energy supply to the rumen, and that the requirement for directly absorbed protein can be predicted by subtracting microbial protein supply from the total protein requirements. These are predicted factorially from the requirements for maintenance, body tissue and fetal growth and milk protein production. If the whole-tract protein digestibility is known, the faecal nitrogen loss can be calculated. Furthermore, if the degradability of the dietary nitrogenous compounds in the rumen is known, the nitrogen utilized by the ruminal bacteria or recycled as urea can be predicted and the supply of digestible undegraded nitrogen determined.

More recently, the introduction of the metabolizable protein (MP) systems in several countries has brought a range of improvements in protein rationing. Among these is the recognition that only fermentable energy will contribute to microbial growth in the rumen. ME from feeds that have already been fermented will be partly

Box 4.1. An example of the use of the metabolizable energy response system to analyse the adequacy of a diet for dairy cows.

A veterinarian is called to a dairy farm where the farmer has recently employed a new herdsperson and has a problem with rebreeding his autumn-calving herd. Many of the cows are not pregnant and the farmer suspects that a large proportion of his cows are not cycling properly for one of two reasons:

1. Some cows are believed to have ovarian cysts. The veterinarian inspects a number of cows and finds that actually there are few cows with this condition.
2. The cows' ration contains inadequate energy, and the prolonged negative energy balance of the cows has reduced conception rates, a view proposed by the farmer's feed merchant.

On finding that the first suspected cause of cow infertility was not likely, the veterinarian is asked to comment on the feed merchant's claim that the ration for the cows had inadequate energy contents. They decide to check the energy balance.

The mean weight of the Holstein-Friesian cows is estimated to be 650 kg. They are producing a mean milk yield of 33 kg, with a butterfat content of 38 g/kg, protein content of 32 g/kg and a lactose content of 50 g/kg.

The feeds available to the farmer are: (i) silage containing 200 g DM/kg and 11 MJ ME/kg DM (730 g DOM/kg DM); (ii) rolled barley containing 850 g DM/kg and 13.7 MJ ME/kg DM; and (iii) a dairy compound containing 860 g DM/kg and 12.5 MJ/kg DM. The farmer has estimated that he is feeding 50 kg silage, 4 kg barley and 6 kg compound feed/cow/day. The questions that the veterinarian must answer are:

1. What are the cows' ME requirements? These are early-lactation cows so the veterinarian assumes that they will be losing about 0.5 kg/day body weight at 16 MJ/kg; if cows lose weight at more than 0.5 kg/day, conception rates are likely to be adversely affected.
2. Is the ration within appetite limits? If it is not, the farmer's estimated intake per cow may be too high.
3. What is the ME provided by the ration and does it match energy requirements?

The veterinarian's findings:

1. The ME content of the milk is 5.1 MJ/kg, and milk ME output is therefore 168 MJ/day (Equation 4.6). The ME requirement for maintenance is 61 MJ/day (Equations 4.4 and 4.5). The total ME requirement can be reduced by 8 MJ/day, because the cows are estimated to be losing 0.5 kg/day. Therefore the total ME requirement is 221 MJ/day.
2. The potential intake of silage DM is 10 kg/day (Equation 4.9), so the farmer's estimate of the cows' intake may be correct.
3. The daily ME intake per cow is:
   - silage: 10 kg DM = 110 MJ;
   - barley: 3.4 kg DM = 46.6 MJ;
   - compound: 5.2 kg DM = 64.5 MJ; and
   - total: 18.6 kg DM = 221 MJ.

Sustaining this level of body tissue loss may reduce conception rates if a cow's body condition is already at a low level, but the ration that the farmer is feeding to his cows appears feasible. The next step would be to score the cows' body condition. If many are below 2, on a 5-point scoring system, then the veterinarian should recommend increasing the concentrate part of the diet to increase energy intake. If most are above 2, they should investigate the oestrus detection rate (number of cows expected to be in oestrus divided by number of cows observed in oestrus). If this is less than 60 %, poor oestrus detection by the new herdsman is likely to be the reason for the problem.

composed of the acid end products of fermentation, estimated to be about 10% of the total ME for silage and 5% for distillery by-products, which will not provide energy substrates for microbial growth. However, different forms of fermentable metabolizable energy (FME) are used with different efficiencies for microbial maintenance and growth, which is not always recognized in the rationing systems. Similarly, lipids are not fermented and will not contribute to microbial growth in the rumen.

The metabolizable protein system recognizes that microbial growth may be limited by rumen-degradable protein supply, not just by energy, and the revised MP system (Alderman and Cottrill, 1993) divided rumen-degradable protein into slowly and rapidly degradable nitrogen. Only about 80% of the latter contributes to the nitrogen requirements for microbial growth, because some of the rapidly degradable protein and even more of the non-protein nitrogen will be absorbed before it can be captured by the ruminal microorganisms. This is most likely to occur if it is consumed rapidly and immediately solubilized, leading to a surge in the ammonia concentration in the rumen.

The rapidly degradable protein can be mathematically predicted from the DM disappearance pattern of feeds suspended in the rumen in fine mesh nylon bags *per fistulam*. This has inherent errors: (i) the bag will allow some unfermented small particles to escape and some particles from outside the bag to enter; (ii) it does not allow the feed to be mixed with the other ruminal contents; and (iii) it may result in selectivity in the ruminal microbial population that ferments the feed. Despite these sources of inaccuracy, the *in situ* method of estimating protein degradation in the rumen has often correlated well with *in vivo* measurements of the flow of nitrogen fractions from the rumen, but some reservations remain about its use for forages. In future, *in vitro* methods are likely to assume more importance and may be based on the solubility of protein, the incubation of feedstuffs in ruminal liquor obtained from an abattoir or near-infrared spectroscopic analysis.

Accepting that the *in situ* method is one of the best currently available, an exponential equation can be used to describe the loss of nitrogen compounds from the bag over a time period of 48 h (Fig. 4.1):

$$\text{Degradability} = a + b\,[1 - e^{(-ct)}] \qquad \text{Equation 4.10}$$

where a = water soluble nitrogen, b = insoluble but potentially degradable nitrogen compounds, which are degraded according to first-order kinetics with the exponential constant e (2.718) and a rate constant c = fractional rate of degradation of nitrogen compounds per hour over time, t.

The potentially degradable nitrogen compounds are transformed into actually degraded nitrogen compounds by estimating the retention time of feeds in the rumen:

$$P = a + \left\{(b \times c)/(c + k)\right\} \qquad \text{Equation 4.11}$$

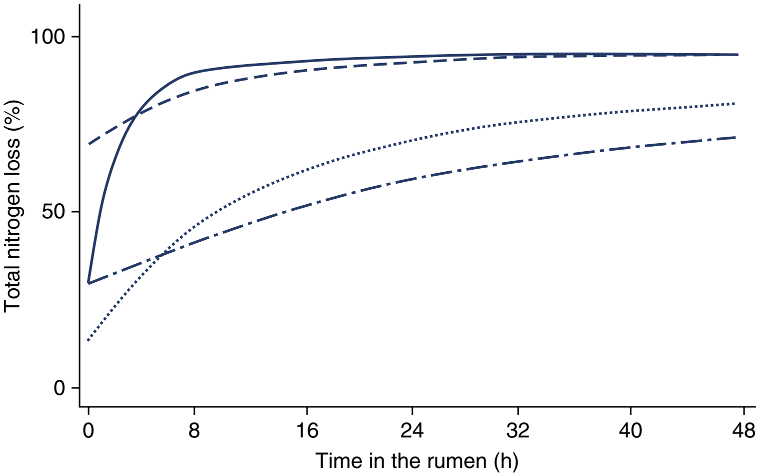

Fig. 4.1. Degradation of nitrogen in different feeds for different periods in the rumen. Key: —— barley; ···· hay; – – – grass silage; — · — · fishmeal.

where P = the effective degradability of a feed at a ruminal outflow rate (k, number per hour) and a, b and c are as defined above. The retention time is largely a function of the level of feeding of the cattle in relation to their size, and the Agricultural and Food Research Council (AFRC, 1992) recommends the use of the following formula in relation to the level of feeding, which is expressed as a multiple of the ME requirement for maintenance:

$$\text{Rate of outflow (number per hour)} = -0.024 + 0.179\,[1 - \mathrm{e}^{(0.278L)}] \qquad \text{Equation 4.12}$$

where e is 2.718 as defined above and L is the level of feeding.

High-yielding cows have high levels of feeding and short retention time, whereas mature beef cattle are likely to have low levels of feeding and longer retention time.

The MP system recognizes that some protein that escapes undegraded from the rumen will not be absorbed at all. This is determined chemically as acid detergent-insoluble nitrogen (ADIN). Feeds with high concentrations of tannins contain ADIN and will have reduced protein digestibility, because of the formation of indigestible tannin–protein complexes in the gastrointestinal tract. Distillery by-products also contain ADIN, which is only partly digestible if it has heated during the distilling process.

An estimate of the total MP supply can be obtained by adding the microbial true protein supply to the supply of protein that is undegraded in the rumen (Fig. 4.2). Alternatively, if the MP supply can be estimated factorially from the N requirements for maintenance and production, endogenous N secretions and urinary N, the requirement for rumen-undegraded protein can be determined by subtracting the microbial protein supply from the MP.

The efficiency of utilization of MP for productive purposes is about 85% if the amino acid balance is optimal. It invariably is not and so values of 60–85% are used for the necessary calculations. However, published experiments have suggested that supplementary protein is utilized much less efficiently than this for the production of milk protein, probably because much of the additional protein is used as an energy source. The utilization of protein as energy and nitrogen sources will need to be incorporated into the MP system, and future research should

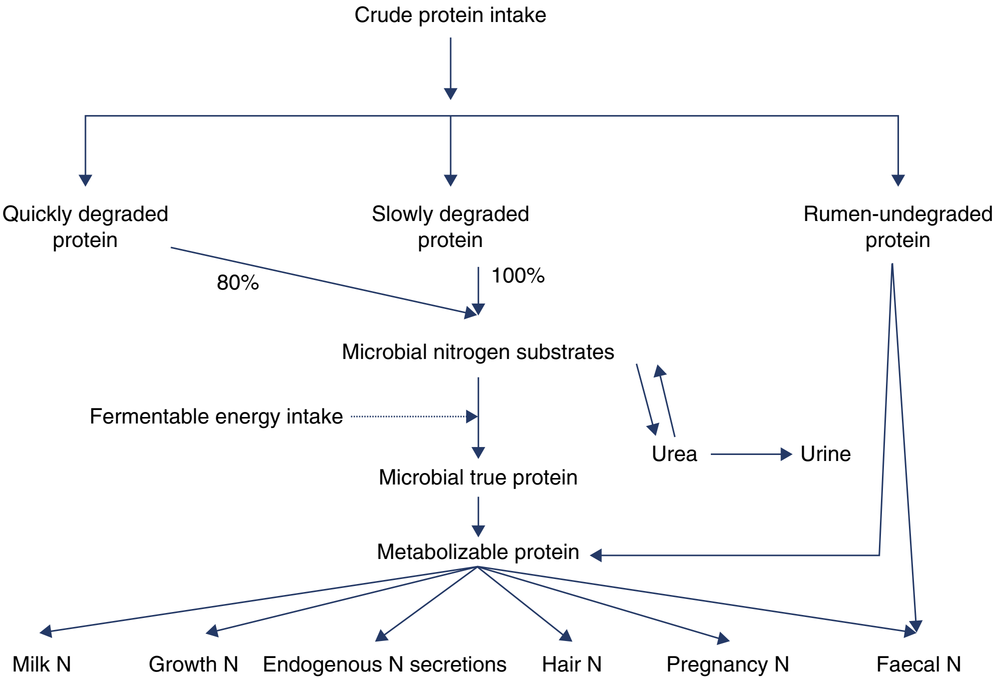

Fig. 4.2. The metabolizable protein (MP) system.

concentrate on modelling the effects of different ratios of lipogenic:glucogenic:proteogenic precursors on the production of milk constituents and body tissue changes in cattle.

Other issues in the MP system that must be satisfactorily resolved are as follows.

1. The increase in feed intake that can occur when protein intake increases. This may also be caused by the use of the additional protein as an energy supply, fuelling increased microbial growth.
2. The energetic cost of converting surplus ammonia to urea in the liver.
3. The optimum amino acid proportions in microbial protein for the different purposes for which it is used.
4. Predicting the rates at which ruminal microorganisms degrade protein from different feeds.

Further refinement of the system should increase its value to the dairy farmer, in particular. Better definition of nitrogen capture by ruminal microbes is already possible and is incorporated into the system devised by Cornell University, USA, described below. In future, it should be possible to predict the MP concentration in a feed by conducting laboratory analyses, in particular the crude protein concentration, the non-protein nitrogen concentration, the solubility of the ingested protein in a buffer solution and the acid detergent-insoluble protein, rather than using *in situ* techniques requiring bags to be inserted into the rumen of animals through a hole in their side, *per fistulam*. The role of peptides also requires further research. Mechanistic models will become available to predict the MP value, which will incorporate a better prediction of passage rate through the rumen than presently used, using rate-limiting factors such as particle size and density and hydration rate to predict the rate of passage of the solid and liquid fractions of the rumen contents separately.

The Cornell Net Carbohydrate and Protein System (CNCPS)

The Cornell Group in Ithaca, New York, has developed a comprehensive system of rationing energy and protein that is widely used as a farm management tool to optimize diet and herd size, predict the emissions in manure that must be managed and improve the annual return over feed cost. The system relies on calculations of requirements based on estimations of carbohydrates and protein fractions consumed by cattle, which allows the different rates of degradation of the fractions to be predicted and incorporated into feeding standards. This is the most widely used system that combines both energy and protein rationing in use today (Tylutki *et al.*, 2008), and it has the advantages of accommodating the use of protein for an energy supply and utilizing common parameters for both nutrients, dry matter intake prediction and body condition changes.

The total carbohydrate content of a feed is divided into neutral detergent-soluble and neutral detergent-insoluble components. The former include fraction A (sugars and organic acids), which is highly degradable, and fraction B1 (starch and pectin), which is of intermediate solubility. Fraction B2 is available in plant cell walls, particularly forages, and is slowly degradable. Fraction C is unavailable in plant cell walls, mainly lignin, which may reduce the availability of some essential minerals, such as iron, by providing organic ligands that sequester the mineral ions and prevent them from being digested.

The total protein content of a feed is divided into three main fractions: A (non-protein nitrogen); B (true protein); and C (unavailable insoluble nitrogen). Fraction A is determined as trichloracetic or tungstic acid-soluble nitrogen and contains nitrate, ammonia, amines and free amino acids, which are instantly degraded in the rumen. Fraction B is subdivided into B1 (globulins and some albumins that are soluble in a buffer and are rapidly degraded in the rumen), B2 (most albumins and glutelins, which are slowly degraded in the rumen at about 10%/h, but are all digested in the small intestine) and B3 (prolamins, extensin proteins and heat-denatured proteins that have not undergone the Maillard reaction, which are degraded slowly in the rumen at 0.1–1.5%/h and are 80% digested in the small intestine). Fraction B3 is determined as soluble in acid detergent but not neutral detergent, and B2 is the difference between buffer-soluble protein (B1) and neutral detergent-insoluble protein. The system is particularly useful to evaluate high-DM silages, where much of the nitrogen is in the A and C fractions and therefore provides little available true protein. The system can also predict the optimum amount of heating to maximize the B3 fraction, which would be of value to high-yielding cows in particular. The B3 fraction can be increased by mild heating but decreased by excessive heating.

Supplies of energy and protein can be predicted to two levels of accuracy: (i) where the user cannot characterize feedstuffs accurately or does not have the necessary ability to use the rumen model confidently; and (ii) where the user has this information and a more accurate estimation is required. In the first case there is a feed composition library with over 800 feeds that can be used to estimate nutrient contents.

Although fatty acids are not an important ingredient of many cattle diets, the individual flows of fatty acids are predicted. This takes into account the intake of individual fatty acids, and uses this information to predict the synthesis of fatty acids by ruminal microbes, the biohydrogenation of mono- and polyunsaturated fatty acids in the rumen, passage of individual fatty acids to the small intestine and intestinal digestion of individual fatty acids that have specified digestibility coefficients.

Nutrient utilization is based on the same fractional principles utilized in the ME/MP systems, but with estimated efficiency of utilization parameters to convert metabolizable components to net components. Rumen passage rate and pH are estimated from feed characteristics, and microbial growth estimations are reduced if feeds are likely to create low rumen pH characteristics. The lactation and pregnancy components are computed in a similar way to the ME/MP systems, but requirements for growth are considerably more complex. An estimation of body composition is made from the proportion of mature weight, which is predicted to be reached separately for beef and dairy breeds at specified body condition scores and ages. Target harvest weights are predicted from fat contents of the carcass equivalent to specified degrees of marbling. MP requirements for mammary gland development are computed separately.

After cattle reach maturity, ME and MP requirements are predicted for changes in body condition score, which are related to body weight. On a 9-point scale, unitary changes in body condition are estimated to result in a change in body weight, fat and protein of 13.5, 7.5 and 1.3 kg/100 kg body weight, respectively. ME and MP requirements can be estimated to reach a specified body condition score in a specified number of days, or ME and MP supply from body condition loss can be calculated. The model for maintenance includes estimates of heat production, utilizing components for tissue insulation and the heat increment of digestion, with modifications for breed that relate to skin thickness.

DM intake equations are utilized from the American National Research Council (NRC) publications on the nutrient requirements of beef cattle and dairy cattle (see ‘Further Reading’). These are based on fat-corrected milk production, body weight change and stage of lactation, and can be modified to allow for reductions in intake at high ambient temperatures.

The CNCPS is a tool for on-farm management of diet, excreta and herd and animal productivity. It is constantly being improved, but with consideration for the processing capacity of on-farm computers. It works well in a US setting and some validation in tropical situations has demonstrated reasonable agreement with observed performance of cattle. The biggest problems in tropical situations are poor characterization of feeds and concurrent mineral and vitamin deficiencies, which are not taken into account in this rationing system.

Mineral and Vitamin Responses

Close relationships between a number of cattle disorders and the supply of certain minerals and vitamins are now well established. Many mineral disorders are locally well known and have usually been given a variety of local names in different regions. They may arise from regional soil deficiencies. Over time, the reduced reliance on home-grown feeds and greater use of purchased feeds, which may have come from areas that are not deficient in the same minerals and are frequently fortified with minerals and vitamins, has reduced the prevalence of locally recognized disorders. In addition, a better understanding of the aetiology of mineral and vitamin disorders has led to effective preventive measures being taken on many farms, particularly through supplementation. However, it is now becoming clear that subclinical deficiencies of many minerals and vitamins can reduce cattle performance and impair the immune responses to disease challenges, as well as potentially affecting their welfare. Such deficiencies are difficult to identify and treat, but the cost of doing so correctly can be small in relation to benefit.

The dairy cow is particularly at risk of mineral deficiencies in early lactation, when her inability to meet the increased output of minerals in milk may limit production and can cause metabolic disease. Supplementary minerals that are absorbed easily and in the correct balance are available and can be most easily added to proprietary compound feeds or total mixed rations, though some care is required to ensure adequate mixing in the latter case. Despite the sensitivity of dairy cows in early lactation, many mineral disorders occur mainly in beef cattle, because they are grazed on poor-quality pasture or rangeland. Indeed, it was often not until mineral deficiencies were recognized and corrected that cattle could be kept in many rangeland areas.

In temperate climates the time of greatest risk to the mineral supply for dairy and beef cattle often occurs in spring, when they are turned out to pasture after winter housing. The rapid growth of grass reduces the concentration of many minerals, and the accelerated passage of herbage through the gastrointestinal tract causes some minerals to bypass the rumen where much of the absorption takes place. Also, in the early grazing season the application of mineral fertilizers on herbage composition has to be carefully considered, as the application of potassium in particular can disturb the balance of other essential minerals in herbage. The minerals that are most likely to be deficient in high-yielding cows are calcium, phosphorus, magnesium and sodium. However, the mineral concentrations in forages vary considerably, depending on where they were grown and what fertilizers were used. Some minerals, e.g. selenium, may be both toxic and deficient to ruminants, depending on the concentrations in feeds, which in turn depend on soil mineral concentrations and availability. The water supply may also contain a significant quantity of minerals and should not be ignored in calculating requirements.

Vitamins tend to function as catalysts or coenzyme factors in metabolism and are required in ultra-trace quantities. Most natural feeds, especially grasses, contain adequate supplies of vitamins, or the precursors that allow the vitamins to be synthesized in the rumen, but storage and preservation of feeds often reduces their vitamin content, making supplementation essential for productive stock.

Major minerals

Calcium

Mammals have elaborate calcium (Ca) homeostatic mechanisms as a result of the need to express this element during lactation. To achieve this they have to accumulate calcium when they are not lactating, principally in bones. During lactation the production of parathyroid hormone (PTH) increases in response to low plasma calcium concentrations. This increases both absorption from the gastrointestinal tract and mobilization from bone. Conversely, when supply exceeds demand the antagonist of PTH, calcitonin, reduces absorption and increases calcium accretion into bone. Vitamin D is also part of the control mechanism, since metabolites of the vitamin that are produced in the liver (25-hydroxyvitamin D, known as 25(OH) vitamin D) also enhance calcium mobilization from bone. PTH also stimulates renal absorption of calcium from the glomerular filtrate. It is only when the deficiency is severe that it promotes the secretion of 1,25$(OH)_2$ vitamin D by the kidney, which increases calcium absorption by increasing the production of calcium-binding proteins. Some hypocalcaemic cows have equivalent concentrations of PTH to normal cows, but their kidneys do not respond to the PTH signals.

Calcium homeostatic problems occur mainly in high-yielding dairy cows on the first day of lactation, with an incidence of hypocalcaemia of 4–10% in dairy cows. The main effects on a cow are that it is unable to walk (parturient paresis or downer cow syndrome) and is susceptible to reproductive disorders, principally dystocia, uterine prolapse, retained placenta, metritis and repeat breeding. There are also reductions in milk production and body weight that are likely in subclinical hypocalcaemia, which is even more common than the clinical form and suppresses feeding and rumination.

At the beginning of lactation, depletion of calcium status occurs suddenly, over about a 10 h period. The large outflow of calcium in milk, together with a depressed appetite around parturition, has the potential to create a calcium imbalance that rapidly leads to paralysis (parturient paresis). Colostrum contains about 2 g Ca/l, and its production at the start of lactation rapidly depletes the body pool of about 12 g of available calcium. In the absence of dietary manipulation of calcium intake, the initial response by the cow to the calcium deficiency is to increase gastrointestinal absorption. It is not until about 10 days later that bone resorption increases (Fig. 4.3).

Parturient hypocalcaemia or paresis, commonly known as milk fever, may ensue if the imbalance cannot be corrected. Intravenous calcium treatment with 8–11 g Ca should be given to hypocalcaemic cows to keep them alive for long enough for them to activate

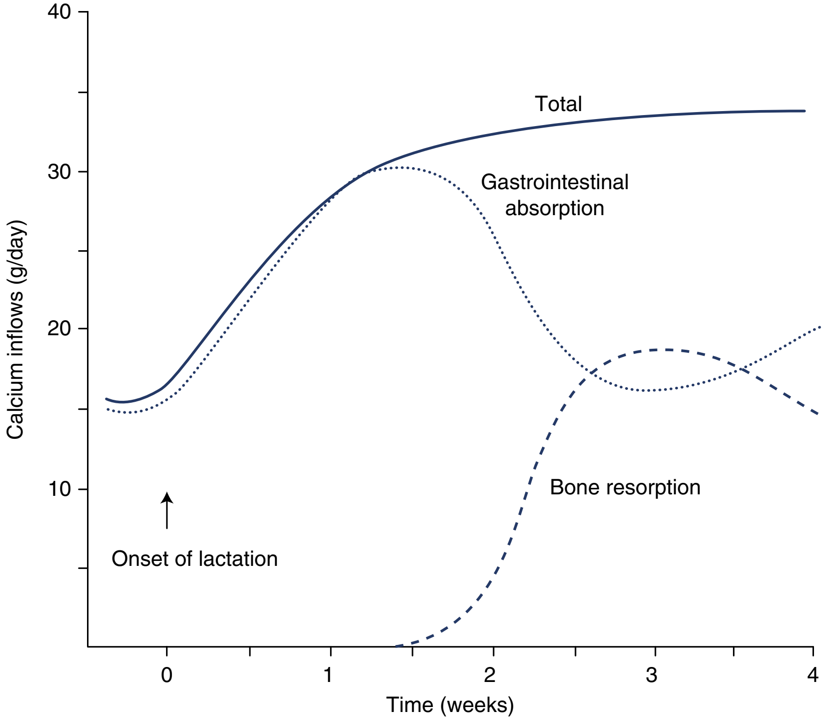

Fig. 4.3. Changes in calcium inflows to the calcium balance in response to the onset of lactation in cows fed a diet with normal calcium content.

their calcium homeostatic mechanisms. The best method of prevention is to encourage cows to begin mobilizing calcium from bone reserves before parturition. If calcium intake can be limited to 50 g/day or less during the latter part of the non-lactating period, PTH production increases and the mobilization of the substantial bone reserves starts before the onset of lactation. This can also be achieved with large doses of vitamin D before calving. During lactation, calcium intake should be about 3 g/kg milk output.

Calcium absorption is determined not just by homeostatic mechanisms but also by the concentrations of other minerals in the gastrointestinal tract. In particular, very high or low concentrations of phosphorus in feed in relation to calcium will restrict its absorption, and a ratio of calcium to phosphorus of 1:1 is optimal for calcium absorption. A high concentration of magnesium also restricts absorption of calcium. An anionic excess in the diet, in particular a high content of chloride or low content of potassium, may be beneficial if it acidifies the blood, since this enhances the 1,25$(OH)_2$ vitamin D response to hypocalcaemia. Sulfur is not very active ionically, so chloride salts are more appropriate in reducing blood pH, but may be unpalatable unless they are mixed into a complete diet. This technique of modifying acid:base balance does not always prevent milk fever, and in several experiments varying the cation:anion balance has failed to alter blood pH, which is normally effectively regulated by homeostatic mechanisms.

Perhaps of greater importance than effects on blood pH are the direct effects of potassium on the absorption of calcium, via the electrochemical transepithelial gradient. It is well established that potassium inhibits the absorption of magnesium by this mechanism, but it also inhibits calcium absorption in the intestine and its resorption in the renal glomeruli. For cattle, the potassium concentration in herbage should ideally be less than 10 g/kg, but this is likely to inhibit plant growth. However, if sodium replaces some of the potassium fertilizer, the sodium can assume some of the functions of potassium in the plant and will reduce potassium concentration to the benefit of any potentially hypocalcaemic cattle consuming the plant.

Hypocalcaemia often occurs concurrently with hypoglycaemia, particularly in cows calving at pasture in autumn, if the herbage has a low DM concentration and limited nutritional value. Feeding forage supplements to cows about to calve will help to reduce the possibility of a calcium imbalance occurring. Hypocalcaemia is also associated with ketosis, displaced abomasum and mastitis (see Chapter 9), diseases that are particularly common in early lactation. Probably the commonality is caused by inadequate nutrition at this time and does not indicate a direct relationship between the diseases. Hypocalcaemia has also been linked to retained placenta, a causal relationship, since low extracellular calcium concentrations reduce uterine muscle tone, as well as that of skeletal and ruminal muscle, producing milk fever and reduced appetite, respectively.

The susceptibility of cows to hypocalcaemia has a genetic component, with a greater incidence in Jersey and Guernsey cows and lesser in Ayrshire. Similarly, Swedish Red-and-White cattle have about double the incidence of the disease compared with Holstein-Friesians. However, heritability values are variable and may be negatively correlated with milk yield, making it difficult to select cows for low susceptibility to hypocalcaemia without reducing milk production.

There is an inverse relationship between a cow's age and blood calcium concentrations, with older cows having a much greater incidence of parturient paresis. Older cows have fewer receptors in both the gastrointestinal tract and bone for 1,25$(OH)_2$ vitamin D and fewer osteoblasts and osteoclasts, leading to a reduced ability to mobilize calcium in early lactation. They also increase rapidly to peak lactation, thereby increasing the drain on calcium reserves.

The rapid demand for calcium at the start of lactation therefore places the high-yielding cow perilously close to metabolic breakdown. Greater attention must be given in future to this early lactation period, selecting cows with a gradual build-up to peak lactation, followed by a long lactation, including as long a period as possible of steady-state production where nutrient demands are met by feed intake. Failure to address the early lactation problem will lead to increased incidence of hypocalcaemia, with adverse effects on the welfare of the cow (see also pages 84–85).

Magnesium

Magnesium (Mg) is not regulated homeostatically to the same extent as calcium, a clear indication that, over the period of evolution of mammalian mineral metabolism, magnesium deficiency was not such a serious problem. It is, however, a mineral that can easily be deficient in lactating cows grazing intensively managed pastures. Some magnesium can be mobilized from bone tissue during a deficiency, but this is unlike calcium in that it is not under the direct control of vitamin D. However, during hypomagnesaemia a lactating cow will considerably reduce milk magnesium content, in just the same way that a cow with milk fever reduces milk calcium content. The acute form of the disorder produces initial signs of increased nervousness, with staring eyes and ears pricked. Muscles twitch and spasmodically contract in tetany, and the cow may stagger in an uncoordinated fashion. Cows may then become recumbent, paddling their legs and grinding their teeth, after which a coma usually sets in and then death ensues (Blowey, 2016). A chronic form of hypomagnesaemia also exists, with a gradual loss of condition and a stiff gait. The annual incidence of hypomagnesaemic tetany in dairy cows varies from 3% to 10% in developed countries.

Potassium fertilizer application early in the grazing season is a major contributing factor. Young grass has a low level of available magnesium, and high potassium concentrations reduce its uptake by the animal. The rumen is the main site of absorption and a rapid efflux of K^+ ions into the bloodstream creates a significant electrochemical potential difference across the ruminal epithelial wall, with the ruminal contents becoming negative relative to the bloodstream. This hinders the absorption of divalent cations, such as Mg^{++}. It can be countered by increasing the sodium content of the ruminal contents, which inhibits the absorption of potassium by the animal (and has the same effect in controlling potassium absorption at the soil–root interface of plants if applied as a fertilizer).

Increasing the plant's sodium concentration can be most easily achieved by reducing the application of potassium fertilizer and replacing it with sodium, as common salt or sodium nitrate. Some metabolic processes in the plant specifically require potassium, but about one-half of the total potassium used by the plant can be replaced by sodium without loss of plant yield. Sodium fertilizer has additional benefits in dry weather, as it increases plant turgor by an osmotic effect in the extracellular compartments of the plant. Nitrogen fertilizer is another risk factor for hypomagnesaemia, since a surplus of ammonium ions alkalinizes the rumen contents, which reduces the dissociation of magnesium ions and hence magnesium availability.

Blood serum magnesium concentrations above 18–20 mg/l of blood serum result in excess magnesium being excreted in the urine. Since magnesium absorption is not actively controlled in the rumen, this is the threshold below which hypomagnesaemia is likely to occur. Magnesium availability from feed is particularly variable, ranging from 15% to 60%. In young leafy grass the lower value is more appropriate, but some magnesium supplements (oxides, carbonates and sulfides) are absorbed to a much greater degree (50–60%). Such supplements can be included in the diet of cows grazing spring grass or they can be spread directly on the pasture. This is time consuming, and the regular tractor passage needed to spread the supplement is undesirable as it can damage the soil structure. Also, if alternative pasture is available, cattle will normally avoid the treated pasture. A soluble form of magnesium can be added to the drinking water in troughs but care should be taken if cows are also using streams or other alternative drinking water sources. Also, during wet weather, which is a common risk factor for hypomagnesaemia because of low intakes of grass, the animal's water intake from troughs is reduced because they are consuming more water in and on herbage.

The classical conditions for hypomagnesaemia are therefore cold, wet weather when cows are grazing young, leafy pasture. Much depends on the natural content of magnesium in the pasture and on many farms cows never experience hypomagnesaemia problems. Ensuring a high soil pH helps to increase herbage magnesium content. The most sensitive indicator of hypomagnesaemia risk is the K:(Ca + Mg) ratio in herbage, which should be less than 2.2.

Magnesium-enriched concentrate feeds can be fed to cattle grazing young pasture, but this is an expensive way of controlling the disease if it is the sole reason for feeding the supplement. Concentrate eaten will directly replace herbage, rather than acting as a supplement, resulting in no nutritional benefit to feeding concentrate other than increased magnesium intake. In addition, many dairy farmers now rely entirely on total mixed rations, rather than parlour feeding, making it difficult to feed small quantities of concentrate supplements to grazing cows. Magnesium bullets are probably the safest option in a high-risk area, even though they can occasionally be expelled from the rumen during the reverse peristalsis of rumination. The bullets dissolve over a 2-month period, which should be sufficient to provide cover during the period after turnout. Cows grazing tropical pastures rarely develop hypomagnesaemia, because milk yields are constrained by low digestibility of the grasses.

The treatment of clinical cases is by administration of magnesium solution either subcutaneously, or in emergencies by slow intravenous injection, followed by sedatives to keep the animal calm and support to prevent muscle damage. Later, the animal should be given 70 g calcined magnesite orally. The sudden onset of the disorder means that the mortality risk is high.

Magnesium requirements can be estimated factorially in a similar manner to energy. For a typical cow, requirements are 18 mg Mg/kg live weight/day for maintenance (principally endogenous losses), 2.7 g Mg/kg live weight gain, 0.74 g Mg/l of milk and 3 g Mg/day for the last 8 weeks of pregnancy. For a typical cow giving 30 l milk/day, the total magnesium requirement would be approximately 28 g/day. Since herbage often contains as little as 1 g Mg/kg DM and a cow may only eat 13 kg DM/day in inclement weather, the potential for deficits to occur is clear.

Sodium and potassium

The close relationship between sodium (Na) and potassium (K) makes it impossible to consider them in isolation. Many cattle, particularly high-yielding dairy cows, do not receive enough sodium from their forage diet to compensate for the losses from the body. These are principally in urine, sweat and, in lactating cows, milk. By contrast, potassium deficiencies do not occur in cattle that are fed a reasonable amount of forage. Forages have a major requirement for potassium in order to maximize growth, but only rarely do they have a specific requirement for sodium. However, cattle have a major need for sodium and will selectively graze areas of pasture that have been dressed with sodium compared with those that have not. It is usual to include sodium compounds in the diet, e.g. common salt. Sometimes it is included in a blended mixture of fertilizers, and cattle grazing sodium-enriched herbage will have an increased intake. The low cost of sodium chloride and, where available, sodium nitrate makes them suitable for this purpose.

Clinical sodium deficiencies occur at pasture concentrations of 1 g Na/kg DM or below and are typified by depressed appetite, pica, low growth rates and milk yields and, in extreme cases, by collapse and possibly death. Many tropical forages contain less than 1 g Na/kg DM. Requirements will be increased if the cattle are in an environment where they sweat more.

The sodium content of pasture is variable and dependent on the soil type, the herbage species and the amount of potassium added. It will usually be highest

Box 4.2. A magnesium balance exercise.

Dairy heifers of 490 kg mean live weight and mean milk production of 30 l/day are grazing pasture with a mean Mg concentration of 2 g/kg DM. It is expected that they are consuming approximately 15 kg herbage DM/day each, with no supplements, and that they will gain weight at 0.6 kg/day. Calculate their Mg balance and decide whether supplementation is required. If so, consider how this might best be achieved.

The solution:

Magnesium intake is 30 g/day (15 kg DM × 2 g/kg DM). Total requirements are 32.6 g/day (for endogenous losses 8.8 g/day, for growth 1.6 g/day and for milk production 22.2 g/day). Intake therefore needs to be supplemented by approximately 3 g/day, which can be achieved by adding magnesium to a feed supplement or water, or through calcined magnesite spread on the pasture. Magnesium bioavailability can be increased by reducing the potassium or increasing the sodium contents of herbage.

in pastures near the sea. The average content in temperate grasses is about 2 g/kg DM, but the optimum for dairy cows is about 5 g/kg DM (Phillips *et al.*, 2000a). This level of sodium in the sward can be achieved by the annual application of about 50 kg Na/ha as a fertilizer, depending on conditions. The grass sodium:potassium ratio is the best guide to the quantity of sodium to apply. The sodium content of the grass is unlikely to be increased above 5–7 g/kg DM even if large quantities of sodium are applied. However, in saline regions or in pasture close to the sea, herbage sodium may exceed 7 g/kg DM and the digestibility of this grass will be reduced.

In addition to preferring sodium-fertilized pastures, cows graze for longer on them and bite the pasture more rapidly, increasing their intake and milk production (Table 4.3). They ruminate longer and this, coupled with a decrease in ruminal acidity caused by recycled sodium in the saliva acting as a pH buffer, increases herbage digestibility and promotes the growth of acetogenic (fibre-digesting) bacteria in the rumen. The decrease in ruminal acidity is particularly beneficial for cows grazing lush pasture with no forage supplements, when it may be reduced to below pH 6. Under such conditions milk fat content typically increases from 37 g/l to 40 g/l.

It was first suggested that low sodium intakes were responsible for a high level of hypomagnesaemia in cows over 50 years ago (Paterson and Crichton, 1964). Potassium fertilizer can restrict the uptake of both magnesium and calcium by herbage plants. Sodium fertilizer reduces potassium uptake by plants and thereby increases their magnesium and calcium absorption. Potassium is the more efficient of the two monovalent cations in activating some plant enzymes, but its adverse effects on the absorption of other minerals in cattle make it advisable to limit its use, particularly when lush pasture is available. Less potassium and more sodium in the rumen therefore increases the animal's absorption of magnesium and calcium, which means that hypomagnesaemia and hypocalcaemia (grass staggers and milk fever, respectively) are less likely to occur.

Table 4.3. Using sodium fertilizer to improve pasture composition for grazing dairy cows in temperate conditions.

	No sodium fertilizer	Sodium fertilizer
Grass sodium (g/kg DM)	2.9	4.9
Grass magnesium (g/kg DM)	1.8	2.0
Grass calcium (g/kg DM)	4.5	4.9
Milk yield (l/day)	18	20
Butterfat (g/kg)	37	40
Cow weight change (kg/day)	0	+0.3
Grazing time (h/day)	8.7	9.6

Sodium also helps the plant to make best use of available sulfur, another element that potentially limits grass growth. Farmers should not rely on applying only nitrogen, phosphorus and potassium to their cattle pastures, but should apply a balanced cocktail of minerals to feed the grass plant. It is essential to consider the effects of fertilizers on the composition of herbage when planning a fertilizer regime. The grass plant must be balanced for minerals, especially sodium, magnesium and calcium. It is often easier and always safer to ensure that grass eaten by the cattle has the right composition, rather than trying to correct deficiencies by adding minerals to the concentrate part of the diet. However, it may be wasteful to apply minerals to pasture in high rainfall, as much is lost by leaching. In rangeland conditions, fertilizer application is often not feasible and salt licks are widely used to ensure adequate sodium intake. It is assumed that the cattle will consume to their requirements and no more. It is not easy to determine whether this is achieved, but the wide variation in attendance at salt licks suggests that other factors, such as social pressure, affect the intake of sodium in these circumstances.

Sodium supplements are also beneficial for young milk-fed calves, where the stress of confinement may impair kidney function and increase sodium requirements. Much of the licking and other oral stereotyped behaviours seen in individually housed calves may be caused by sodium or other mineral deficiencies. Sodium supplements provided to a young calf will condition a greater sodium appetite when it is older.

The sodium intake of cattle is closely related to their water intake, as water is required to maintain osmotic balance. When sodium supplements are included in a complete diet or the sodium content of forage is increased, as occurs when either sodium fertilizers are used or forages are upgraded or preserved with sodium-containing chemicals, such as NaOH, adequate water must be available to the animals. The increased urination by cattle fed conserved feed treated with sodium may cause difficulties in maintaining a clean environment for the cattle.

Phosphorus

Phosphorus (P) is required by cattle for their bone matrix, for energy transfer in adenosine triphosphate (ATP) and adenosine diphosphate (ADP), for nucleic acids and for phospholipid membranes. The absorption is mainly in the small intestine and is actively controlled by vitamin D. In areas where cattle are housed for long periods of the year, their low vitamin D status will increase phosphorus requirements, unless supplementary vitamin D is fed. Absorption declines markedly with age, from nearly 100% in the suckled calf to 43% for cattle over 1 year of age. There is some evidence that a very high calcium:phosphorus ratio (> 10:1) in the feed reduces phosphorus availability. The optimum ratio of calcium to phosphorus to maximize phosphorus absorption is probably between 1:1 and 2:1, since this is the ratio in bones. In many feeds, and especially plant seeds, most of the phosphorus is in the form of phytate, which is readily available (about 70%) to cattle, because ruminal microorganisms have the ability to hydrolyse the phytate phosphorus with the enzyme phytase.

Most low-quality feeds given to beef or dry dairy cows contain little phosphorus, since this declines as the plant matures. Problems are, therefore, most likely to occur in cattle on rangelands where the soil

Box 4.3. A sodium mineral balance exercise.

Early-lactation dairy cows with a mean weight of 650 kg and giving 40 l milk/day are grazing pasture with a mean sodium concentration of 2 g/kg DM. They are expected to consume about 14 kg DM/day. Calculate their sodium balance and discuss whether supplementation is required and how this would be best achieved.

The solution:

The cows’ sodium intake is 28 g/day (14 kg DM at 2 g/kg DM) per cow. Their requirement is 5.2 g/day for maintenance and 25.6 g/day for milk production, a total of 30.8 g/day, which is not met by their intake. Supplementary sodium can be offered as a salt lick in the field or by using sodium fertilizer to increase the sodium concentration in herbage. The latter option may have other benefits, described above. It is important to consider whether some additional sodium might be present in the water drunk by the cattle, and whether ambient temperatures might cause the cows to lose extra sodium through sweating. If magnesium or calcium deficiencies are common, it is essential to consider the balance of magnesium, calcium, potassium and sodium in the cows’ feed, ensuring that the ruminal environment is conducive to adequate absorption of the important elements.

phosphorus status is low and when the forage is mature. Australian rangeland cattle often exhibit signs of phosphorus deficiency. As there is no homeostatic mechanism for regulating blood phosphorus, this is determined by phosphorus in feed and that mobilized from bones. Because Australian rangeland pastures are not calcium deficient, cattle do not mobilize bone mineral and so develop low blood phosphorus levels.

Most excess phosphorus is excreted in faeces and environmental concerns now dictate that farms implement more effective phosphorus rationing, especially for dairy cows (Tayyab and McLean, 2015). Phosphorus losses can be reduced by feeding a diet with a reduced phosphorus concentration when milk yields decline in mid- to late lactation. Some farmers feed a diet with a higher concentration of phosphorus in early lactation, as this increases feed intakes. However, there is little scientific evidence of any direct benefit of supplementary phosphorus to milk production or reproduction in early lactation, except in the situation where low phosphorus contents of the feed greatly reduce intake and the cows become thin.

Phosphorus deficiency is manifested as a stiff gait, bone abnormalities and non-specific conditions such as reduced production (growth rate or milk production), low feed intakes and a depraved appetite, or pica. The latter is not peculiar to phosphorus, but causes animals to search for abnormal feed sources, such as bones or soil, which may restore the mineral deficit. Bone chewing in areas where putrefied carcasses are contaminated with the bacterium *Clostridium botulinum* can cause botulism (Fig. 4.4), and vaccination against this disease is routine in areas where soil phosphorus content is low. Blood plasma inorganic phosphorus content can be used to predict whether cattle have an adequate phosphorus supply and should be in excess of 4–6 mg/dl.

Requirements are difficult to estimate, because absorption is highly variable. If it is assumed to be 60%, most rationing systems suggest that a dairy cow will require about 24 g/day for maintenance and 1.5 g/l for

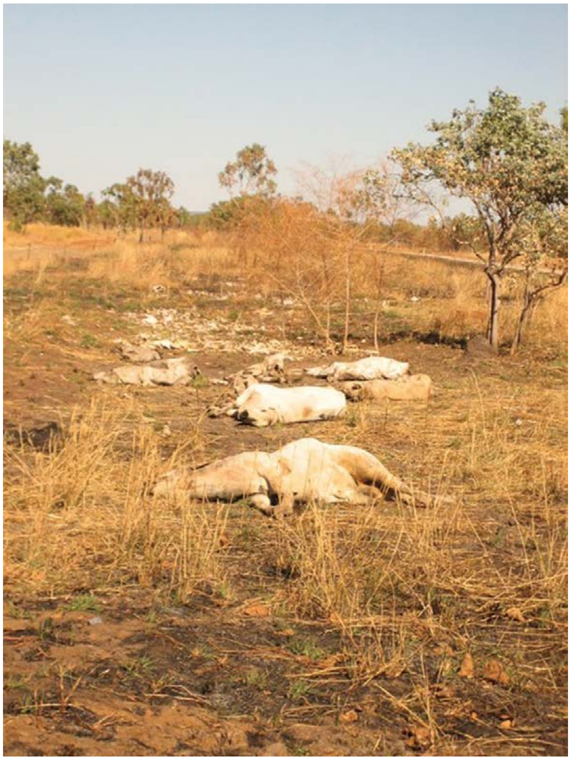

Fig. 4.4. Dead cattle should be removed from the paddocks to prevent botulism. They should be buried, not left to rot at the side of the road.

milk production, or a phosphorus content in the ration of about 0.5% for a high-yielding cow. Growing cattle are likely to require a phosphorus concentration in the ration of about one-half of this value. If phosphorus intakes are inadequate, supplements can be mixed with salt and molasses and provided as field blocks, though cattle are not able to regulate their intake very accurately in relation to requirements. This is the usual supplementation method for range cattle. In more intensive grazing, the phosphorus contents of herbage can be increased by phosphorus fertilizer quite effectively. Some phosphorus supplements, such as dicalcium phosphate or superphosphate, are well absorbed, but rock phosphate is not well absorbed, is unpalatable and, like superphosphate, may contain a high fluoride content.

Sulfur

Sulfur (S) is required mainly for sulfur-containing amino acids and, as a result, requirements are often stated in relation to protein, or rumen-degradable protein, requirements. The ratio of S:N in microbes, milk and tissue is approximately 0.07:1.0, which should therefore be the basis for sulfur requirements. Sulfur is a particularly important element for cattle because the difference between deficiency and toxicity is small.

For most of the 20th century, the sulfur intake of grazing cattle in industrialized countries was increased by the sulfur deposits from emissions to the atmosphere by power stations and other heavy industry, and by the use of low-grade fertilizers, which have high sulfur content. More recently, emissions have decreased and low sulfur availability in the soil can limit grass growth, especially with the termination of application of the slag from industrial processes to pasture. Sulfur fertilizers acidify the upper horizons of the soil and have been used to counteract salinity. Grass crops that are heavily fertilized with nitrogen also need sulfur fertilizer, otherwise they will have a reduced content of true protein and more non-protein nitrogen.

However, although the grass crop increases its growth rate in response to sulfur fertilizer, the sulfur concentration may exceed the toxic threshold for cattle (approximately 2 g S/kg DM) with heavy sulfur applications. Acetic acid production in the rumen is reduced and low milk fat production has been observed in dairy cows. Also, excessive sulfur application to pasture reduces the herbage content of several trace elements, such as copper, molybdenum and boron. In high-molybdenum areas the reduction in copper content with sulfur may be outweighed by the increase in availability to the animal caused by reducing the molybdenum content of pasture. Sulfur toxicity can also occur if high-sulfate molasses or distillers' solubles are fed, if sulfur is added to the feed to control urinary calculi or if large amounts of sulfur-containing amino acids, such as methionine, are added to the diet. There have also been instances of toxicity when ammonium sulfate was added to the diet as a nitrogen supplement, causing liver damage, cerebral necrosis and mortality.

For cattle fed large quantities of non-protein nitrogen, sulfur deficiencies are likely unless supplements are fed. The critical level in feeds is approximately 1 g S/kg DM. Supplements of elemental sulfur are not as well utilized by the ruminal microorganisms as compounds such as sodium sulfate.

Trace elements

Many elements are required only in very small quantities, or traces, but despite this a deficiency in the element can both be regionally common and have serious consequences for the animal. Toxicities are rare in cattle and are considered in Chapter 11. As more research is conducted on the elemental needs of cattle, the essentiality of an increasing number of elements can be proved for cattle, though for many elements this is of little practical importance since they are present in cattle feeds in concentrations well in excess of requirements. Many of the trace elements are ingested as cations bound to phytate in the feed, which are available because ruminal microorganisms produce the enzyme phytase to digest the phytate part of the complex, releasing the element for absorption.

Copper

Copper (Cu) is a component of many metallo-enzymes (especially cytochrome oxidase for energy metabolism, caeruloplasmin for iron transport in blood, superoxidase dismutase to destroy superoxide radicals that cause cellular damage and tyrosine for melanin production). It is also an important antioxidant and is particularly used in the production of blood. It is stored mainly in the liver, which can extract excess copper from caeruloplasmin.

Several minerals will inhibit the absorption of copper by competitive inhibition. These include molybdenum, sulfur, iron, zinc, cadmium and possibly calcium. The complexity of the interrelationships between these elements makes it difficult to predict the proportion of the element that is absorbed, but copper availability from solid feeds is often very low. Furthermore, endogenous copper secretions into the gastrointestinal tract, which are mainly in bile and pancreatic juices, are hard to quantify, rendering the true availability of ingested copper hard to determine. Often, endogenous secretions are ignored and the availability is termed 'apparent'.

Acute copper deficiencies occur in areas with high molybdenum contents in soil and pasture. Copper, molybdenum and sulfur combine in the rumen to form copper thiomolybdate, a complex that cannot be absorbed. Excess iron consumption, in supplements, directly from soil or in conserved forages that are contaminated with soil, will exacerbate the problem.

The main symptoms of copper deficiency, or hypocupraemia, are scouring, anaemia (because of reduced iron absorption) and weak bone formation. Ataxia, or a staggering gait, occurs in calves (commonly known as swayback) and in adult cattle (known as falling disease). Copper deficiency can also be recognized by its effects on hair coloration, particularly around the eyes where the loss of pigmentation causes dark-coated animals to have a bespectacled appearance. The coat also loses its sheen and the copper content of the hair can be used to indicate an animal's copper status, but not as reliably as from blood copper or superoxide dismutase. Diagnosis of deficiency can also be from the blood copper content, which should not be less than 80–100 µg/100 ml for whole blood or 60 µg/100 ml for blood plasma.

Copper deficiencies can cause a reduced growth rate in cattle in susceptible areas. High sulfur content in drinking water reduces copper availability. Although sulfur fertilizers could potentially increase copper deficiency through the formation of copper thiomolybdate in the rumen, this is probably counteracted by a reduced herbage molybdenum content. High molybdenum contents are common in so-called 'teart' pastures (teart is a scouring disease in cattle), such as in south-west England.

Herbage copper content of 5–8 mg/kg DM should be sufficient if there are no complications of high molybdenum content. The maturity of herbage will affect cattle's absorption of copper, being approximately 1% in lush autumn herbage but 7% in hay. In autumn, the quantity of herbage available is often low and soil will be consumed as cattle graze close to the soil surface, with adverse effects on copper absorption because of the iron consumed in the soil. Copper compounds should be added to mineral supplements in areas where cattle have been reported to suffer from hypocupraemia, to increase the dietary copper content to approximately 10 mg/kg DM. Alternatively, copper can be provided in slow-release boluses or needles, which are placed in the rumen, from where some copper will be absorbed, with the majority being absorbed in the small intestine.

The symptoms of copper toxicity are nausea, vomiting, abdominal pain, convulsions, paralysis, collapse and death. It can be treated by administering molybdenum and sulfate, usually as a drench of ammonium molybdenate and sodium sulfate. Copper toxicity is rare in adult cattle, because of the low absorption rate. They will tolerate herbage containing up to 100 mg Cu/kg DM, but can be poisoned by eating soil that has been contaminated with copper, or sometimes by consuming diets in which there has been an error in mineral formulation. If the diet has a particularly low molybdenum concentration, feeds with normal copper content can induce copper toxicity. Copper toxicity can occur in calves, as absorption is much greater at this age (up to 60–80% in the first few weeks of life). As the animal grows the absorption rate decreases rapidly, particularly when it develops a functional rumen. The high susceptibility of sheep to copper toxicity has resulted in maximum copper inclusion rates in ruminant feeds used in the EU of approximately 35 mg/kg.

Iron

Iron (Fe) is required for the formation of haemoglobin, the body's major oxygen carrier, and for oxidizing catalysts. It is also present in blood as ferritin and transferrin and in muscles as myoglobin. Milk has a low concentration of iron, compared with other minerals, but iron deficiencies in suckling calves are rare, because they have an iron store (of about 450 mg) in the liver at birth. Lactoferrin binds iron and controls its release in milk. By limiting iron availability for bacterial growth, it protects milk residues in non-lactating mammary glands and helps to prevent mastitis.

Iron deficiency only occurs in milk-fed calves and may be deliberately induced to produce pale meat, which some consumers associate with tenderness. Iron-deficient calves are anaemic and have reduced appetites, slow growth and limited ability to cope with exercise. Iron is involved in the formation of immunoglobulins, so that iron-deficiency anaemia is associated with reduced immunocompetence. Iron is very effectively recycled within the body and there is little urinary excretion.

Absorption is enhanced when cattle are iron deficient, but a milk-fed calf can still develop anaemia within 8–12 weeks unless iron supplements are provided. Some veal calf producers aim to create low muscle myoglobin content without adversely affecting appetite or growth rate. This requires approximately 25–50 mg Fe/kg of dietary DM, though iron availability is subject to the same uncertainties as copper. However, milk contains only 5 mg Fe/l and the stores provided to the calf at birth are therefore vital. Calves that suckle their dams at pasture invariably start consuming a few leaves of grass before anaemia is established and therefore are not at risk. The iron content of leaves is much greater than that of seeds or milk and iron deficiency does not occur in cattle fed forage-based diets. Indeed, an iron supplement should not be added to the diet of adult cattle at risk of hypocupraemia, because it will inhibit the absorption of copper.

The iron status of calves can be assessed from the haemoglobin content of blood. The critical level is 4.5 mmol/l, below which the muscle myoglobin content will be reduced, but not growth or the animal's ability to exercise. Legally, in the EU all calves must be fed sufficient iron to maintain this blood haemoglobin level; if it is less, a supplement of 25–50 mg Fe/l milk should be provided. Solid feed, required for calves by EU legislation, will also help to prevent low blood haemoglobin levels. In the long term, consumers should be made aware that red veal is just as good quality as white veal and will indicate that the calves have not suffered hypoferraemia.

Cobalt

Cobalt (Co) is utilized in the rumen and is an essential constituent of vitamin B_{12} and its analogues. Deficiencies are common where soils have low cobalt concentrations and are known by a variety of local terms, such as 'pine'. Excessive liming is a risk factor in reducing cobalt availability to plants. The symptoms of the early stages of the disease are a depressed appetite and slow growth, followed by muscular wasting, pica and severe anaemia. Pasture should contain at least 0.1 mg Co/kg DM. Cattle deficiencies can be most accurately diagnosed from liver cobalt or vitamin B_{12} content. The liver stores surplus cobalt in the form of vitamin B_{12} and the mean cobalt concentration should not be less than 0.06 mg/kg DM. A specific instance of cobalt deficiency has been observed in cattle in Australia and New Zealand grazing pasture containing the perennial grass *Phalaris tuberosa*. The plant contains a neurotoxin, *N*,*N*-dimethyltryptamine, which is inactivated by ruminal microorganisms in the presence of adequate cobalt. If there is inadequate cobalt in the rumen, cattle develop an ataxia condition known as 'Phalaris staggers'. The earliest occurrences of Co deficiency in both countries were in regions where soil Co is very low, e.g. in the coastal areas of Victoria, South Australia and Western Australia.

Deficiencies can be rectified by using cobalt-containing fertilizers in susceptible areas. If soils are alkaline, the uptake by the plant is low and direct supplementation of the cattle is necessary, by including cobalt in salt licks, slow-release boluses or even by regular drenching.

Selenium

Selenium (Se) is an important component in the cell enzyme glutathione peroxidase, which controls peroxides in the cytosol that react with unsaturated lipids to cause cell damage. The same control in membranes can also be achieved by vitamin E (tocopherol), which directly inhibits the auto-oxidation of polyunsaturated fatty acids by oxygen metabolites, hence the same symptoms are exhibited for selenium and vitamin E deficiencies.

Selenium deficiency causes nutritional muscular dystrophy, known as white muscle disease in calves. In extreme cases the heart muscle degenerates and myoglobin is released to give the urine a red coloration. Deficiency is widespread where soil selenium concentrations are low, producing feeds with selenium concentrations of less than 0.05 mg/kg DM. Such low concentrations are common, with approximately two-thirds of dairy cows in the USA and Europe being kept in areas where the soils are selenium deficient.

Supplementation is normally provided in mineral mixes in the form of sodium selenite, increasing the selenium content of the diet up to 0.1 mg/kg DM. For cattle that do not regularly receive mineral supplements added to concentrate feeds, such as those on rangeland, selenium can be added to salt licks or given by injection. The benefits of selenium and vitamin E supplementation are not additive, as both achieve the same detoxifying effect, albeit in different parts of cells. However, supplementation with one will have a sparing effect on the physiological requirement for the other. Care must be taken when providing supplementary selenium for cattle, as toxicity can also occur. There are many areas where selenium concentrations in plants, particularly accumulator plants, are in excess of 5 mg

Se/kg DM, which is the threshold for toxic symptoms in cattle. Toxicity will depend largely on the extent to which cattle consume the accumulating plants, which may in turn depend on the availability of other herbage.

Selenium is also important in the immune system, as the respiratory burst by phagocytes during an infection increases oxygen metabolism, resulting in proliferation of hydrogen peroxide and superoxide. These free radicals cause cell damage and limit the bactericidal effectiveness of the neutrophil burst. Supplementation with selenium can therefore help to control mastitis in dairy cows. Current evidence suggests that it is beneficial to increase selenium intake in early-lactation cows to 4 mg/day, which provides about twice as much selenium as the dietary concentration recommended to avoid muscular dystrophy (0.1 mg/kg DM). Herd selenium status can be monitored from blood samples and is adequate when the concentration is between 0.2 and 1.0 μg/ml.

Zinc

Zinc is one of the commonest metals in enzyme complexes, most notably those involved in DNA and RNA synthesis and protein metabolism. Deficiencies are confined mainly to areas with zinc-deficient soils. A variety of symptoms are observed, but impairment of growth and reproduction are the most common. Slow growth is associated with reduced appetite and impaired protein metabolism. Disorders of the integument are also regularly observed, such as parakeratosis in calves, and hoof disorders, such as pododermatitis, in adult cattle. The involvement of zinc in protein metabolism is important for keratin deposition in hooves and in teat canals, where it is a primary barrier to mammary infections. Zinc deficiencies reduce the incorporation of several amino acids into skin proteins. Zinc concentrations are normally high in body hair and the gonads and it is here that zinc concentrations decline most rapidly during a deficiency. The essentiality of zinc for DNA and RNA synthesis leads to impairment of T-lymphocyte proliferation during infection in zinc-deficient cattle, but other components of the immune response are not seriously affected. Inverse relationships between zinc status and somatic cells in milk have been observed but the exact cause is not yet known.

Zinc is stored in a number of tissues, notably the liver and bones. In the liver, it is complexed by metallothioneins that function both to store surpluses and to absorb toxic quantities should they be consumed. A deficiency is best detected by analysing blood plasma concentrations, since a large and rather immutable quantity of the body's zinc is contained in the erythrocytes. The critical concentration of plasma zinc is 0.4–0.6 mg/l, below which deficiency is likely. Requirements are difficult to state precisely, mainly because of the extensive interactions with other elements, in particular copper, calcium and cadmium. However, 30–40 mg Zn/kg of feed DM is generally recommended for most classes of cattle, unless the feed contains a high copper level, in which case requirements will be greater. Zinc toxicity is very rare in cattle (up to 1 g/kg DM can be tolerated), and hence it is quite safe to offer generous supplementation in deficient areas. This can be provided by adding zinc compounds to salt licks, or by zinc fertilizer (which may be required for plant growth anyway), or by direct addition to a complete diet.

Chromium

Chromium is a micronutrient that is commonly deficient in mammals and it is essential for normal carbohydrate and lipid metabolism. The major physiological role of chromium is to potentiate the action of insulin. In calves, the stress associated with long-distance transport and passage through markets often causes bovine respiratory disease or shipping fever. This can be partially alleviated by the administration of chromium supplements. Cattle are predisposed to the disease because of the immunosuppressant effects of the stress. As the cortisol output of the adrenal gland increases with stress, especially when associated with exercise, urinary losses of chromium increase. This is associated with the classical chromium deficiency symptom of elevated blood glucose, which liberates chromium from body stores, thereby increasing urinary losses. Supplemental chromium can enhance the humoral immune response and reduce the cortisol output and rectal temperature of market transit-stressed calves. Administration of chromium to cattle before other stressful events can reduce the cortisol response and increase lymphocyte production (Pechova *et al.*, 2002). Regular exposure to stress reduces chromium losses and increases chromium absorption in the gut at the time of each event, providing evidence that chromium status is homeostatically controlled.

Vitamins

Vitamin A

Vitamin A is required for the formation of epithelial and bone tissue and, in particular, for the formation of retinol, an important component of scotopic vision.

The daily requirements for vitamin A by growing cattle are about 66 International Units (IU)/kg live weight, and for lactating cows about 40,000 IU for maintenance and 4000 IU/l for production. Caretonoids, the precursors of vitamin A, exist in plant material but they are unstable, and preservation and drying of forages can greatly reduce the carotenoid concentrations. Although the conversion rate of the most common form, β-carotene, depends on many factors, to determine the supply from feed it can be assumed that calves and growing cattle produce 1 μg (3.3 IU) of vitamin A for each 6 μg of β-carotene. For lactating cows, the conversion is less efficient, being only 1 μg (3.3 IU) vitamin A per 32 μg β-carotene. Thus, a lactating cow consuming 15 kg herbage DM with a concentration of 100 mg β-carotene/kg of DM will produce 150,000 IU of vitamin A, well in excess of requirements. However, carotene concentrations are usually much lower in conserved feeds: typically, straw contains just 5 mg β-carotene/kg of feed DM, hay 10–20 mg β-carotene/kg of feed DM, grass silage 120 mg β-carotene/kg of feed DM and maize silage 11 mg β-carotene/kg of feed DM.

A deficiency of vitamin A reduces the production of some reproductive hormones, and rebreeding dairy cows may be difficult. Milk yield may also be reduced. Vitamin A can be stored in the liver and released over a period of several months, if needed. Supplementation of dairy cows with 200–300 mg β-carotene/day is recommended if plasma β-carotene concentrations are below approximately 2500 μg/l.

Vitamin D

Inadequate vitamin D intake causes osteoporosis and reduced fertility. Endogenous vitamin D is produced by the irradiating action of sunlight on the skin, provided that there is not too much hair covering it. Cattle that are housed have to obtain vitamin D from their feed or from surpluses that have been stored in adipose tissue. As the concentrations are negligible in most feeds, supplementation is required at a daily rate of 6 IU/kg live weight for growing cattle and 10 IU/kg live weight for adult cows. Compounded concentrate feeds usually contain vitamin D at 1000–2000 IU/kg, which is sufficient for most purposes. However, housed suckler cows that are only fed a small amount of concentrates daily will need a higher level of supplementation.

The conversion of vitamin D into its active form is regulated by concentrations of plasma calcium, phosphorus and parathyroid hormone. Large doses of vitamin D fed to dairy cows around calving will mobilize calcium from bone tissue and increase calcium uptake from the gastrointestinal tract. Such doses are quite effective in reducing the risk of milk fever, with the recommended intake for this purpose being 40,000–70,000 IU/day.

Vitamin E

Vitamin E is an antioxidant that preserves the integrity of cell membranes. In severe deficiencies, the myoglobin content of muscles is depleted and they turn white (white muscle disease) (Willshire and Payne, 2011). Calves are more likely to suffer from vitamin E deficiency than older cattle, because they have few reserves. The standard vitamin E addition to milk replacer is α-tocopherol acetate, which is particularly needed if unsaturated fatty acids are added to the milk to stop them becoming rancid. Soya, maize or palm oils are now commonly added to milk replacers to increase their energy value to the calf.

Cows that are deficient or marginal for vitamin E and selenium are more likely to have retained placentas and may have fertility disturbances. Vitamin E is important for udder health, and supplementary vitamin E and selenium help to control mastitis. The requirements for vitamin E are 1–2 mg/kg live weight, provided that there is sufficient selenium in the diet. Whereas selenium and vitamin E have synergistic effects, vitamins E and A are antagonistic.

B vitamins

Thiamine (vitamin B_1) is synthesized by the ruminal microorganisms, but the latter also denature some of the thiamine in feed. Most thiamine produced in the rumen is absorbed in the small intestine and should be sufficient for all but the highest-yielding cows. However, there appear to be certain conditions when thiaminases are manufactured, such as during acidosis, and the thiamine produced may be insufficient. These conditions are not yet adequately understood to recommend supplementation of cattle. However, if a problem is suspected, a supplement of 10 g/t of compound feed can be added.

Niacin (vitamin B_3) is also synthesized in the rumen but may be deficient. Supplementary niacin potentially increases nutrient digestion rate in the rumen of lactating dairy cows and can prevent high-yielding cows from developing ketosis. Approximately 3 g/day is recommended for high-yielding dairy cows, from 2 weeks before calving to week 10 of lactation.

Vitamin B_{12} is endogenously synthesized in adequate quantities, provided that the diet contains sufficient cobalt. Vitamin B_{12} analogues are also synthesized and, if the diet contains too much concentrate feed, too many analogues are produced and too little active B_{12}. To rectify a deficiency, dietary supplements of either vitamin B_{12} or cobalt can be provided, in particular to high-yielding dairy cows.

Biotin (vitamin B_7) is also synthesized in the rumen, usually in sufficient quantities for high milk yields. Biotin supplements can reduce lameness in dairy cows by improving keratin production.

Water

The requirements of cattle for water are met by a combination of imbibed water, water in feed, or on it as dew or rain in the case of pasture, and that produced by metabolic reactions in the animal's body. Requirements are influenced by ambient temperature and humidity, the nitrogen, sodium and DM contents of feed and milk yield. High nitrogen and sodium intakes in feed have to be excreted in the urine with the addition of water, hence the voluntary water intake must increase to maintain osmotic pressure. For example, feeds with high Na require an extra 0.2 l water/g Na consumed (Phillips, 2016, p. 184). Dry feeds increase voluntary water consumption, both because they contain less water to contribute to requirements and because they require the addition of more saliva before they can be swallowed. If inadequate water is provided, feed intake declines.

The water allocation to cattle can be divided into a requirement for maintenance (0.09 l/kg body weight) and a requirement for milk production (2.0–2.5 l/l milk produced). Thus beef cattle may require 50 l/day and dairy cows up to 100 l. A small reduction in water supply can be tolerated as there is some luxury uptake, but a severe restriction will lead to reduced milk yield. Restrictions in water supply are less well tolerated than other nutrient restrictions and for this reason water restrictions rapidly induce thirst, to encourage cattle to restore their water balance. Restrictions may happen in cold conditions if water pipes in cattle houses freeze and the intake of very cold water will be low; also in rangeland, bores extracting water from the ground may become obstructed and they must be checked regularly. Inadequate water consumption leads to haemoconcentration, inefficient circulation and oxygen transport and poor thermoregulation. It can be detected as reduced skin turgidity, tested as the 'tenting time', and sunken eyes. In extreme cases hypernatraemia and brain lesions ensue.

Lactating cows naturally drink four or five times per day and intake is likely to be restricted if water is provided only at milking times. Cows particularly like to consume water after being milked and after they have eaten, to restore their osmotic balance. Peak intake is likely to be in the evening, when there is a concentrated feeding period. The water supply should be clean and unpolluted.

Allowing cows to have access to streams to obtain their water is likely to limit intake and spread disease, as well as potentially contaminating the streams with excreta. Usually, water is provided in a trough, which can have a bar around it to prevent cows defecating in it. The troughs should be cleaned out regularly, otherwise a sludge develops at the bottom that will reduce intake. In the field, large concrete troughs are sometimes used as they store a lot of water; however, because the cows cannot reach to the bottom these regularly need cleaning out. Field troughs should be centrally situated so that cows do not have to walk far; and it is best to prevent wildlife from using them, because of the risk of disease transmission. Under rangeland conditions the siting of the water supply can influence utilization of the pasture if cows have to walk long distances to obtain water.

Indoor troughs are usually smaller than those in the field and need careful siting. In freestall barns the end of a row of cubicles is suitable, but care should be taken that the floor does not become slippery around the trough, as cows are likely to be making tight turns there and may slip over. If the water trough is sited in the feeding passage, feed may enter it when it is delivered from a mixer wagon or forage box. Shallow troughs that fill rapidly are best, as the water that they provide for the cow is usually clean and fresh. Cows in individual stalls may receive water from a small bowl with a lever that they push with their noses.

In rangelands, water is usually provided from natural sources and from dams. Salinity may reduce the palatability of water, which will only be consumed if it is of pH 6.5–8.5. However, salinity caused by high sodium content can increase intake in an attempt to dissipate the impact of the salts on the body. Adequate subterranean water supplies are necessary for any bore to provide consistently potable water (Fig. 4.5). Cattle may initially refuse to drink the water, after which they consume large quantities and become ill. Over time

Fig. 4.5. A deep bore is necessary for adequate water, particularly during drought conditions.

they may adapt to high sodium concentrations. Other major sources of salinity are carbonates, bicarbonates, sulfates, nitrates, chlorides, phosphates and fluorides. Sulfates are most likely to cause toxicity or refusal to drink, but cattle may eventually become used to them.

Groundwater and artesian water are more likely to be contaminated than surface water. Beef cattle require water with no more than 4000–5000 mg total dissolved solids/l, though they will tolerate 5000–10,000 mg total dissolved solids/l for short periods. For dairy cattle the relevant values are 2500–4000 mg and 4000–7000 mg, respectively. Dehydrated cattle have sunken eyes, loose, flaccid skin and low or zero milk production.

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5

Cattle Feeding

Introduction: Efficiency of Production

The conversion of feed by cattle is inherently less energetically efficient than that by monogastric animals such as pigs, because their digestive system utilizes a double digestion: an initial digestion by microorganisms in the rumen, followed by digestion of the microbial biomass and previously undigested feed by enzymes produced by the gastrointestinal tract of the cattle (Table 5.1).

This complex system is necessary because of the low quality of most feed consumed by cattle, at least when they graze on unimproved pasture. Grain-fed beef are more efficient in energy conversion than range-fed beef because: (i) they grow much faster and less feed is used for maintaining the animals; (ii) less energy is used in movement of the animals – there is an energy cost to the grazing process; and (iii) much of the energy produced in feed in rangelands is wasted, never consumed, for a whole variety of reasons. However, it is easier to feed people directly with the feed grown for livestock in intensive production systems than it is to utilize the rangelands to produce human food. In addition, the energetic efficiency of suckled calf production is low because of the need to maintain the mother as well as rear the offspring. Protein conversion from feed to animal product is also relatively inefficient: on average, it requires about 17 g feed protein to produce each 1 g of animal protein. Other elements are also used inefficiently; for example, inputs of rock phosphates, which are virtually irreplaceable worldwide, are utilized seven times more efficiently for vegetable than for meat production (Reijnders and Soret, 2003). Milk production is usually considered more efficient in its use of non-renewable inputs than beef production, but cheese from intensive milk production is still calculated to be about five times less efficient (in terms of land requirements) and 10–20 times more polluting (in terms of ecotoxic, eutrophying and acidifying compounds) than 'cheese' produced directly from vegetables (Reijnders and Soret, 2003).

Calf Feeding

Colostrum consumption

Beef calves usually remain with their mothers until weaning, which is not likely to occur before 6 months of age. By contrast, dairy calves are usually weaned from their mothers at 12–24 h post-partum, so that the latter can join the milking herd to produce milk for human consumption. By the time of weaning all calves should have consumed colostrum from their mother. Colostrum is a mixture of blood plasma and milk, which is produced until about the fourth day of lactation and is particularly valuable to newborn calves for its high concentration of immunoglobulins (Table 5.2). It usually also contains more vitamins than milk, depending on the vitamin status of the cow.

The permeability of the calf's small intestine to immunoglobulins declines rapidly after about 12 h, and is very low after the meconium has been passed. This is a dark green viscous substance that accumulates in the gastrointestinal tract during the calf's time *in utero* and is usually passed at about 24 h after birth. Licking of the calf's anus by the cow during suckling probably stimulates its expulsion. Calves do not normally produce endogenous immunoglobulins for about 10–14 days if they are deprived of the 'passive' immunity transferred in the colostrum. It is not until 8 weeks after birth that the calf's serum globulin levels are stabilized.

It is important that the calf consumes its dam's colostrum in the first day of life, preferably about 7 kg for each calf, which is sufficient to provide about 400 g of immunoglobulin. European Union (EU) regulations

Table 5.1. The efficiency of feed energy utilization by meat producers (energy output as a percentage of energy input).

Animal	Efficiency (%)
Pig	24
Chicken	14
Goat	8
Rabbit	8
Deer	8
Growing cattle	6
Suckler cattle	3
Suckled lamb	3

Table 5.2. The chemical composition of colostrum compared with that of milk.

	Colostrum	Milk
Fat (g/kg)	36	35
Protein (g/kg)	140	33
Immunoglobulin (g/kg)	60	1
Casein (g/kg)	52	26
Albumin (g/kg)	15	5
Lactose (g/kg)	30	46
Vitamin A (µg/g fat)	42–48	8
Vitamin B_{12} (µg/kg)	10–50	5
Vitamin D (ng/g fat)	23–45	15
Vitamin E (µg/g fat)	100–150	20

specify that calves should receive colostrum within the first 6 h of life. As the immunoglobulin content in milk declines in the first few days of lactation, cows should not be milked in the week before parturition. The adequacy of a calf's immunoglobulin intake can be tested by adding zinc sulfate to a blood sample, with the degree of turbidity indicating the extent of the calf's immunoglobulin absorption.

Inadequate colostrum consumption can arise from lethargy in either a cow or her calf following a difficult calving, or from the calf having difficulty in locating the teats. In the latter case the herdsperson should assist if possible, guiding the calf to the teat while expressing colostrum from it. In rangeland conditions calves may be found alone if their mother has died during or soon after parturition. These can be removed to the homestead and reared artificially, though some farmers euthanize them. If the calf's mother cannot provide colostrum, and no colostrum is available from other newly calved cows, a substitute can be made from a raw egg, milk and castor oil, which acts as a laxative. Egg albumin is rapidly absorbed and provides some protection against septicaemia. After removal from their mothers, the calves should preferably be fed surplus colostrum from other cows.

Artificial milk replacers

From approximately 4 days of age, dairy calves are fed a milk replacer for about 5–6 weeks. Milk replacers are usually based on dried milk powder, produced from surplus cows' milk. Cows are now capable of producing many times the requirements of one calf, but feeding dried milk is not quite so circuitous a practice as it might at first seem, since economic production is difficult to achieve in intensive dairying systems if the calf is allowed to suckle and receive some of the cow's milk, with the rest being taken for human consumption. In the short term the welfare of both cow and calf would be improved by suckling; but even if the calf's milk intake could be controlled and just the surplus used for human consumption, the suckling and bunting of the udder by the calf elongates the udder and the teats, making it difficult for the cow to be milked by a machine. Also, if the calf suckles for several weeks the eventual separation is more stressful for both cow and calf. The Holstein-Friesian breed appears to accept the separation better than other breeds. In some calf-feeding systems, milk is taken from the cow by machine to be fed to the calves in buckets, particularly if milk powder is expensive. This system avoids the adverse effects of calf suckling on the cow and, in particular, the stress of the eventual separation, while retaining the benefits of providing fresh milk for the calf. In some mixed dairy/beef systems in developing countries, calves do suckle cows, with some milk being taken for human consumption (see restricted suckling systems in Chapter 2).

Digestion in the young calf

When the calf imbibes a liquid diet, a groove in the oesophagus automatically closes to allow the fluid to bypass the rumen and reticulum and enter the abomasum directly. Here it forms a curd, and a whey which passes into the duodenum. The casein in the curd is digested in the abomasum of the neonatal calf with the aid of the enzyme rennin. Later the parietal cells of the abomasum produce hydrochloric acid, and pepsin then assists in protein degradation. Young calves also secrete trypsin and pancreatic proteases to digest whey proteins. If the calf imbibes pasteurized or ultra-heat-treated (UHT) milk, the protein is partially denatured and it takes longer for the curd to form and the calf may develop diarrhoea or scours, often with an accompanying *Escherichia coli* infection. Milk fat from the curd is digested by salivary esterase. Calves can digest a wide variety of fats, so the addition of vegetable-based fats to skimmed milk powder is possible. Spray-drying technology allows fats to be incorporated into skimmed milk powder in an emulsified form. The digestibility of vegetable fats is about 5% less than that of milk fat, with some binding of bile acids by insoluble calcium phosphate in the small intestine. Lactose, the main carbohydrate in milk, is almost completely digested, but calves have little ability to utilize starch, sucrose and other carbohydrates in the first 6 weeks.

Feeding milk replacers

Milk replacer powders for calves should contain highly digestible protein that will clot in the abomasum, carbohydrate (in the form of lactose), fat, minerals and vitamins. A traditional source of these nutrients is skimmed milk, a by-product of butter manufacture, containing mainly lactose and milk proteins, principally casein. A typical powder contains at least 60% dried skimmed milk, 15–20% added fat and added minerals and vitamins. Whey (a by-product of cheese-making that is composed principally of lactose and the whey proteins, albumin and globulin) or whey protein concentrate are suitable alternatives but the protein digestibility is less than for skimmed milk.

Milk-derived powders are relatively expensive and often in short supply, so it is advantageous to replace some of the protein in the milk powder with vegetable-based products, such as soya protein. This has to be extracted with alcohol during heating to remove antigens that can cause allergic reactions. The protein in soya is susceptible to digestion by small intestinal enzymes, but it is less digestible than milk protein since rennin, the main protein-degrading enzyme in the abomasum, is specific to casein, the milk protein. Milk protein is about 85–95% digestible, whereas protein digestibility may be reduced to 65–75% if vegetable-based replacers are included at 30–50%. This may still give acceptable calf weight gains, but growth restrictions in the early period of the calf's development may never be overcome. Calves fed soya protein concentrate are also more likely to scour or become bloated. Some antibacterial agents, such as the lactoperoxidase complex, are present in milk but are denatured by processing, so it is useful to add these artificially.

Milk replacer powders have to be fed to the calves either in a bucket, which may have a teat attached to it, or by a machine which mixes the powder on demand. Reconstituted milk powder has a short keeping life, compared with acidified milk powders, and it is normally fed once or twice a day in buckets. If large quantities of milk powder are fed to each animal, or the calves are small, then feeding just once a day is more likely to lead to milk spilling into the rumen and causing diarrhoea (calf scours). In the first week of the calf's life the curd persists for only about 8 h after feeding. Once-a-day feeding also results in less gastric and pancreatic secretions than twice-a-day feeding. When suckling their dam, calves normally have about five meals daily, so once-a-day feeding of milk replacer is likely to overload the digestive tract, especially in young calves, unless they are fed limited quantities of milk replacer and transferred to solid feed early, which will reduce labour requirements.

Feeding a large amount of milk powder to a calf increases its growth rate, and it must be decided whether this justifies the cost. The milk replacer provides only about 0.5% of the total metabolizable energy (ME) requirements of a dairy heifer from birth to first calving, and a high rate of growth initially will lead to strong, healthy calves. Calves require about 360 g milk replacer daily in two feeds of 1.5 l, after finishing their colostrum feeding at day 3 of age, to enable them to grow at a rate that will allow them to calve at 2 years of age. Later this can be gradually increased to 750 g to 1 kg milk replacer daily, diluted to 7 l with water, which should be sufficient for 50 kg calves to grow at about 0.7 kg/day. Alternatively, one feed of a slightly stronger mix can be provided.

Bucket feeding offers the potential to control the calf's intake and minimize cross-infection between calves by limiting contact between individuals. Milk replacer is reconstituted once or twice daily. It is normally mixed with one-half of the water at 46°C and then the remaining water added is either hot or cold, as required to achieve a final temperature of 42°C for optimum digestibility. Feeding from buckets is not a natural process for a young calf, whose instincts direct it to suckle from birth. However, calves can be successfully trained to drink from buckets using two upturned fingers immersed in the milk to simulate the mother's teat. When the calf has learned to suck milk around the fingers, they can be withdrawn gradually and the calf will drink unaided. This process is sometimes difficult for the calf to learn, as standing with their head facing downwards in a bucket, sucking milk into their buccal cavity, is quite different from suckling. In the latter, calves stand with their head extended upwards, squeezing the teat from the base to the tip with the tongue to express the milk. A limited amount of sucking is also involved. Furthermore, suckling a teat with their head in the horizontal position aids oesophageal groove closure, enabling milk to bypass the rumen.

The absence of teat suckling encourages calves to suck on other protruding objects, especially during the period immediately after being fed milk in buckets. They will 'suckle' the bucket handles, bars or other parts of their pen and their neighbours' tongues, ears, tails and navels if they are housed so that they have access to other calves. Sucking the navel keeps it moist and encourages bacterial infections, which concentrate in the navel (navel ill) or joints (joint ill), often leading to septicaemia. The sucking behaviour often persists when the calves are older, in the form of urine or prepuce sucking and tongue rolling in males, and inter-sucking of teats in females (Lidfors and Isberg, 2003).

The stress caused by the absence of a suckling stimulus is exacerbated by individual penning of the calves. Individually penned calves may also spend a lot of time licking objects in their pen, which may be caused by inadequate mineral supply, principally sodium. Sodium requirements may be increased by poor kidney function during confinement stress. Additional salt can be added to the concentrate but this will increase water consumption and urination, so it is important to ensure that the calf has enough clean bedding.

Increasingly, simple bucket feeding is being improved to avoid causing distress to the calf as a result of the lack of a suckling stimulus. The height of the bucket may be increased and a teat attached at the bottom, through which the calf can obtain the milk replacer. Alternatively, a teat may be suspended in the milk, but this does not completely satisfy the suckling drive. Stimulating sucking behaviour encourages the production of salivary esterase, so the stereotyped oral behaviours of bucket-fed calves may help in the digestion of fats. Alternatively a raised trough with teats attached can be used, but it is important that the system is easily cleaned, free of taint, robust enough to withstand calf suckling and safe for calves to drink from.

Milk may also be fed to calves housed in groups by teats attached by a length of pipe to a large container, provided that the milk is acidified to keep it from spoiling. Usually, weak organic acids are added to reduce the pH of the milk to about 5.7, since casein will clot if the pH is further reduced. Stronger acids can be added only if the powder is whey-based, to give a pH of about 4.2, and good calf growth rates are achieved even though the milk replacer does not clot in the abomasum. Acidified milk replacers are usually made available *ad libitum* and intakes may be 20–30% more than if the calves are fed from buckets. The intake depends on the temperature of the milk: whereas the milk is warmed to 42°C for bucket feeding, it is available at ambient temperature for group feeding of acidified milk replacer *ad libitum*. If the milk is at 10–15°C or less, intakes decline and so does the calf growth rate. Variable temperatures are also undesirable. Not all calves respond equally and the stockperson needs to keep a careful watch for any calves that are not thriving on the system. The main advantage of group-rearing calves and offering them acidified milk replacer is that it saves labour, but some of the time saved must be used to check the calves regularly.

The keeping life of acidified milk replacers is approximately 3 days, depending on the temperature, and containers and pipes must always be cleaned with hot water and a mild disinfectant between feeds. Calves reared in groups spend less time sucking things in their pen, but there is more opportunity for cross-infection between calves, particularly via the navel (Cobbold and Desmarchelier, 2002). There should be no more than ten calves in each group, and teats should be inspected regularly for damage as the calves play with them, particularly when milk replacer availability is reduced at weaning. If abrupt weaning is practised, the teats should preferably be removed at this time. During milk feeding the teats should be securely fastened at a height of about 600 mm from the floor. Calves on acidified milk replacer are less likely to scour, despite their high intakes, partly because they consume their milk in small meals and there is therefore less likelihood that it will enter the rumen, and partly because the acidification reduces the likelihood of bacterial contamination of the milk.

In summary, calves fed on acidified milk replacer offered *ad libitum* will consume more milk powder and less solid food than calves fed restricted amounts of a liquid diet based on an artificial milk replacer (Table 5.3). They therefore grow more rapidly, but at a greater cost. As solid feed costs less than one-half that of milk replacer per unit of energy, farmers must decide whether the benefit of extra growth is worth paying the extra feed

Table 5.3. Feed intake and growth of calves on restricted milk replacer fed in buckets and acidified milk replacer fed *ad libitum*, from birth to 3 months of age.

	Restricted milk replacer (buckets)	*Ad libitum* acidified milk replacer (teats)
Milk substitute intake (kg)	11–16	20–30
Concentrate intake (kg)	115–130	105–120
Hay intake (kg)	5–9	6–10
Live weight gain (kg/day)	0.5	0.8
Relative cost per kg gain (restricted system = 100)	100	125

costs. Pedigree breeders may decide that it is, but those producing less valuable animals are likely to want to minimize input costs.

Another alternative to restricted milk replacer or acidified milk replacer offered *ad libitum* is to use machines that make up milk powder for each calf 'on demand'. The machine recognizes each calf by an electronic key suspended around the calf's neck and the teat delivery system should be set to 700–800 mm above floor level. Calves in groups can be fed a pre-programmed amount of milk replacer at body temperature. The milk replacer has to be carefully formulated so that it flows freely in the machine's hopper, and safety arrangements considered so that power or water failures do not leave the calves without their feed supply. The feeders should be calibrated regularly and pipelines and mixing bowl cleaned every other day. The mixing bowl should be set below the delivery teat in case there are leaks and the area should be well drained. The system is expensive but has the advantage that all calves will consume the programmed amount of milk, which is delivered via a teat so that the calves do not get frustrated by the absence of a suckling stimulus.

Another possible milk replacer is surplus colostrum. This can continue to be fed to calves after the period of suckling, as cows produce about 50 l of colostrum in the first 4 days of lactation, which is considerably more than a single calf can consume in that time. It will naturally ferment if stored in barrels; the resulting soured product has a pH of about 4.5 and will keep for about 3 weeks. It supports good calf growth rates, but the acceptability of the product is variable and it is better fed to calves at times of the year when ambient temperatures are not too high. Calves on soured colostrum are unlikely to get diarrhoea, and in particular fewer rotaviruses and coronaviruses are contracted.

Whole milk can also be used for feeding to young calves, and the economics of doing so will depend on the price ratio of whole milk to milk replacer. Weight gains may be slightly greater than on milk replacer because the fat content is greater – about 35 g/l compared with 23 g/l. This practice is encouraged when there are high prices of milk replacers, quotas for milk production from dairy herds and a need for greater self-sufficiency on farms.

Introducing solid feed

For the first few weeks of a calf's life the milk replacer feeding systems described above will provide sufficient nutrients for acceptable growth rates. However, because of the high cost of milk replacer, it is usual to offer concentrate feed from about 1 week of age. EU legislation requires that all calves over 1 week of age must have access to fibrous feed (at least 100 g at 2 weeks of age, increasing to 250 g at 20 weeks). This allows the rumen to develop normally, with papillae and good musculature to support motility. Calves that do not have access to solid feed often develop hairballs in their rumen, caused by the consumption of hair during their licking and grooming activities and the lack of ruminal motility to transfer it through to the abomasum.

Concentrate feed is usually compounded from several ingredients and can be offered either as pellets or a coarse mix. Pellets should be smaller than those manufactured for older cattle, about 3–5 mm diameter. Both pellets and a coarse mix produce similar calf growth rates, but pellets have the advantage that selection of individual ingredients by the calf is not possible and there is consequently little feed wastage, provided that the pellet is suitably hard. If it is too hard, the calves find it difficult to chew. With coarse mixes or soft pellets, there is often a mixture of dust and saliva left in the bucket or trough. Farmers may have difficulty in obtaining or safely storing the correct ingredients for a coarse mix and the price paid will usually be higher than that paid by a feed compounder.

With both feed pellets and coarse mixes, but particularly the latter, it is best to offer only a little bit more than the calves are eating daily, with careful management to avoid restricting the intake of some calves. If milk is offered *ad libitum*, only a small amount of concentrate feed will be consumed during the first few weeks and a greater check to growth rate occurs when the artificial milk supply is stopped. However, it should still be offered from an early age to get calves used to having concentrates available. Intake increases over the first few weeks of life until it is normally about 1.0–1.5 kg at about 6 weeks of age. After this, farmers may restrict the intake of female calves being retained as replacements for culled cows to approximately 2 kg; however, male (bull) calves may continue to receive concentrates *ad libitum* to achieve maximum growth rates.

Calves have high growth potential, relative to intake. To achieve maximum growth the concentration of crude protein should be at least 18%; once they start rumination, the proportion degraded in the rumen should not be more than about two-thirds. Soybean meal is a popular supplement to add protein to the diet.

Mineral supplements should be added to the diet of calves, incorporated into their concentrate pellet or loose mix, otherwise they may engage in searching behaviour by licking their surroundings. Sodium, potassium, magnesium and chlorine can all become deficient when a calf has diarrhoea (scours), and extra calcium and phosphorus are important for bone growth, as well as vitamin D for housed calves that cannot make their own using sunlight. The calcium source is important in determining the availability of the element to the calf, with calcium in milk being particularly well absorbed (*c.* 95%). Iron is the trace element most likely to be deficient, with two iron-binding proteins, lactoferrin and transferrin, being responsible for the transmission of iron from cow to calf and the restriction of iron availability to any bacteria that might enter the milk. Inadequate concentrations of these proteins are common in milk and responses to iron supplements can be observed as early as 2 weeks of age. Later, when the intake of solid feed has increased, blood haemoglobin levels are restored and supplementary iron is unnecessary.

Forage for young calves

Offering forage to young calves is controversial, since too much reliance on low-quality forage reduces growth rates. Young calves that have too much coarse forage develop a large rumen at an early age, which makes them look ‘pot-bellied’. However, forage is important for the creation of stable rumen conditions, especially a consistently high pH. The addition of straw to an all-concentrate diet at an inclusion rate of 15% will increase intake, demonstrating that they have a requirement for fibre in their diet. Stable ruminal conditions at an early age will help to avoid digestive disturbances, such as bloat or scouring. Some farmers use concentrate pellets that contain chopped straw, but these do not have the physical nature of long forage that is important for ruminal development. Similarly, cereal ingredients in concentrates should be rolled or flaked but not ground, to stimulate ruminal activity.

Forage offered to calves should be of the highest quality and palatability. Fresh, leafy grass is best, but this is difficult to provide in sufficient quantities for large numbers of calves. In some developing countries calves are let out to pasture during the day and brought in at night to be fed milk replacer. This provides the calves with exercise, mental stimulation, companionship and nutritious feed, but the system requires more labour than conventional systems. Allowing calves access to fresh air reduces the risk of disease transmission, but in cold climates it would be unwise to let them outside in inclement weather unless shelter is available.

Fresh grass is eaten avidly by calves from an early age, and when fed to calves in individual pens it reduces any behavioural problems caused by insufficient suckling before solid feed is taken in reasonable quantities. Forage should be palatable to encourage calves to start eating early, not necessarily highly digestible, since ruminal capacity does not limit intake in the first few weeks of life, but dust free, sweet smelling and not too dry. Silage tends to be avoided by young calves but good-quality hay or straw will be eaten in sufficient quantities. Small bales of hay are easier to handle than silage in the calf house, and they keep fresh for longer, but many cattle farms only make silage. The crude protein content of hay is usually less than silage and it is less degradable in the rumen. The higher intakes of hay may offset its low crude protein content. Straw is suitable for calves, provided that it is not dusty. It rarely has any offensive odours that would reduce its acceptability. The palatability of straw for calves can be improved by spraying it with molasses, but producers should be beware of the high potassium content of molasses that may reduce sodium availability, leading to the licking problems referred to above. Sugarbeet pulp is a good source of roughage for calves, as it is highly digestible and supports a high ruminal pH.

Weaning calves

A calf’s age at milk replacer removal (usually termed ‘weaning’ even though the calf has already been taken from its dam) may determine its ability to grow adequately in early life. Weaning too early and without adequate, high-quality solid feed intakes may lead to reduced growth rates for much of the calf's first year of life, though for beef cattle there is no indication that this will affect carcass composition. In feral cattle, which have minimal human interference, female calves do not naturally sever the bonds with their mother even when they are mature. Male calves will leave the matriarchal group soon after sexual maturity. Suckling can continue until the cow prepares to have her next calf, which may be 1 year or more after the birth of the first calf.

Individual calf rearing is time consuming, especially if they are fed twice per day. Group rearing on solid feed is probably better for the calves' welfare than rearing on a milk-based diet in individual pens, since isolated calves develop abnormal licking behaviours and are socially inexperienced when they are eventually put into groups. The best option, feeding milk individually by machine to calves in groups, is expensive.

Economics normally dictate that calves stop getting milk replacer at between 5 and 8 weeks of age. Small calves, in particular those from Channel Islands breeds, should be moved to solid feed at the later age, otherwise the mortality rate may be high. Small calves are easily overfed with milk, so they need to be fed proportionately less and weaned later. Feeding at a proportion of body weight – up to 12% daily, split into two feeds – will help to eliminate overfeeding of small calves. Calf mortality should not be more than 6% for homebred calves. For calves that are sold through a live auction market, the mortality rate is sometimes as high as 14%. The risk of mortality is particularly high in the spring because of the accumulation of pathogens, especially *E. coli*, in the calf house.

When deciding the optimum age at which to move calves on to solid feed entirely, farmers should consider the size of each animal and how much concentrate feed is being consumed. Often calves are weaned in batches, for convenience, and for some calves it may be too early and some too late. If a farmer can wean according to weight, Holstein-Friesian calves should be at least 50 kg, and preferably 60 kg, before milk is withdrawn. The calves should be eating a daily minimum of 0.6 kg and preferably 1 kg concentrate. Because they are usually weaned in batches to form their subsequent groups, there will be a range of ages and weights.

There is no evidence that gradual weaning over 1 week is better than abrupt weaning on 1 day but, as a general rule, sudden changes to the diet should be avoided as it takes some time for the digestion system to adapt. Sudden changes may stress the calf but, if solid intake is adequate, abrupt removal of milk is facilitated. Gradual weaning may be achieved by reducing the concentration of milk replacer or omitting one feed per day, though this can lead to restless calves at the time of the missing feed. The amount that the calf is fed can be gradually reduced; for example, calves fed acidified milk replacer *ad libitum* can have the pipe to the milk store disconnected for a period of the day, which may lead to excitement in the calves every time it is reconnected.

Restricted suckling systems for calves

In developing countries cows often suckle their calves as well as being milked by humans, known as restricted suckling (see Chapter 2). There are several benefits for farmers.

1. The system avoids use of expensive milk powder for the calves.
2. Total cow milk production (calf milk + milk for human consumption) is increased because the calf is able, by bunting the udder, to extract residual milk that would otherwise be left by the machine in the udder. This increase in yield persists even if the calf stops suckling, suggesting that the long-term production potential is increased by a period of suckling. The amount of milk obtained by the calf can be regulated by controlling the number of suckling periods each day, normally one or two, and their length, which is usually about 20 min. It is nevertheless difficult to ensure that calves have adequate milk, and that the optimum quantity is removed by machine for sale.
3. The extraction of residual milk helps to reduce mastitis levels, as there is a smaller milk reservoir in the gland supporting bacterial growth.
4. Milk letdown is facilitated for zebu (*Bos indicus*) cows, which do not readily release their milk unless a calf is present. Usually calves suckle the cows first, and any surplus can be milked by machine for sale after the calves have been removed. A common problem with restricted-suckling systems is that the calves are removed before they have had sufficient milk, which maximizes the saleable milk yield but often leads to high calf mortality. *Bos taurus* cows release milk in the absence of calves, so the latter can suckle after the saleable milk has been extracted by machine.

In this case the calves will be drinking high-fat milk, because the first-expressed milk has a low fat content, with the fat globules being retained in the alveolar tissue. The milk extracted for sale under such circumstances will be of reduced fat content.

Extension of the post-partum interval to rebreeding is common, with *ad libitum* suckling causing early lactational anoestrus in some cows, extending the interval to first oestrus by about 5 weeks, compared with systems where cows are milked only by machine. Twice-a-day suckling still results in a significant lengthening of the interval to first oestrus post-partum but there is much less effect if the calves are only suckled once a day. These reproductive delays are caused by a reduced luteinizing hormone (LH) output by the pituitary gland when the calves suckle. A further problem with restricted suckling is that extra milk production from the cow is often not compensated by provision of additional feed, with the result that body condition declines.

Single calf suckling systems

Some beef production systems allow cows to suckle their calves for several months, which usually results in rapid growth of the calves as long there is enough grass to support milk production by the cow. Some of the traditional beef breeds may produce less than 1000 l per lactation, which is only just enough for a single calf. This single calf suckling system is best suited to hill and poor-quality rangeland conditions, or dairy farms in which older, lower-producing or mastitic cows may be used as nurse cows for calves. On hill farms, spring-calving cows are often fed low-quality rations during winter, based on straw and a small daily concentrate feed, and will then restore their body weight when they are turned out to pasture in spring with their newborn calves.

Calving is easier for the cows if they have not put on too much weight over winter. Calf performance will be quite adequate provided that sufficient grass is available, and spring calving is favoured in the more extreme hill conditions because it reduces winter feed requirements. Autumn-calving cows need higher energy feed in winter if they are to sustain milk production for their calves, though weight lost in winter is usually restored in summer at pasture. If feed availability is restricted in winter, autumn-calving cows are less likely to conceive, whereas spring-calving cows are on a rising plane of nutrition when mated in summer and conceive more readily.

Feeding Growing Cattle

Mixed-grazing and conserved-feed systems

In temperate regions cattle are usually fed conserved forage during late autumn, winter and early spring, and they graze pasture during the rest of the year. Autumn-born calves are therefore fed indoors for approximately their first 6 months of life. Most are fed hay or straw up to weaning and then silage until they are turned out to pasture, as it is easier to handle, more readily available and of greater nutritional value. Intake should steadily increase as the calf gets older and develops the ruminal microflora to digest the silage, until the calf is eating about 12–15 g/kg live weight. Calves respond particularly well to supplementary protein that is protected from ruminal degradation (bypass protein) until they are about 5 months of age, because the rumen is unable to supply sufficient nitrogen for absorption. In other parts of the world calves are grazed, but during drought periods it is necessary to offer supplementary conserved feeds, usually hay (Fig. 5.1).

Fishmeal was a traditional source of bypass protein for calves, even though it is not always readily accepted by cattle and does taint the meat if the cattle are to be slaughtered soon after. The feeding of fishmeal to cattle is prohibited in several countries because of concerns about disease transmission, stemming from concerns

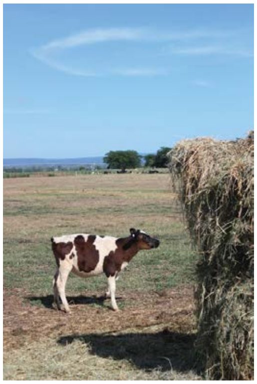

Fig. 5.1. Calves need supplementary feeds at pasture, especially during drought periods.

originating during the bovine spongiform encephalopathy (BSE) outbreaks in the late 20th century. The requirement for rumen-undegraded protein depends on forage quality: if the forage is rapidly broken down by ruminal microbes, then the ready availability of volatile fatty acids in the rumen to supply energy to the calf will need to be complemented by bypass protein. Usually, silage will supply sufficient rumen-degradable protein for maximum microbial growth, as the silage protein is about 80% rumen-degradable. An exception is the protein in formaldehyde-treated silage, which is usually only about 65% degradable.

High growth rates in weaned calves can only be sustained on a silage-based ration if supplementary concentrate is continued at between 1 kg/day (if the silage is highly digestible, 68–70 D-value[1]) and 2 kg/day (if the silage is less digestible, 60–68 D-value). The concentrate supplement should include a protein source, such as soybean or sunflower meal, and may include a source of protein that is of low rumen degradability if the forage is high energy. The more concentrates that are fed, up to perhaps 5–6 kg/day per calf, the faster the calves will grow, but they will then grow more slowly when they have been turned out to pasture.

The feed additive sodium monensin is an antibiotic that has a greater adverse effect on the Gram-positive ruminal bacteria that produce acetate, methane, hydrogen and lactate than on the Gram-negative bacteria that produce propionate and succinate. The additive improves calf growth rate by increasing the proportion of the rumen volatile fatty acid propionate at the expense of acetate and methane production. It can be administered as a slow-releasing bolus at pasture, which avoids a check to growth that is likely if it is removed from the calves' diet when they are turned out to pasture. It has the added benefit of reducing the risk of bloat, acidosis and coccidiosis. Concern that routine administration of antibiotics in cattle feed would promote the development of new strains of bacteria prompted the EU to ban the use of sodium monensin from 2006 (see Chapter 3).

When calves are turned out to pasture, it is important to continue offering concentrate feed for 2–3 weeks to minimize any sudden change in the quality of feed available for the ruminal microorganisms. The concentrate feed need not have a high protein concentration, because this is in ample supply in fresh herbage. It could be based on cereals, rolled to improve digestibility and with a vitamin supplement added, sufficient to supply 1,000,000 IU vitamin A per tonne and 2,000,000 IU vitamin D per tonne and minerals to complement likely deficiencies. It is especially needed during wet weather, as grass intake is reduced. It is also useful to offer hay in a rack to provide supplementary fibre. Hay will help to maintain a high ruminal pH for adequate fibre digestion. If the grass is young and leafy, young calves should be allowed out for only a few hours each day for the first week, otherwise they will develop diarrhoea caused by the limited amount of fibre. They may then lose condition, as the limited time that the grass remains in the gastrointestinal tract reduces nutrient absorption, and a reduction in gut motility further reduces intake.

In temperate conditions, autumn-born calves turned out in spring can be stocked on good-quality pasture at high stocking densities (up to 15 calves/ha) as individual consumption will be low. If the sward is of low quality and little fertilizer is applied, this rate should be reduced. It is most important to keep the herbage in a young, leafy state, otherwise its nutritional value declines rapidly. This stocking rate should be relaxed as grass growth declines, perhaps with the introduction of fields that have been used for silage making (termed aftermaths). This will help to reduce the risk of parasite infection, as will moving the calves to pasture that has not been grazed since the previous year. A second reduction in stocking rate could be made in late summer, down to about five animals per hectare, perhaps after a second cut of silage or when in-calf heifers are removed to enter the dairy herd.

A salt lick should be provided if the cattle are to achieve high growth rates at pasture, particularly in areas where the pasture is naturally deficient in sodium, or high temperatures increase sodium loss through sweating. The salt lick should be placed in a container so that it does not get contaminated with earth, and preferably should be protected from rain.

Clean water is also essential. Water from a stream or pond may be diseased, so mains water should be provided if possible. In intensive grazing situations it is unwise to rely on cattle gaining their water supply from natural sources, as they will damage the banks and pollute the water with excreta. If cattle are detected with infections, such as tuberculosis, it would be prudent to clean out all water troughs immediately and thoroughly. Cattle drink mainly from the surface of troughs and, in large-capacity troughs, the turnover of water at the bottom of the trough may be low. Organisms such as *Mycobacterium bovis*, which causes tuberculosis, can survive for up to 1 year in such water. Intermediate hosts for cattle diseases may obtain their water from cattle troughs. For example, in north-western Europe the badger can spread tuberculosis to cattle. If there is no obvious water source for badgers on a farm, or if there are signs of badgers accessing water troughs (such as scratch marks on the sides of the trough), measures should be taken to prevent badgers from using troughs by raising these to a height of at least 0.8 m and making it difficult for them to climb up the sides.

Spring-born calves, which are usually turned out to pasture when younger than autumn-born calves, are often stocked at an even higher density – up to 30 calves/ha of best-quality pasture. Shelter is required in exposed areas. There is a limit to the extent to which grazing can be intensified in an attempt to keep the pasture in short, leafy condition, as such small calves are selective grazers. A leader–follower grazing method can help to control grass growth, by grazing older cattle after the young calves (see Chapter 6). Normally there will be about eight to ten paddocks that will allow for a minimum period of 21 days regrowth before each grazing.

In temperate regions grass quantity and quality decline in autumn. In hot, arid regions, even if the rainfall is evenly distributed over the year, the increased grass transpiration rate in summer will eventually deplete soil water reserves and reduce grass growth. A concentrate supplement, such as rolled cereals, will help to maintain growth rates when grazed herbage is inadequate, but the profitability of this will depend on availability and alternative uses, for example in human nutrition. A mineral supplement should be provided too if deficiencies are common in the region. Forage supplements can also be offered during the summer if dry weather reduces the amount of fresh herbage on offer. However, substitution rates for herbage are likely to be greater than for supplementary concentrates. If supplements only substitute for grass intake, the profitability of the cattle-rearing system will decline as they are more expensive.

In temperate conditions cattle should be housed whenever the conditions deteriorate, i.e. when the grass is too short (less than about 6 cm tall), or when the land is too wet and continued grazing would damage the sward. Young cattle do less damage to a sward in wet conditions than adult cows because of their light weight, but they should only be left outside in winter if there is adequate grass available and, where necessary, shelter.

When cattle are rehoused it is preferable to feed them silage, rather than hay, as it is usually of better quality in terms of its energy and protein content. Good-quality silage requires little supplementary concentrate, but the addition of 2 kg concentrates/day will help to ensure that dairy heifers achieve adequate growth to calve at 2 years of age. If autumn-born heifers are required to calve at 2 years of age, they should be inseminated at about 15 months of age in midwinter. After this time the concentrate feeding can be reduced in expectation of good growth during the following summer grazing. In tropical situations such compensatory growth is less predictable, because of the variability in forage quantity and quality.

Dairy heifers must achieve an adequate pre-calving weight (500 kg for a small-framed Friesian, up to 630 kg for a large-framed Holstein-Friesian), otherwise first-lactation yields will be reduced as nutrients are required for growth. In addition, a heifer does not settle well into a herd if she is much smaller than the older cows. However, the heifer must not be too fat or the incidence of dystocia will be increased, and a herd manager should aim for a body condition score of 3.0–3.5 at calving on a 5-point scale. Holstein-Friesian heifers should be inseminated, either naturally or artificially, when they are at least 60% of their mature weight.

Rearing heifers on a ration that achieves rapid growth in the pre-pubertal phase can have adverse effects on mammary gland growth. If high milk yields are the objective, it is best to provide more energy during and throughout the 2 months after conception and also during late gestation, rather than before puberty. This increases mammary gland development and, in particular, the amount of mammary DNA, allowing for the provision of extra cells that will secrete milk during lactation. In summary, attainment of an adequate frame size, but avoiding overconditioning, should be the aim in heifer feeding.

Steers are usually killed at the end of their second winter at 18 months of age, after receiving a higher-quality diet during the last half of the winter than offered to a dairy heifer. A poor-quality diet with low levels of supplementation will retard growth and lengthen the finishing period (Table 5.4), resulting in a large-framed animal and increased total feed requirements. This may be justified if high-quality supplements are expensive. The producer must decide whether the potential to finish at a heavier weight – 50 kg heavier in the example given in Table 5.4 – is worth the extra expenditure on feed and other variable costs. Often it is not, because the feed is inefficiently converted into live weight at this advanced stage of growth.

Many beef cattle in temperate regions are born in autumn and slaughtered at 18 months of age, with two

Table 5.4. The effect of amount of daily cereal feed on the growth and total feed requirements of housed beef cattle fed silage.

	Rolled barley (kg DM/day)		
	2.0	2.4	2.8
Silage intake (kg DM/day)	5.3	5.1	4.8
Live weight gain (kg/day)	0.7	0.8	0.9
Finishing period (days)	285	220	165
Slaughter weight (kg)	525	500	475
Total barley requirement (kg)	670	620	525
Total silage requirement (t)	6.0	4.4	3.2

periods indoors at the beginning and end of their life and a period at pasture in between. The length of each period varies with region and, in particular, climate. If feed is not of good quality throughout, it can be difficult to get the cattle to reach the preferred level of fat cover by the end of the second housed period. Most commonly this is due to poor growth during the summer grazing period, because of inadequate stocking rate in the early part of the grazing season (so that the herbage becomes rank and of low quality), inadequate control of parasitic infection (especially ostertagiasis, parasitic bronchitis and fascioliasis) or inclement weather adversely affecting grass growth. In the final housed period, cattle may fail to reach an adequate fat cover for slaughter because low-quality forage is not compensated by the offering of additional high-energy feed, such as barley (Table 5.4). Usually approximately 1 t of concentrates will need to be fed to each animal in total, including the concentrates that have to be fed before the second winter housing.

If the quality of the ration is insufficient for cattle to finish within 18 months, they must be turned out to pasture for a second summer, which is common for large-framed breeds, such those from continental Europe – Charolais, Limousin, etc. Although these have a faster growth rate than smaller breeds, they will still reach the same level of fat cover at a later date, and at heavier weight, than smaller-framed breeds of cattle.

If the steers are to be finished after a second summer at pasture, feeding in the second winter can be reduced to make good use of compensatory growth in the final summer, thus saving on expensive supplements. Suitable rations for an animal weighing 250–300 kg at the start of its second winter would be about 20 kg silage at 20–25% dry matter (DM) content, or correspondingly reduced intakes if DM content is greater than this, and 0.5–1.0 kg rolled barley daily. If straw is fed, the cattle will only eat just 3.5–4.0 kg daily and high-energy supplements, such as 3 kg of cereals, must be provided to compensate for the low digestibility of the straw if rapid growth is required.

In their second summer the stocking rate of the cattle must be lower than that of the previous summer – perhaps 3.0–3.5 steers or heifers per hectare on a well-fertilized ryegrass sward. A leader–follower system of grazing (see Chapter 6) suits cattle in a 24-month system, but requires small fields or paddocks to allow the two groups of cattle (first year and second year) to be rotated around the pasture area. If a mixture of breeds is being finished, the removal of cattle of the small-framed breeds, such as the British beef breeds, part-way through the grazing season will allow the stocking rate to be relaxed to provide more grass for the large-framed, later-maturing breeds, such as the continental breeds.

In a dairy heifer replacement rearing programme, pregnant heifers should be fed concentrate or other feeds in the dairy cow diet before they enter the herd, to encourage the rumen to develop a suitable microflora to digest the post-calving diet. Supplementary magnesium may be needed to avoid hypomagnesaemia in early lactation.

Beef cattle production from conserved feeds

Many producers experience difficulty in obtaining adequate growth rates of beef cattle at pasture, particularly towards the final stages of growth. This is principally because climate variation makes it difficult to plan stocking rates, supplementary feeding levels and fertilizer rates. With intensification of cattle production, some producers have chosen to feed their cattle conserved feed throughout their life. Advances in forage conservation techniques, a good market for the finished product and widespread use internationally of larger cattle breeds with high growth potential have favoured this system. Turbulence in the beef export markets in the latter part of the 20th century, because of the depressed beef market in the wake of the BSE crisis, led to lower-cost systems being favoured, but increasing demand for livestock products in the early 21st century has created favourable situations again for intensive beef production.

Permanent feeding of conserved forage to cattle in pens is particularly appropriate to exploit the growth rate potential of bulls, which would otherwise normally be castrated if they are to be grazed safely. They are usually fed hay until about 12 weeks of age, after which they receive silage as their main forage. Feeding silage can be a problem in warm conditions, since exposing it to air for more than 1 or 2 days risks secondary fermentation. This is less likely to occur if the farm has many animals and several long, narrow silage clamps, from which the silage is removed in neatly cut blocks rather than being pulled out by a tractor with a bucket or fore-end loader, so that the exposed face is minimized. Grass and maize silages are a popular choice, with the latter being of lower protein content and requiring a supplement, such as soybean meal.

Alkali-treated straw is an alternative forage and is equivalent to medium-quality grass silage in terms of its ability to support cattle growth. If ammonia is used to treat the straw, the resulting product will contain much non-protein nitrogen, an adequate nitrogen source for the ruminal bacteria. Supplementary sulfur may be required for rumen microorganisms to grow enough sulfur-containing amino acids, such as methionine and cysteine. If straw alone is used, a non-protein nitrogen product, such as urea, can be poured on to the straw to increase its nitrogen content. Root crops, such as swedes, can be used to replace some of the forage; however, if they comprise more than about one-third of the diet, the high water and low protein contents reduce weight gain.

If forage is of poor quality, producers have the choice of increasing the amount of concentrates fed, to ensure that the cattle finish at 12 months of age (Table 5.5), or to extend the period of finishing. This will reduce forage intake and the time to reach slaughter condition and increase weight gain, stocking rate and profitability (Table 5.6). A cereal-based concentrate is adequate when grass silage is fed, but young cattle will respond particularly well to the inclusion of high-protein feeds that bypass the rumen, though this may be at the expense of later growth (Table 5.7).

Table 5.5. The effects of silage digestibility (D-value) on feed requirements to achieve a growth rate of 800 g/day in steers.

	Silage D-value		
	55	60	65
Rolled barley (t/animal)	0.84	0.59	0.26
Silage (t/animal)	3.4	4.4	5.5

Beef cattle production from cereals

The rapid growth of cattle fed an all-cereal diet can sometimes be utilized to profitably obtain a quick turnover of cattle but, increasingly, cereals are required for feeding to humans or for their more efficient use in feeding to pigs and poultry. In well-managed systems, approximately 6 kg concentrate DM is required for 1 kg of weight gain, compared with about one-half of this quantity in pigs and poultry, even less in fish, but nearly twice as efficient as cattle on forage-based diets. The cereal or lot feeding system has been most viable when both calves and cereals are available at low cost.

Calves are usually weaned early at 5 weeks of age and are then fed an all-concentrate diet. For the next 2 months, the diet should have a crude protein content of 17% for maximum growth, including a source of protein that does not readily degrade in the rumen. At 12 weeks of age the crude protein content can be reduced to 14%, and then at 30 weeks it can be further reduced to 11–12%, which may be provided by rolled barley alone. Roughage is not usually provided, except that cattle may be bedded on straw, enabling them to eat sufficient long fibre to avoid ruminal tympany (bloat). If low-fibre cereals such as maize grain are fed, the inclusion of some fibre in the diet will increase weight gain, provided that it is not more than approximately 20% of the dietary DM by weight. Less than 10% roughage in the dietary DM is likely to result in reduced energy intakes and cattle bloating. Ground maize will predispose to this condition, so it is better to feed whole cobs; and lucerne may also cause bloating. Any changes to the diet should be made gradually, otherwise cattle may reduce their intake and then suffer digestive upsets when intake is restored.

Table 5.6. The performance and profitability of silage-fed beef cattle offered high and low concentrate levels.

	High concentrate	Low concentrate
Concentrate intake (kg/day)	2.3	1.9
Silage DM intake (kg/day)	2.5	2.8
Live weight gain (kg/day)	1.06	0.96
Slaughter weight (kg)	454	444
Finishing period (months)	12	14
Effective stocking rate (no./ha)	10.4	5.6
Relative gross margin (high concentrate = 100)	100	76

Table 5.7. The effects of addition of a high-quality, protein-rich supplement (fishmeal) from weeks 17 to 38 on the weight gain of beef cattle during the early growth period and afterwards.

	2 kg barley	1.9 kg barley + 0.1 kg white fishmeal	1.8 kg barley + 0.2 kg white fishmeal
Live weight gain, 17–38 weeks (kg/day)	1.1	1.2	1.3
Live weight gain, 38 weeks to slaughter (kg/day)	0.9	0.8	0.8

Barley, sorghum and maize are the most common cereals used and should be dried to 14–16% moisture content for optimum conversion efficiency and safe storage. Cereal diets for bulls should have a mineral/vitamin supplement added to them, containing vitamins A and D, salt and limestone. Grain processing should aim to preserve the roughage content of the grain, just breaking the seed coat so that the endosperm is exposed for digestion. Rolling or crimping is best, rather than grinding, which diminishes roughage value of the grains. In the tropics the residual bagasse from the sugarcane plant, after the sugar has been extracted, can be used, but it has a low digestibility. Sugarcane molasses, urea and a source of protein that escapes rumen degradation can replace concentrate successfully.

Many cattle are fed just cereals in their final stages of growth in feedlots, having been reared on more extensive farms. The cereals are important in obtaining a good fat cover on the animals, which the market may require. Feedlots may house any number of cattle from a few hundred to over 100,000. They are most extensively used in the Americas and Australia, where marbling (fat in the muscle tissue) is valued for good eating quality. In the USA there are about 2000 feedlots with a capacity of 1000 head of cattle or more, many of which have contracts with abattoirs to provide animals of certain specifications.

Cattle are often deliberately placed on a high-fibre diet for approximately 30–60 days before they enter a feedlot to receive a high-concentrate finishing ration. Either straw or rough grazing is usually employed for this purpose, but some grain may be fed to familiarize cattle with feedlot diets and conditions to ensure that the change from pasture to concentrate-rich diets goes with minimum physiological stress. The process of preparation for feedlot finishing is known as backgrounding or preconditioning. It is often used to control weight gains so that the cattle are large enough and gain enough muscle and bone before laying down a fat covering and marbling. If cattle are grown at a rapid rate continuously, they will acquire the desired fat cover at a light weight.

Feeding the Dairy Cow

Dairy cows have been selectively bred to produce considerably more milk than required by any calf and, if management is good, they will produce it for three-quarters of their life in the dairy herd. This requires a much greater intake of nutrients than the traditional high-fibre diet of cattle, in particular at the beginning of lactation; so, if changes in cow genetics consistently increase milk yields, nutritionists have to find methods of increasing cows' nutrient intake.

Preparing for lactation

After the end of lactation cows have relatively little time to prepare for the next one – usually only 50–70 days. The longer time is required if cows enter the dry period in poor condition. The rapid transition from lactation to being dry and then returning to lactation requires major hormonal changes and this, coupled with the movement of cows to new groups and surroundings, can easily stress cows and prevent them getting a good start to their next lactation. The management objectives should be to minimize this stress and prepare the cow nutritionally for the production of high milk yields in the early part of the next lactation. Adequate exercise is also important to reduce stress and avoid dystocia and lameness later.

Different feeding regimes are necessary, depending on how close the cow is to calving. Immediately after the cessation of lactation the cow's appetite is good, and medium-quality forage is sufficient for their nutrient requirements. If cows are overfed at this time, they are more likely to develop dystocia and a displaced abomasum. This diet for the 'far-off period' can be maintained until 3 weeks before calving. A high-quality ration should then be offered close to calving, the 'close-up period', when intake is likely to decline by 5%/week in the first 2 weeks, and then by 30% in the week before calving. The more concentrated diet offered close to calving helps to maintain energy intake. The amount of concentrates provided depends on the condition of the cow and the desired milk output but would typically be 2–4 kg/day. In the case of a first-calving heifer, it can be achieved by adding a group of heifers to the milking herd if they are fed concentrate in the parlour, so that they can be fed concentrates when the cows are milked. This makes them associate the visit to the parlour with a food reward and prepares them for milking, rather than them being suddenly faced with the procedure after calving.

Effects of transition feeding on lactation

Feeding a high-nutrient-density diet during the dry period prepares the cow for milk production by: (i) supporting growth of the ruminal papillae, which takes about 5 weeks of exposure to cereals; and (ii) allowing cows to lay down additional body reserves that can be used in early lactation, when the nutrient requirements for milk production exceed those provided from feed intake. The preparation of ruminal papillae is particularly important for first calving (primiparous) cows that may be unable to adapt to a high concentrate:forage ratio, making them prone to metabolic disorders in the early part of their first lactation, particularly laminitis in the hoof. Feeding a total mixed ration, rather than separate concentrate and forage, will help to prevent metabolic upsets.

The disadvantage of high concentrate feeding pre-calving is that cows that are overfat at calving are more likely to develop dystocia and consume less feed post-partum than thin cows. Overfat cows rely more on catabolizing body tissue for their energy and, to some extent, protein requirements, and their low intake and negative energy balance in early lactation makes them less likely to conceive. The time to first ovulation is increased and progesterone secretion reduced, leading to longer inter-calving intervals. Cystic ovarian disease, ketosis, lameness and mastitis are more common.

The herdsperson can assess the energy status of early-lactation cows by condition score change, which should increase gradually to about 3.5 at calving on a 5-point scale. If it exceeds a score of 4.0, then disease problems are more likely to occur. The herdsperson should also know that cows with low feed intakes post-partum have low milk protein contents and there is an increased risk of these diseases if the milk fat:protein ratio exceeds 1.5 for Holstein-Friesian cows in early lactation.

The optimum protein rationing strategy during the dry period is to feed a ration with approximately 13–14% crude protein of low rumen degradability. Cows fed at this level are less likely to mobilize body protein to support the growth of the fetus than cows fed a ration with lower crude protein or high protein degradability. They can, therefore, preserve body protein reserves, which can then be used to maintain milk protein content during early lactation. If a ration with more than 13–14% crude protein is offered during the dry period, the energy cost of detoxifying surplus plasma ammonia by converting it into urea in the liver is significant and wasteful. Ideally, a forage with low protein and energy density should be fed with a protein supplement of low degradability in the rumen. This will allow cows to conserve body protein reserves without becoming overfat, which would be likely if a high-protein/high-energy forage was fed, leading to rapid microbial growth and fat accretion in body stores. Autumn-calving cows are dry in the late summer period, which may coincide with pasture that is high in energy and degradable protein content. Intake can be restricted only by stocking them at a high rate.

The importance of feeding additional concentrates to cows in the dry period also depends on the post-calving diet. If they receive a high-energy diet, perhaps as a total mixed ration, little or no benefit in milk production will be obtained from additional feeding in the dry period. If they are to be fed a diet restricted in energy and protein content during the lactation, additional feed offered during the dry period will help to build up reserves that will be useful in early lactation, but it will make the cows more susceptible to metabolic diseases. It is biologically more efficient to produce all the milk output directly from feed, rather than via stored body tissue, but this may not fit in well with the farming system. In temperate regions, for example, summer-calving cows are likely to have more pasture available and of better quality during the dry period than in early lactation.

Calcium intake requires careful management before and immediately after calving. During early lactation the output of calcium increases dramatically (see Chapter 4, Fig. 4.3) and this may be more than the cow can provide from body stores in the bone tissue. Cows can regulate calcium absorption and limit excretion by the production of parathyroid hormone from the parathyroid glands. If it is possible to restrict calcium intake before calving to approximately 3 g/kg DM, increased parathyroid hormone production will encourage the absorption and reduce the excretion of calcium from the gastrointestinal tract. This gives the peri-parturient cow a greater ability to conserve calcium stores, which is critical during the early lactation period. When non-lactating cows are at pasture during their dry period, calcium intake will often be much greater than this, so parturient hypocalcaemia continues to be a problem in grazing dairy cow systems.

The dietary cation–anion balance affects blood pH and absorption of calcium. A negative balance in the close-up period of approximately −10 meq/100 g creates a mild acidosis, stimulating bone mobilization and releasing calcium into the bloodstream prior to calving. This can be achieved by replacing potassium in the ration with magnesium sulfate or ammonium chloride, but these are unpalatable and unlikely to be eaten unless they are added to a total mixed ration. After calving, a positive balance (ideally +30–40 meq/100 g) will cause a mild alkalosis, conserving calcium for lactation.

The problem of hypocalcaemia is exacerbated by the reduction in feed intake at calving, which reduces calcium absorption to a low level, and by the high milk yields produced in the very early stages of lactation by dairy cows that have been selected for high yields. The problem is extremely rare in beef cows, which give a much lower yield than dairy cows in the first few days of lactation. A particular difficulty in balancing the ration of non-lactating cows occurs with the use of white fishmeal as a supplement, if it can legally be used. Although it is a suitable source of rumen-undegradable protein, which preserves protein stores as described above, it also has a high calcium content and is therefore not suitable in herds with a significant incidence of hypocalcaemia.

Feeding during lactation

Milk output from a dairy farm is often controlled by a contract or quota, so accurate rationing is essential if the farm is to match its milk production with the permitted sales of milk to a processor or retailer. Much research since the late 1950s has been directed at improving the predictability of cows' milk production. For example, given knowledge of the feed quality and intake and the extent of the cow's nutrient reserves, milk production can be estimated quite accurately for intensive production systems with high-producing cows. However, the majority of the world's dairy cows are in small farms in developing countries and much less is understood about these production systems. For these cows the diet is much more likely to comprise mainly by-products, including cereal straws and waste material after cereal processing.

The lactation can be divided into three phases (Fig. 5.2). The first is characterized by a rapid increase in milk production to a peak, with low feed intakes due to the involution or shrinkage of the gastrointestinal tract. There is a more pronounced peak milk yield than in other mammals, or even in beef cows, and it is during this early lactation period when most metabolic and some infectious diseases occur. Taking this into consideration, a future priority for dairy cow breeding will be to develop cows that have a flatter lactation curve, i.e. they do not ascend to such a high peak of milk yield, and a high output is maintained for a longer period of time.

The deficit between the nutrients required for milk production and the nutrients available from feed consumption is met by mobilization of body fat reserves and, to some extent, body protein and mineral stores. Nutrient deficit is primarily caused by the failure of feed intake to increase as rapidly as milk production in early lactation, and so it is not until the second (mid-lactation) phase that peak DM intake is attained and energy balance is restored.

A high-energy diet will accelerate the return to maximum intake, which is one advantage of allocating more concentrates to the early lactation period. An early return to maximum DM intake will advance the nadir of live weight that is usually reached during this second period. Excessive weight loss during this period will reduce both milk yield and the chances of conceiving and maintaining a viable embryo, and will increase the risk of acidosis. If cows have few body reserves, it is unlikely that they will be able to endure a period of underfeeding without milk yield being reduced. If forage for housed cows has to be restricted because of inadequate supplies, both the expected duration and the severity of the restriction should be taken into careful consideration when deciding whether to purchase additional feeds.

In the third phase the early-lactation body tissue losses of up to 80 kg for a high-yielding cow should be regained, probably at about 0.50–0.75 kg/day. The decline in milk yield from its peak, which has been at a rate of about 2.5%/week since peak milk yield, continues and will accelerate if the cow is pregnant.

This is a typical bovine lactation, but in reality every cow is different. First-lactation cows have a flatter lactation curve (Fig. 5.3) because they do not initially have the same milk production potential as multiparous cows and, in addition, they have to divert nutrients to weight gain. Hence the increase up to peak lactation is particularly pronounced for high-yielding, older cows, compared with cows in their first or second lactation,

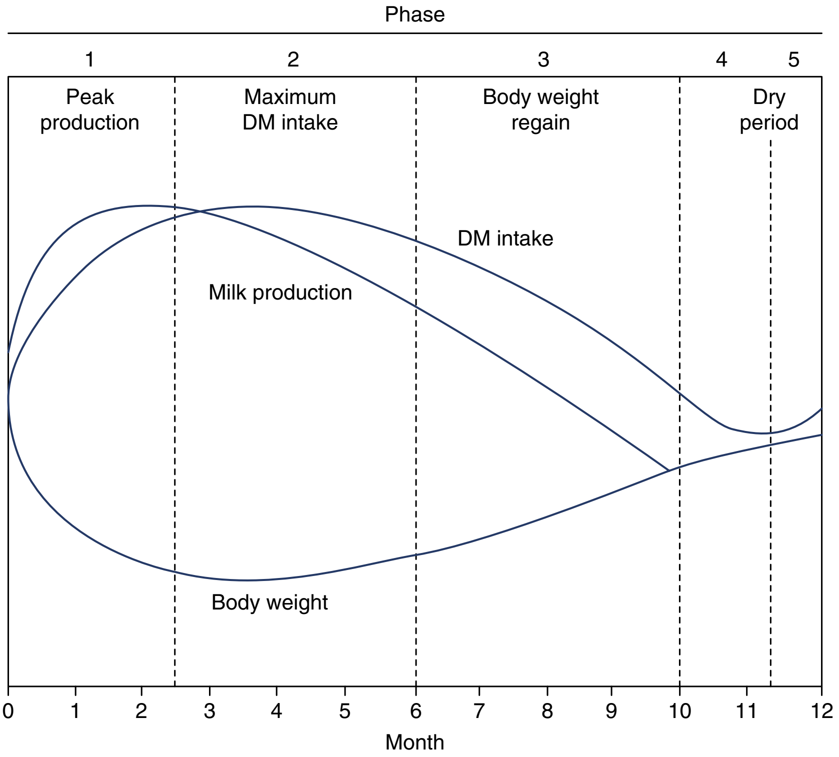

Fig. 5.2. The changes in milk production, dry matter (DM) intake and body weight over the year of a typical dairy cow.

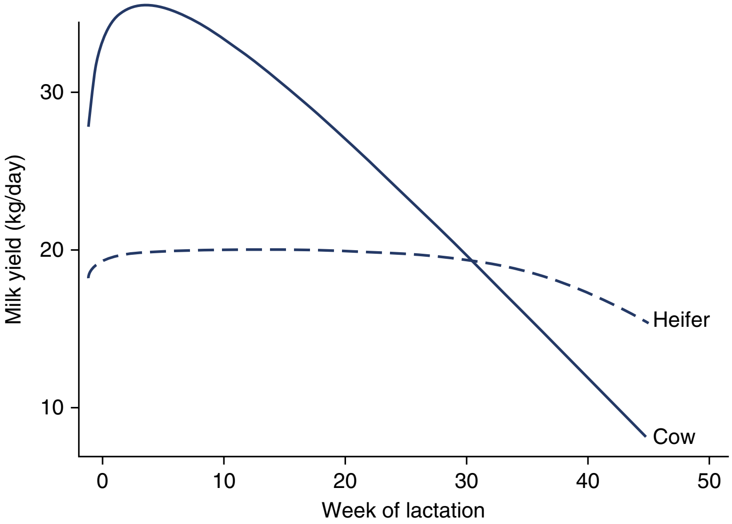

Fig. 5.3. Changes in the level of milk production of cows and heifers during their lactation.

whose lactation is maintained for longer. Total milk yield increases at least until the fourth or fifth parity as cows get heavier and have greater milk-producing capacity (Fig. 5.4). Reductions in yield after this time are more likely to be caused by disease, in particular mastitis, rather than senescence. However, there are many examples of cows continuing to give high milk yields well into their late teens.

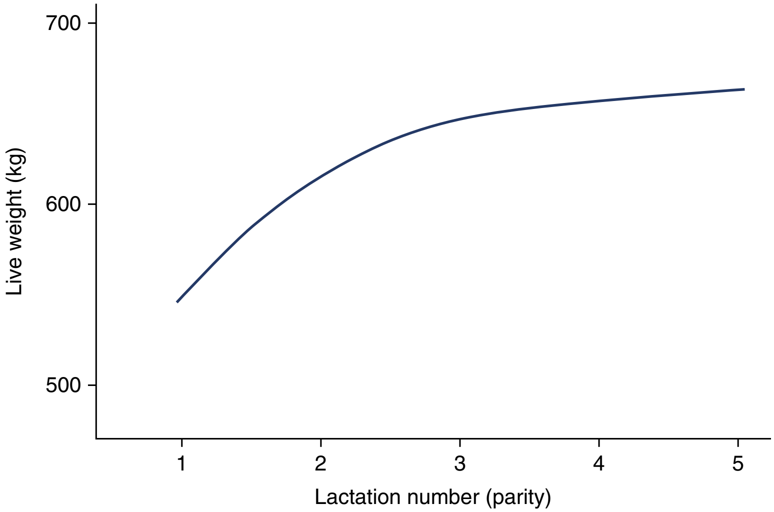

Fig. 5.4. The typical increase in live weight of dairy cows with lactation number.

Nutrition and milk composition

In most situations farmers are paid for milk by: (i) volume; (ii) the content of nutrients of value to humans; and (iii) its cleanliness. All of these are affected by nutrition, and the effects of nutrition on milk yield and quality are intrinsically linked.

Milk fat

Milk fat is produced by both the synthesis of fatty acids in the mammary gland and the absorption and secretion into milk of dietary fatty acids, with the digestion of feeds by microorganisms contributing to modification of the fatty acid profile in feed before it is secreted as milk or stored in the body (Table 5.8). Acetic acid is the main precursor for milk fat synthesis and, as the acetogenic bacteria digest plant cell walls, the fibre content of the diet is the most important determinant of the fat content of the milk. The ratio of lipogenic nutrients (acetic acid, butyric acid and long-chain fatty acids) to glucogenic nutrients (propionic acid, glucose and some amino acids) therefore determines milk fat content, in particular the acetate:propionate ratio (Fig. 5.5). Fibre digestion is impaired if the ruminal pH is less than 6.3, with acid detergent fibre digestibility being reduced by about 4% per 0.1 unit reduction in ruminal pH. Therefore, feeding large quantities of concentrates that are rapidly digested to acid end products in the rumen should be avoided.

Ruminal pH can be maintained by feeding alkali-treated forage or grain, or by stimulating saliva production, which contains sodium- and potassium-based buffers, through feeding forages. Ruminal pH is largely determined by the rate of production and composition of volatile fatty acids and saliva, not by the pH of the feed. A high-yielding dairy cow, producing 300 l saliva/day, will add more than 3 kg of sodium bicarbonate and 1 kg disodium phosphate to the rumen daily.

Table 5.8. The concentration of the major fatty acids in lipids from fresh grass, milk and meat.

Fatty acid	Carbon chain number: number of double bonds	Grass	Milk	Meat
		(g/kg lipid)		
Myristic	14:0	10	120	30
Palmitic	16:0	110	310	260
Stearic	18:0	20	110	140
Oleic	18:1	50	240	470
Linoleic	18:2	120	30	30
Linolenic	18:3	620	10	10

The buffering capacity[2] of the ruminal solids is important in determining ruminal pH. When the rumen is subjected to an acid challenge after heavy concentrate feeding, there is less possibility of milk fat content being reduced if the ruminal contents are able to absorb the acid without the ruminal liquor pH varying too much. The requirement for alkali supplements to counteract low ruminal pH is therefore determined by both the ruminal pH and the buffering capacity of the ruminal contents. Rumen buffers raise the pH to the

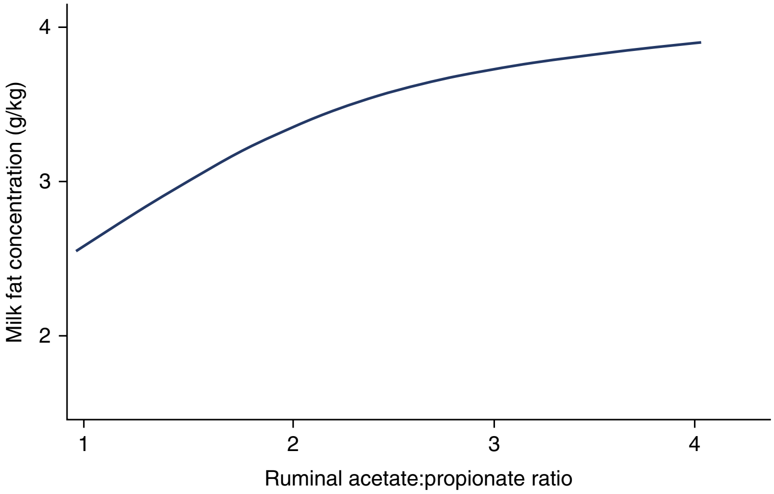

Fig. 5.5. Variation in milk fat concentration with ruminal acetate:propionate ratio.

required level of 6–7 but not beyond. Some alkalis, such as magnesium oxide, are both good acid-consumers and alkalinizing agents, and will increase ruminal pH above 6–7. They are not buffers. Other potential alkalinizing agents, such as limestone, do not dissolve at normal ruminal pH. Sodium bicarbonate is the most commonly used ruminal buffer. Sodium chloride is pH neutral but can still increase ruminal pH by increasing the amount of sodium bicarbonate in saliva.

Milk fat content starts to decline if the proportion of forage in the diet is less than 40%. The reduction becomes increasingly severe if the forage content declines to very low levels: at 10%, the milk fat content is likely to be only 20 g/kg, or just over one-half of the normal content. Some forages have better potential to support milk fat production than others, so a direct measurement of the digestible fibre content of a diet will relate more accurately to its potential for milk fat production. Milk fat reduction occurs when the diet contains less than about 300 g neutral-detergent fibre/kg DM. Two situations in which the forage intake might appear adequate but low-fat milk is produced are: (i) where cows are grazing young, leafy grass with little fibrous stem; and (ii) where the forage has been ground or comminuted to a particle length of less than approximately 0.6–0.7 cm. A total mixed ration is an effective way of avoiding excessive acid production in the rumen and low milk-fat content, as rapid intake of large quantities of concentrate is avoided. Feeding concentrates frequently, perhaps four to six times per day through an out-of-parlour feeder rather than twice per day in the parlour, can also help, but this is not sufficient if the diet is too low in fibre. If a high-concentrate intake is required, it is best to use ingredients with a high content of digestible fibre, such as sugarbeet pulp, rather than a concentrate high in starch, such as cereals. Low-energy diets, such as those based on straw, also restrict milk fat synthesis. High-protein diets reduce milk fat content by increasing milk yield, emphasizing that the effects on composition cannot be considered in isolation from the effects on milk yield.

The incorporation of unsaturated fatty acids into milk is possible if fats are protected from ruminal fermentation. Normally, no more than about 6% of unprotected fat should be included in the diet, otherwise ruminal digestion is adversely affected, in particular because of:

- physical coating of fibres, preventing microbial attack;
- toxic effects on some microorganisms, modifying the ruminal microbial population;
- inhibition of microbial activity due to the effects of fatty acids on cell membranes; and
- reduced cation availability from formation of insoluble complexes with long-chain fatty acids.

Fats are more toxic to ruminal microbes when they are unsaturated, but whole oil seeds may escape rumen digestion when fed to high-yielding dairy cows with rapid rumen turnover and adverse effects on ruminal digestion are therefore minimized. Protecting fat from rumen digestion by complexing it with formaldehyde, or with calcium to form a saponified product, can enable it to be used as an energy supplement and a means of increasing the unsaturated fatty acid content of the milk. Lipid–calcium and lipid–protein complexes are insoluble, and hence undegradable at normal ruminal pH (6–7), but they degrade rapidly in the acid conditions of the abomasum (pH 2–3). If unprotected unsaturated fats are fed, they are mostly hydrogenated in the rumen. The feeding of calcium soaps of unsaturated fatty acids are most likely to avoid degradation in the rumen if ruminal pH is consistently above 6. Rations for high-yielding dairy cows often have a high concentration of rapidly fermented starch, which reduces ruminal pH below 6, resulting in dissociation of the calcium soap. The addition of dietary buffers may then be necessary.

The incorporation of unsaturated fatty acids into milk is likely to reduce the keeping quality of milk, as they are easily oxidized (Liu *et al*., 2010). Free fatty acids, in particular butyric acid resulting from lipolysis, give the milk a rancid flavour. The addition of an antioxidant, such as α-tocopheryl acetate, will lengthen the keeping life of the milk, but in many countries milk cannot have substances added to it before sale. There may be consumer resistance to the addition of antioxidants to milk. In butter, increasing the content of unsaturated fatty acids makes it spread better at low temperatures.

Milk protein

Responses in milk protein concentration to changes in nutrition are less than for milk fat but there is a positive relationship between the dietary energy supply and milk protein content. Energy intake can be increased by increasing concentrate intake or forage quality.

The response in milk protein content is mainly caused by the release of amino acids from being deaminated to supply energy. Cows that are catabolizing body tissue to provide for their energy requirements, therefore, tend to have low milk protein concentrations, as some of the feed protein will be utilized for energy. To maintain milk protein contents of at least 3.0–3.5 g/kg it is preferable for cows to calve at a condition score of no more than 3.0–3.5 so that they eat more. Typically, an increase of ME intake of 10 MJ/day during lactation increases milk protein content by about 0.6 g/kg. However, the response follows a diminishing response curve, with smaller responses in milk protein content at high-energy intakes. An increase in milk protein content is accompanied by an increase in milk yield, making it difficult to increase milk revenue by this method if milk sales are restricted by a quota or volume contract. In some cases high yields can lead to low milk protein levels; for example, the feeding of fat supplements to increase milk yield can reduce milk protein content by up to 3 g/kg.

Cows often have to mobilize body protein during their non-lactating period to sustain the growth of the fetus. This can be avoided by feeding a protein supplement of low rumen degradability at this time, thus preserving body protein for the forthcoming protein requirements for milk production. Additional crude protein fed during lactation will also increase milk protein levels if the ratio of protein to energy intake is optimized for the ruminal bacteria, enabling feed intake to increase. If the ratio of crude protein to ME in the diet is too high, surplus ammonia will be converted into urea and some will pass into the milk to increase the milk non-protein nitrogen content. This is of little value to cheese manufacturers, even though farmers will be paid for it. High milk urea nitrogen is therefore a good indicator of feeding excess protein.

Some amino acids may be deficient for maximum growth of ruminal microorganisms in a high-yielding cow, particularly if she is fed a maize silage-based diet. Supplementation with amino acids that have been protected from ruminal degradation can then give economic responses in milk yield and increased milk protein content. Responses are variable and it is difficult to predict which, if any, amino acids will be in short supply. The essential amino acid methionine is the most likely to be deficient in high-yielding cows, but lysine may be co-limiting if they are fed a maize silage-based diet. Lysine is also catabolized in the mammary gland to support the production of non-essential amino acids. The non-essential amino acid glutamine constitutes 25–30% of the major milk protein, casein. It is also glucogenic and is likely to be deficient for longer than other amino acids at the start of lactation.

The optimization of the amino acid content of the diet could assume considerable importance, as control of nitrogen emissions from cattle has become an important environmental consideration. Feeding the correct amino acid balance for maximum microbial growth and for inclusion in the dietary undegraded protein is important, rather than assuming that excess nitrogenous compounds can be excreted or partially recycled. Typical essential amino acid contents in the major cattle feeds are shown in Table 5.9.

Table 5.9. Concentrations of some essential amino acids (percentage of crude protein) in typical cattle feeds.

	Soybean meal	Maize gluten feed	Maize gluten meal	Dried distillers' grains	Dried brewers' grains	Fishmeal	Barley	Maize silage	Grass silage
Methionine	1.5	2.4	3.2	1.9	2.2	2.9	1.6	0.9	1.2
Lysine	6.6	2.9	1.7	2.2	3.2	7.6	4.6	1.8	3.4
Isoleucine	5.7	4.3	3.8	3.7	7.2	4.6	3.7	2.8	4.7
Valine	5.5	5.0	4.5	4.8	6.1	5.5	5.4	3.7	6.0
Leucine	7.7	9.1	15.7	11.1	11.5	5.1	7.0	6.5	3.5

Minerals in milk

The concentrations of some minerals in milk reflect blood plasma concentrations, and often dietary status, but the epithelial cells can act as a barrier or may transport the minerals after complexing with organic compounds. Most calcium is organically bound with casein, phosphate or citrate. The concentrations of iron and copper are homeostatically regulated and plasma concentrations do not affect milk concentrations. Hence, concentrations of the main iron compounds in blood – haemoglobin and ferritin – do not influence milk iron concentrations. Milk sodium and zinc concentration are also homeostatically regulated but a severe deficiency can reduce milk concentrations. By contrast, selenium, which is of major importance for human nutrition, is not homeostatically regulated and therefore milk concentrations reflect those in plasma.

Vitamins in milk

Vitamins are transferred unchanged from blood to milk, so increases in a cow's vitamin status are reflected in higher milk vitamin concentrations, particularly the fat-soluble vitamins. The most important vitamins in milk are A, B_2 and B_{12}. Reducing the fat content of milk reduces the concentration of A but not of B_2 or B_{12}. In regions where soil cobalt is deficient or marginal, there can be reduced growth of suckling calves with vitamin B_{12} deficiency.

Taints in the milk from feeding

Milk readily acquires taints or flavours from the cattle feed, particularly if it is collected in an 'open' system, i.e. exposed to the environment, by collecting into cans in the cowshed and transferred to churns. Brassicas and beets may produce a taint if fed within 3 h of milking and they are better fed after milking. Other strong-smelling plants, such as wild onion or stinking mayweed, can taint the milk, particularly if cows are short of grass and eating near hedgerows. Feeding practices that lead to acetonaemia should be avoided, as this can taint the milk with a pear-drop taste, and silage that has fermented to produce butyric acid can also produce milk taints.

Feeding by-products can reduce the quality and stability of milk. For example, brewers' grains have high concentrations of unsaturated fatty acids and a high level of trans-fatty acids, which affects the stability of milk by making it susceptible to oxidation. High levels of transition metals in feeds can promote this oxidation, through decomposition of lipid hydroperoxides. Flavours are easily transferred from by-products to milk.

In developing countries, the distribution and storage conditions for feeds are often inadequate to avoid adverse effects on feed and milk quality, especially under the extreme temperature conditions found in the tropics. Unsaturated fatty acids in the milk especially may oxidize and cause undesirable flavours. Metals can precipitate oxidation, but addition of antioxidants such as vitamin E retard the reaction. Some metal containers for milk storage may themselves add undesirable metallic taints to milk.

Feeds for dairy cows

Silage

The nutrient requirements of dairy cows are usually greater than those of beef cattle. In regions where insufficient pasture is available all year, farmers conserve surplus growth to feed to dairy cows when it is either too cold for grass to grow or too dry. In temperate conditions, most of the surplus is conserved as grass silage, which is cut at a younger stage of growth than hay and, therefore, tends to be more nutritious. In the humid tropics, making good-quality silage is difficult for a number of reasons: (i) the high temperature and humidity make controlling the fermentation difficult; (ii) the high fibre contents of tropical grasses make it difficult to chop them finely enough to exclude oxygen; (iii) low digestibility limits the fall in pH; and (iv) legumes have buffering systems that impede the fall in pH needed to preserve as silage. In subsistence farming regions of the tropics, the equipment and facilities for silage making are often not available, so hay making is more usual. Nevertheless, the intensification of cattle production in some tropical regions has led to investment in silage-making facilities.

The digestibility of silage in the cow's gastrointestinal tract is one of the most important factors influencing its value to dairy cows for milk production. This is mainly determined by the age of the grass at cutting but a rapid fermentation (with an additive, if necessary) and efficient sealing of the clamp are also important in producing grass silage of high palatability and digestibility. Additives will be required if silage is wet, or not finely chopped, and if it has a low sugar content, to sustain a rapid anaerobic fermentation. Three main types of additive are used: soluble sugars, inoculants (both of which act by encouraging the bacterial fermentation) and acids, which simulate the end products of fermentation to prevent further degradation of the grass. Acid additives may be combined with the sterilizing agent formaldehyde to ensure that further fermentation is prevented.

The preferred type of fermentation is by lactic-acid-producing bacteria, which cause a rapid reduction in pH and stable conditions in the ensiled material. If air is not squeezed out of the silage after it has been put into the clamp and if the sealing of the clamp is not sufficient to exclude air, then clostridial bacteria may multiply. The butyric acid produced is weaker than lactic acid and fermentation is slower with more extensive breakdown of protein. Usually about 40% of the crude protein is true protein, but it is the composition of the non-protein nitrogen that is the best indicator of silage fermentation quality. In well-made silage, only 5–12% of the non-protein nitrogen is in the form of ammonia; in 'butyric' silage this may be 20–30% and thus the proportion of non-protein nitrogen that is ammonia is used as an indicator of silage quality.

Once the clamp is opened for feeding and exposed to air, there is a risk of bacteria or fungi fermenting the crop, with associated loss of digestible material and, in some cases, a health risk to the cattle consuming the silage. A tower silo minimizes exposure of the silage to air and the weather during feeding but at a much greater cost than silage 'clamped' between walls made of concrete, wood or earth. Silage clamps should ideally have a concrete floor, which is hardwearing but likely to be eroded by the acids in the effluent. An earth floor allows the effluent to seep away but the silage fed to the cattle may be contaminated with earth. Only high-DM silage can be stored in tower silos and there may be significant field losses if the grass has to be dried slowly in damp conditions in the field.

Grass for silage may be cut up to four times each summer in temperate conditions but more normally only two cuts are taken, which provides a fresh area for grazing, or aftermath, at the end of the grazing season. This allows the stocking rate to be relaxed at this time, when grass growth is slow. The more frequent the cutting, the greater is the digestibility of the silage, since the grass will be cut at a younger stage of growth. When considered over the same period of the grazing season, a frequent cutting system provides flexibility in the availability of aftermaths but reduced yields of high-quality silage (Table 5.10). This will often lead to greater milk

Table 5.10. A comparison of grass growth, dairy cow performance and profitability of two- and three-cut systems of silage conservation.

	Two-cut	Three-cut
Herbage yield[a] (t DM/ha)	9.3	7.8
Herbage ME content (MJ/kg DM)	9.3	11.1
Utilized ME from herbage (GJ/ha)	91	84
Silage DM intake (kg per cow)	9.3	10.1
Milk yield (kg per cow)	19.5	20.7
Live weight gain (kg/day)	0.24	0.36
Cow feeding days/ha	1,020	800
Milk yield (kg/ha)	19,707	16,457
Relative margin[b] per cow	83	100
Relative margin[b] per ha	107	100

[a] After field and storage losses have been deducted.
[b] After purchased feed has been deducted.
DM = dry matter; ME = metabolizable energy.

output and profit margin per cow but the increased intake per cow can reduce the number of cow feeding days. An increase in the digestible organic matter concentration in the DM (D-value) of 10 g/kg will increase silage DM intake by approximately 0.25 kg and milk yield by 1.3 kg. About one-half of this increase in milk yield comes from increased intake and the other half from increased digestibility.

It is not just the digestibility of the silage that indicates whether the cows will produce high milk yields. Quality is also indicated by the fermentation and DM characteristics. If the DM content is less than about 180 g/kg, DM intake is reduced and effluent losses from the clamp are considerable (Vérité and Journet, 1970). Wilting grass before it is ensiled will help to reduce the effluent production and the weight of material that has to be transported to the silo. Wilted silage is therefore often of better quality than direct-cut silage, leading to increased DM intakes and milk yields.

Grass cut for silage may be chopped to varying degrees by the harvesting machine before ensiling (single-chop, double-chop and precision/fine-chopped, producing particles that are approximately 10 cm, 5 cm and 1 cm long, respectively). The fermentation is usually better with precision-chopped material, as it is easier to exclude air by rolling with a tractor after it has been put into the clamp. Heavily consolidated precision-chopped silage can be difficult for cows to remove from a self-feed clamp, especially if they are heifers losing their milk teeth.

Maize silage has several advantages over grass silage: (i) manure can be applied in large quantities before planting and less nitrogen is therefore required; (ii) only one harvest is needed, at the end of the growing season, compared with two to three for grass silage; and (iii) ME content is high, though protein content is less than grass silage (Table 5.11). However, the water requirements of the maize crop are high, limiting its geographical range. The same machinery can be used for harvesting and feeding as for grass silage. If the maize is left to become mature before harvesting, more of the energy is in the cob and the rest of the plant is of low digestibility.

Table 5.11. The composition of typical maize and grass silages.

	Grass silage	Maize silage
Dry matter (g/kg)	18–30	25–35
Metabolizable energy (MJ/kg DM)	10	11
Crude protein (g/kg DM)	17	10
Crude fibre (g/kg DM)	30	20

In the tropics, high temperatures allow the maize crop to mature rapidly. Whole-crop silage is most common in developed countries with industrialized dairy production. In developing countries the cobs are usually harvested for human consumption or to provide feed supplements for pigs, leaving a fodder residue that can be either chopped and fed directly to cattle or grazed *in situ* by the cattle during the dry season. It does not provide sufficient energy for high milk yields or even support high growth rates in beef cattle, but it will sustain cattle during a dry season when there is often little other fodder available.

In temperate regions, maize for silage is usually harvested when the grain is at the medium to hard dough stage and the DM content of the crop is about 300 g/kg, which represents a good compromise between yield and quality. Earlier-maturing varieties are extending the range of latitudes in which maize silage can be grown.

FEEDING SILAGE. The silage intake of groups of cows must be monitored so that average individual intakes can be calculated. In high-production systems silage is usually fed *ad libitum* so that cows always have some available. In traditional feeding systems in byres, it was possible to monitor individual intakes; however, most cattle are now fed in loose-housed groups. After the silage has been made, the farmer should assess its weight to determine whether enough is available to meet cows' intake requirements for the year. If the silage is clamped, this can be determined from knowledge of the size of the clamp and the density of silage within it.

Silage can be taken directly from a clamp by the cows (self-feeding), or it can be mechanically taken from the clamp and fed directly to the cows. Self-fed silage, usually regulated by a barrier or electrified bar suspended from angle-iron driven into the silage, is a low-cost alternative. The rate at which these barriers move forward determines how much silage the cattle are allowed. The angle-iron should be driven further into the silage at daily or twice-daily intervals, providing fresh silage each time. Electrified barriers frighten some cows, reducing their intake. Young cattle are most likely to be timid about feeding and often visit the feed face at night. To minimize any constraint on young cattle feeding, the silage face should be sufficiently wide to provide at least 150 mm of face width per animal and it should be lit throughout the night. Self-feed silage is a low-cost system that requires regular management but keeps the cows occupied in 'vertical grazing'.

Mechanical extraction of silage from a clamp is usually in cuboid blocks with a block-cutting machine, or it can be teased from the clamp by a fore-end loader, which has the disadvantage that air will enter both the extracted silage and the clamp, accelerating secondary fermentation in warm conditions. Silage is usually then fed along a passageway or in a circular feeder. If fed in a passageway, cows should be restrained behind a barrier that allows them to put their heads through to feed but not to walk on the silage or pull their heads back through the barrier while they are still eating, to prevent waste. This is usually achieved by having a tombstone or diagonal bar configuration on the upper half of the barrier (see Chapter 8, Fig. 8.3). Cows must lift or twist their heads before they can withdraw them from tombstone and diagonal barriers, respectively.

In passageway feeding systems, aggression and other deleterious behaviours are encouraged by the short time spent feeding (approximately 6 h, compared with 7–8 h for self-feeding and 9–11 h for grazing) and the lack of comfortable lying areas. Any advantage of reduced labour and machinery for feeding may be offset by having a large area to clean, which produces dirty water that has to be disposed of safely. Passageway feeding is used to achieve high intakes, especially since it is suitable for combining silage and concentrates together in a total mixed ration (TMR). A forage wagon can be used to feed just silage or to create a simple mixture of feeds. TMR is made up in mixer wagons, described later in this chapter. The forage wagon delivers feed alongside a barrier and a simple mixed diet can be made by layering concentrates and silage on top of each other, but it will not be well enough mixed to ensure that a diet of equal concentrate:forage ratio is consumed by all cows. The simplicity, however, is attractive. Some ingredients, such as rumen-undegraded protein or mineral/vitamin supplements, need to be accurately rationed to cows, otherwise they may cause metabolic disturbances. These might be rationed to the cows through individual feeders either outside or inside the parlour.

A further option for feeding silage that is popular on small farms is to wrap silage bales with three or four layers of plastic, or place it in a plastic bag. Silage made in this way loses less effluent and the fermentation is restricted. It can be offered in a circular feeder on a concrete standing or in a 'sacrifice field'. This method of feeding silage can also be used to supplement grazing cattle and the feeder is moved when damage to the sward occurs.

Hay

Hay is grass that has been preserved by removing the moisture that microorganisms require for survival. This is usually achieved by drying the crop in the sun for up to 5 days, with regular turning by mechanical or manual means to accelerate desiccation. This laborious process has resulted in a decline in the popularity of haymaking on many intensive cattle farms because of improvements in silage-making machinery and increases in herd size. Silage is more suitable for feeding to large numbers of cattle, as machinery is readily available that can conserve and feed large quantities rapidly. Hay can be made into small bales of about 20 kg, which are suitable for human handling, or large bales of 500–1000 kg, which are handled mechanically. Hay is usually made in one harvest of mature grass, since the grass naturally declines in moisture content as it matures, reducing the need for field operations. This harvest is usually taken about halfway through the grazing season. Excessively long field-drying risks leaf shatter and loss to the ground, and the remaining hay will be of low feeding value. Energy losses from the grass plant are high during haymaking because of continued plant respiration. However, if the same grass is used to make either hay or silage, the protein value of the hay would usually be greater than that of silage, because there is less protein denaturation during the conservation process.

Grass can be artificially dried in a barn with forced air. This reduces energy losses in the plant, with less leaching, respiration and bleaching of nutrients than a field crop, but has high energy requirements for drying. The end product is of better quality than field-dried hay and safer, because field hay is often baled before it is properly dry and moulds form in storage. Mouldy hay causes an illness in humans called farmer's lung, which is an immune complex hypersensitivity, and in cattle it can cause abortion. When people handling hay contract farmer's lung, antigens stimulate antibody production by the immune system, which react with further antigens to form immune complexes. These activate complement and attract phagocytes, which release lysosomal enzymes, causing tissue damage. To avoid this, hay should contain less than 17% moisture in storage.

Straw

In many parts of the world, straw or other crop residues, such as maize stover, are important feeds for cattle, particularly beef cattle. These are the stems and leaves of plants that are left over after the grain has been removed for human consumption. The available energy content is low, as most of the energy is locked up in the form of cellulose and other structural carbohydrates that are lignified. Cattle will have low intakes of straw because its rate of breakdown in the rumen is slow. The protein content of straw is much less than that required by most milk-producing or growing cattle, often only 40 g/kg DM. The content of minerals and vitamins is also low.

For high-yielding dairy cows straw is only valuable if a supplement that provides fibre to maintain ruminal function and animal health is needed. Most cows will consume some of their bedding in a straw yard, but it contributes little to their energy requirements. Straw cannot be included at more than 20% of DM intake in the diet of highly productive cattle without milk yield suffering otherwise ruminal turnover and microorganism degradation of forages will decline. The energy value of straw that is normally given in feed tables (6 MJ/kg DM) may even be too high in these circumstances.

Straw can be improved by treating it with chemicals, especially alkali agents such as sodium hydroxide or ammonia (Sarnklong *et al.*, 2010). These reduce the lignification of the structural carbohydrate, increasing breakdown by ruminal microorganisms. The cost is often high and the availability and corrosive nature of the chemicals are often a problem. In developing countries, urine can be used as an ammonia source, and ammonia-treated straw has been successfully used in India and Sri Lanka. Techniques of pre-digestion with microorganisms may surpass chemical treatment in both effectiveness and economic viability.

Straw can be harvested together with the cereal grain in the form of 'whole-crop' or arable silage. This is more common for maize than for either barley or wheat. In theory, harvesting costs can be reduced and high DM yields can be achieved, but there is a risk of significant losses during processing and/or storage. The system is less flexible than if the grain and straw are harvested separately. In addition, not all the grain will be utilized by the animal, because it is less processed than when it is harvested separately. In the tropics, treatment with urea before ensiling will improve preservation.

Concentrated feeds

Concentrated feeds, or concentrates, are based on cereals or other high-energy and protein feeds. They are usually compounded into a pellet, sometimes with the addition of a binding agent such as sugarcane molasses, but usually the combination of sugar caramelization and starch gelatinization holds the pellet together. Pellets are brought on to the farm either in bags or loose, then delivered by an auger into a feed bin. The cost of these processes makes compound pellets an expensive form of cattle feed per unit of energy or protein.

Dairy farmers must decide how much concentrated feed to provide and how to distribute it over the lactation. Dairy cows can give yields of 7000 l per lactation on high-quality forage alone, but in most situations there is an economic response to providing at least a low level of concentrates. In developing countries, fewer concentrate supplements are fed than in the industrialized countries, and they are often of lower quality or comprise mainly by-products, because cereals are relatively expensive and are reserved mainly for feeding to humans. The shortage of energy supplements in particular restricts milk output in these regions. Worldwide, the increasing human population and alternative uses of high-energy products for fuel are forcing a re-evaluation of the desirability of feeding large quantities of cereals to cattle.

In deciding whether enough concentrate feed is being fed to dairy cows, a farmer should estimate the anticipated increase in milk yield and determine a break-even point where additional concentrate feed would provide no additional financial return (Fig. 5.6). However, feeding additional concentrates will do more than simply increase milk yield and the farmer should consider the changes in milk composition and savings in forage when concentrate intake is increased.

With increased concentrate feeding, milk fat content will progressively decline and, to a lesser extent, protein content will increase, as the ratio of glucogenic to lipogenic precursors increases. However, at most levels of concentrate intake, both milk fat and protein *yields* increase with concentrate intake. At very high intakes, perhaps in excess of approximately 12 kg/day, the ruminal fermentation suffers from excessive acid production, leading to a rapid decline in milk fat content with additional concentrate, and milk fat yield declines (termed low milk fat syndrome). This will be an uneconomical level of concentrate to feed to cows.

The saving in forage when concentrate supplements are fed should enable the stocking rate of cattle on the farm to be increased. However, in dairy cows under a milk production contract or quota, this will increase milk output and may cause the farm to exceed its quota.

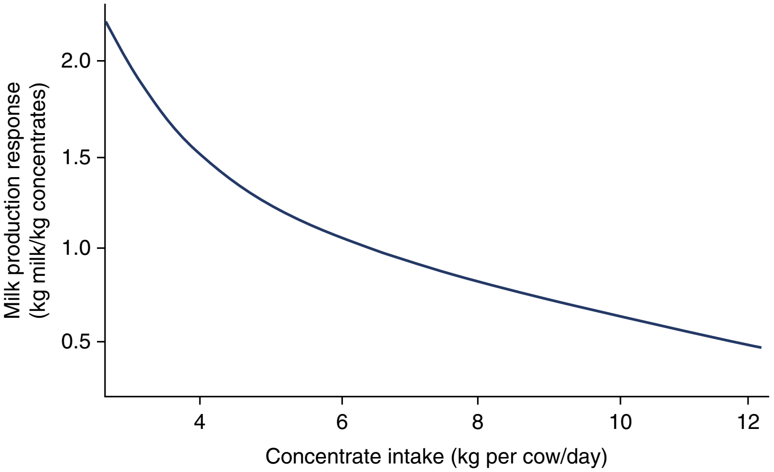

Fig. 5.6. The additional milk produced per kilogram of concentrate provided at different levels of feeding a typical dairy cow.

In this situation alternative enterprises, such as a beef production unit, may utilize some of the land. The dairy farm manager must decide how to maximize income to the farm and this will entail looking at responses to the different resources on the farm, in particular the most limiting ones (Table 5.12).

Farm studies have demonstrated the effects on farm profitability of feeding different levels of concentrates to Friesian dairy cows (Leaver and Fraser, 1987). Although the relative profitability depends on the prevailing economic situation, in particular the cost of the major resources in relation to the value of the output, feeding additional concentrates would be expected to increase the gross margin per hectare (largely because stocking density increases) and reduce the gross margin per litre (because feed cost per litre increases). Under strict contract or quota limitations, therefore, farmers are likely to feed low levels of concentrates, but if the land area of a farm is restricted the farmer may prefer to feed more. The output per cow is likely to be particularly important to farmers keeping pedigree cattle for sale, because large amounts of concentrates increase the cows' performance, encouraging other farmers to purchase the cattle.

Emissions of major pollutants, especially methane and nitrogen, are likely to be affected by the concentrate feeding regime. Increasing the quantity fed per cow will increase methane output but, because of increased milk yield, output per litre may decrease (Table 5.13). Concentrate manufacture, delivery and feeding to cows all have greenhouse gas implications, which may negate any benefit of high concentrate feeding systems. The output of nitrogen, mainly in urine, is likely to be increased at high concentrate intakes and is also increased in relation to milk output.

Table 5.12. Annual performance, profitability and emissions of dairy cows in two 'farmlets' fed contrasting levels of concentrates (from Leaver and Fraser, 1987).

	Concentrate level	
	High	Low
Concentrate intake (t/year/cow)	2.2	1.0
Milk yield (kg/cow)	6000	5100
Milk fat content (g/kg)	40.0	40.8
Milk protein content (g/kg)	34.8	33.8
Relative gross margin[a]/cow	100	104
Stocking rate (cows/ha)	2.61	2.15
Relative gross margin[a]/ha	100	79
Relative gross margin[a]/l	100	116

[a] Total income minus variable costs, including purchased feeds.

In traditional systems where cows are individually tethered in stalls, the forage allocation is usually restricted because it has to be delivered to each cow by hand. Hay is often fed rather than silage and, because it is usually of lower quality than silage, the forage will often provide less than the energy requirements for maintenance of the cow. In these circumstances, increasing the concentrate allocation results in a major increase in milk yield, because the additional concentrate acts as a true supplement, rather than simply substituting for forage. Potentially, each 1 kg of concentrate is able to supply the energy requirements for 2.5 l of milk, but not all the concentrate is used for milk production. The response in milk yield is greater from early-lactation cows, because they allocate more of the nutrients to milk production and less to weight gain.

Table 5.13. Methane and nitrogen output from dairy cows fed low- and high-concentrate rations.

	Low concentrate	High concentrate
Concentrate intake (kg DM/day)[a]	1.0	5.2
Grass intake (kg DM/day)[a]	16.9	16.3
Total intake (kg DM/day)[a]	17.8	21.5
Milk yield (kg/day)[a]	17.6	21.5
Methane output (g/cow/day)[a]	346	399
Methane output (g/l fat-corrected milk/day)[a]	19.3	16.0
Nitrogen intake (g/day)[b]	499	618
Nitrogen excreted (g/day)[b]	355	467
Nitrogen excreted (g/l/day)[b]	12.9	14.5

[a] Lovett *et al.* (2005).
[b] Mulligan *et al.* (2004).

In restricted-forage systems it is beneficial to allocate more of the total concentrate ration for the lactation to cows in early lactation.

In loose-housing systems, forage is often fed mechanically *ad libitum* and concentrates are fed individually, either in the parlour or in the barn. In this case, additional concentrates will substitute for some of the forage intake and the total intake will not increase as much as when forage is fed at a restricted rate. There is little benefit in offering extra concentrates to cows in early lactation, because the substitution rate is greater in early lactation than later, when appetite has increased.

The allocation of concentrates to dairy cows should take account of their physiological state: lactating or non-lactating, pregnant or non-pregnant. Most dairy farmers prefer to feed more concentrates to those cows giving the most milk, even though loose-housed cows fed high-quality forage *ad libitum* produce similar responses regardless of their level of milk production. Cows may produce different amounts of milk either because they have a different genetic potential for milk production or because they are at different stages of lactation. As intake of all nutrients (but especially energy) increases, milk yield increases up to a certain level of intake, after which no further increase can be obtained from greater nutrient intakes (Fig. 5.7). Extra nutrients

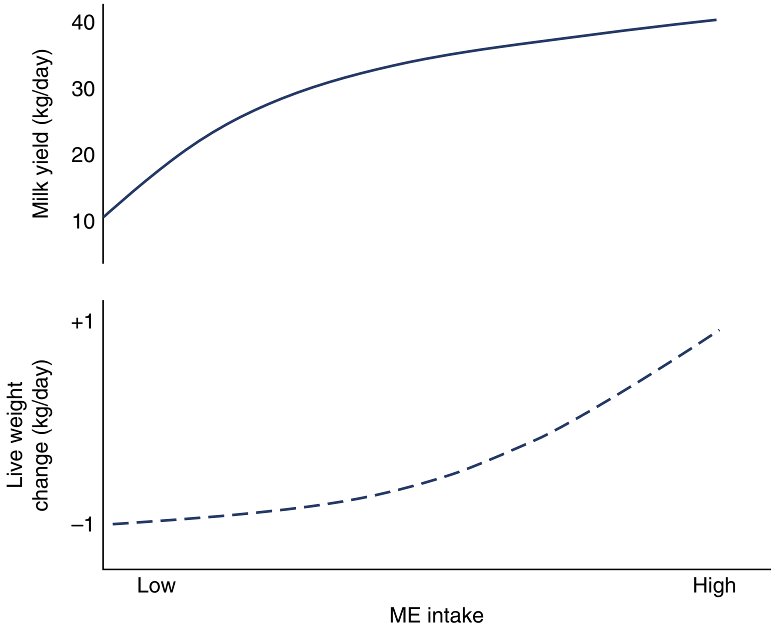

Fig. 5.7. Responses in milk yield (——) and live weight (- - -) of a typical dairy cow to increasing metabolizable energy (ME) intake.

are either stored in body tissue, to be used at a later date, or excreted. As shown in Fig. 5.8, if the responses of a high- and low-yielding cow to an increase in ME intake are compared, they are the same for both cows, but at high energy intakes an increase in energy supply may produce a response from the high-yielding cow but not from the low-yielding cow.

Even though the response of high-yielding cows to increased energy supply from concentrates may be offset by a similar reduction in low-yielding cows if they receive fewer concentrates, it may be worthwhile allocating rumen-protected protein and mineral/vitamin supplements solely to cows with high yields. Whereas additional energy can be stored as body lipids, this is not so universally true for protein that is undegraded in the rumen and some minerals. Both are required mainly by high-yielding cows, which will benefit from an additional supplement, particularly if they have enough body condition to use lipid catabolysis to provide some of the necessary energy requirements.

The allocation of concentrates to cows that are of different genetic potential should not be confused with that for cows that are high or low yielding because of their stage of lactation. If all the cows are offered the same concentrate allocation at the same (flat) rate, the reduced allocation in early lactation – relative to cows fed according to their milk yield – will be partly compensated for by increased silage intake. Feeding according to milk yield has the potential to overfeed concentrates in early lactation. This is because: (i) fewer nutrients are required to produce each 1 l of milk in early lactation, as it contains less fat and protein at this stage; and (ii) in early lactation cows mobilize body fat accumulated during the non-lactating period.

Feeding too much concentrate in early lactation can lead to inadequate fibre intakes, low milk fat concentrations, acidosis and laminitis. Thus feeding to yield is less suitable for high-concentrate feeding systems, because the cow consumes insufficient fibre in early lactation. However, a high concentrate:forage ratio enables cows to achieve peak energy intake sooner than a cow fed a high-forage ration. This leads to a reversal of the negative energy balance at an early stage of the lactation and a greater chance of the cow becoming pregnant again. Thus a low, flat rate of concentrates fed throughout the lactation may underfeed cows in early lactation, compared with feeding to yield, if the forage is of poor quality or restricted in availability.

While acknowledging that flat-rate feeding systems may theoretically be better for cows fed a high level of

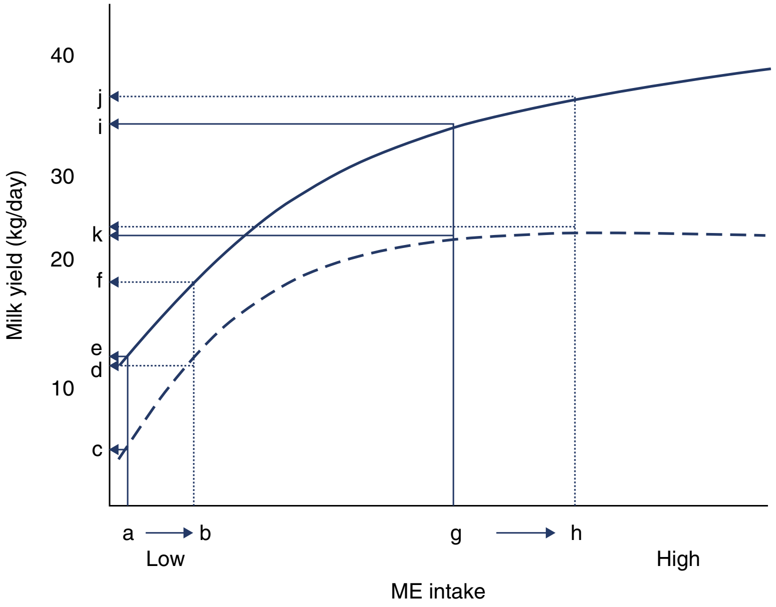

Fig. 5.8. Theoretical responses of a high-yielding cow (——) and a low-yielding cow (- - - -) to increases in metabolizable energy (ME) intake, at both a low level of intake (a → b) and a high level (g → h). At the low level of intake, milk yield increases from c to d for the low-yielding cow and from e to f for the high-yielding cow. At the high level of intake, absence of response in the low-yielding cow is indicated at k; whereas the high-yielding cow increases her yield from i to j.

concentrates over the lactation, forage quality and quantity must be considered in determining concentrate feeding policy. Autumn-calving cows that are fed conserved forage during winter and turned out to pasture in spring are in mid- to late lactation by turnout, and farmers reduce the concentrate allocation at this time if there is good-quality grass available. Spring-calving cows will usually be offered a reduced concentrate ration when they are housed in the autumn because they are in mid- to late lactation.

Under temperate conditions, summer-calving cows are likely to require most concentrate supplement overall, as grass in late summer is not sufficient to support high yields in early lactation, and they will then usually lactate through the winter on a silage/concentrate mixture. However, in most countries, the milk price is increased in periods when there is little fresh feed available for the cows, depending on the ease of providing conserved feed. For example, in sub-Saharan Africa, the milk price typically doubles during the winter dry season; and in temperate systems a greater milk price is offered in late summer because of the shortage of grazed grass at this time and a reluctance of farmers to start providing their feed conserved for the winter.

Feeding all the cows their concentrates at a flat rate through the winter or dry season has the advantage of simplicity and it can be fed on top of, or mixed in with, their forage, rather than through individual feeders in the parlour or cow housing. If individual feeders are used for feeding concentrates according to milk yield, a regular check should be made that the correct quantities of concentrates are delivered by the feeder, and that once released from the feeder the concentrates are consumed by the cow that programmed their delivery, not another cow that enters afterwards. Small cows have limited capacity to consume concentrates in the parlour, probably no more than 3–4 kg in the time that they spend being milked, which is about 5 min.

Cows can be fed approximately according to their yield by grouping them into high-, medium- and low-yielding groups and a non-lactating group, which are fed a progressively reduced level of concentrates in a total mixed ration. As the lactation advances, cows will be moved from the first group to the last, producing a feeding pattern where the concentrate feeding rate is stepped down on two or three occasions. Disadvantages of this ‘stepped’ feeding system are that the regular movement of cows between groups upsets their social order, and sudden, large changes in concentrate allocation may disrupt ruminal function.

The risk of upsetting ruminal digestion with high-concentrate diets and causing low milk fat concentrations or, at worst, acidosis has led to the use of digestible fibre, such as from beets, in concentrates rather than starch from cereals. The starch in compound pellets is exposed to rapid degradation by the ruminal bacteria. Also concentrates may be fed at a low level several times during the day, rather than just twice during visits to the parlour. This will help both to eliminate those bursts of acid production by the ruminal bacteria that reduce the efficiency of ruminal function and to improve the efficiency of capture of ammonia, by ensuring a more even degradation of the concentrate feed over time. Out-of-parlour concentrate feeders can be programmed to offer each cow her daily concentrate feed in several doses, usually four, available at 6 h intervals. Cows in such a system know quite accurately when the 6 h have ended and it is time for a new allocation, as they can be seen waiting at the feeder. Concentrates can be provided at the same time as automatic milking to encourage cows to be milked more frequently.

Total mixed rations

A TMR is a mixture of feeds that provides the sole source of nutrients for cattle. Nutrients may be utilized more efficiently than when fed separately, especially if high levels of concentrated ingredients are fed, which are then digested more slowly. This reduces the risk of ruminal acidosis. Typical diet formulations for early-, mid- and late-lactation/dry cows are given in Table 5.14.

Table 5.14. Diet formulations for early-, mid- and late-lactation/dry cows.

	Lactation stage		
	Early	Mid	Late/dry
Yield level (kg/day/cow)	30–40	20	10
Forage DM as proportion of total DM	0.3	0.5	0.7
Dietary concentrations: Energy density (MJ/kg DM)	12	11	10
Crude protein (g/kg DM)	17	14	12
Modified acid-detergent fibre (g/kg DM)	16	25	30
Calcium (g/kg DM)	8	6	5
Phosphorus (g/kg DM)	4.5	3.5	3.0
Magnesium (g/kg DM)	1.8	1.5	1.5
Sodium (g/kg DM)	1.8	1.5	1.5

TMRs are usually a mixture of forage, especially silage, and concentrated ingredients, made up in a mixer wagon with a capacity of about 3 t. Mixer wagons mix, chop and weigh the diet before feeding. The TMR is usually made by loading cereal supplements or by-products after putting in the main ingredient: silage or haylage. The internal mixing system comprises either internal agitators (paddles) that mix the diet well in a vertical plane but not horizontally (this can be a problem when small quantities of a mineral/vitamin supplement are added to the mix), or opposing screw augers that move the feed backwards and forwards. Screw augers are likely to compress a wet feed, which then becomes blocked at one end of the wagon. Paddles tease out the feed and are better for handling wet feeds.

Cows should not be able to select individual feed items from a TMR, except larger feed ingredients, such as potatoes. If there is variation in the consistency of the total mixed ration, it may be necessary to formulate and pellet a premix that includes some of the ingredients that are added in small quantities. If farmers are feeding their own cereals, a roller mill will be required as cattle cannot utilize whole grains effectively. As well as a mixer wagon, a cattle farmer making TMRs requires good feed-handling and storage facilities. Feed can be conveyed by auger into above-ground hoppers, which can then deliver into the mixer wagon by gravity, or it can be stored on concrete in covered yards or, preferably, in secure buildings, but pest prevention will be necessary. Silage and some types of by-products (e.g. brewers' or distillers' grains) have to be added by front-end loader.

Forage boxes are a simpler alternative to mixer wagons; they only have a movable chain and slat floor internally and a delivery chute. Feeds can be layered and some mixing then takes place as the feed is delivered, but selection of individual ingredients by the cows is likely. Because mixer wagons are expensive, some farmers make a simple diet with forage and some by-products in a forage box and supplement it with high-quality supplements fed individually to cows. Machine maintenance is greater for mixer wagons than for forage boxes and they use considerably more power (typically 15, 25 and 35 kW/t of DM are required for a forage box, augered mixer wagon and agitated mixer wagon, respectively).

A TMR allows cows to be milked without simultaneously being fed concentrates, reducing dust in the parlour. Cows that are fed in the parlour are sometimes agitated because of the food reward that they get, but it may be necessary if they are difficult to collect from fields. For some high-yielding cows the relief of udder pressure is reward enough and these cows usually come in ahead of low-yielding cows.

One advantage of TMRs is that inexpensive by-product feeds can be incorporated into a mix, and the low palatability of, for example, citrus fruit products can be masked by the strong taste of silage. Concentrate costs may be reduced by about 10% by using 'straight' ingredients, rather than a compound pellet. However, feed compounders may formulate optimum concentrate pellet ingredients to match forage quality. Feed preparation may be centralized in a region with many cattle farms and distributed daily to each farm.

If good storage facilities are available, advantage can be taken of low feed prices at certain periods of the year, in particular during summer when there is good-quality grass available. Farmers must be able to provide the skilled management and careful rationing required for feeding TMRs to cattle. Typically, they take about 1 min/day per cow to feed, or more if long straw is included. This is a significant commitment compared with the time normally spent each day in other management activities for each cow (milking, 2 min; cow movement, 0.3 min; parlour cleaning, 0.5 min; manure removal, 0.7 min; cubicle littering, 0.4 min). Feed will keep for several days if the temperature is less than about 10°C but at high temperatures mixing needs to be done every day to avoid spoilage with mould. In cold conditions cows can be fed three times a week (thus avoiding weekend feeding) without the risk of the ration spoiling, provided that uneaten feed is regularly returned to the cows. Infrequent feeding reduces aggression between cows during feeding times.

Feed intakes are high with total mixed rations and there is a danger of cows getting over-conditioned, leading to fatty livers and the risk of associated diseases, particularly reproductive failure. Feed waste can be high – for example, loss of feed to vermin either in storage or after feeding in the cattle building. The most common pests are rodents and birds, such as starlings or pigeons. Feed particles may also be blown around the farmyard when the feed is delivered from a high-level storage bin to the mixer wagon in exposed sites. Farms with a high level of bird infestation in buildings may find that cows' backs become dirty as a result of droppings from roosting birds in the rafters. Plastic webbing can protect buildings from bird entry, but in exposed sites this is not durable.

Conclusions

Feeding systems are important because feed comprises a large proportion of the costs of keeping cattle, typically about 70%, and also because the feeding regime influences product quantity and quality, most notably the fat and protein in milk from the dairy cow and the amount and type of fat in beef cattle. The feeding system also influences the welfare of cattle, especially that of young calves removed from their mothers at an early age. Providing a suitable feeding system will prevent ill health and stress, and it will present a calf with the necessary supply of nutrients to enable it to survive to adulthood. Good feeding preparation for periods of major challenge to cattle, such as early lactation for dairy cows or feedlot feeding for finishing beef cattle, is important to reduce the difficulties posed by these challenges. Feeding also has a significant influence on the impact that cattle have on the environment, both locally and globally – an impact that is now recognized as contributing significantly to global climate change.

Notes

[1] Digestible organic matter in the feed dry matter (DM), DOMD.

[2] The amount of acid or alkali that has to be added to alter the pH.

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6

Grazing Management

Introduction

Cattle evolved as herbivores using both grazing and browsing as feeding mechanisms, but their form, behaviour and temperament are best adapted to grazing. However, following genetic modification to increase milk yields, the consumption of grass alone cannot supply the nutritional requirements of high-yielding cows; neither does grazing always make the most efficient use of limited land stocks. Thus we have seen the development of permanent housing systems, particularly in areas where land is too arid for cattle grazing, such as much of Israel, or is in short supply for crop production, such as in the Nile delta and South-east Asia. Grazing systems have continued to be prosper in areas where milk yields are modest (5000–7000 l/year per cow), or beef cattle are kept, and grass grows throughout most of the year, such as in the temperate regions of New Zealand, Ireland, Tasmania and the western parts of the UK.

The most successful grazing systems are in regions with a high rainfall that is evenly distributed throughout the year and a mild climate. In the more mountainous regions rough grazing predominates: for example, in the UK, there are 7 million hectares of grassland in a total agricultural area of 20 million hectares, but 6 million hectares of this is rough grazing which can only support beef cattle, rather than dairy cattle.

Providing conserved feed for cattle has the advantage that the quantity and quality of the feed can be carefully controlled, and housing cattle means that they are close at hand for observation, treatment and milking. However, conserved feed is more expensive than grazed grass, and cows tend to stay healthier when they are outside. The public perception is that grazing dairy cows are less stressed than housed dairy cows: they have room to move and fresh air.

Breeding for increased efficiency of feed utilization by cattle is likely to mitigate against grazing systems. In temperate production systems, an average of 65% or less of the grass that is grown is harvested by cattle, compared with 75% for silage making. Also, the animal's maintenance energy requirements are typically increased by 25% in grazing systems, compared with housed feeding. However, cows use the period at pasture to recuperate from winter housing, and permanent housing may compromise the welfare of dairy cows (Phillips *et al*., 2012). Permanent housing will nevertheless be encouraged by increasing possibilities for mechanization of dairying, e.g. robotic milking, and by continuing escalation of labour costs.

Good-quality temperate pastures of adequate height will support maintenance of a dairy cow and nutrients for approximately 25 l milk/day. Cows with higher output will require supplementation. At the start of a grass-growing season, the high energy and protein content of grazed grass encourages cows to produce high milk yields with high protein contents but the low fibre content usually results in low fat contents. Typically, a dairy cow eats grass at about 20 g dry matter (DM)/min, compared with 40 g DM/min for conserved forages, which means that grass intakes can be inadequate. Energy requirements have to be partly met by catabolizing body fat tissue and the cow loses condition. Towards midsummer grass growth is often limited by water and nutrient supply; its feeding value and milk yield fall. In temperate conditions, spring-calving cows therefore tend to have a steep rise to a high peak milk yield and a sudden decline, compared with autumn-calving cows that usually make less use of grazed grass over the year because most of their lactation is outside the grass-growing season (Fig. 6.1).

In autumn, the quantity and quality of the grass are usually low, even though moisture availability may improve as transpiration rates decline with cooler temperatures. Herbage growth is of lower nutritional value than herbage produced in spring, even though the metabolizable energy values are often similar, because

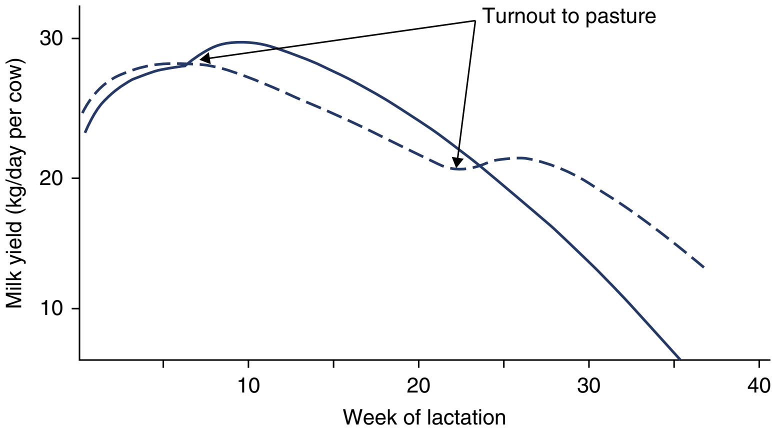

Fig. 6.1. Typical lactation curves for autumn-calving (- - -) and spring-calving (——) dairy cows in temperate regions.

protein degradability in the rumen is high, the moisture contents are high and the pasture is heavily contaminated with faecal deposits. In addition, there is a dense mat of dead grass leaves and stems at the base of the sward that has escaped defoliation, which cattle are reluctant to consume. Thus grass grown in autumn will not support high milk yields unless it is supplemented with forage and concentrate feeds.

Stocking Density

The objective in planning the stocking density of cattle is to provide adequate herbage of high quality. In grazing systems, the dynamic nature of grass growth means that skill is required to ensure that the grass is kept young and has a high leaf content but still is present in sufficient quantity. Some cattle, particularly high-yielding dairy cows, never achieve high intakes from pasture, because their rate of intake is too low. Determining stocking density on a farm that feeds only stored fodder is much easier.

As stocking density increases from low to high levels, so the output in milk production per cow or growth of beef cattle declines but output per unit area increases, with more of the herbage that has been grown being harvested by the cattle. At very high stocking densities the output per unit area may decline as well as the production per animal, since the grass will be short and slow-growing, and most of the intake is used just to maintain unproductive cattle. Thus herbage growth may decline as the grass leaf area (and hence sunlight capture) is reduced by excessive defoliation, and weed species will more easily establish themselves. The optimum stocking density for average-yielding dairy cows should provide sufficient herbage to each cow to allow her to produce 90% of her potential milk production, the remainder coming from supplements.

For a good-quality ryegrass sward that is supplied with fertilizer in warm temperate conditions, this is likely to be six to seven cows per hectare. Such conditions are usually present for the first third of the grazing season in temperate climates, at the end of which a first cut of silage may be taken on one-third of the farm. The stocking rate can be relaxed after this to perhaps four cows per hectare by introducing silage aftermaths and perhaps relaxed again to three cows per hectare after a second cut of silage taken at the end of the second third of the grazing season. This integration of silage and grazing land allows stocking density to be gradually reduced over the grass growth season, providing adequate herbage for grazing cows as growth declines.

Best-quality fresh herbage is of considerably greater nutritional value than conserved forage, since the latter can only be efficiently harvested when the grass is tall and relatively mature. However, high-yielding dairy cows may have difficulty harvesting sufficient material in the time available if the grass is too short, and they will then quickly lose weight. Cattle are reluctant to graze for more than half of the day and most lactating cows spend about 8–10 h/day grazing. As grass has a high fibre content, they need to spend 6–9 h/day ruminating, most of which is when they are lying down at night. Cattle prefer not to graze during darkness, which limits the time available for grazing. If herbage availability declines, cows increase their grazing time and biting rate[1] in an attempt to compensate for small bites, but cows on very short pasture may stop grazing if they are fed supplements.

In intensive grassland systems requiring predictable milk yields for contract or quota management, farmers should understock their pasture to ensure that grass is still available if dry weather or low temperatures reduce growth rates. Then they can minimize their use of expensive supplements. In dry conditions, the high DM content of the grass encourages high DM intakes, but in wet conditions, if the water content of the grass (including surface moisture) exceeds about 82%, intake can fall rapidly. This is because of the difficulty cows have in chewing wet grass and the reduced saliva produced to get the bolus to a suitable form to swallow.

In dry conditions farmers cannot grow as much grass as in high rainfall areas but more of what is grown can be harvested. In the wetter regions more grass is wasted by cattle through trampling, smearing it with mud, conservation losses (hay, silage) and a failure to match requirements with growth. Here farmers may confine cows to a concrete area with soft bedding, such as woodchip, for up to 18 h per day to prevent the grass being damaged. Cows are reluctant to lie down on wet grass and providing a clean, dry lying area will encourage them to rest, preferably for at least 8 h per day.

Good farmers are conscious of the fact that grass is constantly growing and that, if it is not harvested within a few weeks, the leaves senesce and the nutrients are returned to the soil. Senesced leaves retranslocate much of the valuable mineral content to growing leaves and the residues are absorbed into the humus layer of the soil to support further growth.

Measuring Grassland Production and Utilization

Given the dynamic nature of the interaction between cattle and the land that they graze, measuring grassland production and utilization is important for efficient land management. Two principle measures are taken: herbage available and herbage utilized.

Grass height is the most common measure of available herbage, though the ability of any grass sward to support high intakes by the cattle depends not just on the grass height but also on its density. These are the two main features of the sward that affect intake. Others include the proportion of leaf relative to stem, the nature of the leaves (hairy or smooth) and the degree of soiling of the leaves with faeces or soil. Of importance to the growth of grass is the leaf area index, or leaf area per unit soil area, which should be approximately 5 for optimum growth. This is not easy for farmers to measure, whereas height can be used to determine whether the optimum quantity of grass is available to support adequate intakes and whether the grass is tall enough to be growing efficiently. The height can be measured with a sward stick, which is placed on the ground and a sliding sleeve is lowered until it touches the tallest tillers, with height being read off the calibrated stick. Alternatively, a plate of about 30 cm^2 may replace the sleeve and again the height is read off the calibrated stick (Baxter *et al.*, 2016). This 'rising plate' meter produces measured heights that are about 1 cm less than those from sward sticks, because the grass is compressed by the weight of the plate. It is unsuitable for measuring grass heights of less than 5 cm as the grass cannot support the plate's weight.

Rising plate meter readings can be related to the quantity of herbage present in the field using calibrations determined locally. With experience, farmers can assess herbage availability for cattle, which is likely to range from 1500 kg DM/ha in a well-grazed sward to twice this amount in an undergrazed sward or one ready for grazing. In New Zealand it is recommended to move dairy cows to new pastures when herbage availability declines to 1300–1700 kg DM/ha. Near-infrared reflectance (NIR) meters can be used to determine the proportions of yellow (old) and green (young) grass in the sward but must be calibrated for each site. With any of these devices, fields should be walked in a 'W' pattern and about 40 measurements taken per hectare or field, depending on the variability in grass height. As the grazing season progresses, the sward develops into a mosaic of short and tall grass, requiring more detailed measurements. The areas of tall grass surround the faecal deposits and are eaten only if herbage is in short supply.

Global positioning systems (GPS) can be utilized to assess ground cover in rangelands, allowing an evaluation of many different sites relatively quickly. Such measurements can be made to estimate changes in ground cover over time. This will be affected by both stock numbers and rainfall. GPS units can be fitted on to collars on the cows, coupled with information from geographic information systems (GIS) on NIR patterns, which can be used to determine vegetation types. This can provide a detailed map of utilization of different areas of a farm by cattle and is particularly useful for rangelands. The combination of GIS and electric collars fitted to cattle are being tested to provide a virtual fence, in which cattle are given a mild shock if they stray into a forbidden area, which encourages them to move back into the desired area.

Satellite information of ground cover is becoming increasingly robust, especially when enhanced by historical site data on the geology, topography, woody plant density, rainfall and fire frequency. An ability to detect groundcover trends over long periods of time is particularly useful in monitoring the effects of management systems, taking into account any climate change patterns evident for the region. One limitation is that groundcover cannot be accurately assessed in areas with more than about 20% trees. Another is the resolution: currently, it is not possible to determine individual species composition, which is important in determining the carrying capacity of the land (for example, Indian couch grass is less productive than black speargrass). Drones are likely to be used for this purpose in future.

It is possible to combine satellite measurements of groundcover with land-based measurements of localized site condition, which includes data on perennial, palatable and productive pasture species, the presence of weed species and soil condition. An Australian system of site classification ascribes four conditions to each site, based on productivity potential: Classes A, B (75% of A potential), C (45% of A potential) and D (25% of A potential). Satellite imagery can also be used to monitor rangeland utilization and condition for the benefit of long-term land improvement. Samples of faeces and, where available, feed can be used to estimate the crude protein content of the diet and DM digestibility by near-infrared reflectance spectroscopy (NIRS). Such faecal profiling has major potential for monitoring cattle nutrition in the rangelands. Grazing permits can be issued accordingly and account taken of rangeland improvements, such as new watering points, water pipelines and fences.

On a whole-farm basis, grassland utilization can be estimated from the intake and growth of palatable feed. The latter can be predicted from the land area, the proportion of bare ground, total standing dry matter, species contributing to biomass and their composition. Alternatively, intake can be predicted indirectly from the annual energy output of the cattle, known as the utilized metabolizable energy (UME). First, ME output is calculated from tabulated values of ME requirements for milk production, weight change and body maintenance (see Chapter 4). ME contributions from feeds that have been imported on to the farm are deducted. The area utilized by the cows is estimated, taking into account other stock that have used the land or conserved forage produced from it. UME is derived from the product of mean cow ME output per year from herbage (grazed and conserved, in gigajoules (GJ)), the number of cows and the land area. In temperate climates, maximum UME is about 120 GJ/ha on small areas of land; good dairy farmers achieve about 80 GJ/ha over the whole farm and average farmers about 50 GJ/ha. Generally, grassland utilization is positively correlated with farm profitability, but measures of grassland utilization should be used in combination with other measures of efficiency. An overstocked farm may have a high UME but a large proportion may be used for cow maintenance at the expense of milk yield. Thus, although less grass may actually be grown if stocking rates are high, more of the grass that is grown is utilized. Applying large quantities of fertilizer will usually increase UME but that does not necessarily mean that grassland utilization is efficient. Utilization measures should ideally be combined with estimates of grass growth, as predicted from the site class, climate and level of fertilizer application, to give an estimate of utilization efficiency.

Utilization measures on rangeland cattle farms can be used to predict the efficiency of feed management. Above 20% utilization, animal production may decline, i.e. the weaning rate and weaner and cow live weight will decrease. Furthermore, the bare ground proportion is likely to lead to accelerated soil and water loss if utilization is more than 40%. In extensive rangeland situations, the proportion of a property that is actively grazed may be the best measure and can be as low as 40% in the Gulf region of Queensland, Australia. Tree cover is one reason for low grazing rates; another, in some developing regions managed by indigenous people, is a shortage of breeding cattle. Water availability has a pronounced influence on rangeland utilization, and the introduction of plastic watering troughs and pipes has improved grazing patterns by allowing a greater number of watering points on rangelands. Furthermore, water utilization has been made more efficient by controlling the output of subterranean aquifers using taps and pipes – for example, the Great

Artesian basin of north-east Australia. Distribution of grazing sites also affects utilization and cattle should not have to walk more than about 2 km to find a fresh site.

Grazing Systems

The dynamic nature of grass growth makes it preferable to be flexible in the movement of cows around the pasture. In dairy systems it helps if the milking unit is in the middle of the grazing block, otherwise cows have to walk long distances to the milking parlour. Usually, the cows are kept close to the milking unit overnight so that they do not have far to walk for the first milking, and this can lead to a transfer of soil fertility to these fields and overgrazing. Within a field, the land by the boundary hedges is often the most fertile. Cattle shelter there, especially overnight, and return more excreta to this area.

The simplest grazing systems keep cows on the same pasture all the time (termed continuous grazing or set stocking), though extra land may be added after silage cuts to compensate for reduced growth as the grazing season progresses (Fig. 6.2). Alternatively, a farmer may rotate cows around the grazing area, which may be split up into fields of several hectares, each with cows in for a few days at a time, or into 15–25 paddocks or cells where cows would normally spend only 1 day at a time. In paddock grazing, it usually takes 2–3 weeks for a complete rotation. Cows should be removed from a paddock when pasture height is about 8–10 cm if intake is to be maximized (Fig. 6.3). This critical grass height, below which DM intake begins to decline, is usually 1–2 cm lower for continuously grazed ryegrass swards, because the herbage density is greater (Fig. 6.4).

The net herbage growth (herbage growth minus senescence) is maximized in a temperate ryegrass sward at 3–5 cm, but there is only a slight reduction if the sward height is 5–8 cm. If herbage is taller than about 9 cm, the tillers develop many stem internodes and become highly lignified and of low digestibility. The amount of leaf present is likely to be no greater than that present in a sward maintained at 3 cm. Conversely, if the herbage height is reduced below 3 cm there is a considerable reduction in growth rate. Also when herbage is very short, cattle may uproot tillers when grazing and the plant is often not consumed but left on the pasture. When herbage is very short, the cattle have little opportunity for selection; when the herbage is tall, cattle select leaf in favour of stem and green material in favour of yellow/brown grass. This has higher nutritive

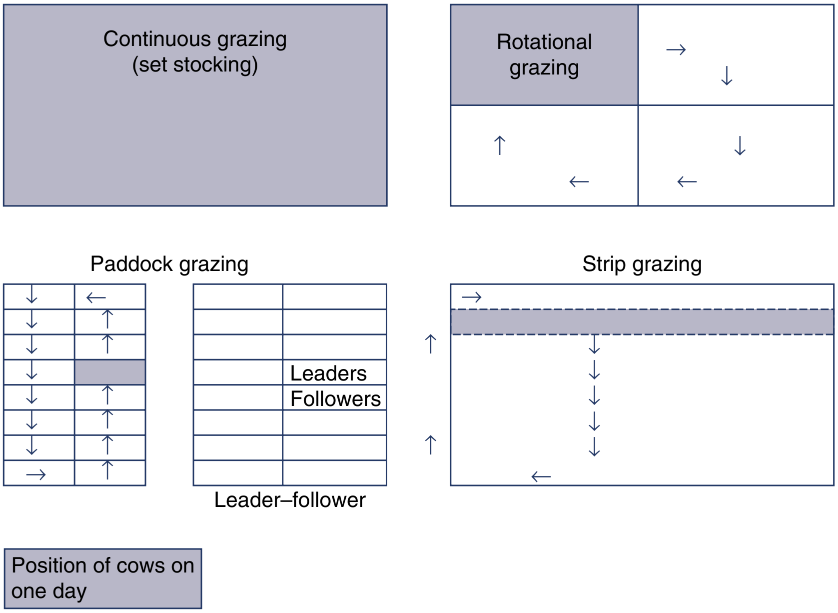

Fig. 6.2. Diagrammatic representations of the continuous, rotational, paddock and strip-grazing land utilization systems.

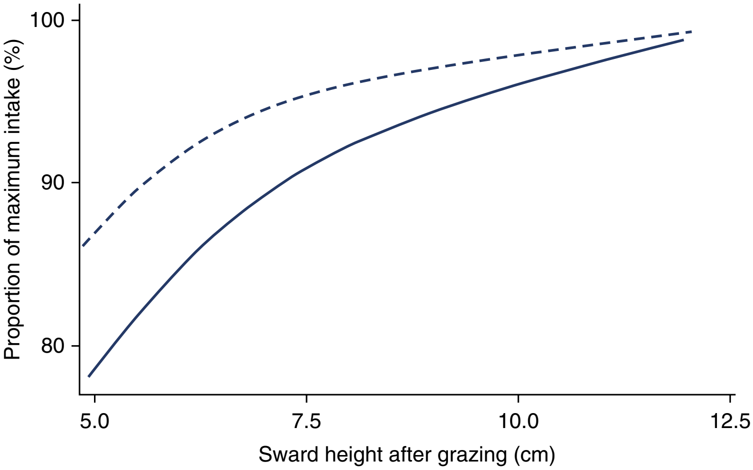

Fig. 6.3. The relationship between the intake of pasture by cattle and the sward height post-grazing for rotational (——) and continuous (- - - -) grazing systems.

Fig. 6.4. At short grass heights, cattle have to graze for longer and intake declines.

value, with more nitrogen, phosphorus and energy. Cattle grazing a high clover sward may select more fibrous grass, which contains less energy and protein than the clover but reduces the risk of ruminal tympany (bloating).

Rotational grazing is more flexible than continuous grazing, providing the opportunity to shut up fields or paddocks for conservation if they are not required for grazing. Herbage availability can also be assessed more easily than with continuous grazing. Grass growth is similar under rotational and continuous grazing systems, but utilization may be higher under rotational grazing. In wet conditions, some paddocks in a rotational system may suffer severe poaching/pugging damage when hooves destroy the sward structure, whereas in continuous grazing systems the damage may be less severe but more widespread. A disadvantage of rotational grazing is the requirement for a large amount of fencing, now usually electric, and many water troughs and gates. It is, however, usually quicker to get cows in for milking from a small paddock than from several large fields. Cows should not be rounded up for milking with the aid of a dog or motorized vehicle, as they tend to be rushed down the track, leading to more lameness and poor milk let-down in the parlour.

Rotational grazing requires more cow tracks. All cow tracks to the pasture should preferably be formed of concrete or some other durable material. In stony soils, such as those with flints, and on muddy tracks, the small stones can cause punctured soles, white line separation and solar abscesses in the hooves.

Another way of rotating dairy cows around a field is to divide it into strips using an electric fence. Usually just one fence is moved across the field and cows have access to previously grazed strips and a water trough, but sometimes a back fence is included to allow grass in the previous strips to regrow before the cows have consumed all the strips in the field. New strips are offered to the cows at least once daily and most farmers move the fences so that the cows have a fresh strip after each milking. Like paddock grazing, strip grazing allows effective rationing of the grass to the cows and may limit the treading damage to the pasture as the cows spend only limited time on each day's ration.

A system that helps to overcome the problems of inadequate grass for high-yielding dairy cows is the leader–follower rotation. The herd is divided into high- and low-yielding groups and the former graze paddocks or fields first, before the low-yielders. In practice, unless the followers are very low-yielding or dry, the advantage in yield to the high-yielders is offset by a similar reduction in the low-yielders.

Rotational grazing is better than continuous grazing for mixed grass and legume swards, because the legumes need a period to recover after heavy grazing as they are dicotyledons and are more completely defoliated than the monocotyledonous grasses. In continuous grazing, cows can overgraze an area of high clover content. Paddocks are also suited to an extended grazing system in winter, allowing cows to have access to small areas of herbage to augment their winter ration and to give them some exercise and better conditions underfoot. If they are allowed access to a large area they may damage the sward structure with their hooves and cause poaching damage. This might be acceptable if the area is scheduled for subsequent reseeding, in which case it is termed a sacrifice paddock.

Free drainage and light soils are essential for winter grazing. In mild temperate areas it is common for cows to be given a few hours of access to pasture land each day during winter, as long as the weather is suitable. In areas where there is a risk of frost damage, tall leafy grass may be killed off by the frost (winter kill) and a large dead-matter content in spring will retard new growth. In such circumstances, it is better to use sheep to graze the pasture down to 3–4 cm over the winter, ensuring that they are removed before the start of spring so that new growth is available for the cows. Mature autumn herbage can be saved for winter grazing (foggage, or standing hay) but is not of much nutritional value for lactating dairy cows. Extended grazing can reduce the need for concentrate supplements and improve the cows' performance by supplementing silage with leafy herbage.

In rangelands, grazing can be subdivided into paddocks or cells, with the same advantages as in more intensive grassland systems. Such rotational grazing systems have become popular in the USA and South Africa but have so far had little application in the large rangeland properties of Australia. Feed availability can be more effectively judged and pasture species can be manipulated. Cattle can be moved to a new cell when palatable species become depleted, thus allowing recovery before they return to the cell. The concentrated cattle population in the cells exerts significant treading impact, which may break up soil structure in areas with hardened soil pans. Fencing distances are considerable and electric fences are usually necessary. Movement of cattle between cells is time consuming but can be facilitated by training cattle to move under electric fences raised by a pole to access a new allocation of herbage in the neighbouring cell. Such low-stress stock handling will make the regular moves easier and lead to contented cattle. Cattle should not be pushed too fast and must be allowed to feel that they are leading the way into the new cell. In regions prone to flooding, electric fences may earth to the ground, and even barbed-wire fences may be extensively damaged during the wet season.

A final system for utilizing fresh herbage is cutting it on a regular, usually daily, basis and carrying it to the cattle, sometimes called zero grazing or, in developing countries where it is manually carted, cut-and-carry. In temperate climates the cattle are housed; in hotter climates they may simply be provided with a roof for shelter. The system is labour intensive but it makes good utilization of the herbage that is grown, since it ensures a complete cut and minimal wastage. Some damage to the land is possible in wet conditions if tractors are used. It does not require the land to be fenced or water to be provided and may be favoured if cows have to voluntarily visit an automatic milking plant regularly or there is a risk of cattle being stolen or attacked if they are out in the fields. The impact of permanent housing systems on cattle health is discussed in Chapter 5.

Youngstock Grazing

Youngstock require high-quality grass for maximum growth but often do not receive the accurately rationed pasture allowances that are provided for lactating cows. Dairy youngstock are typically set stocked at a low rate on a distant part of the farm, as they do not need to be brought in regularly for milking. Youngstock benefit from rotational grazing through the control of gastrointestinal helminths. In cold conditions, however, the life cycle of the helminths is longer than the rotation and there may be residual infective larvae after one rotation. Cattle in their first grazing season are usually dosed with anthelmintics and moved to pasture that has not been grazed that season. A leader–follower system, in which animals in their first grazing season lead the rotation and resistant cattle in their second season follow, offers some protection to the calves against gastrointestinal helminths (Table 6.1).

If rotational grazing is too labour intensive, cattle should be moved to clean grazing at least once a year. The reduction in grass growth as the summer progresses can be accommodated if the cattle graze one-third of the area for the first third of the grazing season, up to a first cut of silage, then two-thirds of the area for the second third of the season, at the end of which a second silage cut is taken, and finally the whole area for the last third of the season. Some infective larvae can overwinter, since the life cycle is extended in cool conditions, and the only way to be sure that pasture does not contain infective larvae is by alternating cattle and sheep grazing annually, or by grazing cattle on land that has only been used for conservation in the previous year. Gastrointestinal helminths are specific to cattle but the liver fluke (*Fasciola hepatica*) can infect both cattle and sheep. Cattle can be protected by anthelmintic-releasing intra-ruminal boluses, but this may lead to older cattle and even lactating cows being susceptible to infection, as immunity does not accumulate during the rearing period.

Table 6.1. The effects of providing an anthelmintic to calves grazed in a leader–follower system and in separate rotations (from J.D. Leaver, with permission).

	Leader–follower		Separate rotations	
Anthelmintic	Yes	No	Yes	No
Calf growth rate[a] (kg/day)	0.79	0.79	0.63	0.48

[a] No difference was observed in heifer growth rate.

The growth of cattle may be checked if their diet is suddenly altered, as a result of the time required for the ruminal microflora to adapt. After a diet change, cattle often do not gain weight for 2 weeks or more. Changes in cattle weight should be interpreted carefully, since they will have different weights over the day and because gut fill varies with the digestibility of feeds. There can be a weight reduction of 20 kg or more when cattle are transferred from a diet of conserved feeds to lush pasture, as the high digestibility of the latter increases the rate of passage through the gastrointestinal tract and reduces the weight of the contents of the tract. It is important to buffer the transition from a conserved forage diet to grazed herbage by continuing to offer conserved feeds at pasture for at least 2 weeks. These can be offered in racks or round-bale feeders in the field, preferably on a hard-standing area if the field is susceptible to poaching damage. They are also often placed on the pasture, with minimum losses as long as the soil is freely drained. Conserved feed can also be used to buffer changes in herbage availability or quality and, being of lower quality than pasture, tends to be eaten only when pasture is in short supply.

Pasture Supplementation

Grazed pasture cannot always supply sufficient nutrients to provide for maximum growth or milk production. Cows capable of giving high milk yields usually need high-quality concentrate supplements even when provided with best-quality pasture. The level of milk production that can be supported from pasture alone depends on the herbage availability and quality and the cow's body reserves. On temperate pasture, cows are rarely able to produce more than 25 l milk/day from pasture alone for more than a few weeks. On tropical pastures, 15 l/day is usually the maximum. The additional nutrients required by grazing cattle are usually energy and nitrogen, and very high-yielding cows are likely to increase milk yield in response to protein that bypasses the rumen. Concentrates may be provided to grazing cows according to pasture height and milk yield.

The critical grass height below which a cow's intake begins to decline is less at the end of the growing season, compared with the start: more grass is rejected because of its maturity or being close to faeces. Grass is initially rejected around faeces because the cows dislike the smell – a natural anti-parasite strategy. Later, a crust forms on the surface of the faeces, particularly if the weather is hot and sunny, but the herbage is still rejected because the nutritional value has declined. Faecal deposits are degraded by insects, bacteria and worms in a few months in warm conditions, especially if dung beetles are present, but in cool temperate conditions it will take 6 months or more to degrade.

Pasture supplements can have several roles:

1. Increasing intake when herbage is in short supply, especially if there is insufficient to keep the cattle alive.
2. Easing the transition to or from a diet of conserved feed at the beginning and end of the grazing season.
3. Increasing the intake of cows that cannot consume enough grass to sustain a high milk yield.
4. Rectifying nutritional deficiencies in pasture; for example, forage supplements can be used to increase digestible fibre intake, resulting in increased fat content of milk.
5. Maintaining nutrient intake when inclement weather reduces the intake of pasture.

Pasture may be insufficient to support high levels of production from dairy cows if it is short, because the cows only take small bites, even though they increase grazing time and biting rate in an attempt to compensate. Intake may also be reduced by an inadequate grazing time when photoperiod declines in the autumn, or through high herbage moisture content, dead matter content or faecal contamination. If adequate pasture is available, the reduction in unit herbage DM intake for each DM unit of supplementary feed may approach or even exceed 1.0. The degree of substitution indicates the extent of the benefit that can be expected from supplements and can be calculated as follows:

$$\text{Substitution rate} = \frac{\text{Reduction in DM intake of pasture (kg)}}{\text{DM intake of supplementary feed (kg)}}$$

Usually, a concentrate supplement is more rapidly digested than the pasture herbage, and cattle increase their intake with each additional portion of supplementary feed, i.e. the substitution rate is below 1.0. This also happens if the supplement provides a nutrient needed by ruminal microorganisms that is not contained in the base forage. Substitution rates are higher when the basal forage is of better quality. If, however, forage supplements are offered with pasture, the substitution rate may exceed 1.0 if they are digested more slowly and total DM intake is reduced (Phillips, 1988). Cattle tend to eat forage supplements even if better-quality grass is available, because these can be consumed rapidly. Thus, the cow does not necessarily always optimize energy intake but takes account of the ease with which feeds can be consumed. This could optimize energy retention, rather than intake, if the energy expenditure in feed procurement is taken into account. Secondly, young, leafy grass can lead to unstable ruminal fermentation, with low ruminal pH, low milk fat contents and bloating. Consuming supplementary forages will stabilize ruminal conditions and increase milk fat production, even if milk yield and protein content are reduced. Thirdly, cows strategically maintain a varied diet so that ruminal microflora are prepared for future changes in diet.

The advantages of providing forage supplements are twofold: (i) they are usually less expensive than purchased concentrates per unit of energy or protein; and (ii) most cows retain grazed pasture as the majority of their diet even when offered forage supplements, unless the pasture availability is severely restricted. It may be difficult for farmers to decide when the pasture is too short for cows, but giving them the opportunity to supplement their diet with forage, offered usually after milking, will allow them to decide. Measuring herbage height is time consuming for farmers and can be misleading, because other factors, such as herbage density and species, also affect intake.

Forage supplements should be offered at times when the cattle would not normally be grazing intensively; for example, for dairy cows this might be after morning milking but not just after the afternoon milking, which is when the longest grazing bout begins. After morning milking cows often lie down to ruminate, having consumed sufficient herbage in their early-morning grazing bout. If feed is offered at this time, good-quality hay is best as it can be left from day to day without spoiling. Opening silage clamps in warm weather and feeding out just small amounts can lead to spoilage at the surface. This can be reduced if the clamp is long and narrow and silage is removed by a block cutter. If farmers are keen to use this system of 'buffer feeding' on a regular basis, it may be worth investing in clamps that can be filled at either end, allowing feeding at one end and filling at the other.

Cows will not usually consume the conserved forage for more than about 30–60 min and should be returned to their pasture promptly. If pasture is in very short supply, or cows are being milked three times a day, they can be kept indoors overnight. This will reduce grazing time and may cause hoof problems if cows are housed in wet passageways and then turned out with soft hooves on to stony land. Maize silage is particularly suitable for overnight feeding of grazing cows, as its high-energy and low-protein content ideally complements medium-energy, high-protein grass. Forages can also be fed continuously in a feeder in the field but there is likely to be feed wastage and sward damage in the vicinity. If offered directly on the pasture, the treading damage can be minimized by moving the feeding place regularly. Buffer feeding in this way will increase the predictability of a dairy cow's performance, which is important for the management of a farm's contractual quota.

Concentrate supplements may be preferred by farmers to forage supplements because of the lower substitution rate, higher rumen-undegraded protein content and reduced waste, but both are likely to be more expensive per unit of energy than grazed grass. Maximizing yields of milk from grazed grass has been, and will continue to be, a key objective for profitable milk production. With low-yielding cows, if adequate herbage is available the substitution rates of concentrates for grazed herbage may approach 1.0, i.e. for every 1 kg DM of concentrate supplement offered, the cow reduces her herbage DM intake by close to 1 kg. This is clearly unprofitable use of concentrate supplements. However, if cows are giving high yields over several weeks (> 25 l/day), they will need a supplement of least 2–4 kg concentrate/day to achieve an adequate energy intake. Such cows can also benefit from extra rumen-undegraded protein in the concentrate. A high magnesium concentrate may be fed at a low rate (*c.* 1 kg/day per cow) for 1–2 months after turning cows out to pasture as a means of preventing hypomagnesaemia.

Beef cattle require supplementation in rangeland conditions if the land that they graze is prone to drought or flood. Low protein intakes are a common problem on such land and a urea-based supplement is often provided with the necessary addition of minerals, such as phosphorus, known to be deficient. Provision of nitrogen in this way enables cattle to utilize the energy in a mature feed supply. To sustain growth through the dry season a urea, molasses and straw-based mix is often provided, or just urea and molasses in a liquid form. Urea may also be given as a loose mix (with salt and a phosphorus source).

Legume Swards

Legumes fix their own nitrogen by virtue of symbiotic bacteria that colonize the cortex of their roots. Cattle benefit from the high protein content of legumes; for example, cattle on a ryegrass and white clover sward will produce greater milk yields or will grow faster than those on a pure ryegrass sward, as a result of the higher digestibility and nitrogen content of white clover compared with the ryegrass (Table 6.2). White clover has less hemicellulose and cellulose than ryegrass, though it has slightly more lignin. Often, white clover has more minerals than ryegrass, particularly magnesium, calcium, iron and cobalt. Even when compared at similar digestibilities, clover supports higher milk production and growth rates than grass. Cattle will normally preferentially graze areas of the sward with high clover contents, which may lead to its depletion in the sward.

Table 6.2. Typical composition (g/kg DM) of clover and perennial ryegrass.

	Perennial ryegrass	White clover
Nitrogen	28	44
Cell wall	427	216
Cellulose	240	173
Lignin	27	38
Hemicellulose	161	8

Mixed grass and clover swards should aim to have at least 30% clover to achieve the equivalent of fixation of 200 kg N/ha. Fixation of up to 280 kg N/ha is possible but, on average, only about one-half of that is achieved. Stocking densities on high-clover swards are therefore likely to be less than those for a highly fertilized sward containing only grass, typically about two-thirds. Grass has a growth response up to about 400 kg N/ha. Such high application rates of nitrogen fertilizer are rare and, in most cases, uneconomical and undesirable because of the nitrogen and carbon emissions to the atmosphere associated with fertilizer use. In temperate swards, white clover (*Trifolium repens*) is more persistent and disease resistant than red clover (*Trifolium pratense*), and in hotter climates subterranean clover (*Trifolium subterraneum*) is a common alternative.

Maintaining clover in a sward can be difficult and the clover content should not be greater than 50% if bloat is to be avoided. High clover contents often occur soon after seeding if establishment is good. In hill pastures, clover requires seed inoculation with the appropriate *Rhizobium* species. Usually 3–4 kg clover seed/ha is included in a mixed grass/clover seed mix. Low soil pH will hinder establishment and growth, as will inadequate calcium, potassium and phosphorus status of the soil. Large-leaved varieties are used for lowland swards and small-leaf wild varieties for more marginal areas. As a sward matures, nitrogen fixed by the rhizobia that are associated with the clover in root nodules promotes grass growth. However, since grass has a more erect profile than clover, the light reaching the clover plants is often reduced as grass growth is increased, and the clover content declines.

Legumes usually require higher temperatures than grasses to grow; for example, white clover grows at 9°C or higher, compared with 6°C for grass. Thus, it may be shaded out by fast-growing grasses in the cooler parts of the grazing season. As a result, the clover content may start at 20% of the sward in spring and increase to 40% by mid-season. Shallow-rooted clovers are more susceptible to drought than deep-rooted grasses. It is unwise to use nitrogen fertilizer or large amounts of farmyard manure or slurry on high-clover swards, because of the promotion of grass growth. However, it is possible to provide a strategic application of 50 kg N/ha in spring to achieve additional grass growth before the clover starts growing. Such a sward must be grazed well to prevent grass shading the clover. Vigorous grass growth in spring will prevent weeds becoming established, which is important because many broadleaved herbicides cannot be used as they kill the clover.

Sheep can deplete the clover content of a sward in winter if they are brought on to a dairy farm for winter grazing. They select clover plants in the sward in a way that cattle, with their broad dental arcade, cannot do. A period of rest is required for white clover to recover; otherwise, sustained defoliation will deplete reserves and reduce the clover-growing points. For this reason, rotational grazing is preferred. The difficulties in maintaining a high clover content in a sward mean that clover growth is less predictable than grass and it is therefore less persistent.

Other legumes

Lucerne (alfalfa, *Medicago sativa*) is a legume that is commonly grown in warm climates for grazing or conservation, usually as hay. Bloat is a problem for grazing cattle if the lucerne is not sufficiently mature. In tropical regions there are several leguminous trees and shrubs that are suitable for cattle grazing or forage conservation.

Leucaena is a shrub that is of particular value because of the high nutritive value of its foliage for cattle, as well as its rapid growth in good-quality soils. Height management will ensure maintenance of a productive crop. The deep-rooted plant is resistant to drought and grows best in the humid tropics, except where psyllid insects cause widespread damage. It is also grown in sub-humid conditions but may require irrigation. It is susceptible to frost when immature, and regular frosting with heavy grazing will weaken plants. It can be successfully intercropped with grass and is usually grazed in rotation to allow the plant time to recover.

Leucaena contains a toxin, mimosine, which reduces weight gain but can be degraded by a bacterial inoculant or by reducing the content of leucaena in the diet to below 30%, particularly if it is lush and growing vigorously. In extreme cases cattle will have sudden loss of appetite, hair loss, sores and ulcers in the buccal region, damaged liver and kidney and sudden death. The degradation product of mimosine (dihydroxy pyridine (DHP)) is also toxic, but the adverse effects of leucaena can be reduced if the ruminal microflora includes the bacteria that destroy DHP. There are other leguminous trees and shrubs of value for cattle grazing but many contain anti-nutritive compounds and render cattle susceptible to bloat.

Pasture bloat

Bloat can be observed as an acute swelling between the last rib and the hip on the left side of the cow when viewed from behind. Bloated cows are restless, finding lying uncomfortable, and they may eventually die of heart failure or suffocation as a result of inhaling ruminal contents. Pasture bloat is caused by the creation of a stable foam in the rumen, usually as a result of the rapid digestion of legumes but also of young leafy grass that has recently received nitrogen fertilizer. Lucerne is the most likely of all legumes to cause bloat, with cows sometimes dying within a few hours of entering a field for grazing. Some legumes have developed a chemical, tannin, which reduces the speed of protein digestion. Its bitter taste discourages cattle from eating it. Tannins are present in sufficient quantities in birdsfoot trefoil (*Lotus corniculatus*) to prevent the production of stable foam, and in white clover the concentration increases sufficiently at flowering to make it safe to graze. If a mixed grass and clover sward has enough clover to cause bloat (more than about 50% of the herbage by mass), it should be left ungrazed until the clover inflorescences appear, after which it can be grazed or conserved.

Cows are most likely to become bloated in the late evening after a day's grazing, or when they are offered the legume suddenly, for example after a drought, or after they have eaten wet legumes, which reduces production of saliva that contains a mucin that disperses foam in the rumen. Herbage that has been frozen is particularly likely to cause bloat, as the rupture of plant cell walls releases the potassium-rich solutes. High-potassium feeds, such as molasses, also predispose cattle to bloat, whereas grasses rich in sodium are resistant, due to the stimulation of salivation by sodium-rich feeds and the foam-dispersing properties of the salivary mucin.

Forage supplements slow down the rate of digestion and reduce bloat, but grazing supplements may not be eaten by some cows in sufficient quantities if there is adequate herbage, particularly if the supplements are based on straw or other low-quality forages. Mineral oils help to disperse the foam and can be added to a concentrate feed or sprayed on to the pasture or the cows' flanks, to be licked off as needed; linseed oil is often used. A surfactant product, poloxalene, also breaks up the foam and can be used as a drench for clinical cases or included in feed blocks as a preventive measure. Often walking a cow from the field to the farm buildings to receive medication will alleviate bloating. It is important to keep a bloated cow on her feet if possible, as death can follow soon after recumbency. Over time most cows acclimatize to feeds that encourage bloating but lactating cows are particularly susceptible because of their high intakes. There is also a genetic component in the susceptibility of cattle to bloat, with cows of the Jersey breed being particularly prone to the disorder.

Pasture bloat remains a serious problem for farmers in countries like New Zealand, where the cattle rely on pasture with little or no application of nitrogen fertilizer and high legume content. In Europe, the greater emphasis on controlling nitrogen emissions is encouraging farmers to use high-clover swards for their cattle, potentially leading to more serious problems with bloat.

Maintaining Grassland Productivity

Grassland needs a return of nutrients if the land is to remain fertile, to replace the nutrients that are removed by the animals and lost from the soil by leaching. However, over-application of fertilizer (particularly nitrogen) is wasteful (particularly of the fossil fuels used to manufacture it) and can lead to pollution of groundwater. The grazing system adopted for cattle will determine the need for fertilizer and losses to the atmosphere and groundwater. For instance, high-clover swards have less need for fertilizer because of the ability of the legume to fix nitrogen, with the result that less nitrogen is leached compared with highly fertilized grass swards.

Nitrogen is the first limiting nutrient for most grassland and is applied in larger quantities than the next most limiting nutrients, usually phosphorus and potassium. Applying large quantities can make up for poor soil fertility. Under temperate conditions the annual herbage DM yields range from 8 t/ha for a poor-quality site with 300 kg N/ha applied, to 13 t/ha for a first-class site with 450 kg N/ha applied. However, such high levels of N application are rare and only occur when fertilizer is inexpensive and product value is high. Today, most grassland farms apply less than 150 kg N/ha.

The time of application of the first nitrogen of the season is critical to the successful stimulation of grass growth. If it is applied too early, it may be leached through the soil to groundwater without having been used by the grass plant. If it is applied too late, the stimulus to grass growth may be lost because the grass has passed its vegetative growth phase. The optimum time of first application can be estimated from the sum of the mean daily temperatures from the beginning of the growing season. If this is hard to determine, in the northern hemisphere the sum of temperatures from the beginning of the year, for example in the UK about 200°C, can be used. Most nitrogen should be applied in late spring and early summer, when leaching is unlikely because the grass crop is growing fast, and the soil moisture deficit is increasing as a result of the high evapotranspiration rate. The difficulty for farm management is that the early application of nitrogen results in a large proportion of the annual production of herbage being grown early in the season, far more than the requirements of the cattle. This gives an opportunity to conserve one or two cuts of silage early in the season to provide the winter forage. Some farmers will take a third or even a fourth cut later in the season. Frequent cutting will produce high yields of good-quality forage.

Phosphorus is less likely to leach and can be applied at any time in the growing season. If applied at the beginning of the season, it is available if needed at any time in the season. Potassium fertilizer should not be applied to rapidly growing grass in spring as it reduces magnesium availability and may trigger hypomagnesaemia in cattle. The return of potassium in excreta should be considered when estimating potassium requirements. The low magnesium content of rapidly growing grass swards and its low availability commonly causes hypomagnesaemia, but the risk can be reduced by fertilizing pasture with sodium and sulfur fertilizers.

In summary, some form of nutrient return to grazing land is essential to maintain land fertility as nutrients are constantly removed by the cattle. The grazing of cattle will return many of the nutrients that are consumed but some may be leached from the soil as they are returned at high concentrations, especially in urine. If the sward is conserved rather than grazed, more fertilizer, particularly potassium, will have to be applied. This may be as artificial fertilizer or as livestock manures. Particular care is required in the return of livestock manures to the land, to avoid applications during high rainfall and when the soil is saturated with water. As well as leaching losses, smearing of the grass can occur, reducing grass growth and the intake by cattle.

Some grassland is irrigated to maintain high levels of production. This will increase the predictability of grass growth but the feasibility will depend on the cost of the water and applying it to the land. Irrigation methods have been improved to be less wasteful of water but the shortage of water for agricultural and human use has meant that this expensive technique is often reserved for more valuable crops.

Conclusions

Grazing cattle on pasture is a dynamic process that requires skill and experience from the farmer. Care has to be taken that the right swards are prepared and maintained for the cattle and that the right numbers of cattle are grazed on the land for the correct period of time. Supplementation with forages and concentrates can be used to maintain the provision of nutrients to cattle at times when pasture is inadequate. Maintaining soil fertility is critical, and may be achieved with the use of leguminous plants, or by use of artificial fertilizers. The latter are increasingly unpopular because of the associated pollution of the atmosphere, but legumes require careful management.

Note

[1] Cattle sever the sward by compressing herbage against their upper palate and jerking their heads backwards. Throughout this volume, this is referred to as ‘biting’.

Further Reading: Cherney, J.H. (ed.) (1998) *Grass for Dairy Cattle*. CAB International, Wallingford, UK.

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7

Breeding and Reproduction

Introduction

Cattle are polygynous animals, i.e. males mate with more than one female, which has resulted in significant sexual dimorphism. The bull is larger and stronger, particularly in the neck, shoulder and size of horns, which increases his ability to fight for access to females. In feral cattle herds males live a solitary existence, leaving the herd once they reach sexual maturity. Older males dominate the younger bachelors and have priority of access to females. During oestrus, the females indicate to distant males that there are receptive animals in the matriarchal group by mounting each other. Males also mount each other in intensive husbandry conditions but this is probably redirected aggression rather than any evidence of sexual motivation.

Reproduction in feral cattle is more seasonally synchronized than in farmed cattle and most cows give birth in spring so that peak lactation coincides with the period of maximum feed availability. Modern domesticated cattle show less seasonality of reproduction. The neonatal development is rapid, which is typical of prey animals. The precocious calves stand rapidly and usually suckle within 6 h of birth, after which the permeability of the gut to the passive transfer of immunity from the cow rapidly diminishes.

With domestication came changing roles for cattle, as they were destined to become one of the main meat providers and the main milk provider for humans. The environment in which cattle were kept post-domestication provided new challenges for cattle breeders, as seasonal calving became a disadvantage and improved feed availability and quality allowed high levels of milk production and rapid growth rates. For most of their domesticated life, opportunities for selection of cattle would have been limited, but recently breed improvement has accelerated and increasingly effective techniques have been developed to bring about the required changes.

Breed Improvement

The form, behaviour and productivity of cattle have changed considerably since they were first domesticated about 10,000 years ago. Over time, natural selection has gradually been complemented and, to some extent, replaced by artificial selection. During the early phases of domestication, primitive farmers probably selected for the following characteristics:

- lack of aggression/docile temperament;
- short flight distance in reaction to human presence;
- small and manageable size;
- ability to adapt to an unnatural environment;
- willingness to eat unconventional feeds; and
- overt sexual behaviour in the female.

Opportunities for selection were limited when village cows were communally grazed and bulls were few in number. Later, during the Industrial Revolution, the pace of breed improvement was increased in an attempt to meet the greater demand for cattle products in the newly industrialized countries.

Robert Bakewell (1725–1795) was one of the first farmers to attempt to systematically improve the quality of cattle, and he was unique in his era for two characteristics. First, at a time when most farmers practised cross-breeding, he selected a breed of cattle that he believed would respond well to selection, the local Longhorn of northern England (not to be confused with the Spanish Longhorn), and used inbreeding (selecting within a breed) to achieve genetic improvement. Secondly, while most farmers in the UK were using cattle for both milk and meat production, he developed his selected breed exclusively for meat production. He selected in particular for the ability to fatten quickly and to develop subcutaneous fat deposits in the hindquarters. Eighteenth-century labourers needed to consume more energy than many of today's workforce and they required meat with more fat than we consume nowadays. Also, surplus fat was rendered to produce the tallow used in candles.

Bakewell's influence on livestock breeding spanned the early years of the Industrial Revolution and he was a key component of the agricultural revolution that started in the mid-18th century. The movement towards land enclosures in the UK gave farmers better control over cattle breeding and thereby gave them more scope for breed improvement. Bakewell's legacy was perhaps not so much the improved Longhorn breed, as this proved to be of limited value in his homeland, but the way in which he managed to change this and other breeds through a process of scientific research. He kept meticulous records but, as is common with industrially sponsored agricultural research nowadays, he did not divulge these to others. The end result of his labours was sufficient evidence in itself: an animal that was clearly more useful for meat production than the original Longhorns that had previously been mainly used for draught purposes in the days before mechanized tillage. However, the UK wanted a dual-purpose animal, for milk and meat production, and in this respect the improved Longhorn was less successful than the Shorthorn that was developed at the same time for combined milk and meat production.

Bakewell was the first in a long line of pioneer breeders in the UK who developed breeds for a variety of purposes. In the 18th and 19th centuries, the variety of British cattle breeds that had been developed was to be particularly useful during the expansion of the British Empire, when cattle with different characteristics, such as heat resistance, were needed to feed the expanding populations at home and in the colonies. The British (human) population increased from 7 million in 1760 to 31 million in 1881 and the greater affluence associated with industrial development increased the demand for beef.

Bakewell was also ahead of his time in the way in which he managed his cattle. He placed great importance on fertilizing his pastures with manure, leading to increased production per unit area. This was probably forced on him as a result of his small farm size. He kept his cattle in individual stalls in winter, which reduced poaching damage to his pastures, and bred his Longhorn cattle with ingrowing horns (bonnet style) to enable them to be stocked at a high rate. Cattle horn in those days had many uses, including the manufacture of combs, buttons, knife and whip handles and a cheap lantern glass when prepared in thin sections, and was another valuable attribute of the Longhorn breed.

More recently, the reluctance of British cattle producers to relinquish their dual-purpose animals, in common with producers in many parts of Europe, has contrasted with the former colonies of America and Australia where single-purpose cattle systems prevail. In Europe the income from calves for meat production makes a significant contribution to dairy farmers' total income, so an integrated industry evolved. In the colonies the availability of extensive grazing pastures for the raising of beef cattle led to the development of single-purpose systems, which are usually more efficient at producing either meat or milk than the dual-purpose breeds.

Modern Cattle Breeding

The rapid increase in the development of cattle breeds during the agricultural revolution of 1750–1880 was followed by a period of consolidation. With two world wars in the first half of the 20th century, agriculture was in a depression by 1950. In the latter half of the century new technologies were implemented to meet an increased demand for cattle products, mainly caused by increased affluence in developed countries and increasing populations in developing countries. Some of the technologies, such as milking cows by machine, which was invented in about 1860, had remained unused until there was a ready market for the new technology. Demand has been maintained in developing countries, even if demand for beef products has declined in some developed countries. The development of improved techniques of cattle breeding led to some pioneering discoveries that paved the way for the development of artificial methods of controlling reproduction in humans, once the ideas had been accepted in livestock. The first major development was artificial insemination of cows with stored bull's semen. Even with the development and commercialization of embryo transfer and cloning techniques, it is artificial insemination that has so far had the greatest impact on breed improvement and this has been much greater in cattle than in other livestock sectors.

Cattle breeds of the world

The following section describes some of the major cattle breeds of the world in alphabetical order, illustrating the diversity and specialities of some of the most popular breeds.

Aberdeen Angus

The Aberdeen Angus is a small, early-maturing breed of black cattle (Fig. 7.1) that was developed from naturally polled and small-horned cattle that had existed in Scotland from prehistoric times. It is used exclusively for beef production and produces a marbled flesh with good eating qualities. The breed was improved in the 18th and 19th centuries, when naturally polled cattle were selected because they were easier to handle. The absence of horns is a dominant trait, thus ensuring that the offspring of first crosses are polled. Its small size and early maturity make it particularly suitable for fattening autumn-born calves off pasture at 18 months of age.

Ayrshire

The Ayrshire is a specialist dairy breed of cattle that is usually brown and white, and is kept mainly in Scotland, Scandinavia and North America (Fig. 7.2). It was developed initially in the 18th century by crossing black Scottish cattle with short-horned cattle of Dutch origin, West Highland cattle and Shorthorns. It is slightly smaller than its main rival, the Holstein-Friesian, and produces less milk, hence its declining popularity. The fat and protein contents of the milk are somewhat greater than those of the Holstein-Friesian.

Belgian Blue

The Belgian Blue breed has its origins in the Belgian red or black-and-white pied cattle, which were crossed initially with Friesians and Shorthorns in the second half of the 19th century and later with Charolais cattle at the beginning of the 20th century, when the breed was officially formulated. The cattle are large, with females usually weighing about 750 kg and males in excess of 1200 kg, and they are used for intensive beef production. The breed is unique for its high proportion of cattle that have prominent (double) muscling in the hindquarters. This characteristic has been genetically identified on the *mh* locus of a chromosome, theoretically enabling it to be transferred to other breeds. The upsurge in demand for lean meat in the latter part of the 20th century created a rapid increase in demand for these cattle. Sires are now often used to improve the beef characteristics of offspring of extreme dairy types of Holstein cow and also in hill suckler herds.

Brown Swiss

The Brown Swiss (as it became known, after being originally called Swiss Brown, or *Schweizerisches Braunvieh*) is one of the most ancient breeds of European cattle still in regular use, with evidence of small red cattle being kept in Switzerland as early as 1800 BC. A medium-sized breed, it now has a grey–brown coat and has been developed primarily for milk production, with special application in high altitudes. The short hair is complemented by pigmented skin, which gives protection against ultraviolet radiation when the cattle graze at high latitudes or in sunny climates. Brown Swiss cattle are better adapted to heat stress than other dairy cow breeds (Fig. 7.3). Originally used for milk, meat and draft purposes in Switzerland, their long period of development, particularly in the USA, has produced a breed that is better than most for milk production, while retaining some potential for beef production. The breed is used in many countries, especially central and Eastern Europe and the USA.

Fig. 7.1. Aberdeen Angus cow.

Fig. 7.2. Ayrshire cow.

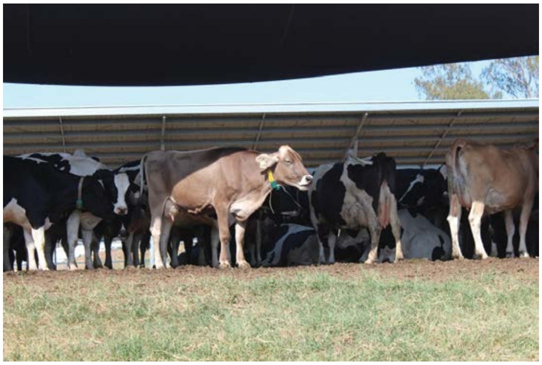

Fig. 7.3. Brown Swiss cows tolerate heat stress better than Holstein-Friesians.

Fig. 7.4. Charolais cow and bull.

Channel Island breeds

This is a collection of fine-boned, small cattle breeds that have been developed intensively for milk production. The milk from Channel Island cows contains more fat and, to a lesser extent, protein than other dairy breeds. The most widespread breed is the Jersey, whose females weigh only about 400 kg. They are normally fawn-coloured, although they can range from dark brown to almost white, with the extremities becoming gradually darker at the tips. The Jersey was developed at least in part from the breeds of north-west France, but since 1789 a reservoir of pure stock has been maintained on the island of Jersey by forbidding cattle imports. This has enabled it to resist diseases such as tuberculosis. Its use has been widespread in tropical regions because of its resistance to heat stress but Jersey cows are particularly susceptible to milk fever (hypocalcaemia). The cows mature quickly, are docile and easy to handle and can consume large amounts of forage for their size. They are unrivalled as producers of milk fat, but nowadays this is less valued than milk protein, as much of the milk sold for liquid consumption has some of the fat removed to increase consumer appeal. However, their energy output in milk is just as high as from Holstein-Friesian cows, per unit of metabolic weight, so they must be considered to be an efficient dairy breed.

Charolais

The Charolais is the most important French breed for beef production. It attained worldwide popularity in the 20th century because of its large size and rapid growth rate. Charolais cattle were developed from cattle imported into France during Roman times. They are heavy boned, since they were primarily used for draught purposes, with meat production being of lesser importance. Mature cows weigh 800–900 kg and bulls in excess of 1200 kg. They are white or cream and the skin is light brown (Fig. 7.4), giving some resistance against sunburn.

They are slow to mature compared with the British beef breeds and are most suited to fattening at an older age, with some supplementary feed. The Charolais bull can be used to sire dairy cows but calving difficulties are likely if the cows are small. By comparison with the Hereford, a smaller breed, crossbred calves from Charolais bulls are born up to 3 days earlier and about 4 kg heavier. Charolais cattle have less subcutaneous fat than the British beef breeds and are therefore well suited to modern requirements for lean meat. The potential to grow to a large size also suits today's market, as the initial investment in the calf can be fully utilized in producing a large animal for slaughter and processing.

Hereford

Although the Hereford was originally used for milk production and draught purposes, as well as meat production, it is now exclusively used for meat production. It was developed in the county of Hereford in England. Early breed improvement in the 18th century produced an animal that matured early and would fatten off a pasture-based diet but was still well suited to the demands of traction. Its docile character was useful for those working animals in the yoke. Another attribute that was incorporated into the breed early on was the distinctive colour marking (red/brown body and white face, chest, bottom line, tail switch and feet) (Fig. 7.5). The white features, especially the face, are dominant and enable farmers to recognize the breed of crossbred calves, giving them confidence when buying stock that they will fatten at an early age. In the middle of the

Fig. 7.5. Hereford cow and calf. Note the characteristic white face and 'socks'.

Fig. 7.6. Holstein-Friesian first-lactation cow with her 1-hour-old calf. Licking the anus directs the calf to her udder.

20th century the breed was developed into a smaller, more stocky shape that was suited to producing joints of beef of manageable size. The relatively early maturity of such cattle enables them to be finished off pasture at about 18 months of age. More recently, the breeding emphasis in Hereford cattle has been for larger animals, with the increased tendency to finish cattle at a heavier weight.

The Americans developed a polled Hereford subtype from the 1890s onwards and they also increased its size, which improved growth rate. Importation of the polled American Herefords has led to most registered Herefords in the UK now being polled. The inferiority of Hereford cattle to cattle of continental European breeds in slaughter weight was largely responsible for its reduced popularity in its native UK towards the end of the 20th century. With the emphasis now turning to less intensive feeding and ease of management, the Hereford is regaining popularity at home and is still a popular breed worldwide.

Holstein-Friesian

Friesian cattle came originally from the north-west of the Netherlands – in particular, Friesland. In the 20th century, the cattle from this region were developed into the highest-yielding dairy cow breed in the world. Nearly all the cattle are black and white (Fig. 7.6), though a few are red and white.

They are now in widespread use in most intensive dairying systems throughout the world, comprising, for example, over 90% of the American dairy herd. Both the Dutch and British Friesian cattle were until recently considered dual-purpose but intense selection for milk production in the USA in the 20th century produced a strain called the American Holstein, using cattle that came predominantly from Schleswig-Holstein in Germany and Friesland in Holland. American Holsteins are taller than Dutch Friesians and weigh 750–800 kg, compared with 650 kg for a traditional Dutch Friesian. The recent intermingling of Friesian and Holstein cattle in many countries has led to the breed often being classified as Holstein-Friesians. New Zealand Friesians are smaller and have a high capacity to produce milk from forage. In most Friesians, and particularly Holsteins, the fat and, to a lesser extent, protein contents of their milk are low, though there have been recent efforts to increase these by breeding. Even though milk production efficiency is high because of their high yield potential, if the milk yield is corrected for solids content they are no more efficient than other extreme dairy breeds, such as the Channel Island breeds. However, their large size is beneficial in reducing the labour requirement per litre of milk produced, as labour input is largely a function of the number of cows on a farm. In countries with integrated milk and beef production systems, the loss of meat production potential in this breed is of some significance.

'Holstein' has nothing at all to do with corruption for 'Holland': the breed was named for the then German province of (Schleswig)-Holstein from which, as it happens, many black-and-white Dutch cattle embarked for shipment to the USA, though most were shipped from the Dutch province of Friesland.

Limousin

The Limousin breed was developed in mountainous conditions in central France. The cattle are an orange–brown colour, with short legs and a large, well-fleshed rump. The cattle are of nervous disposition and consequently can be difficult to handle. Breed societies have reduced this problem through intensive selection for docility. Limousin cattle are smaller than the other major continental breeds (Charolais and Simmental), with cows normally weighing about 600 kg. Originally developed for the purposes of draught and meat production, beginning in the 16th century, the Limousin has been extensively improved for meat production purposes since the 1860s. It has recently been exported to many European countries, as its low level of subcutaneous fat and high potential for growth suit modern requirements. Towards the end of the 20th century, it became economically and technically feasible to feed high-quality supplements and high-energy maize silage to cattle, making it easier to finish late-maturing cattle such as the Limousin fast enough to be profitable. The Limousin is particularly suited as a crossing sire for Friesian cows, as the calves are relatively small at birth and there are very few calving difficulties.

Longhorn

Spanish Longhorn cattle were popular in the USA, where they thrived on poor-quality pasture as a slow-growing, meat-producing breed. The breed's ability to calve without assistance was, and still is, valuable in the extensive ranches of the USA, but continental European breeds are now becoming more popular. The Texas Longhorn was initially improved by crossing with the Shorthorn and more recently with the Hereford and Aberdeen Angus. The ability of the Longhorn to deposit most of its fat subcutaneously may again assume importance, as the fat can then be rapidly separated from the meat. Its ability to calve without assistance is valuable in extensive systems but its low growth rate compared with cattle of continental European breeds will deter all those seeking profitable beef production from medium- or high-intensity systems.

Simmental

The Simmental is one of the most popular dual-purpose cattle breeds for milk and meat production. It originated in the Simme Valley in Switzerland and is widespread throughout central and Eastern Europe. Originally they were also used for draught purposes; hence they are large, sturdy cattle with heavy bones. This helps them to graze mountain pastures, where fine-boned cattle have reduced life expectancy because of their inability to cope with the harsh conditions.

The Simmental is recognizable in various strains, such as the Swiss Simmental, Austrian Simmental and Fleckvieh (German and Austrian Simmentals). All are red or red–yellow and white, with the head being predominantly white (Fig. 7.7). Although good milking cattle, Simmental-cross cows have been popular in recent times for suckling purposes, producing high-quality calves for meat production. As a crossing sire for dairy cattle, the Simmental produces calves that are slow to mature; indeed the bullocks usually require 24 months to finish even with supplementary concentrates. In this respect, the Simmental is similar to the Charolais, which is only slightly larger.

Welsh Black

Although not widely known outside Europe, this breed is a good example of a modern suckler cow, as its small size is beneficial because the maintenance costs of the dam are kept low (Fig. 7.8). Traditionally dual-purpose, the Welsh Black has good milk-producing characteristics that are useful for suckler cows and the breed is particularly hardy, enabling it to thrive on upland pastures of poor quality.

Zebu (Bos indicus)

Zebu cattle evolved from *Bos primigenius namadicus* cattle in India but have since been taken to Africa, the Americas and Australia, where their heat tolerance and natural resistance to tropical diseases enables them to thrive in areas where *Bos taurus* cattle cannot. They generate less heat than *B. taurus* cattle, partly as a result of their low productivity, and are characterized by a single hump on their back (Fig. 7.9), which allows fat to be stored in a concentrated reservoir, rather than subcutaneously over the whole body. This facilitates heat loss, as does their large

Fig. 7.7. Simmental cow.

Fig. 7.8. Welsh Black cow.

Fig. 7.9. *Bos indicus* steer, resistant to heat stress because of the concentration of fat tissue in the hump, and the large ears, dewlap and preputial sheath to aid heat loss.

surface area relative to their body volume, which is achieved by having folds of skin in their dewlap and preputial sheath, large ears and long, thin legs.

These effective cooling mechanisms allow the cows to continue milk production at extreme temperatures and the bulls to remain fertile in situations where the proportion of viable sperm in *B. taurus* cattle is diminished because of the heat. The hair of zebu cattle is short, sleek and often white, allowing the sun's rays to be reflected, and the underlying skin is usually pigmented to prevent cancers, particularly around the eyes. Their behaviour is unpredictable and they have a lively temperament, making them difficult to handle. This needs to be carefully considered when selecting a breed of cattle suitable for live export, for example. They survive well in extensive grazing conditions where little handling is necessary.

Their breeding performance is not as good in their native environment as that of *B. taurus* cows in temperate conditions. They take longer to reach puberty, have long gestation lengths and post-partum anoestrus. When oestrus does occur, it is short and difficult to detect, often occurring at night when it is cooler. However, zebu cows tend to live longer than *B. taurus* cows and have strong maternal traits, hence their reluctance to release their milk without a calf being present. Normally the calf is tied at the head of the cow while milk is taken by machine or by hand.

Meat from *B. indicus* cattle tends to be tougher than that from *B. taurus*, especially in the grilling cuts, which is due to their high susceptibility to pre-slaughter stress. This problem can be overcome by effective stress control before slaughter, electrical stimulation of the carcass, ageing and correct hanging technique during processing and, in the long term, selection of improved strains.

Two of the most common types of zebu cattle are the Brahman – developed in the USA and now extensively used in northern Australia – and the White

Fig. 7.10. White Fulani cow and calf in Nigeria.

Fulani of the Sahelian region of Africa (Fig. 7.10). Their growth rates tend to be less than those of European breeds, their oestrus short and not easy to detect and their meat is less tender. In India the Gir and Kankrej are typical breeds (illustrated as the brown and grey cattle, respectively, in Chapter 1, Fig. 1.2). However, these breeds have a unique role in tropical regions, where European breeds struggle with the hot conditions, disease risks and low feed quality. In particular they are resistant to the cattle tick and screw worm. Crosses with *B. taurus* breeds, such as the Brangus (Brahman × Aberdeen Angus), Braford (Brahman × Hereford) and Santa Gertrudis (Brahman × Beef Shorthorn), are popular in intermediate climatic conditions.

Breed improvement

The structure of the cattle industry in most countries that have substantial beef production allows for genetic progress in elite pedigree herds to be passed on through commercial herds. Cattle farmers who take a special pride in the quality of their stock are often members of a breed society, which allows them to sell pedigree stock of the breed nationally and sometimes internationally. Commercial farmers will then purchase the high-quality animals to replace breeding cows or bulls in their herds. Their quality is known from ‘estimated breeding values’, determined from the animal’s performance, that of its relatives, the heritability of the trait(s) being selected for and relationships to other traits.

The terminal sires used in the commercial herds will have more influence than individual cows purchased, as they individually produce large numbers of offspring. Sires are often brought in from outside the herd to allow the herd to benefit from heterosis, or improved (hybrid) vigour when cattle with very different traits to the existing herd are chosen. Replacement cows are more likely to be home-produced. Cows may be kept deliberately small, to reduce their maintenance costs, and mated with bulls with inherently larger size characteristics, to increase the growth potential in the offspring. However, the breeding of larger bulls has led to reduced fertility, as with selection for any extreme traits. If two main breeds, A and B, are used to achieve the benefits of heterosis, after breeding cows of breed A to a sire of breed B it may be necessary to breed the AB female offspring back to a sire of breed A. Alternatively there are many composite breeds worldwide that have been developed to have the right characteristics for local conditions, e.g. Brangus, Santa Gertrudis and Droughtmaster. Many of these new breeds have both *B. indicus* and *B. taurus* content, to maximize hybrid vigour.

Breed societies record the details of all animals born on each farm and usually publish records of all cattle in the society annually. These details include the date of birth of calves, their parentage and society number. Such cattle are called pedigree because their ancestry is known. Herd registers may be ‘open’, in which case non-pedigree cattle can be admitted provided that they meet the breed requirements for the colour and type of animal. Herd owners may be required to ‘grade-up’ their cattle by using a pedigree bull over a prescribed number of years. Alternatively, if a herd book is ‘closed’, it will only admit cattle to its register if both parents are also registered pedigree members.

Pedigree cattle usually attract a premium compared with non-pedigree or ‘commercial’ cattle. This premium is largely dependent on the breeders being able to demonstrate superior performance in their stock to potential purchasers and they must therefore look after the animals well. The cattle are usually fed a high-quality diet to maximize performance, either milk production or growth rate, and this is not necessarily the most economic diet if milk or meat, rather than breeding stock, were the only output from the farm. High-quality diets allow the cattle to express their genetic potential but this often does not represent commercial practice. However, under all but the most extreme conditions, the ranking of the cattle for performance criteria will not be affected by the quality of diet, and pedigree cattle that perform better than commercial cattle on a high-quality diet will do the same on a low-quality diet.

Breeding objectives

Determining breeding objectives is the first step in developing a structured breeding programme (Kluyts *et al.*, 2003). Economic traits and profit maximization are likely to be prominent in the objectives and are often determined from 'bioeconomic models'. However, many beef cattle farmers also consider traits of less obvious economic value: how easy the cattle are to look after, how well they fit into a low-input environment, whether they are healthy and their welfare is good, and the farmer's own personal satisfaction of breeding good-quality cattle are important objectives. Criteria used have tended to move away from type traits to more economically related parameters, as the relation to profitability becomes clear. The objective in trait selection is usually to achieve the most rapid genetic progression towards these goals. Distinction should be made between breeding objectives and the selection criteria used to achieve these, e.g. lean percentage and backfat thickness measured ultrasonically, respectively. Some traits, such as feed intake, are commercially important but hard to measure.

Beef cattle

FEED UTILIZATION EFFICIENCY. Feed is the major cost in most beef cattle production systems, comprising about 80% of the variable costs. Therefore, improving the efficiency of beef cattle production is usually directed at reducing the feed conversion ratio[1]. A key determinant of the feed conversion ratio is mature weight, since it declines as cattle approach maturity, growth slows and is directed to fat tissue, which requires over twice as much energy per gram as muscle to be laid down. Thus, to avoid selecting for large mature size, it is preferable to select for low feed intake, controlled for the weight of cattle and expected rate of gain.

Beef cattle improvement has always been hindered by difficulties in measuring feed intake (Kluyts *et al.*, 2003) and many breeders select on the basis of weight gain, usually to a fixed age of 400 days. This favours breeds with heavy mature weights, especially the late-maturing breeds from continental Europe, which have high growth rates. The apparent increase in efficiency of these continental breeds, such as Charolais, Limousin and Simmental, is therefore an artefact of testing at a specific age. However, even though they are not more efficient in their conversion of feed to meat, they do allow farmers to take their cattle to heavier weights, which can suit systems with a long growing season and it also dilutes the high price paid for a calf, per unit weight. The increase in mature weight tends to increase birth weight and may lead to increased calving difficulties if such animals are crossed with small dairy cows, such as first-calving heifers.

Breeding for cattle that can survive on crop by-products or grazing with low management inputs is likely to be popular as competition increases for land to produce food for a growing world population. Reduced emissions of greenhouse gases during the digestion process may also be included as a target for breeding beef cattle.

CARCASS TRAITS. Possible carcass traits to select for include carcass weight, which has good heritability, and eye muscle area, rib fat and rump fat, all of which are moderately heritable. Within a breed, animals with a high ratio of muscle to other tissues at a certain stage of their development are likely to have increased value. A genetic mutation has appeared in the Belgian Blue and Piedmont breeds, which increases the rate of muscle growth by interfering with the regulator myostatin. It was predicted many years ago that the increase in popularity of Belgian Blue cattle would encourage the 'double-muscle' trait to be included in beef breeding programmes (Arthur, 1995). Double-muscled cattle have an increased ratio of muscle to fat, particularly in the male, and they have smaller organ weights. The increase in size of the muscles is accompanied by an increase in tenderness, which increases the commercial value of both fore- and hindquarter cuts. The trait is controlled by a major gene, which has also been recognized in other animals, including humans. In Belgian Blue cattle, the trait is associated with difficult calving in pure-bred animals, and such animals require specialist management to avoid caesarean births. The increased cost of care during calving may be financially justified by increased growth rate potential but the practice arouses concerns for the welfare of the cows and may be the subject of future legislation or other control.

Fat distribution and composition are likely to be a target for genetic modification, with intramuscular fat being reduced because of health concerns. Subcutaneous fat will be a more desirable way of storing energy surpluses, though not in hot climates because of its effect of reducing an animal's ability to lose heat. It is likely that large breeds will be favoured, so that they can be slaughtered early while they are laying down mainly muscle tissue, not fat, and will have grown to be a reasonable size. Intensive rapid-finishing systems are likely to be rare as a result of demand for high-quality feeds for animals or humans that can use them more efficiently than cattle.

REPRODUCTIVE TRAITS. The low reproductive rate of many beef cows encourages breeders to include this characteristic in breeding programmes, even though it partly derives from undernutrition and a natural suppression during suckling. An ability to reproduce under poor feed conditions would be advantageous in many marginal regions and is likely to favour small cattle with low maintenance requirements. Female reproductive traits are not easily improved, with heritability values of just 10–20% for traits such as calving interval and ease of calving. However, scrotal size, a key indicator of a bull's fertility, is quite highly heritable.

ENVIRONMENT AND WELFARE TRAITS. Apart from characteristics focused on the production potential of cattle, future beef breeders must concentrate on environmental and welfare-related traits to preserve the acceptability of their businesses. Reduced methane production may be feasible in certain animals. There is considerable influence of the host animal on its microbiome and selection for reduced methane output could not only reduce environmental pollution from cattle but also improve feed conversion efficiency.

Breeding to reduce or eliminate the stress associated with dehorning is already a focus of activity in Australia. In extensive beef production systems in hot climates, 80–90% of cattle are of *B. indicus* type and possess horns. Breeding cattle without horns will prevent a significant additional stress that dehorning creates when the cattle are brought in for treatment once or twice per year. Eliminating the need for dehorning because of its impact on welfare is therefore a key objective. Genes are being sought that could convey the polled characteristic between breeds. Similarly, male castration is criticized for its welfare impact but is still widely practised to control the behaviour of the cattle. If breeds could be modified so that males were calm and of good temperament, even without castration, a painful procedure would be rendered unnecessary. Breeding for good temperament in this way would be likely to increase growth rates. The development of a temperament score in Australia, assessed as the speed at which cattle exit a crush, has allowed this characteristic to be incorporated into breeding programmes. Improving temperament can bring immediate benefits in growth rate.

STRUCTURAL TRAITS. Structural traits relate to the form and function of cattle, including leg and udder characteristics. Correcting structural traits that are extreme and undesirable must be seen as a long-term investment in the well-being of both the enterprise and the cattle. Leg traits are most commonly bred for, as lameness is a serious problem in many farms.

ECONOMIC TRAITS. Some experts argue that it is better to select just for increased profit per animal rather than for specific traits, such as leg conformation. The problem with this approach is that economics are transient, often changing in just a few months, whereas breeding achieves improvements over many years.

Dairy cattle

MILK YIELD. Selection for high milk yield has been the major emphasis of breeders in the past, which has tended to favour large dairy cows, such as the Holstein-Friesian breed. Large cows reduce the labour requirement per unit of milk, but changing cow size rapidly may result in housing conditions being unsuitable. The physiological limits to production do not appear to have been attained, as cattle do not produce much more milk per kilogram body weight than other mammals. The cow does, however, lactate for a greater proportion of its life than most other mammals, so the stress of prolonged lactation may be considerable. The short lifespan of most cows in intensive dairy systems (normally about 4–6 years) is testament to the stress that they have to endure, when one considers that cows in less extensive systems often live to 20–25 years of age before they show signs of senescence.

One of the deleterious effects of breeding for high milk yield has been to exacerbate the peak of lactation. It is the short period from the commencement of lactation to peak lactation that contains a high risk of metabolic breakdown, largely because intake is insufficient to provide the major nutritive requirements of the cow at this time and body tissue is consequently mobilized at a high rate. Dairy cow breeders will probably focus in future on extending the lactation of cows, to diminish early lactation metabolic problems. It will only be possible to use cows with extended calving intervals if it is not desired to concentrate calving into certain periods of the year. As with beef cattle, it is important to breed for efficiency of milk production, including a measure of feed intake if at all possible. If measures are taken only in the short term, selection will favour cattle that channel nutrients to milk production at the expense of live weight gain.

MILK COMPOSITION. The inverse genetic correlation between milk yield and the concentration of many solid components of the milk, particularly fat, resulted in a decline in milk solids content as milk yield increased in the third quarter of the 20th century. This was undesirable, as the transport costs of milk solids increase as milk is more dilute. Compared with some other mammals, for example seals, cattle produce large volumes of dilute milk. Since the late 1980s, increasing the concentration of some milk constituents has been a focus for some breeders, so that milk fat content of the Holstein-Friesian cow, in particular, has increased from below 3.5% to nearly 4.0%. Recently, milk fat has become less valuable than milk protein in industrialized countries and maintaining a high milk fat content is now a low priority. Milk products typically represent about 30% of saturated fat content in a Western diet, but although there might be benefits in reducing saturated fat content, there are currently no economic advantages to farmers. The strong genetic correlation between milk protein and fat content makes it difficult to affect just one of these components.

Reducing milk lactose content could be a beneficial objective in countries where lactose intolerance is common. However, the production of the enzyme lactase, which is required for lactose digestion, depends on the amount of milk that is consumed. People who traditionally consume large quantities of milk, such as those in Scandinavia, have little problem with lactose intolerance in adulthood because they retain lactase activity. However, although lactose malabsorbers represent 90% of the human race,[2] most people can consume small quantities of milk, if these are introduced gradually into the diet, without any difficulty in digesting the lactose.

For infant feeding, it would be useful for cows' milk to be more similar in composition to human milk, with the ratio of cow to human milk solids contents currently being 3:1 for protein, 7:1 for casein and 1:1.6 for lactose. Herds may, in future, specialize in producing milk for certain functions. For example, cows' milk contains the protein lactoglobulin, which is hard to digest in liquid milk and is not present in human milk. The modern techniques of gene identification and transfer may enable the regulatory genes to be identified and switched off. Other possible specialized production systems could include increasing the casein content – to increase its value for cheese production – and increasing the phosphate content, which would increase the stability of the micelles and also calcium uptake. The ability to modify the mineral content of milk is limited for some elements by the mammary gland's homeostatic mechanisms, which closely control the concentration of major mineral nutrients in milk, including calcium, iron and sodium.

ECONOMIC AND DISEASE TRAITS. The tools for the economic improvement of dairy cow enterprises through breed improvement are well developed but care must be taken not to emphasize short-term economic traits at the expense of long-term viability of the breed or strain. Modern selection methods rank cows on profitability indices, which compare the margin over feed and quota costs for each daughter in every lactation. A typical formula for the profit index would give the highest weighting to protein production, less to fat production and only minor value to milk yield. These weightings are determined as the predicted transmitting ability (PTA), which is the predicted level of production that an animal is capable of passing on to its offspring above or below a predetermined baseline. In the UK the baseline is updated every 5 years to reflect national herd improvement and the PTA value is accompanied by the year of calculation.

More advanced profit indices are available, which include structural (type) characteristics with important economic merit and association to longevity (De Vries, 2017), such as the profitable lifetime index, in which the milk production value of a bull's offspring is weighted for a lifespan value. The milk production value is the margin over feed and quota costs per lactation, determined annually. The lifespan value is calculated from conformation traits, such as good feet and udder, which are given a PTA. Thus, indices used by farmers increasingly compare cows for lifetime performance because the value for individual lactations is not representative of the lifetime yield, which has more economic significance. In this way, disease susceptibility is incorporated into breeding programmes. However, the genetic correlation between lifetime performance and milk yield in a particular lactation is often less than 0.3.

Management traits may assume increased importance on individual farms with specific problems, with calving ease, milking speed and temperament being three of the most important, partly because of public concerns for the welfare of dairy cows. Disease traits are assuming an important place in the setting of breeding objectives, particularly because of their importance to welfare. An antagonistic relationship exists between many disease incidence traits, such as mastitis, and milk yield. Somatic cell counts (SCC) can be used to indicate mastitis severity but caution should be exercised in breeding cows with low SCC that may not respond well to bacterial challenge from acquired infection. Unfortunately, although disease incidence traits are economically and ethically important enough to be included in breeding objectives, the heritabilities of the traits are often disappointingly low.

REPRODUCTIVE TRAITS. The recent reduction in reproductive performance in dairy cows in intensive production systems with Holstein cows is likely to increase the importance of these traits. However, dairy cow reproductive traits usually have a heritability of less than 0.10 and there is an antagonistic genetic relationship with milk yield. Longevity, or stayability, as it is more correctly known, also has a low heritability, about 0.05 (Strandberg, 1996). Despite this, there would be major advantages in enabling cows to live longer in herds. Milk yield is increased over the first few lactations and risk of calving problems reduced, even if the risk of some diseases increases. The public is concerned about cow wastage and the cost of replacements is high.

The ability to include reproductive and disease traits in a breeding index depends on what measures are taken. Calving to first service interval could be included as a reproductive trait, but it must be remembered that if more traits are included less progress will be made in any individual trait. If no health or reproduction traits are measured, longevity in the herd could be included but it should be adjusted for production.

STRUCTURAL AND OTHER TRAITS. Structural traits may be included in a breeding index but in most cases little is known about their correlation with economic functions, so they are most likely to be used by farmers to correct traits that they feel are particularly deficient in their herd. Previous selection may have had adverse effects on structural traits; for example, selection for milk yield alone results in a deterioration of udder characteristics. Body traits tend to have heritabilities of about 0.25–0.45, udder traits 0.20–0.30 and feet and leg traits 0.15–0.25. It is difficult to relate structural traits recorded in different countries, as there is no common recording system.

The newest dairy cow improvement schemes are attempting to locate regions on the 30 pairs of bovine chromosomes that have a significant impact on profitability. These regions are known as quantitative trait loci (QTLs). Other factors that could be selected for include welfare parameters, such as disease resistance, or reproductive success, which could enable the recent decline in dairy cow fertility to be overcome. The detection of QTLs will enable specific traits to be selected much more rapidly in the progeny of a particular bull. Blood or hair samples can be used to obtain the genetic material required for detecting QTLs. Multiplying up the selected genes is now theoretically achievable by cloning but care has to be taken that this does not erode the genetic diversity of the parent stock.

At present the origin of the genetic donors still largely determines whether they develop successfully or not, with those from the embryo being most likely to succeed. Since high-producing cows are generally more profitable in a range of environments, it is likely that further concentration on high-producing Holstein cows will follow a more widespread use of cloning techniques. In certain environments, particularly those that are not conducive to high milk output per cow, locally evolved genes can increase the ability of carriers to thrive in the environment. This has been demonstrated in tropical climates, where the disease resistance provided by locally adapted breeds enables them to perform better than imported cattle that were bred for high-output temperate conditions. Often, the benefits of both types are realized by crossing imported cattle with local breeds, with the greatest benefits of hybrid vigour being afforded to the first generation (F1) crosses.

Managing the Breeding of Cattle

The great variety of cattle production enterprises worldwide use many different approaches to the management of cattle breeding. At one extreme, extensive rangeland enterprises use only natural mating and the only intervention of relevance is to remove calves once a year, for sale, which encourages rebreeding. At the other extreme, in intensive dairying enterprises cow reproduction is managed with the aid of artificial techniques for insemination, managing the oestrous cycle with exogenous hormones, embryo transfer and cloning high-value animals. A potential problem with the artificial breeding techniques to restrict breeding to the most valuable animals is the potential loss of genetic diversity. In artificial insemination, farmers only use a small number of high-value bulls. This could create risks in the future if priorities for breed development change. For example, the priorities at present focus in most countries on increasing the genetic potential for output of milk solids per cow, in particular milk protein. This is most likely to be achieved if additional high-concentrate feed is provided to meet the extra nutrient demands. However, such food may in future need to be reserved for human consumption. Flexibility in the future breeding programme is lost irreversibly by restricting genetic resources to animals capable of fulfilling a limited range of objectives. There may be public concern about restricting genetic resources as well as using artificial methods of reproduction in cattle.

Calving Patterns

A cow's breeding cycle determines when her milk is produced. Changes in breeding cycle take several years to introduce into a herd, so strategic decisions must be taken on the best time to calve the cows to make best use of the farm's resources and payment structure for milk output. Breeding may be either random at any time of year or controlled or 'blocked' by the farmer to certain times of year, which can be achieved by limiting access to the bull or artificial insemination for specific periods, or by controlling the cows' reproductive cycle by administration of hormones artificially. Provided that farmers know when cows are at the right stage for insemination, they can control when they breed.

In countries using most of the milk produced for manufacturing, such as New Zealand or Ireland, a block calving pattern is usually employed because there is a relatively small year-round demand for fresh milk compared with the demand for milk products. This enables farmers to manage calving so that peak nutrient demand by cow and calf coincides with peak grass growth in late spring/early summer. Most of the cows will calve in a period of 2–3 months in spring, so that more milk can be produced from grass in summer and the amount of supplementary feed required in winter is kept to a minimum. It also gives the farmer a quiet period when most of the cows are dry (non-lactating), which may be particularly important for small herds run by one person, with no additional staff who can be left in charge.

Block calving allows synchronization of the major activities, such as calving, insemination and drying cows off, to specific times of year. Extra labour can be brought in to cope with increased demand in peak periods. In relation to oestrus detection, it is advantageous to have several cows coming into oestrus at one time, as the chances of them forming into a sexually active group are increased, with the herdsperson being more easily able to detect cows that are in oestrus and ready for insemination.

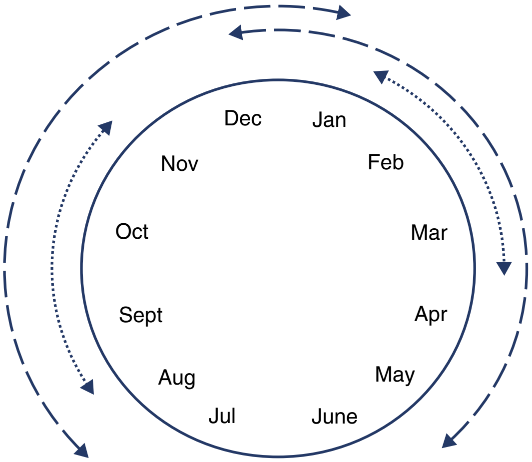

Fig. 7.11. The distribution of calving for cows calving in the autumn or spring in either a blocked (<·······>) or spread (<– – –>) pattern.

Regions with a need to produce milk all year for the liquid market and to keep the factories for milk products working at a uniform rate are more likely to have herds that calve all year round. For example, in the UK calving is focused on two or three times of the year: autumn, spring and, to a lesser extent, summer (Fig. 7.11). As pasture is usually of poor quality and quantity in late summer, there are milk price incentives for producing milk at this time. Farmers who calve their cows in early summer usually have to feed supplementary forage and concentrates when the cows are in mid-lactation in late summer. Sometimes cows calving in midsummer remain inside after calving, to be fed conserved feeds. Farmers have to judge whether the increased cost of production is justified by the higher milk price.

In summary, block calving has several advantages:

1. Management is simplified, with activities at specified times of year.
2. There is a quiet period when the entire herd is dry.
3. There is more incentive to keep to a tight calving schedule, as cows that calve outside the main calving period may have to be culled.
4. Cows can be programmed to calve so that feeding and reproductive management is simplified, efficient and sustainable. For example, conception rates are naturally reduced in late spring/early summer because cows conceiving then would calve in midwinter, with peak feed requirements soon after the period when

there is little natural feed available. In hot weather (more than about 30°C, depending on the humidity) oestrus is short, less intense and more likely to occur at night, and conception rates are reduced. Block calving herds can avoid these periods for conception. Conception in cold climates is not usually adversely affected in winter unless the ambient temperature is below −10°C, in which case mounting activity is often suppressed.

There are also disadvantages of block calving:

1. Peaks of labour requirement occur, e.g. at calving time, which may stretch the farm's resources.
2. Cows may have to be culled unnecessarily if they calve outside the main calving period, particularly older cows with high milk yields but longer-than-average intervals between calvings. For example, if the mean calving interval is about 395 days, as it is for Holstein-Friesian cows in the UK, an average cow that calves for the first time at the beginning of a 3-month calving period can only survive for four lactations before she calves outside the main calving period of the rest of the herd.
3. Heifer rearing is constrained to either a 2-year or 3-year period to first calving, when some farms might like to first-calve their cows at about 30 months of age. The first calving must be planned for the beginning of the calving period, particularly if the farm's mean calving interval is long.
4. A 365-day calving interval, which would enable cows to remain in a tight block-calving pattern indefinitely, may not be the optimum for high-yielding cows. These cows may have to cease lactating when giving over 10 l/day, predisposing them to mastitis. Routine administration of antibiotics at cessation of lactation is undesirable, because of the development of antibiotic resistance; therefore a gradual reduction in milk extraction is preferable. For low-yielding cows, a 352-day interval between calvings produces the maximum milk yield (Fig. 7.12). In temperate regions, the difficulty in obtaining high milk yields from grazing cows in late summer makes it particularly important for farmers with spring-calving herds to operate a tight block-calving system. Unless large amounts of supplementary feed are fed in late summer, cows that calve in late spring will have low lactation yields (Fig. 7.13). Farmers with summer-calving cows may have a deliberate policy of starting to feed conserved forages early, but this will often not be the case for the remnants of a spring-calving herd. In parts of the world where rainfall is high and farmers want to make the best use of grazed grass possible, spring-calving herds predominate.

Oestrus in the Cow and its Detection by the Herdsperson

Oestrus is the behavioural manifestation of sexual receptivity in the cow (the term derives from the similarity between this behaviour and that when they are attacked by the gadfly, the Greek name for which was *oistros*). Oestrous behaviour lasts for approximately 14 h immediately prior to ovulation in each 21-day cycle and is longer in cows than in heifers. It is enhanced by the presence of the bull, through a process known as

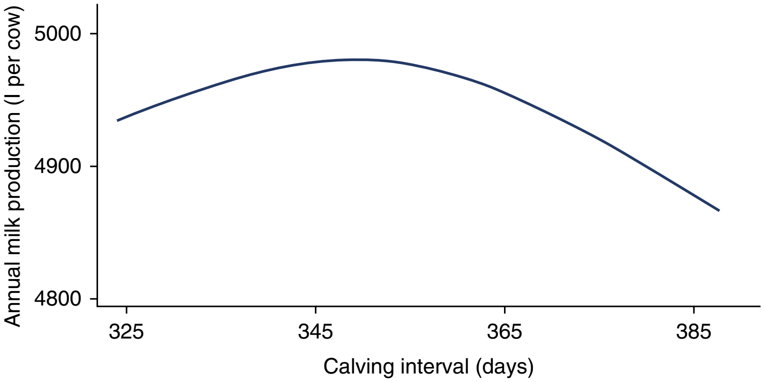

Fig. 7.12. The relationship between the annual milk production and calving interval for low-yielding cows giving a mean milk yield of almost 5000 l during their lactation.

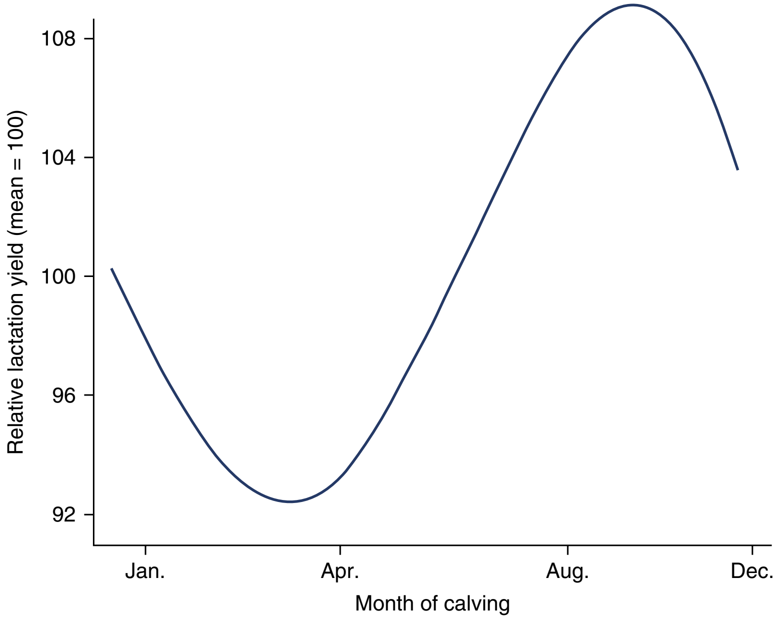

Fig. 7.13. The relative lactation yields of Friesian cows by month of calving in the temperate climate of the United Kingdom.

biostimulation. The first signs of oestrus are normally displayed about 40 days post-partum, though it can be considerably longer in conditions that are not conducive to reproduction. Some cows undergo a 'silent heat' at the time of the first oestrus post-partum, in which ovulation occurs but there are no visible signs of oestrus.

Recognition of oestrus by the herdsperson is essential if the cows are to be served by artificial insemination. The definitive sign is that a cow allows herself to be mounted by another cow. Cows will not voluntarily perform this activity outside oestrus but they may be mounted against their will if they are in a situation in which they cannot escape. Young heifers are particularly at risk of being mounted forcibly. Cows normally stand to be mounted about 50–60 times at each oestrus event but for about one-quarter of cows it is fewer than 30 times. It is therefore necessary for the herdsperson to be able to detect all the signs of oestrus and know at what stage of the oestrous cycle they are performed.

The oestrous cycle

The oestrous cycle can be divided into the following periods:

- pro-oestrus, 10 h;
- oestrus, 14 h;
- metoestrus, 10 h; and
- dioestrus, 19–20 days.

In pro-oestrus, a cow becomes restless and will separate herself from her associates if possible. She becomes aggressive to other cows to assert her dominance and right of access to a bull, if one is available. At the start of oestrus, she gathers with other cows that are at a similar stage of the cycle, forming a sexually active group. The larger the sexually active group, the more exaggerated is the sexual behaviour between the cows. Overt sexual behaviour may be shorter in a large sexually active group than in a small one, because of cows becoming exhausted and satiated. The activities performed by cows in the group include interactive mounting, resting their chins on each other's backs and rubbing them up and down, sniffing and licking the genital region of other cows to detect the pheromones produced during oestrus, vocalizing and sampling the urine of other cows.

At the start of oestrus, cows mount other cows but are not mounted themselves. In this way, wild cattle probably evolved this distinctive behaviour as a signal to bulls that grazed far from the matriarchal group. The behaviour indicates that there are receptive cows in the group. The mounting cow is usually in pro-oestrus or oestrus and would expect to benefit from the bull's attention after he has copulated with the cow being mounted, which is always in oestrus. Bulls have legendary capacity for repeated service of many cows. In fact, a bull's service potential can be estimated using a short 20 min test, counting the number of services that he manages during this period. Ten or more services indicates that a bull could be used to mate with 80 cows, whereas just two services indicates the potential to mate with just 40 cows.

In the middle of oestrus, a cow stand stands motionless waiting to be mounted and will also mount other cows, often accompanied by pelvic thrusting that confirms the mounted cow's state of receptivity. A heightened electrical sensitivity in the vagina of the mounted cow at this stage of the cycle encourages her to be receptive to mounting. Vaginal mucus production increases and the herdsperson may see mucus emanating from the cow's vulval labia or on the floor behind them when they are lying down. During this stage of oestrus, cows bellow repeatedly and are very restless.

In metoestrus, cows recover from their activities by lying and resting. They make up for lost feeding, which is reduced during oestrus. In dioestrus, there are no signs of sexual activity except occasional mounting, signifying a temporary build-up of oestrogen.

Oestrus detection

The oestrus detection rate for a herd of cows can be determined by dividing the number of cows observed in oestrus over a predetermined period by the number of cows that would be expected to enter oestrus during this period. The latter is determined from a knowledge of which cows are cycling and assuming a 21-day oestrous cycle. The target detection rate should be 80% but frequently it is less than 60%.

A significant problem in detecting oestrus is its variable length and intensity. About 20% of cows will have oestrus periods of less than 6 h and in 5% of cows it is more than 18 h. Some of this variation is unavoidable, such as the reduced oestrus displayed by young cows. However, the herdsperson should always strive to provide an environment that allows cows to maximize their oestrus display. A floor with a firm foothold and a well-lit environment with few encumbrances are important. High stocking densities help to bring cows into contact with each other more often and stimulate sexual activity. Often oestrus is shown by grazing cows when they are collected together for milking. As previously indicated, the size of the sexually active group is influential, with large groups promoting a short, intense oestrus compared with small groups. However, the introduction of new members to the group may stimulate renewed interest in sexual activity in cows that have been members of the group for several hours. The number of cows that are sexually active will depend on the size of the herd and the proportion of the cows that are cycling at the time, which in turn depend mainly on the season and the spread of calving. For example, in a small herd of 10–15 cows it is unlikely that there will be more than two cows interacting sexually at any one time.

Typical frequencies of the different oestrous behaviours are shown in Table 7.1. Other signs include Flehmen behaviour, mucus dripping from the vulva and the cow's flanks being streaked with dirt and steaming after mounting activity. Flehmen is an up-curling and retraction of the upper lip and partial opening of the mouth to allow air to reach the vomeronasal organ, usually coupled with extension of the head in the direction of the odours. The vomeronasal organ senses pheromones, especially sexual, and it is accessed via two openings in the roof of the mouth. The herdsperson may also notice individual cows being more aggressive and bellowing. It is easier to see mucus production from the vulva in an oestrous cow if she is tethered. In cowsheds where the cows are tethered the herdsperson usually looks after fewer cows than when they are loose in their sheds. Thus oestrus detection is often not as difficult as for large herds of loose-housed cows.

The short duration of oestrus in many cows makes it particularly hard to detect, unless the herdsperson is able to spend a considerable amount of time with the herd. The greater reliance on mechanical aids, the increased need for detailed records and modern housing systems that mean that cows are now more likely to be

Table 7.1. Typical frequency of oestrous behaviours (adapted from Phillips and Schofield, 1990).

Behaviour	Events per hour
Mounted with standing reflex[a]	3
Mounted without the standing reflex	1
Sniffing/licking the genital area	5
Chin rubbing/resting	6

[a] About one-half of these occur with pelvic thrusting.

managed as large groups rather than as individuals, all reduce the contact between the herdsperson and the cows within their care. The problem is most acute soon after calving, when the herdsperson should watch for the first oestrus, so that they can be alert 21 days later for the oestrus at which the cow will probably be served. A weekly computer printout of cows that are expected to enter oestrus each day will assist in achieving a high detection rate. Cows should not be served before 42 days post-partum, as conception rates are likely to be less than 40%, whereas they increase to 50% by 50 days post-partum. There is, therefore, usually only one initial oestrus that should be recorded but no action taken. Many believe that this first oestrus post-partum is silent. However, the true incidence of silent oestrus is only about 5%, though the limited behaviour exhibited at first oestrus leads to many displays being missed.

Poor nutrition may reduce the oestrus display, but not sufficiently to make it difficult for the herdsperson to detect. Cows with high milk yields and old cows usually have a limited oestrus display, as well as young cows that are afraid of interacting with, and being mounted by, older cows. Lame cows are also reluctant to mount or be mounted. Oestrus is less manifest for *B. indicus* than for *B. taurus* cows, often leading to a reduced reproductive rate in the former. High temperatures depress oestrus display and encourage cows to show oestrus at night. Some farmers in developing countries employ people to watch the cows at night for oestrus, paid on results.

In Western Europe it has been traditional to have small herds, often run by families, but in recent years these herds have expanded, leaving the farmer with less time to look for oestrus. Under such conditions, oestrus detection rates are only likely to be acceptable (> 80% of oestrus events detected) if the cows are watched three times a day for 15–20 min at a time. These occasions should include an observation before morning milking and one late in the evening. Cows do not show much oestrous behaviour when there are other activities taking place, such as feeding or milking. Ideally, oestrus detection should be a team activity, including everyone who is involved with the cows. A blackboard hung in the milking parlour can be used by members of the team to note any cows that have been observed engaging in oestrous behaviour, and cases confirmed by the herdsperson should be entered into a computer record.

The importance of oestrus detection on dairy farms has led to a number of detection aids being developed. Most of these will only assist the herdsperson and cannot replace careful observation. The only system with the potential to eradicate herdsperson observation altogether is the attachment of pedometers to the lower leg or around the necks of all cows that are expected to be cycling. These record the number of steps that a cow takes, which increases three- to fourfold during oestrus. The scale and predictability of the increase mean that it can provide an accurate system of detection without herdsperson confirmation of standing-to-be-mounted behaviour. The device records step number by a mercury switch, mechanical pendulum or piezo-electric member and it usually relays the information to a data-capture unit in the parlour, though some transmit directly to a signal-emitting unit on the device itself. Most pedometers indicate that oestrus has occurred when the number of steps taken between two milkings doubles, but greater accuracy can be achieved with an algorithm based on information accumulated over several days.

The opportunities for accurate insemination are greater when step number records are downloaded from the pedometers three times daily with thrice-daily milking but satisfactory performance can be obtained with twice-daily readings. Pedometers have the disadvantages that they are expensive to produce and can easily become detached from the cow's leg. Sometimes step numbers change for reasons not associated with oestrus: cows being lame or turned out from their winter quarters to pasture, for example. Other oestrus detection aids for the herdsperson include tailhead indicators, milk indicators, video cameras and cervical mucus conductivity measurements. Tailhead indicators are the most popular. These rely on the pressure that a mounting cow puts on the tailhead, which triggers either the release of a dye from a capsule stuck on to the tailhead, or the scuffing of paint put on the tailhead by the herdsperson. These can be read automatically by cameras. Penis-deviated teaser bulls can be prepared surgically; they will mount cows and indicate which are in oestrus, or a crayon can be attached to the chin of a vasectomized bull. Such surgical intervention and artificial manipulation of cow reproduction appear unwise in the light of public concern about cattle welfare.

Milk indicators include the following.

1. Milk progesterone concentration, which declines below 1 ng/ml for 3–5 days around oestrus. The reduction in milk progesterone content is potentially useful if the point of decline can be determined, otherwise a single low value will not determine the stage of oestrus sufficiently accurately. There are kits available that indicate whether the progesterone content of milk is indicative of oestrus, using a colorimetric test that takes about 20 min.

2. Milk yield, which usually declines after the onset of oestrus because it is withheld in the mammary glands. The reduction in milk yield can provide associated evidence but the scale of the change depends on when a cow is milked relative to the time that she enters oestrus. Cows that are first milked several hours after the onset of oestrus have a significant decline in yield and milk fat concentration at the first milking, caused by milk being withheld in the mammary gland. There is usually a corresponding increase in yield at the next milking as the withheld milk is released.

3. Milk temperature, which increases by about 0.1°C during oestrus. This small increase in milk temperature at oestrus is difficult to record, particularly if it is measured after air has entered the system to cause temperature fluctuation. Subcutaneous implants may in future be able to overcome some of these problems, recording parameters in blood rather than in milk.

Cervical mucus conductivity increases during oestrus, since more sodium ions are produced. This can be measured in the vagina, preferably about 5 cm from the cervix, using a probe with two or three copper electrodes on the end. However, the variation caused by air pockets in the vagina and the risk of introducing infection reduce the value of this method of oestrus detection.

Oestrus detection aids are useful but are no substitute for a good stockperson engaged in regular observation of cow behaviour, who has a knowledge of what to look for to determine the best time to serve cows and provides an environment that is conducive to sexual activity in the cows. The mounting display during oestrus is unique to cattle and has probably been selected for and exaggerated by artificial selection of cows with an overt display. It is important that every stockperson understands its significance and knows how to create conditions that favour its exhibition.

Artificial Insemination

Artificial insemination involves semen collection from a bull, storage in a low-temperature refrigerant such as liquid nitrogen and subsequent injection into the cow's reproductive tract with a syringe. This may be preferred to insemination by a bull, because the rate of genetic progress can be increased, there is no cost or danger associated with keeping a bull on the farm, conception rates may be increased and movement of bulls around herds, which is stressful for them, is eliminated. Artificial insemination is much more commonly used for dairy than for beef cattle. To achieve genetic progress in a herd with a bull, it must be proved as being of high potential by test-mating it with at least 20 cows. The farmer then has to wait 4–5 years until the performance of the offspring is known. Even if the bull is proved as having high genetic merit, he can only be used for a maximum of four matings per week, giving him limited reproductive capacity compared with the 30,000 matings per year that are possible when a bull is used for artificial insemination.

Sexed semen is now available, using a dye that binds to DNA and a flow cytometer to accurately distinguish between X and Y chromosomes. Although the process takes about 1 h, it has considerable potential to improve the efficiency of both dairy and beef farming by avoiding the production of unwanted male or female calves, respectively. The technique can reliably skew the sex ratio, with about 90% accuracy, but it reduces sperm viability and is costly. It has gained widespread acceptance in the USA, usually for first-service dairy heifers showing good signs of oestrus as a means of reducing unwanted male calves in the dairy industry. Females, however, may then be surplus to requirements for herd replacements, depending on the replacement rate in the herd.

Effective use of artificial insemination requires the availability of a skilled inseminator at the precise time of the cow's cycle when the likelihood of conception is highest. This may not cause a difficulty in most developed countries but in many developing countries it is difficult to organize if there are poor road links to farms, irregular communication channels and a lack of skilled labour. Providing the necessary resources for artificial insemination is relatively more costly in developing countries, especially if the transport and semen storage costs are high.

Successful artificial insemination requires an accurate knowledge of the stage of the oestrous cycle of the cow in order to inseminate her at the right time. This may be assessed by herdspeople watching their cows to determine when they are standing to be mounted by other cows – the only definitive sign that they are in oestrus. However, the ever increasing number of cows that herdspeople have to look after may give them insufficient time to watch cows for signs of oestrus. This may be partly responsible for the recent decline in dairy cow fertility. It is much more difficult for the herdsperson to detect oestrus than for a bull, which can detect that a cow is preparing to enter oestrus up to 4 days before the event.

Accurate timing of the artificial insemination requires the herdsperson to know when a cow enters oestrus, since the maximum chance of conception occurs at 12–24 h after the onset of oestrus. Oestrus lasts normally for 12–16 h and ovulation occurs approximately 12 h after the end of oestrus. Many farmers use the following a.m./p.m. rule to determine when to inseminate their cows, provided that they have the choice of inseminating cows after the morning or afternoon milking: cows that are seen in oestrus during the morning are inseminated after the afternoon milking and those that are still in heat in the afternoon are re-inseminated the following morning. Those that are first seen in oestrus during the afternoon or evening are inseminated after milking on the next morning. If a farmer can only have cows inseminated once a day, cows seen in oestrus before the morning milking should be inseminated that day, otherwise they should be inseminated the following day.

Conception

Once the cow has been served, uterine conditions must be suitable for conception and implantation to take place. Conception rates will be low if the cow is served too close to calving, before the uterus has involuted. Feeding is also important and cows should be on a rising and high plane of nutrition for the greatest chance of conception. Each increase in weight gain of 0.1 kg decreases the calving-to-conception interval by 30 days on average. Cows should be in condition score 2–3 on the 5-point scale, with those that are either fatter or thinner being likely to have conception rates less than 50%. Both energy and protein intakes are important to consider, and some minerals, e.g. phosphorus. The season of the year also affects conception rate, with cows served in early autumn having high conception rates, as they would naturally give birth in early summer when there is plenty of grass available.

The conception rate can be estimated by calculating the proportion of cows served that are diagnosed pregnant 40–70 days later. For cows served naturally, the conception rate should be approximately 70%; for those served artificially about 65%, depending on the inseminator. Some bulls have low conception rates because of poor-quality semen, so excessive use of one bull may be risky unless conception rates for other cows that have been inseminated with his semen are known.

Other important measures of reproductive rates, apart from the oestrus detection rate and conception rate, are the calving index (interval between calvings), the number of services per conception and the calving-to-conception interval. The calving interval is normally assumed to be optimal at 365 days. This minimizes loss of milk as a result of a prolonged dry period but still gives the cow time to recover if lactation is terminated at 305 days. Increasingly, farmers are questioning the wisdom of stopping the lactation of high-yielding cows early to achieve a 365-day calving interval. This is especially true if the value of the calf is low. Regarding the interval from calving to conception, if it is assumed that gestation lasts for 280 days, then to achieve an annual calving at the same time each year the calving-to-conception interval should be 365 − 280 = 85 days. If the conception rate is 50% and the oestrous cycle 21 days long, then the cow must be first served at 65 days post-partum to conceive at, on average, 85 days post-partum. Working back, if a cow has to be served for the first time at 65 days post-partum, and she begins to cycle at 40 days post-partum, then there are only 25 days in which to observe oestrus, i.e. approximately one cycle. A herdsperson therefore can only afford to miss one oestrus before each cow needs to be served. This emphasizes the importance of seeing the first oestrus post-partum, recording the date and waiting to see the next one 21 days later.

Hormonal Control of Reproduction

The bovine oestrous cycle can be divided into the follicular and luteal phases. During the follicular phase, the ovarian follicle develops in response to the secretion of follicle-stimulating hormone (FSH) by the anterior pituitary gland. The follicles produce oestrogen, which controls oestrous behaviour. After stimulation by oestrogen, the gland then produces a surge of luteinizing hormone (LH), which triggers ovulation or release of the ovum from the follicle. The follicle turns into a corpus luteum, or yellow body, which produces progesterone to act on the uterus to produce a suitable environment for implantation and prevent further ovarian activity. If the ovum is not fertilized, the uterus produces prostaglandin, which kills the corpus luteum, allowing progesterone levels to increase and FSH to act on a new follicle.

A herd with reproduction problems should be investigated systematically to identify the cause of the problem, starting with the oestrus detection rate. If this is low and oestrus detection aids fail to bring improvement in reproductive performance, and if no bull is available, the herdsperson may be encouraged to synchronize the cycles of non-pregnant cows with exogenous hormones, followed by artificial insemination.

Exogenous hormones should not be used as a replacement for good management. Expectations of high milk yields, often stimulated by use of exogenous somatotrophin or cows of high genetic merit, inadequate feed to match requirements in early lactation and insufficient time for the herdsperson to look after the oestrous cycle of each cow are often responsible for problems of poor reproductive performance, and these cannot be easily overcome with exogenous hormones.

There are two main methods of reproductive control: (i) administering prostaglandins that induce early regression of the corpus luteum; or (ii) supplying progestagens that act as an artificial corpus luteum.

Prostaglandins

Originally erroneously thought to come from the prostate gland in males, these hormones cause corpus luteum regression from day 6 to day 16 of the cycle. The next cycle in a group of cows injected at the same time can then be synchronized and insemination planned in relation to the exhibition of oestrus. Two injections given 11–13 days apart will ensure that all animals will have a functional corpus luteum at the time of the second injection, provided that they were cycling originally. Following the second injection, cows should come into oestrus 3–4 days later. The variation in time to oestrus is significant in adult cows, as a result of the stage of follicle development when the injections are given, and therefore they cannot be inseminated at a fixed time after the second injection. This is, however, possible with dairy heifers, which have a more predictable time to first oestrus, and insemination at 72 h and 96 h after the second injection usually gives good results. One insemination at 80 h is possible, or insemination after observed oestrus, which is better as long as oestrus detection is accurate.

One disadvantage of using prostaglandins is that cows that are pregnant and are treated in error will abort. Similarly, pregnant women who administer the treatment are at risk of abortion if some is absorbed through the skin. Prostaglandins should be administered only after veterinary examination and by a veterinary surgeon (veterinarian), in view of the potency of the hormones in humans. An alternative use of prostaglandin is in the early post-partum period, when it stimulates uterine involution and early return to oestrus cyclicity, but routine use on all cows at this stage in the reproductive cycle, rather than just problem cows, is not usually justified.

Progestagens

Progestagens mimic the luteal phase of the cycle and, as such, may be useful in both cycling and non-cycling cows. Treatment is required for a period of 10–12 days, usually administered by a progesterone-releasing intravaginal device, and may be combined with pregnant mare's serum gonadotrophin (PMSG) to stimulate follicular development. Usually about 85% of cows enter oestrus after this treatment. Overdosing with PMSG can lead to multiple births in beef cattle, which is usually considered undesirable. After removal of the silastic coil that is impregnated with the progesterone, an injection of prostaglandin is given 2 days later to ensure regression of the corpus luteum. This routine provides an accurate synchronization of oestrus and cows can be inseminated at a fixed time, 56 h after implant withdrawal (Odde, 1990).

Embryo Transfer

The transfer of fertilized ova (embryos) from a donor female to recipient females is usually combined with superovulation (drug-induced stimulation of the ovaries to increase production of mature oocytes) of the donor female. Together, the two techniques are known as multiple ovulation and embryo transfer (MOET) (Black, 2015), a system that is now in use worldwide. The technique is principally used to increase calf production from the best cows, in the same way that artificial insemination is used to extend the number of offspring from high-value bulls. The technique can also be used to induce twinning, to speed up a selection programme or to export stock to developing countries without the attendant problems of adaptation of cattle to hot environments after growing up in temperate conditions. It could potentially also be used to obtain high-value beef cattle from low-quality dairy cows, in conjunction with cloning and embryo-sexing techniques once they become established procedures in commercial cattle breeding. The average number of transferable embryos from a superovulated dam is about five, but with considerable variation caused by different rates of ovulation, fertilization of the ova and recovery of fertilized ova (Gordon, 2003).

Management of the donor cow

Donor cows are superovulated by administration of exogenous gonadotrophins (gonad-stimulating hormones), usually PMSG. This is long-lasting and a single injection is adequate but may need to be counteracted with anti-PMSG post-ovulation to prevent a second wave of follicles. FSH is an alternative but it has a much shorter half-life, requiring several injections over a period of 3 days. After superovulating with PMSG or FSH, a prostaglandin injection is given as a luteolytic agent.

Good results can be obtained when superovulating if the following conditions are adhered to:

1. Adequate cow nutrition and absence of stress.
2. Donors prepared so that they are superovulated in mid-cycle, possibly using an induced oestrous cycle.
3. Donors inseminated with high-quality semen at 12–24 h after the onset of oestrous behaviour. Bulls differ in fertility and best practice must be followed when inseminating. The insemination can be repeated after 12 h if the cow is still in oestrus. Embryos are recovered about 7 days post-ovulation by flushing a sterile solution through the uterus. This is either introduced surgically or, in the case of milking cows, non-surgically via the cervix. With docile cows, a flank incision is possible, but for rangeland cattle a ventral incision is most likely to be required together with a general anaesthetic. Any uterine damage resulting in haemorrhaging is likely to be embryotoxic.

Freezing and sexing the embryos

The first bovine embryos were successfully frozen in the early 1970s. Nowadays over one-third of recovered embryos are frozen and thawed before implantation. After recovery of the embryos they are washed several times, including in trypsin to inactivate any viruses, and then frozen in phosphate-buffered solution, with added glycerol as a cryoprotectant. Freezing should start within 4 h of recovery. The embryo dehydrates as the temperature is lowered and this determines the optimum freezing rate: too fast and lethal ice crystals form intracellularly; too slow and the embryos become excessively dehydrated. Only top-grade embryos should be frozen. An alternative to freezing is to store the embryos in acid buffer solution for 24–36 h before implanting in recipients.

Sexing embryos allows cows to be impregnated so that they produce female offspring, in the case of a dairy herd, or male offspring in the case of a beef herd. This means that large numbers of unwanted calves are not produced, thereby increasing efficiency and reducing ethical concerns about their premature slaughter. Sexing is achieved by removal of a small number of cells from the embryo, which are then subjected to a polymerase chain reaction (PCR) analysis that can detect the presence of Y-chromosome genes.

Management of the recipient cows

The cycle of recipient cows must be synchronized with that of the donor, at least within 24 h, which is often achieved by prostaglandin injections for both donor and recipient. If the embryos are frozen after being collected from the donor, the preparation of the correct number of recipients is necessary. As with the donor cows, the recipients should be well nourished, in good health and free from stress. The embryos can be inserted either surgically or non-surgically. In surgical transfer of embryos that are at the morula to blastocyst stage, a small abdominal incision is made to expose the uterus and the embryos are transferred to the lumen of the uterus via a pipette or catheter tip. Younger embryos are inserted into the oviduct, allowing them time to develop before being exposed to uterine conditions. Non-surgical transfer is similar to artificial insemination, with the embryos being deposited one-third of the way up the uterine horn. Sterile procedures are essential for both surgical and non-surgical transfer, with particular care necessary to prevent faecal contamination of the reproductive tract in the case of non-surgical transfer, to eliminate any risk of infection.

Cloning Cattle

Cloning cattle has the obvious attraction that large numbers of offspring can be produced from outstanding individuals, from a food production perspective. It has been technically possible for about 10 years, by taking a nucleus from a somatic cell of an adult and inserting it into an enucleated egg whilst at the same time sensitizing the egg to receive the nucleus. The egg is then impregnated in a recipient mother. This is potentially valuable for high-quality cows but not for bulls (because semen availability does not usually restrict the reproductive rate of bulls). However, there has been ongoing debate about the ethics of the practice. The mortality and morbidity rates of cloned animals are very high and there are concerns about reduction in biodiversity. As a result, Europe is firmly against commercial cloning on ethical grounds, but it is actively supported in China, Australia and to a lesser extent the USA.

Pregnancy Diagnosis

The importance for economic production of rapidly returning cows to pregnancy after they have given birth requires that cows should be checked for pregnancy as soon as possible after service. It can also be important to identify cows that are pregnant to ensure that they are given appropriate management, fed an improved ration in late pregnancy and not transported long distances. Accurate testing is required for cattle transported over long distances, as parturition at this time would be dangerous to cow and calf. It is also important in the rangelands to avoid farms having to carry non-pregnant cattle, reducing the availability of resources for other cattle.

The earliest opportunity to test for pregnancy comes about 21 days after the cow was served, by investigating whether she exhibits another oestrus. Although this may be observed by the herdsperson as a behavioural oestrus, it can also be tested hormonally by measuring the progesterone content of the milk in dairy cows. If the cow is pregnant, the corpus luteum will produce progesterone. If she is not but is in the follicular phase, the progesterone concentration will fall to less than 1 ng/ml over a period of 3–5 days around the time of oestrus. A problem with this method is that the cow may have been served when she was not in oestrus – if, for example she was incorrectly diagnosed by the herdsperson. Repeated samples could detect this anomaly but are not always practical for large numbers of cows. A hormone produced by the cotyledons of the placenta, oestrone sulfate, can be detected with some success but not until mid–late pregnancy. Some farmers diagnose pregnancy themselves using non-return to oestrus and the cow's body condition as indicators. They are only accurate about one-half of the time and a small proportion of cows (about 7%) naturally exhibit signs of oestrus during pregnancy.

The most popular method of pregnancy diagnosis is an internal examination of the reproductive tract, including detection of the ovaries, cotyledons, fetus and pulse in the uterine artery by a lubricated gloved hand entering via the rectum. This is known as rectal palpation, which is highly accurate in its detection of pregnancy and relatively quick, with a throughput in good handling facilities of about 60 cows per hour. The initial signs of pregnancy – asymmetry of the uterine horns, the presence of fluid in the larger horn and the presence of an amniotic vesicle – can be detected at 30–35 days after service by experienced operators. There is a risk of introducing infection, damage to the rectal wall, potentially causing peritonitis, and even embryo loss if the palpation is too vigorous, making this procedure one that should preferably be conducted by a veterinarian or at least a trained and accredited operator. An incorrect decision can lead to an animal being culled unnecessarily. At this stage, and up to 65 days post-service, the date of conception can be accurately determined. After 65 days, the amniotic vesicle becomes too flaccid to be recognized, but the fetus can be palpated and the date of conception determined to within 1 week by assessing the extent of development of the fetal head. Most commonly, pregnancy diagnosis is conducted at 90 days post-service, by which time the uterus is flaccid and both the placentomes and fetus can be palpated.

Another alternative is ultrasound examination of the uterus, which can be performed as early as day 26 after service and is quick and easy to do. The procedure, however, requires expensive equipment and carries a greater risk of fetal loss. The portable ultrasonic scanners use an external probe to detect reflections of low-energy sound by the fetal cardiovascular system. Internal scanners are also available, with a visual display of reflected sound waves. The automated methods require less operator skill than rectal palpation.

Parturition

Parturition is a critical time for both cow and calf and is particularly difficult for a first-calving heifer, because of her inexperience and the small size of the pelvis through which the calf has to pass. Other risks include pre-partum damage to the fetus, failure of the neonatal calf to maintain its immune status and the stealing of the calf by other cows or, in rangeland conditions, predators. Many inexperienced herdspeople are eager to give as much help as possible but patient observation is the best assistance in most cases. Normally, a grazing cow will retire from the rest of the herd and find a quiet, sheltered place to give birth, such as under a hedge. The herdsperson should recognize impending calving; and, if difficulties are anticipated, it is better to bring the cow to a calving box before parturition starts rather than waiting until later. The signs of impending calving are a relaxation of the muscles around the tailhead, an enlarged vulva and distension of the udder, often with milk leaking on to the ground. The relaxation of the tailhead region occurs about 24 h before the calving and is the best sign of impending calving. The herdsperson may also notice that the cow appears restless and agitated but this actually starts several weeks before parturition.

Parturition is accomplished in three stages: cervical dilation, calf expulsion and placental expulsion.

1. Cervical dilation is terminated by the breaking of the waterbag and appearance of the calf's hooves. The normal duration of this stage is 2 h but it is often longer in heifers.
2. Calf expulsion normally takes about 1 h. The cow is usually standing initially but lies down to give birth. In this second stage, uterine contractions occur with increasing frequency, usually every 15–20 min, accompanied by strong abdominal straining to contract the diaphragm behind the calf and force it through the birth canal. The expulsion of the head is the most difficult procedure and its size may make it difficult for heifers to achieve calf expulsion unaided. Alternatively, help may be required if the presentation is abnormal, for example if the head or the back legs are presented first rather than the forelegs. Assistance with a difficult calving should be given initially by the herdsperson, if necessary with the use of a traction aid if the cow's efforts to expel the calf seem inadequate. If this is not satisfactory, a veterinarian should be requested to give assistance.
3. Expulsion of the placenta: this usually occurs about 4–6 h post-partum. The cow usually eats the placenta to guard against possible predators.

After the calf has been born, the herdsperson should ensure that it is breathing, if necessary clearing the nostrils of mucus and stimulating it by vigorous rubbing and movement. Cow and calf should remain together for at least 24 h to ensure that adequate colostrum has been consumed.

Future Trends

Cattle, both male and female, have over the centuries been revered as a potent symbol of fertility. It is ironic that poor reproductive performance is now responsible for major inefficiencies of production in both dairy and beef herds. The recent decline in dairy cow fertility is particularly of concern and, like the decline in human (male) fertility, is of unknown aetiology. There are many possible reasons – high milk production, intensive and stressful housing conditions, reduced care by the herdsperson or even environmental pollution. It is clear that one calf per year is attainable over a long lifespan. This is not a high reproductive rate in comparison with other mammals but, when combined with the stress of high production in adverse environments, reproduction is often the first casualty. Difficulty in breeding can only be seen as symptomatic of the poor husbandry of many cattle. Herdspeople are now expected to look after many more cattle than previously, with the aid of mechanization, and this has adversely impacted on cow reproduction. However, the annual production of one calf from each dairy cow may be unnecessary in the foreseeable future by more widespread use of semen and embryo sexing, by prolonging the lactation and by reduced demand for calves for beef production from the dairy herd. In future it is also likely that many calves for beef production will be produced solely in specialist suckler herds in less-favoured regions. The possibility exists to clone the most successful animals in both dairy and beef herds, though the success rate is low. Excessive artificial or genetic manipulation of cattle reproduction is likely to meet with public resistance. Restriction of the genetic diversity must also be viewed with caution, as future requirements from cattle producers may require different cattle characteristics than those needed today. For example, a reduced contribution to environmental problems and an ability to thrive in a wide variety of conditions are likely to be more valuable than high milk yields and growth rates.

Notes

[1] Feed dry matter (DM) intake/live weight gain. Feed conversion efficiency is the reciprocal of this, i.e. live weight gain/feed DM intake.

[2] 100 % of people from the Far East, 73 % of US Negroes, 42 % of French, 20–30 % of Britons and 3 % of Scandinavians.

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8

Housing and the Environment for Cattle

Introduction

The housing of cattle is an economic necessity for profitable farming in many parts of the world, rather than being a physical necessity for the animals themselves. Housing allows herdspeople to work in relative comfort and, with the aid of machinery, effectively and rapidly service the needs of cattle. Dairy cows are the most likely to be kept indoors for a significant part of the year, to provide better nutrition than just pasture grass during cold or dry periods, to limit damage to pasture land by hooves and to facilitate mechanized milking and other aspects of routine animal care. As lactating cows have to visit a milking parlour several times a day, having them close by in a building is an obvious saving of the time that would be used to collect them from a field. The objective of most farmers in housing cattle is therefore to provide an economic system of indoor production with high labour efficiency.

Some people might anthropomorphically believe that cattle are more contented in a natural environment outdoors and in some situations this is undoubtedly true. However, for a high-yielding cow grazing sparse pasture or a cow kept outside her thermoneutral zone on pasture without shade, this may not be the case. Studies giving cattle the choice of indoor or outdoor environments have demonstrated that they will mainly choose to remain indoors during inclement weather or when feed availability is greater than that offered in the fields. Remembering that humans have extensively modified their own environment to improve their comfort and the facilities available to them, it is wrong to imagine that cattle are always best kept outdoors, especially if the ecosystem fails to provide for nutrition, protection from the weather and opportunities for individual care and attention by veterinarians. However, the high stocking density necessitated by housing may make normal social relationships difficult, and the opportunities for rest and locomotion are likely to be limited by the unnaturally hard floor, crowded living areas and hardware that restricts cow movement (see Chapter 1, Fig. 1.2). Thus cows may restrict their movement whilst lying indoors, changing lying positions less frequently, and may lie down for longer than cows at pasture.

The objectives of good-quality housing for cattle are:

- a comfortable environment, with adequate feed and water supplies, that meets the behavioural and physiological needs of cattle;
- a comfortable and safe working environment for the stockperson;
- minimum injury to stock;
- minimum opportunity for transfer of diseases;
- ready access for cows to handling facilities and, in the case of lactating cows, the milking parlour; and
- protection of the land area of the farm from damage by cattle treading or overgrazing.

Much planning should go into the design of cattle housing, because it is an infrequent investment and it can be costly to rectify mistakes. Cattle houses must be designed with future requirements in mind, considering the following issues carefully.

- How profitable will the cattle enterprise be in relation to other enterprises on the farm or other possible uses of the resources?
- Will it be desirable to change the size of the herd, or the breed of cattle?
- Will the breeding policy change the genotype and hence requirements of the cattle over time?
- Will there be changes in associated facilities for the cattle? For example, should the milking parlour expand in size or will an automatic milking system be adopted?

The financing and positioning of future building expansion should be considered, so that an efficient and profitable design is eventually achieved. Future building developments in the locality must be anticipated. Recent advances in materials have produced lightweight, large-span buildings without any central supporting pillars. These allow much greater flexibility, with more space for large machinery to be used inside the building, better ventilation and more flexible use patterns.

The designer of cattle buildings also has to try to anticipate the changes in input/output cost structure and the legal requirements for cattle farming. The following points should be considered.

- Will the proposed unit be economical in its use of resources that are increasingly valuable, such as water?
- Can excreta be efficiently moved away from the cows and treated?
- What are the desired levels of mechanization and labour to service the building?
- Are noxious odours released close to human habitation?
- Is the welfare of the cows constrained by building design?

Keeping Cattle Indoors or at Pasture?

In temperate regions, few dairy or beef cattle are now left outside during winter, because of improvements in both housing systems and techniques for conserving herbage as silage and feeding it mechanically to the cattle. In good grass-growing areas, cattle are stocked at high rates on pasture, which increases the risk of poaching or pugging damage to the pasture at times of high rainfall. Some respite for the pasture by housing cattle for part of the day is increasingly common.

Lactating dairy cows differ from other cattle because they have to visit a milking unit at least once a day and it is therefore easier for the herdsperson if they are housed close to the parlour. Cows benefit from access to pasture for a short time each day, for example between morning and afternoon milking. It gives them an opportunity to exercise and makes a useful contribution to their diet, as well as reducing the amount of excreta to be stored and disposed of safely. In countries experiencing frost and ice in winter, it is necessary to keep the pasture short during winter to reduce frost damage and this can be achieved with regular brief grazing periods. In temperate climates there may be continued grass growth during winter which is best removed by grazing for a good spring growth to occur. The aim for high-yielding dairy cows should be to provide only young, leafy grass at all times for high-yielding dairy cows.

Most cattle are fed conserved feeds for at least part of the year, because grass and other crops for grazing will only grow in warm, wet conditions. Permanent housing is increasingly favoured because of the greater control of the diet and the cows that is achieved. Automatic milking systems work better with housed cows, rather than requiring cows to walk long distances from pasture to be milked. However, permanent housing systems can have adverse consequences on cow behaviour and health. For example, at pasture cattle normally graze for 8–12 h/day, during which time they take 30,000–40,000 bites. Depriving them of the opportunity to do this by feeding them only conserved feed, which can be consumed in about half the time, can lead to abnormal behaviours, such as feed tossing and tongue rolling. Intensive all-year housing is often associated with the feeding of conserved feeds, since in most areas cutting fresh grass is not possible for part of the year, such as periods when the soil is too wet for harvesting machinery to operate or the land is too dry or cold for it to grow. In developing countries year-round feeding of fresh grass that has been harvested by hand or a small mower to tethered cows is common.

Conservation of grass for storing and feeding mechanically has been facilitated by a transition from hay to silage, the development of silage additives to expedite anaerobic conditions and the introduction of rapid harvesting and ensiling procedures to ensure minimum respiration and ensiling losses. The intake of silage is less than that of the fresh material from which it was made, because of the fermentation process and presence of protein breakdown products. Consequently, supplementary concentrates are needed to avoid low milk production.

Housed cows show more aggressive encounters with each other than do grazing cows but they tend to be more ritualized. The reduced distance between cows indoors makes all forms of social interaction more likely, including grooming (which helps to pacify animals close in the dominance order), oestrous behaviour and fighting. Cubicles (free stalls) provide opportunities to escape and increase the cows' perception of personal space, but the low level of comfort provided by most cubicles results in the cows spending less time lying down in these than when they are housed in strawed yards.

Cows walk at least twice as far every day when they are kept at pasture than when they are housed in cubicles or a strawed yard. Some of this is necessary for feed selection and occupies the cow in a natural behaviour, whereas indoors more time is spent just standing or in aggression and other undesirable behaviours. Indoors, the repeated contact of the hoof with wet, acid excreta predisposes cattle to heel necrosis and erosion of the heel bulb (underrun heel). This produces a pitted area that may reach sensitive tissue and lead to infection. It also predisposes cows to digital dermatitis and laminitis, with the constant wetting of the heel softening the tissue. Laminitis and, to an extent, solar ulcers are promoted by the high level of concentrates that must be fed to compensate for the lower nutritional value of silage compared with fresh grass. In deep-strawed buildings, hoof wear is less than in cubicle buildings or at pasture, a problem that can be rectified in partial housing systems, when cows are at pasture for some of the year. If cattle are permanently housed in strawed yards lameness is likely to be reduced but regular trimming will be necessary to control hoof growth. Care is necessary to control bacterial accumulation in the straw, as interdigital dermatitis is more common in these yards. This may be associated with interdigital hyperplasia caused by straw damaging tissue in the interdigital cleft. Some hoof disorders, most notably white line separation and punctured soles, are the result of small stones becoming embedded in the sole, usually during passage down a stony track to and from milking. On farms with stony and especially flinty soils, these conditions can be avoided by permanent housing, though other options, such as adding a new surface to the farm tracks, are available.

Requiring cows to lie on dirty bedding increases the risk of them acquiring mastitis, especially infection with *Arcanobacterium pyogenes* (*Trueperella pyogenes*), and other pathogenic bacteria such as *Peptococcus indolicus*, during wet, warm periods (summer mastitis), with *Hydrotaea irritans* (the headfly) as the vector. In summer the coliforms that cause environmental mastitis proliferate indoors because of higher temperatures. If cows spend part of the year at pasture, their housing should be cleaned and disinfected during this time. The period of rest, together with the sterilizing effect of sunlight during the summer, will produce a clean environment for the cows to be housed in the autumn. Mastitis can be reduced in permanently housed cows by providing an exercise paddock. Some mastitis forms, such as 'summer' mastitis, commonly occur in permanently housed cows in the second part of the winter, suggesting that an accumulation of bacteria may predispose cows to the disease. Mastitis can also be promoted by a low vitamin E status in the cows, as a result of eating conserved feeds.

Some cows that are housed all year have unacceptably low reproduction rates, particularly if they become too thin in early- and mid-lactation. Oestrus is potentially easier to observe indoors than at pasture and the close proximity of cows encourages a more vigorous oestrus display, as long as the floor surface provides a good grip and the cows have adequate space.

The high risk of health and behaviour problems for housed cows suggests that their welfare is likely to be better if they are at pasture for part of the year, but housing makes management of high-yielding cows, in particular, easier, which is why such systems are increasing worldwide.

The Cattle House

The most important elements of any cattle house are the floor, which is the point of direct contact for the hooves, the lying area, which provides cattle with the opportunities for rest, and the feeding system, which should allow all animals to obtain a healthy and nutritious diet, without fear of other animals.

Flooring

The floor is the physical point of contact of the animal with its environment and it affects their ability to sustain normal locomotion, as well as determining the extent of wear to the hooves and the conduction of heat away from the animal. Floors must be able to withstand heavy animal traffic (for example, if the house has a high stocking density), which would rapidly destroy any grass sward. Floors have to be harder than outdoor surfaces and non-absorbent to allow effective removal of excreta from the area. Concrete is preferred because it is relatively durable and inexpensive. It can be laid with a variety of types of corrugated surfaces that help to prevent the animals slipping, from a tamped surface, which is created at the time of laying by stippling the surface with a plank of wood, to a grooved surface, which is usually created with a cutting device in floors that have worn smooth over time.

Slipping is a particular problem for lactating cows, which may not be able to get up if their legs splay. Inflatable bags positioned under a cow may assist her to rise to her feet but the problem is better addressed by taking preventive measures. Falls, slips and splays on smooth floors can damage ligaments, muscles and even bones, but a very rough concrete floor can also damage the sole of the hoof and cause excessive wear. A high risk of slipping reduces a cow's welfare and mounting activity at the time of oestrus is reduced. On concrete the heel bulb deforms, increasing the surface area in contact with the ground and the force applied to the hind part of the hoof. Eventually the heel bulb may become eroded, causing the hoof to tilt backwards when in contact with the ground and the toes to lose contact with the ground, with the concomitant risk of becoming overgrown. Frequent scraping of concrete floors to remove slurry leads to the ridges created by tamping being worn away.

Slipping can be minimized by increasing the friction provided by the floor, determined as the coefficient of friction (force required to move an object over a floor divided by the weight of that object). If the coefficient of friction of a floor is less than 0.4, cows are likely to slip (Fig. 8.1). The risk of slipping is greatest at the beginning of the stride (just before the leg thrusting phase), when the forward horizontal force of the cow is large relative to the vertical force of the cow's mass and the friction provided by contact between the hoof and the floor is reduced.

Particular attention should be paid to floor quality in areas of heavy cattle traffic, such as around water troughs and in the feeding area. In dairy farms, heavy traffic also occurs in the milking parlour and in places where cows are required to turn sharp corners suddenly, such as in leaving a building to go to be milked or entering or leaving the parlour. As cows turn a corner, the outer and inner limbs rotate, putting pressure on the outer and inner claws of the respective limbs. In high-risk areas, the floor can be treated with an aggregate embedded into a resin, which increases friction and should reduce slipping. The use of electric goads in and around cattle buildings should be avoided, because they force sudden movement and frighten cows. The animals should be allowed to move at their own preferred pace.

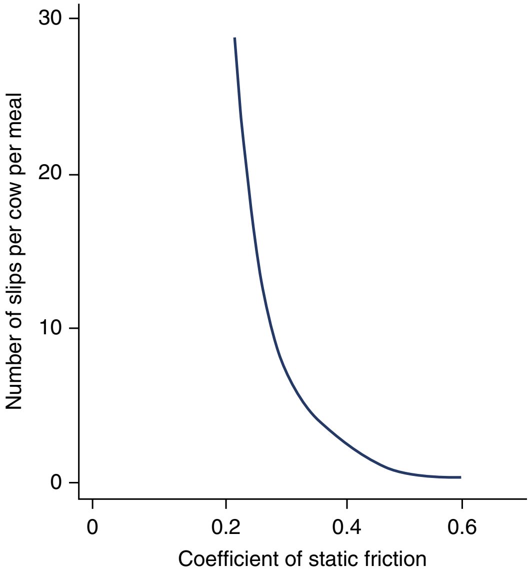


Fig. 8.1. The relationship between the floor frictional properties (coefficient of static friction) and the number of slip movements of cows measured during eating.

Other environmental and cattle factors that will influence the likelihood of cattle slipping include the following.

- Wet surfaces are more slippery than dry surfaces, so regular removal of surface water is preferable.
- Tamped surfaces are rather better than grooved surfaces at providing a slip-resistant surface.
- Cows with small, upright feet are more likely to slip than cows with large, overgrown toes, which means that care must be taken in breeding cows with such hoof conformation.

Slatted floors

These are usually made from concrete beams (slats) placed parallel to each other, with a small gap or slot in between each pair. Poorly constructed slatted floors cause cattle to walk with their heads down, fixing their gaze on the floor ahead of them and helping them to position their hooves carefully. Walking is brief and slow on slats, compared with solid floors, and cattle spend less time grooming their hindquarters because of the risk of overbalancing. However, well-designed slatted floors allow cattle to be kept at high stocking densities without bedding and to remain reasonably clean.

If the slats are narrow there is a significant strain on the concrete, particularly if they are long, but if they are wide there is inadequate disposal of faeces through the gaps. Optimum slat width is about 150 mm, with 40 mm gaps in between the slats. Concrete slats should be in T-section to encourage dung to fall into the pit below (Fig. 8.2). Great care should be taken that slats have been manufactured from high-grade concrete to the required loadings for the class of stock to be kept on them, including the necessary reinforcement.

Facilities for feeding cattle

Many cows are kept inside and fed conserved feeds for at least part of the year because grass and other crops for grazing will only grow in warm, wet conditions at other times of year. Inside, cows can be accommodated in areas where they are free to move around and lie down (loose housing), or they can be tethered by a chain or with their head between two bars in individual stalls (tie stalls). If loose housed, cows usually either have access to feed delivered along a passage or they help themselves from silage that is clamped between two walls or in racks outside (self-feeding).

Passageway feeding

If feed is offered in a concrete passage, the cattle must be prevented from walking on it by a barrier. The design of this barrier is important, as cattle will strain to obtain feed sometimes, exerting a lot of forward pressure on the barrier. It is also important that the design of the barrier prevents the cows taking a mouthful of feed and retreating with it behind the barrier, since there will be some waste of the feed as it falls from their mouths to the floor. To achieve this, the barrier may be in the form of tombstone-shaped units, usually made of wood, making it impossible for them to retreat with a mouthful of feed without raising their heads (Figs 8.3 and 8.4). Alternatively, diagonally sloping metal bars will have the same effect, making cattle turn their heads sideways before moving away from the barrier. The barrier should be firmly secured to the ground, otherwise the force of cows feeding will move it forward. Sloping the barrier forwards at the top (Fig. 8.4) will reduce the forward pressure exerted by the cattle.

The feed should be provided either on the passage floor or in a trough. At least 0.2 m per adult cow of feed trough is required to avoid aggression when feed is first put out, even if it is available *ad libitum*. Cattle prefer fresh forage and not material that has been turned over by other cattle. Feed tossing occurs when they take mouthfuls of feed and throw it into the middle of the passage or over their heads, particularly if the feed is not presented at floor level but in a raised trough or bunk. It is a time-consuming job to return it back to the cattle manually but a tractor-mounted blade can be used for this purpose. Feed tossing also makes the cows' backs

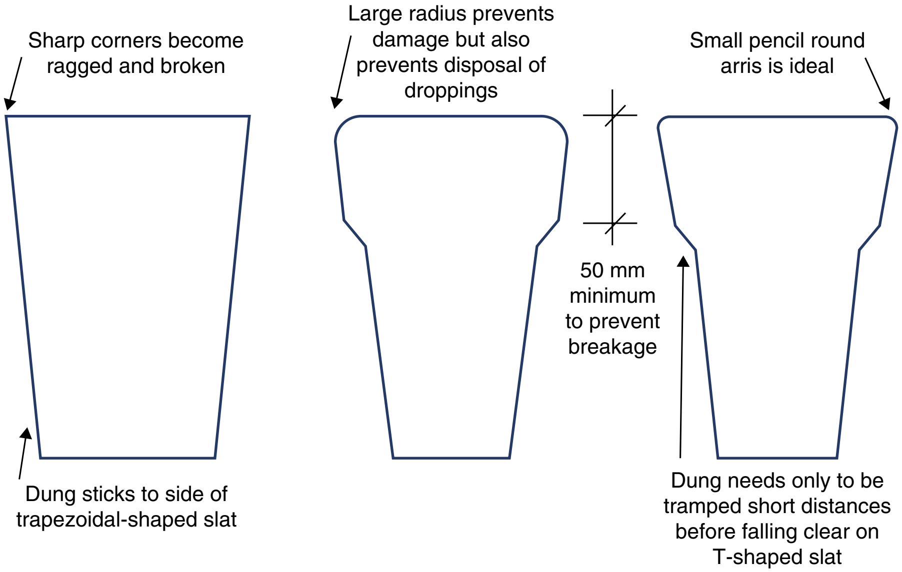


Fig. 8.2. Different section shapes for concrete slats for cattle houses. (Reproduced by courtesy of General Concrete Products Ltd, Newcastle upon Tyne, UK.)

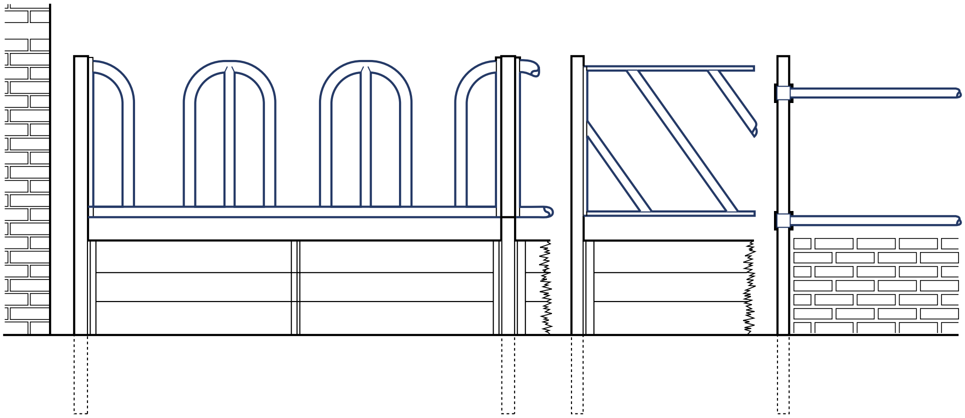


Fig. 8.3. Schematic feeding barriers for cattle. From left to right: tombstone barrier, diagonal barrier and twin-bar barrier.

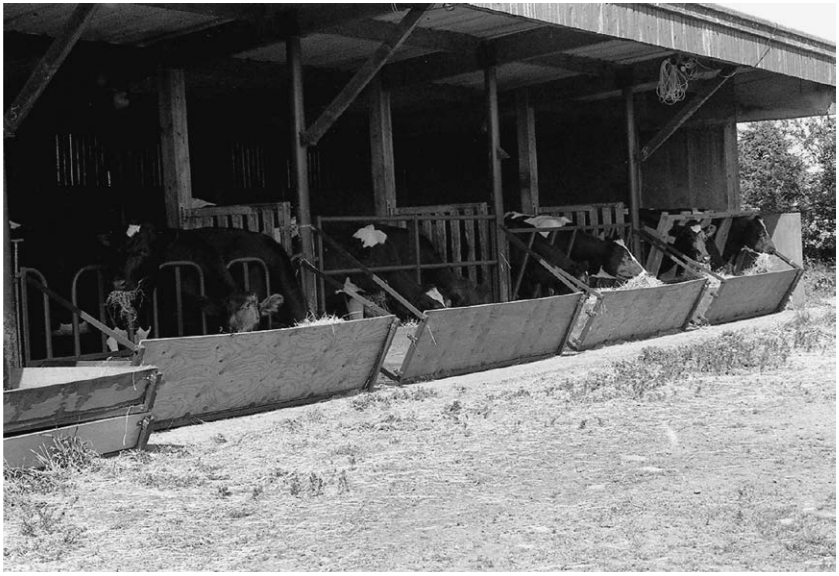


Fig. 8.4. Experimental feeding barriers for cattle. From left to right: tombstone barrier, twin-bar barrier, diagonal barrier and sloping barrier.

dirty and wastes feed. If the feed is in a trough at floor level, cattle find it harder to toss their feed forward but it will rarely hold enough feed for more than a day. A horizontal wire or bar on an open barrier will discourage them from feed tossing, but will need to be raised up for young cattle as they grow. This problem probably arises because housed cattle do not spend long periods each day tearing grass from a sward, as they would have to do when grazing, during which they take about 30,000 bites.

Self-feeding

Cattle may take their feed, usually silage, directly from a supply stored on the floor, which is usually clamped between two walls and covered to prevent air entering. A barrier is needed between the cattle and the clamped feed to prevent wastage, so that they cannot trample on feed that has fallen to the floor after being extracted. The aim should be to keep an even face of silage, which will be easier if the material that has been ensiled is all of similar quality. Cows refuse to eat silage that is mouldy, contaminated, overheated or has undergone a fermentation producing butyric acid.

The barrier for self-feeding of silage clamps is either free-standing, typically a metal pole attached to a wooden frame, or an electrified metal pole or wire about 1 m from the floor, suspended from a metal bar that has been driven into the silage. This bar is hammered further into the silage as feed is removed from the clamp, at least 15 cm/day, to avoid a secondary fermentation when silage is exposed to air. Secondary fermentation reduces palatability and is more likely in warm weather. A roof cover for a clamp of silage is not essential, but it protects the clamp from rain and allows the area to be used for other purposes if required. Many covered clamps have been converted to cattle housing as herds expand.

One disadvantage of self-feed silage is that it can only be put into the clamp up to a height of about 2 m, because this is the maximum height that cows can reach to remove the silage (depending on their size), whereas if it is removed mechanically the height can be increased to 3–4 m, provided that the clamp walls are strong and high enough and a guide rail is visible at the sides of the clamp during loading by tractor. Another possibility is to make a tall clamp and remove the top layer with a mechanical block cutter to be fed to the cows in a circular feeder, of the type used to feed round bales of silage or straw to cows. Silage can also be loaded into tower silos and then fed automatically. An alternative feed supply should be available in the event of a mechanical breakdown.

Outdoor silage clamps that are used for self-feeding should be lit at night for the comfort of the cattle, otherwise intakes will decline. If clamps are located some distance from their housing, the route that cows should take to the clamp must be lit. Lights can be controlled by photoelectric sensors. In high-rainfall areas, the cattle often get wet and dirty if they feed at an uncovered clamp outside, increasing the time required to clean them in the parlour. Silage in an uncovered clamp can also get wet if the cows are not eating through it rapidly, potentially reducing intakes.

Silage in a clamp is usually compacted by a tractor running over it. If the silage is finely chopped, the compactness may make it difficult for some cows, particularly young animals that are losing their milk teeth, to remove the feed from the clamp. It may then be necessary to take some silage out mechanically and offer it in a feeder. Other potential problems are the bullying of young cattle at the feed face, or their reluctance to feed if an electric barrier is used.

Facilities for lying down

Cubicles/free stalls

In cubicle or free-stall housing, cows are given access to raised lying beds of *c.* 2 m × 1 m, usually with an absorbent material (bedding) on a concrete surface. They can walk into and back out of these beds, but they should not be able to turn around on them, which could lead to them getting stuck. The beds are separated from each other by a divider, usually constructed with metal or wooden bars, which requires cows to lie down at much closer proximity than they would on pasture. At best, a cubicle divider creates a barrier between neighbouring cows and increases the feeling of personal space. At worst, it acts as a restriction to movement of the cow, especially when she lies down and gets up, and may lead to damage to the cow's legs. Cows like a solid division at the front of their cubicle to increase their feeling of personal space. If no barrier is present, direct respiratory contact may increase the risk of transmitting respiratory disease, such as tuberculosis.

The number of cubicles and their size are critical to cow comfort and safety. There should be at least one for each cow (Fregonesi *et al.*, 2007), unless the cows are in a large group, in which case there may be a limited opportunity for the number to be reduced on the assumption that not all cows will want to lie down at once. Most cows have preferred cubicles and for this reason it is better if there is at least one per cow. Broken dividers should be mended promptly, so that the number of available cubicles is not reduced for any period of time.

The size of the cubicle bed should be designed for the average cow in the herd to be able to lie down and get up in comfort (Ceballos *et al.*, 2004). However, if heifers come into a herd at a low proportion of their mature weight the largest cows may find it difficult to get into a cubicle designed for an 'average' cow, and the smallest cows can turn around and perhaps get themselves stuck. Therefore, the uniformity of the herd should be considered during the design phase. If relatively uniform, the dimension of the base should be determined from the weight of the average cow in the herd: length in metres = 1.75 + (0.00068 × weight in kg); width is one-half of the length. Adequate length is most important and existing cubicles that are too short can sometimes be lengthened by putting wooden sleepers at the end, provided that it does not make the passageway too narrow.

Cubicles are often too small, as cows have got larger in recent years with breeding for high milk yields. Occasionally the cubicles are too big, which may encourage cows that are not used to them to turn around rather than back out to leave the cubicle. Young cows may also dislike backing out of cubicles into a crowded passageway, as this exposes their vulnerable flanks and udder to attack by other cows. Similarly, cows may get stuck in the front of a cubicle if they shuffle forward, since they need to be able to lunge forward as they get up (Fig. 8.5). Sometimes a 'brisket board' is positioned on the floor at the front of the cubicle to stop cows going too far into the cubicle and becoming stuck.

If there is a big variation in cattle size within a herd, some young heifers may get stuck in the large cubicles if they try to turn around but large, old cows may find the same cubicles uncomfortable. Hence young heifers should have adequate size when they enter the herd. Cows normally rise by pushing up with their rear legs first; but if the cubicles are uncomfortable and the cattle have difficulty in getting up, they may reverse the normal pattern of behaviour, choosing to get up with their front legs first. They may sit like a dog in the cubicle, rather than in the normal lying position.

The divider between cubicles is critical to the successful utilization of the lying space for cows. It may have one, two or no points of insertion into the cubicle base. Metal bars often corrode at this point, so it is advisable to paint them or use a plastic sleeve for protection. The divisions usually have a lower rail to stop cows invading their neighbour's space. Its height is critical: too low and cows may get their legs trapped underneath; too high (which is more likely), they may roll underneath and injure themselves when attempting to get free. Standard height is about 350–450 mm and about 1 m for the top rail. Sometimes the lower rail is replaced with a twisted rope. This can stretch under pressure from cows, but still prevents them from straying too far into their neighbour's space.

The 'Dutch Comfort' cubicle division minimizes the length of the lower rail (Fig. 8.6) to allow space sharing between cows (Phillips, 2002). A U-shaped tubular steel section is positioned close to the wall to prevent cows moving into the next cubicle. The distance of this section from the wall should be no more than 350 mm, otherwise young heifers turn into the hole and get stuck. Cows in 'Dutch Comfort' cubicles tend to lie in the laterally recumbent position, whereas those in more confined cubicles lie sternally recumbent. In uncomfortable cubicles cows are restricted in position changes, which are much less frequent than at pasture.

A neck rail is usually attached to the top of the cubicle divider at right angles to it, about 450–500 mm from the front of the cubicle. This encourages the cow to back out as she stands up and, if she defecates as she rises, the faeces will then fall on to the floor and not the cubicle base. If the neck rail is positioned too far from the wall, it is awkward for the cow when getting up.

The cubicle base should be slightly sloping (a 70–80 mm fall over the length of the cubicle) so that urine drains into the passageway. It also allows cows to

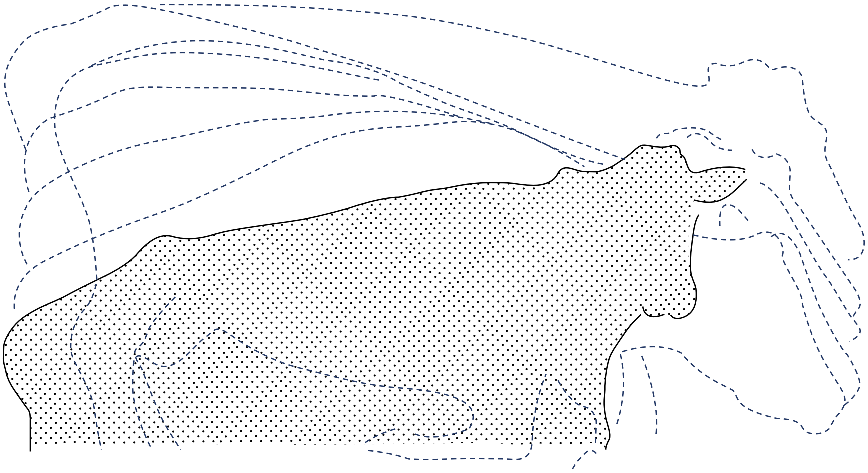
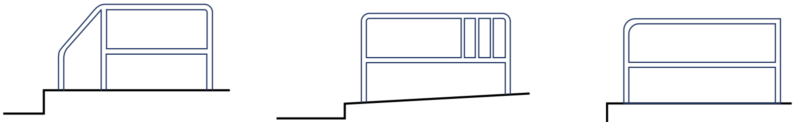
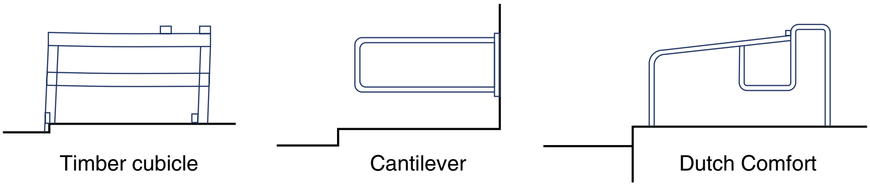


Fig. 8.5. The forward space demand of rising movement for an 800 kg Friesian cow.



Newton Rigg Auchincruive Cross rail



Timber cubicle Cantilever Dutch Comfort

Fig. 8.6. Different types of cubicle division for dairy cows.

lie slightly uphill, which relieves pressure on the diaphragm on a hard surface. The base is usually made of concrete 100 mm thick on top of a well-consolidated base, providing a bed that is at least 200 mm high. This prevents slurry being pushed on to the bed when the passageways are scraped clean. If higher than about 250 mm, cows are reluctant to enter and it is uncomfortable when they stand with their front legs on the cubicle and back legs in the passage, as well as putting more weight on to the rear hooves, potentially increasing lameness. Concrete bases are usually insulated with tiles or polystyrene beneath the surface in cold climates. The base can also be made of bitumen or earth. Cows find the latter comfortable, as they hollow out a bed that is moulded to their shape, in contrast to flat concrete. Fresh earth must be added at regular intervals as it is removed by the action of the cows' feet into the passageway. Cow comfort in cubicles can be increased by putting waterbeds on top of the base or, alternatively, putting old car tyres into a hollowed-out base and covering them with an impermeable material.

The cubicle base should be covered with a bedding material. In addition to improving the cow's comfort as she lies in the cubicle, the bedding should also cushion the impact as she lies down, absorb moisture from urine and provide a clean surface to lie on. Straw is the most common and one of the best materials used, and it is usually the cheapest form of bedding when provided to a depth of 50 mm (Norring *et al.*, 2008). The base may have a lip or kerb 50–75 mm high at the passageway end, to retain bedding in the cubicle. However, if the cubicle is too short, it is uncomfortable for cows to lie on the lip and they may prefer to lie in the passageways, where they will get dirty. Chopping straw to 5–10 cm increases its retention on the bed and prevents slurry pumps becoming blocked with long straw. The centre of the cubicle quickly becomes devoid of straw as it gets pushed to the side by the movement of the cow, so fresh straw should be provided at least three times a week and preferably daily. Straw is not very absorbent but it is free of bacteria, unlike moist sawdust, which can harbour mastitogenic organisms such as *Klebsiella* species.

Both straw and sawdust can create a dust hazard when used as bedding. Wood shavings are a suitable alternative, if available, and shredded paper or newsprint has also been used but it can cause ink contamination of the cows' udders. Sand can be used to a depth of 50–100 mm but it is not absorbent and is likely to wear the slurry pump. Increasingly, farmers are installing rubber mats and carpets to provide a permanent solution to cubicle bedding. Mats are comfortable but expensive and they may need regular cleaning at the joins between the cubicles. Carpets have the advantage that they can be rolled out under the cubicle divisions, avoiding the need for joins, but they quickly get compressed and need additional bedding material for adequate cow comfort. Many farmers resort to using both bedding and mats. Soiled litter at the rear end of the cubicle should be removed at least two or three times per week, and the herdsperson should regularly sprinkle a small amount of lime there to sterilize the area where the udder may be challenged by mastitogenic bacteria.

Cubicle passageways should be at least 2.2 m wide to allow cows to pass comfortably behind others that are standing half out of the cubicles. The feed passage should be wider, at least 2.8 m, to ensure that cows can pass freely behind other cows that are feeding. Slurry should be removed frequently, either by a tractor-mounted rubber scraper used once or twice daily during milking when the cows are out of the building, or by automatic scrapers attached to a chain running up and down the passageways, usually for most of the day. These keep the passageways clean but they also wear the concrete more rapidly to leave a slippery surface. They are not an acceptable way of making cows lie in cubicles if the latter are of unsuitable design. Care should be taken that cows' tails are not trapped by the scraper as it passes down the passageway, by having a trip device installed into the electric motor. Areas that cannot be reached by tractor-mounted or automatic scrapers should be cleaned by a hand scraper daily.

Passageways should be arranged so that there are no blind alleyways where subordinate cows can be trapped by dominant cows. Frequent cross-passages between the cubicles and feed passageways encourage a good flow of cows in the building. Relative to other environments, there is a lot of aggression between cows in a cubicle house. Most is highly ritualized, with the dominant cow swinging her head in the direction of the subordinate cow, which moves out of the way or at least lowers her head to indicate that she accepts the dominant status of the other cow (Phillips, 2002). The more extreme forms of agonistic behaviour are mainly seen at pasture, where cows engage in head-to-head contact, wheeling around in a test of strength, with the victor eventually gaining access to the vulnerable flank areas of the vanquished cow. Such an overt display would be dangerous in a cubicle passageway, which is often slippery and crowded with other cows. The thwarting of aggressive interactions may induce a certain amount of tension, leading to cows seeking hiding places, such as in the cross-passages or standing partly in a cubicle.

Strawed yards

Strawed yards provide cattle with free access to an area with deep, soft bedding, but there are no individual beds. They are often used for housing growing male beef cattle, which soil cubicle beds if provided (because they urinate from the middle rather than the back end of the body) and for whom a constant cubicle size would be impractical. Strawed yards for beef cattle are frequently uncovered, it being difficult to justify the cost of a roof on financial grounds alone. When the straw accumulates and is mixed with faeces, urine and large amounts of rainwater, it may make it difficult for cattle to move around their pens, hence such systems work better in low-rainfall areas. Many traditional farms in Europe had a portion of the yard covered, giving the cattle somewhere dry to lie in wet weather. However, these units are often difficult to clean mechanically and are gradually being phased out.

Strawed yards are also used for dairy cows, in which case they are usually covered. They may include a concreted passage next to the feeding trough, to provide a clean, hard surface for them to stand on while feeding, which is also useful to allow cows in oestrus access to an area in which no cows are lying down. Ease of access to and from the building, for example for milking, is improved. If there is no concrete passage, the high frequency of treading in the area around the door and frequent defecation and urination make the straw wet and the cows dirty. A concrete passage also helps to provide an abrasive surface to wear away hoof growth.

Strawed yards are advocated for dairy cows to improve their welfare, since many cubicle systems fail to provide adequate comfort, with cubicles that are too small or poorly designed. When given the choice between cubicles and strawed yards, cows invariably prefer the latter, because the bedding is deeper and there is greater freedom of movement. In strawed yards cows are likely to spend 2–3 h longer lying down each day.

Greater freedom of movement brings its own dangers, as cows in oestrus may accidentally tread on lying cows, and particularly on exposed teats, sometimes tearing the teat wall. For a lactating cow this is painful, and a high stocking rate should be avoided to minimize the problem. Oestrous behaviour is more exuberant in strawed yards than in a cubicle house, with more time spent mounting, more pelvic thrusting by mounting cows and more lordosis (standing reflex with a curved spine), because of better footing and freedom of movement. This makes oestrus easier for the herdsperson to detect. Cubicle houses may have slippery floors and there is a danger of cows knocking into the cubicles on dismounting. Compared with pasture, the close proximity of the cows in a cubicle house or strawed yard encourages sexual activity.

Regular provision of adequate straw is vital to good management of a strawed yard. Usually at least 1 t of straw per cow is required over a 6-month period, and some farmers use 2–3 t per cow if it is readily available from an arable enterprise. Providing plenty of straw keeps the cows clean, thereby minimizing the time required to clean the cows in the parlour and reducing the risk of environmental mastitis. This amount of straw is five to ten times the amount used in a cubicle system.

Over a period of several weeks, the bedding in a strawed yard warms as microorganisms grow and release heat. If the straw is not removed, the heat will eventually sterilize the composted mixture in the lower regions of the straw bed. Some farmers leave the removal of straw until after the cattle have been turned out at pasture, which is often one of the quietest times of the year, but in this case the strawed yard must be designed to accommodate a rise of up to 1 m in the surface level of the straw. This may involve raising any dividing gates or barriers. It is, however, better for the health of the cows if the straw/excreta mix is removed on a more regular basis, say every 3 weeks. In this way, the bed can be kept relatively clean and mastitis is less likely.

SPACE ALLOWANCES. Strawed yards should preferably be rectangular, with the feeding trough down the long side to allow maximum access to feed. If the trough area per cow is less than about 0.2 m, cows are likely to become dirty and have an increased risk of mastitis. The yard will be dirtiest around the access points where there is heavy cow traffic. Holstein-Friesian cows are usually provided with 8–9 m^2 of strawed area each, compared with cubicle housing which requires about 6 m^2 each. Grazing cows have several thousand square metres each, and beyond 360 m^2 form a stable spatial relationship to each other, keeping about 10–12 m from their nearest neighbour during grazing or while lying down. Cows lying in cubicles are usually less than 1 m from their neighbours, who may be their preferred partner, and those in strawed yards are usually within about 2 m. Housed cows therefore must tolerate a much closer presence of other cows than those at pasture.

Any determination of the minimum space requirements for cows in strawed yards should take into account their need for lying space, walking, oestrus display and fresh air, allowing for adequate ventilation. The space required for walking and oestrus may be provided by a hard-standing area, which is often a concrete passage where the cows stand to feed but can also be provided by an outside dirt-lot area. An allowance should be made for accumulation of the straw in the lying area if any fences (as opposed to walls) are used to restrain the cows. A step may be needed between a concreted feeding passage and the lying area. Space allowances provided should be at least the minimum recommended (Table 8.1), except where the cows are kept in high ambient temperatures, such as in Israel and California, where bedded areas should be approximately doubled to allow adequate ventilation around each cow. In such countries shade is best provided by a shallow-sloped, high roof with no sides, preferably with the building sited perpendicular to the prevailing wind to allow maximum cooling (Fig. 8.7). The floor may be covered by woodchips with compost on top to protect the udder. This will provide a comfortable lying area. A cheaper form of protection is a simple shade-cloth, erected on elevated ground to aid drainage (Fig. 8.8).

Tie stalls

In many parts of the world dairy cows were traditionally tethered in stalls and this system is still common in some large herds in Eastern Europe. With the need to increase labour efficiency, especially in animal husbandry systems in Eastern Europe after the political changes of the 1990s, tethering in cowsheds became less common as it had a high labour requirement for feeding and milking cows individually. This encouraged the adoption of mechanized systems developed in Western countries. Cows in tie stalls also tend to have poor reproductive performance compared with loose-housed cows.

In the stalls, cows are either tied by the neck with a chain or kept with their head in a yoke, the former giving the cow more freedom of movement. They can get up and lie down but not turn around. An electrified wire (cow trainer) is sometimes suspended just above the cow's back to encourage her to move backwards as she arches her back to defecate or urinate, so that excreta fall in the passage behind the cow's bed. The cow trainer reduces contamination of the bed and

Table 8.1. Space allowances for cows in strawed yards.

Live weight (kg)	Bedded area (m^2 per cow)	Hard-standing (m^2 per cow)	Total area (m^2 per cow)
600	5.50	2.00	7.5
650	6.00	2.00	8.0
700	6.25	2.25	8.5
750	6.50	2.50	9.0

Fig. 8.7. Angled shade for dairy cows in Queensland, Australia, over a lying pad with woodchip base covered with compost on top, scarified regularly to provide a comfortable lying area.

Fig. 8.8. A simple shaded area for a dairy herd, built on an elevated platform to aid drainage.

hence mastitis but can also restrict the cow's movement. An incorrectly placed trainer will seriously inhibit movement and make oestrus detection difficult. Tie stalls are shorter than cubicle beds for loose-housed cows to try to ensure that excreta fall into the passage and not on to the back of the bed.

Stalls usually have a simple partition between cows, often of solid wood to reduce draughts. Cows are fed in troughs at the front of the stall, either concreted/tiled in which case they can be easily cleaned or, more traditionally, wood, which is difficult to keep clean. Water is usually provided from a small bowl in the stall, triggered when the cow presses a nose plate. Cows are milked in their stalls and either the milk is collected into cans and then transferred to churns or a bulk tank for collection, or passed directly into a pipeline. Milking units for can collection are transferred between cows but for a pipeline system they can be suspended from a gantry, which reduces the labour requirement.

Tethering cows restricts their freedom of movement, which infringes most modern welfare codes and can cause leg disorders, particularly swollen knees and hocks and joint stiffness. This is more likely if there is insufficient bedding or the stalls are too short. There is little opportunity for normal cow social behaviour, which means that there is no aggression (sometimes a problem in cubicle systems) or teats trodden on (a problem in strawed yards). In many traditional tie stall systems the bond between the stockperson and the relatively small number of cows under their charge is much stronger than it is in loose-housing systems. On balance, the inability to perform natural behaviours overrides other considerations and it is therefore recommended that cows are untied and allowed to exercise daily.

Exercise areas

An exercise or loafing area, without straw, is often provided with housing for dairy cows. Cows may be allowed into the area during the day, or just for a period after milking. Incorporating such an area close to the housing system has the advantages of making oestrus easier to detect (as cows have the space to exhibit mounting behaviour), reducing lameness and generally improving cow welfare. If cows are restrained there after milking it will allow their teat canals to close before they lie down, reducing the risk of mastitis-causing bacteria entering their mammary glands. Depending on the prevailing weather conditions of the region, it may be partially covered or entirely outside, allowing about 9 m^2 per cow. Hot climates favour provision of a partially covered area for shade. In high-rainfall areas a roof for shelter and a concrete base are required to keep the cows dry and clean. In dry areas, sawdust, woodchips or rice hulls may be used to cover the floor if available, to a depth of approximately 80 cm. Feed and water troughs should be provided within the exercise area if cows are held there for several hours each day.

The exercise area may be pasture adjacent to the housing, preferably divided into a few paddocks that can be used in rotation, at a stocking density of about 50 cows/ha. These may need to be regularly reseeded to prevent poaching damage. One of the paddocks may have to be sacrificed in very wet weather to avoid damaging the other paddocks. This could also be used in icy conditions when the cows will not graze. Basing the exercise area on pasture gives cows relief from walking on concrete, provides a cooler place to rest than a concrete or earth floor during hot days and keeps the cows cleaner, provided that it is well managed.

Consideration should be given to runoff of dirty water from the exercise area and drainage pipes may be required. Concrete areas will need to be scraped regularly to remove excreta into a tank or lagoon, or an underground tank installed with slatted floor covering. A buffer zone may be planted with riparian-zone trees, as well as shrubs and grasses to filter dirty runoff water before it reaches the groundwater. Manure piles must be inaccessible to the cows.

Transition cow and calving accommodation

Transition or dry cows are those that have finished one lactation and are preparing to start the next. They need special attention to their diet to prepare them and regular inspections in case there are any complications, especially within 3 weeks of birth, when they are referred to as 'close-up cows' and are fed a special diet. Initially they are usually housed in a yard or clean pasture area, as this gives them the freedom of movement and comfort that they need during late pregnancy. If projected calving dates are not accurately known, the cows should be brought into the transition cow accommodation after cessation of lactation, at about 300 days. A stall housing system is too restricted an environment for transition cows, and cows should not calve in free or tie stalls.

A few days before calving, cows should be moved to an isolation box or to pasture to provide a stress-free environment, which may also be used for sick cows. The box should be at least 3.5 m × 4 m, giving the cow some room for manoeuvring during parturition, and there should be one box for every 10–20 cows in the herd, depending on the spread of calving. Cows should be regularly inspected for signs of impending calving. In the day before calving the time that they spend lying down decreases. Cows are susceptible to mastitis at drying off and at the time of calving, so indoor calving boxes should be kept clean and disinfected between calvings. Cows that have been induced to calve early are especially susceptible. The floor and walls of the calving area should be of impervious material for easy cleaning and there should be a deep bed of straw provided. It should be well lit and free from draughts that might chill the newborn calf.

As long as they can be regularly inspected, cows can also give birth at pasture quite satisfactorily, preferably isolated in a paddock. There is less likelihood of post-natal infectious disease occurring in either cow or calf if calving takes place on clean, dry pasture.

Calf Housing

Calves from the dairy industry are usually removed from their mothers at just a few hours or days of age and transferred to separate accommodation, in order that their mothers can produce milk for sale. Neonatal calves are particularly vulnerable to infectious diseases, because of their poorly developed immune system, and later their weaning and transition from monogastric to ruminant digestion renders them susceptible to gut infections and nutritional disorders. The severity of these possible problems depends on the suitability of their housing system. Because of the risk of transmission of diseases, many calves are kept in individual pens until they are weaned off reconstituted milk at 5–7 weeks. However, these pens are often open-sided, which allows some contact between neighbouring calves. A minimum pen size of 1.5 × 2.0 m should be provided up to 6 weeks of age, so that the calf can lie with its legs and head extended. Each pen is usually provided with two bucket holders (one for reconstituted milk powder and one for water) and a rack for a fibrous feed, usually straw or hay. Milk powder can also be fed from a high-level bucket with a drinking nipple attached, which is a more natural method of taking milk for the calf. Buckets should be washed daily and left upturned to dry, otherwise they could become a source of cross-contamination. Such a confined environment inevitably restricts the calf's exploratory behaviour, locomotion and development of social skills. Compared with group-reared calves, those reared individually are slow to socialize when they eventually enter groups and are usually lower in the dominance hierarchy.

Adequate drainage of the bedded area is important to reduce the relative humidity of the air and disease transmission either directly from the bed to the calf or by aerosol infection. The surface of the bedding must be dry to prevent bacterial proliferation. Drainage is especially important for calves on a predominantly liquid diet, which produce large quantities of urine. A floor slope of 1 in 20 will allow adequate drainage, while still being comfortable for calves to lie on.

Often calf pens are placed outside in hutches, with a gap of about 2 m between calves, which minimizes pathogen transmission between calves but prevents physical contact between them. Hutches provide the calf with an indoor and outdoor area, with straw usually provided in both. In the EU, calves in individual pens must have direct visual and tactile contact with at least one other calf through the walls of their pen, to allow the calf the opportunity to socialize directly with other calves. They cannot be tethered except for a short period (1 h) in groups for feeding. Group housing is compulsory after 8 weeks of age, except where calves have to be removed for veterinary treatment. Minimum space allowances for group-housed calves of different weight are legally prescribed (1.5 m^2, 2.0 m^2 and 3.0 m^2 for calves weighing less than 150 kg, 150–199 kg and 200 kg or more, respectively). Adequate bedding must be provided, which is usually straw, but sand and wood shavings are also used.

After weaning, calves should not be housed with older stock that may transmit pathogens. Good ventilation and low relative humidity are both essential in maintaining a healthy environment. These are more important for calf health than for keeping the calf warm. Many farmers like to enclose calves in a confined space in order to reduce heat loss, particularly during cold conditions, but adequate ventilation is most important at low temperatures because of the high humidity in the air. High humidity encourages pathogen transfer and causes condensation on the walls and ceiling of the building, which can make the bedding damp. Insulation of the ceiling or provision of a double roof will help to reduce condensation in potentially damp environments. The lower critical temperature, at which the calves start shivering to keep warm, ranges from 9°C at birth to 0°C at 4 weeks of age in buildings with minimal draughts. A balance must be struck between good airflow through a building and draughty conditions at the level of the calves, which will weaken them. In extreme climates calves may be kept in controlled environments, with artificial heating or cooling and forced ventilation.

In normal climatic conditions most calf houses rely on natural ventilation, providing the necessary six air changes per hour and 8–10 m^3 of airspace per calf. This can be provided by a monopitch building or by building pens into the side of a double-span building (Fig. 8.9). In either case, care should be taken to avoid draughts at calf level by ensuring that there is a barrier to air that enters through the eaves cooling rapidly and falling on to the calves' backs. This can be a row of straw bales on top of the pens, or a solid board partition. Such a provision is most important for young calves and is particularly necessary in winter, when the air cools more rapidly on entry to the building. Many calves are challenged by pneumonia when they are housed in poor housing with stale air and damp conditions. The dominant organisms are parainfluenza-3 virus and bovine respiratory syncytial virus (BRSV).

Housing Bulls

Beef cow herds are usually at pasture and it is normally considered safe for the bull to accompany the cows, as they are not disturbed often by humans. Dairy cows, however, are often housed and the bulls have to be close to them to be able to inseminate cows when they are in oestrus. If the bull is with the cows all day, it can create problems when they are brought in for milking. Many dairy farmers avoid having to accommodate bulls by using artificial insemination on their cows. If dairy bulls are used on a farm, they are often kept in solitary confinement near the milking parlour because of the risk to humans that they pose when running with the cows. They are then joined with oestrous cows when necessary. A beef bull will sometimes be run with dairy cows and may also cause problems when humans move the cows. Sometimes he can be left in the field when cows are being removed for milking, but he will be reluctant for this to happen if there are cows in oestrus that are leaving the field.

If a bull is kept on a dairy farm, the housing must be secure and simple rules must be followed to ensure the safety of people working on the site. The animal must be free to roam within its accommodation box, which should include a lying area of at least 16 m^2, with walls 1.5 m high. Some protection above this height is preferable to prevent young people unwittingly entering the pen. Warning signs should be posted on the outside walls or the entry door. The bull should be fed and watered from outside but regular, positive contact between bull and stockperson is to be encouraged. The floor should be non-slip and care must be taken that the bull's feet do not become overgrown because of lack of exercise or too rich a diet.

The pen should be sited somewhere that the bull is likely to receive stimulation from passing cattle and humans. Positioning the pen adjacent to the collecting

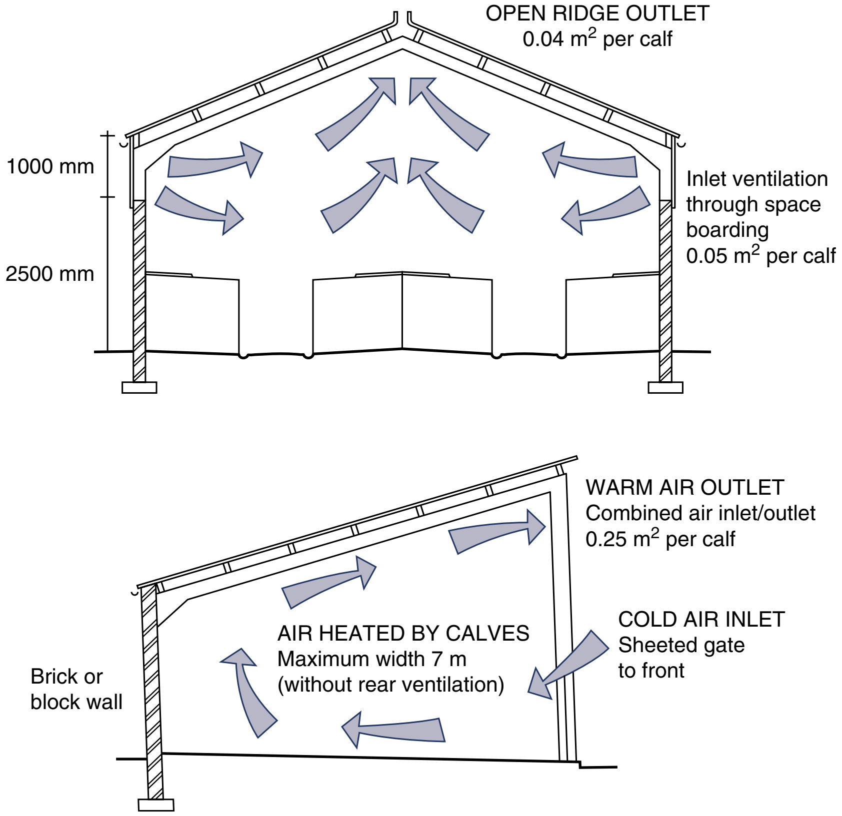


Fig. 8.9. Airflow in monopitch and ridged-roof buildings.

yard where cows wait to be milked is desirable, as the bull will encourage cows to demonstrate oestrus in a place where the milker can record the cows easily. Adequate stimulation will avoid the bull masturbating to release tension. Regular handling will encourage the bull to relate well to people but he quickly detects if the handler is fearful of him. It is better if the same person handles the bull, as a confident relationship should develop, but handlers should never tease, taunt or be aggressive to bulls. Accidents are just as likely to happen during play as aggressive acts.

A service box should be next to the bull box so that the bull can be introduced easily without risk to the handler. Both the bull pen and service box should be equipped with escape gaps, 30–40 cm wide, to allow the handler rapid exit if necessary, and at the corner of the service box there should be a pen where a cow can be introduced and led out in safety.

Cattle are social animals and, although bulls in semi-wild conditions have a greater inter-individual space than other classes of cattle, they still require companionship for good welfare. Isolation may be necessary for the protection of other cattle and humans on a dairy farm, but it is also part of the reason for the aggressive nature of many dairy bulls.

The Environment for Housed Cattle

Ventilation

Ventilation is required in cattle buildings to remove excess heat, moisture, noxious gases (such as ammonia), pathogenic microorganisms and flies. An adult cow exhales about 20 l water/day and 700 W of heat. Warm air ventilation, which is needed in cold-climate pig and poultry housing, is rarely required for cattle, even young calves. In the most extreme cold climates in which cattle are kept, such as in central Canada, the heat produced by the fermentation of feeds digested in the rumen is sufficient to ensure that the temperature inside the cattle house is adequate without artificial heating. Dairy cows readily withstand temperatures below freezing with little reduction in milk production. Closing ventilation ports leads to the accumulation of moisture and noxious gases. Young calves without a functional rumen are much more susceptible to chilling.

Adult cattle ventilation is normally achieved by the natural influx of external air into the building, which rises as it is warmed by heat from their bodies, and leaves the building through the ridge. This is known as the stack or chimney effect, which ventilates the building by the vertical movement of airstreams of different temperatures as a result of convection (Fig. 8.10). Air that enters the building initially falls, as it is colder than internal air. As it is warmed and rises, it takes with it pollutants that have accumulated around the animals. In winter, the internal–external temperature difference is greater and the air falls faster and further from the entry point, creating a risk of chill to young cattle. Air usually enters the building under the eaves or through slatted (Yorkshire) boarding on the upper half of the walls. Air should leave either through an open ridge or slots cut in the roof, but if this space is insufficient, some air may leave through the slatted boarding of the walls, resulting in stagnant upper air space and moisture and gas accumulation. Inlet openings should be at least half the size of the ridge outlet but if necessary they should be partially closed in extreme winter weather. In very large single-span buildings there may not be sufficient upward lift of the waste air to allow it to reach the ridge, so a number of smaller double-span buildings is better.

There are several situations in which artificial ventilation is required for cattle.

1. Hot climates in which the natural ventilation of cattle buildings is insufficient to cool high-yielding cows, in particular. Fans are most commonly used, usually sited at places where cattle are in closest proximity, for example milking parlours and feeding passages, where they can benefit directly from the increased airflow (Fig. 8.11).

2. Calf buildings in cold climates, due to the inadequate temperatures to lift the waste air and expel it

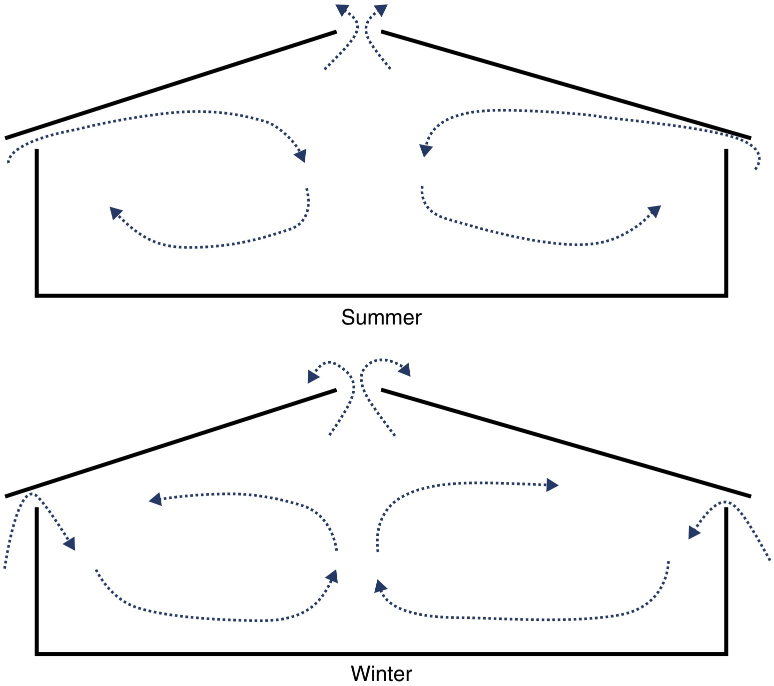


Fig. 8.10. The movement of air in summer and winter in a naturally ventilated cattle building.

Fig. 8.11. Fans to cool cows at the feeding bunk in 35–40°C in Queensland, Australia, powered by a bank of solar panels. Note the offset roof to increase draughts.

from the building. Open ridges and sides may result in loss of the heat generated by the calves, which are then chilled by incoming air. It is difficult to overcome the effects of high stocking rates by artificial ventilation. For instance, the benefit in reduced microbial population of doubling the air space per calf (i.e. halving the stocking rate) can only be achieved by a fivefold increase in the air change rate.

3. Transporting cattle over long distances in hot regions and at high stocking densities, for example in ships from Australia to Asia and Europe (Fig. 8.12). Higher ventilation requirements and back-up power supplies have been recommended since some high-profile shipments lost many hundreds of cattle following ventilation failures. However, the forced ventilation systems are of limited value if air temperatures exceed 40°C, which they frequently do in the Middle East ports, and they are noisy and provide uneven ventilation over the ship's decks. In situations in which there is little animal movement for up to 3 weeks, some animals may be chilled and risk pneumonia, while others experience heat stress. In trucks, decks are often open, so mechanical ventilation is neither needed nor would it be practical.

The visual environment

Day length

Most humans take artificial light for granted, enjoying a well-lit environment for most of the day regardless of the natural day length, but many cattle are kept in houses with little or no artificial light, making inspection of the animals impossible for long periods of the day. In the past veal calves were deliberately kept in a dim light, which discourages activity, thereby increasing growth efficiency and enabling them to cope with their small crates and lack of stimulation from their mother or other calves. However, most veal calf units have now either been forced to introduce adequate supplementary lighting and more adequate space allowances, for example those in the EU, or have done so voluntarily because of public concern.

At extreme latitudes the naturally lit period of the day (the day length) in winter may be less than 8 h. Cattle prefer to perform some activities in the light, in particular feeding, since feed selection may be difficult without a clear sight of what is on offer. If supplementary light is provided, cattle extend their feeding into the evening, enabling them to maintain a more even

Fig. 8.12. Loading dairy cows on to a ship for long-distance transport overseas.

supply of nutrients to the ruminal microorganisms. As day length increases in midsummer, grazing cattle also spread out their meals over the longer daylight hours. In a cubicle house crowded with dairy cows, walking and feeding may be more stressful in the dark, since the ritual aggressive displays that normally maintain the social hierarchy become more difficult. Providing supplementary light could alleviate some of these stresses and should cover both the feeding and lying areas. If only the lying area is lit, cows stay in the cubicles and do not go as often to feed. The transition from a lit area to an unlit area can be uncomfortable for cows, as it takes about 15–30 min for their eyes to adapt.

Day length perception is relative rather than absolute, with internal measurements made between 6 h and 18 h after dawn and compared with previous day lengths. The optimum day length for dairy cows is 16–18 h, from the perspective of maximizing milk yield, allowing cows a quiescent period of 6–8 h at night. A declining day length, i.e. in autumn, may be more stressful than one that is short but not declining. In natural lighting conditions cows sleep for longer in winter than in summer, but not if supplementary lighting is provided in winter. More sleep has evolutionary benefits, to conserve energy and reduce the risk of predation in winter when feed supplies are scarce by hiding the animal from predators.

Day length also affects reproduction: cows calving in spring have delayed conception compared with cows calving at other seasons of the year. Again, there would have been evolutionary benefits because cows that conceived in spring would give birth in midwinter, when less feed was available. In winter, heifers naturally enter puberty later than in other seasons and they lay down more fat and less bone and muscle, which would have helped them survive feed shortages in the past. Providing supplementary light in winter can reverse these trends, producing leaner carcasses that may meet market requirements better, or allow them to be bred earlier. In lactating cows, supplementary light during winter reduces the fat content of milk. This may be because pre-domestication it was advantageous for cows in the short days of winter to produce milk with a high fat content for their calves, which is reversed by supplementary lighting.

Light intensity and colour

High light intensities encourage cattle to be active, since they provide a more visually comfortable environment. However, some high-intensity spot sources of light, e.g. halogen lights, produce glare. Using a small number of high-intensity lights in cattle buildings produces major contrasts in illumination intensity across a building, especially if they are mounted at a low height. Fluorescent tubes or sodium lights are better options and they are more energy efficient. Sodium lights produce an orange light. Cattle are particularly responsive to red colours, which they can readily distinguish from green or blue, even though they cannot distinguish blue and green colours as well as we can. Perceiving red colour would have been useful to detect blood or the reddened rump of an oestrous female. It is probably no accident that, in the early stages of a Spanish bullfight, the matador uses a large fuchsia-coloured cape, which arouses the bull. In the final stages, he uses a small red cape held directly in front of them, which focuses the bull's attention for a final, well-directed charge, whereupon he plunges a sword into the bull's spinal cord just behind the neck.

Perception of visual stimuli

Understanding what cattle see is difficult but necessary if we want to provide the best environment for them. Of major relevance to visual perception is the positioning of the eyes on the sides of the head, giving cattle a visual field of 330 degrees, compared with 180 degrees in humans. This was an advantage for prey animals and all stockpeople should know that approaching cattle from behind provides no guarantee of remaining unseen. One consequence of having a wide visual field is limited binocular overlap, about 40 degrees in cattle, which may restrict the extent of their depth perspective at close quarters. Their region of best visual acuity is spread over a wide area, about 130 degrees, in comparison with less than 1 degree in humans. This is achieved by having a 'visual streak', where retinal ganglion cells are concentrated in a horizontal line across the retina, giving them excellent vision for objects on the horizon, again useful for prey animals. When combined with motion parallax (positioning of moving objects by the overlap of monocular images), it gives an excellent ability to detect moving objects on the horizon. Cattle are better at detecting danger using their left eye, which links through to the right brain hemisphere, whereas familiar and safe objects are better viewed with their right eye, connecting to the left brain hemisphere. Thus it is better to design handling facilities with this in mind, allowing cattle to be managed from the left side.

Cattle possess an effective tapetum, or reflective layer behind the retina, which effectively allows light to be counted twice as it passes through the retina. This suggests that they have good vision at low light intensities – better than humans, who have no tapetum. Nevertheless, cattle graze little at night, a vestigial defence mechanism, and when they do they take longer selecting each mouthful of grass.

Noise and vibration

Housing environments are usually very noisy for cattle, with heavy machinery used for feeding and cleaning, metal gates and doors banged closed and bellowing cattle. They are also exposed to persistent noise during milking and transport. Cattle hear high-frequency sounds much better than humans; their high-frequency hearing limit is about 37 kHz, compared with only about 18 kHz for humans (Heffner and Heffner, 1992). Their region of best auditory function is at a higher frequency (about 8 kHz) than humans (about 4 kHz), and their low-frequency hearing limit is similar to that of humans (about 25–30 Hz).

Despite being better than humans at hearing high-frequency sounds, cattle have less ability to pinpoint the direction from which it comes, to within an arc of about 30 degrees, compared with 1–2 degrees for humans. The practical inferences are that some high-frequency noise that humans cannot hear will be audible to cattle and may disturb them, but they will not be able to accurately determine where it is coming from to take evasive action. Physical damage to the ear does not occur until 110 dB, and hence the regular passage of aircraft overhead does not damage the ears of cattle. Some noise may even be welcomed by cattle. Music in the milking parlour, for instance, encourages cows to enter, though this could be because of the pacifying effect on the herdsperson.

Discomfort or injury is actually more likely to arise from vibration than noise in an industrial farming situation. Vibrations, such as from the regular passage of heavy machinery, can cause both physiological and psychological problems for cattle. The physiological problems are due to motion of internal organs and possible resonance of the fluid-filled vascular system. Low-frequency vibrations, in the region of 2 Hz, are most likely to lead to muscular and neural fatigue. Psychological problems are mainly due to stress responses, and the development of long-term anxiety and fear is possible. Stress responses to each event are likely to be short-lived but, if occurring regularly, could cause physiological harm. Abortions sometimes occur in response to prolonged whole-body vibrations.

Vibration from machinery or heavy traffic may cause discomfort, particularly in cows lying on concrete floors that are close to a road with heavy traffic. This causes low-frequency vibrations which travel further than high-frequency vibrations and are most likely to be a disturbance, in the same way that low-frequency noise is less easily attenuated than high-frequency. Exposure of cattle to vibration during transport by truck and ship may add to the multiple stresses experienced in a relatively short time. Ship vibration is known to reduce the welfare of seamen, and cattle lying on metal floors will be subjected to the full range of vibrations.

Both vibration and noise in the milking parlour can reach levels sufficient to cause stress in cows, as well as making the working environment unpleasant for the milker. The vibrations can have an accelerating force of up to 1 m/s^2, sufficient to cause discomfort, and noise levels can exceed 75 dB, also likely to cause a stress response (Gygax and Nosal, 2006). Signs of cow discomfort as a result of vibrations in the parlour include reluctance to enter, defecation before or during milking, restlessness and incomplete milk ejection. Adequate damping of the parlour machinery can attenuate vibrations and noise and will lead to improvements in welfare for both cow and milker.

Housing pollutants

Excreta

Accumulation of a slurry of faeces and urine in a building creates an unhealthy and noxious environment, which cattle avoid if given the opportunity. As well as producing unpleasant odours, chiefly from ammonia and sulfur compounds, it is acidic and both moistens and softens the hoof, leading to a high rate of abrasion on concrete, particularly of the heel. It is removed by scraping passageways with a rubber blade, tractor-mounted or manual, or by using slatted floors, which allow the faeces to be pressed through the gaps into a pit. Slats work well as long as the stocking density is adequate for cattle hoof action to keep pressing the faeces through, otherwise dried faeces accumulates in the gaps. Slurry in pits has to be emptied regularly and care should be taken that gases do not accumulate, such as hydrogen sulfide emitted during mixing.

Having large areas of concrete in and around cattle accommodation increases the volume of dirty water that has to be disposed of in a way that is sympathetic to the environment. Concrete is used because the concentration of cows rapidly destroys a sward and pugs the ground in high-rainfall regions. For example, rapid-exit milking parlours, introduced to accelerate the milking process, have a large apron of concrete around them that the cows traverse as they leave. The recent introduction of automatic milking systems, in which cows walk to the parlour when they wish, rather than as a group under the direction of the herdsperson, reduces cow traffic around the parlour and the need for concrete at this point. In future, natural systems of distributing excreta on the land may be preferred, by reducing areas of heavy cow traffic and allowing them extended access to pasture, so that fossil fuel use for feed procurement and excreta return is eliminated.

Volatile compounds

These include noxious gases, pathogens and odours. Problems in most cattle houses are much less than in pig or poultry buildings, because of the lower stocking density and natural ventilation. However, in calf houses, build-up of pathogens presents a particular problem and in cold regions they may have to be ventilated artificially. Of the range of noxious odours that occur at high stocking densities, ammonia (created by the volatilization of nitrogenous compounds in excreta) presents the greatest risk to the welfare of cattle. Like hydrogen sulfide, it causes irritation of the eyes and throat. In cattle buildings irritation of the mucous membrane of the respiratory tract leads to reduced pulmonary clearance of bacteria. The maximum concentration for long-term exposure in cattle buildings should be approximately 15 ppm.

Ammonia concentrations in buildings with slatted floors that store excreta under the floor are likely to be about twice those of buildings with solid floors where excreta are removed regularly. Concreted exercise areas where excreta are not regularly removed also have significant ammonia emissions. High stocking densities of cattle being transported long distances in ships usually produce concentrations of approximately 30 ppm. On land the separation of manure and urine prior to storage will help to reduce emissions, as the urine can be stored under cover. Storage of solid manure should be on level land, rotated each year and covered by a layer of straw, soil or peat at least 20 cm deep. If allowed to run off into watercourses, ammonia is extremely toxic to aquatic animals, such as mayfly larvae.

Microbes

A wide range of microorganisms, including bacteria, fungi and plasmids, can contaminate the aerial environment of housed cattle and are a particular risk factor for calves. High temperatures and humidity lead to high concentrations of microbes in the aerial environment. Some of the organisms are zoonotic and particular care is required by those who are managing the cattle. Respiratory infection in adult cattle is comparatively rare, except for the bovine respiratory disease (BRD) complex, which is common when the cattle are stressed. Outbreaks of *E. coli* scours coincide with elevated aerial contamination. It is also suspected that bovine tuberculosis is transmitted in cattle housing.

Poor air hygiene is a major contributory factor in calf respiratory diseases. In temperate climates, it is best to ventilate calf houses naturally, while taking care to avoid draughts at calf level. Solid walls are essential to at least a height of 1.5 m. The air inlet area should not be as great as in adult cattle houses, since the calves do not generate sufficient heat for an effective updraught of warmed air. Cold air falls rapidly on entry and may chill calves in pens, particularly in winter when there is a large difference between ambient and internal temperatures.

Adequate disinfection is essential between batches of calves, and in a block-calving herd this usually means after the main period of calving. Calf pens and the building should be cleaned with a high-pressure hose, disinfected with an iodophor or chlorine-based detergent and rested until needed for the next batch of calves. If this is not done, there is likely to be an accumulation of contamination and a rapid spread of calf diseases. All-in–all-out systems of calf rearing, in which pens are disinfected between batches, usually have fewer losses than continuous-flow systems. Nevertheless, in industrial-scale operations there is an increasing tendency to occupy calf accommodation continuously. Calf hutches provide a suitable microclimate for the calf but the restriction of movement and lack of contact with other calves is contrary to normal welfare standards.

Dust particles stress the respiratory system and pose a significant risk of associated disease, in particular pneumonia. Dusty feed, particularly hay, straw and a loose mix of concentrates, should be avoided because of the risk of accompanying microorganisms. Dust particles are created by cattle disturbing the dirt in feedlots, which aerosolizes particulate matter (PM), but they are also created from sloughed skin particles, bedding and feed. The particles include both inhalable dust that is deposited in the upper respiratory tract and respirable dust that is deposited in the exchangeable region of the lungs. Both are potentially dangerous, because of pathogens or mutagenic/allergenic substances that can be carried into the respiratory tract, but particles that are 2.5 µm or less in diameter (PM2.5) are considered a more serious hazard, because they are more likely to enter the lung alveoli. As a result, maximum concentrations in air may be legally prescribed, for example by US federal and state agencies.

Cattle housing is most likely to become dusty in hot, dry conditions. Some bedding types – for example, sawdust or straw chopped *in situ* before distribution – can create dust challenges in cattle housing. Feedlots create dusty conditions, especially in the evenings when cattle are most active and humidity is low. Bulling and aggressive behaviour that disturbs the substrate often occurs at dusk and cattle should be kept quiet and settled to avoid this, for example by feeding in the evening as well as the morning to keep them occupied during this high-risk period for dust generation.

Bovine epithelial and urinary antigens can become airborne and invoke antibody responses in people working in the environment. These are associated with allergic reactions. Of particular importance is extrinsic allergic alveolitis, or farmer's lung, which is derived from dusty feed and can affect both cattle and stockpeople, but the transition of many dairy farms from making dry feeds (predominantly hay) to wet ones (predominantly silage) has reduced the prevalence of this disease. Farmers still have a particularly high incidence of respiratory diseases, of which farmer's lung is just one example. Organic dust is also dangerous because of the fire hazard it creates when it accumulates around light fittings.

Milking Facilities

For dairy farmers, collecting milk from the cows has always been one of their most important tasks. Most cows are now milked mechanically, though hand milking prevails in some developing countries. Cows are usually walked to a specialized building for milk collection, the parlour, situated close to a room for cooling the milk and storing it in a tank. Since the tank must be accessible from a road to take the milk to a processing plant, this constrains the layout of dairy farm buildings.

The first attempts to mechanize the milking of cows were made in the 19th century, by inserting cannulae into the teat canals. Some applied pressure to the outside of the udder to stimulate milk let-down, and in the latter part of that century a vacuum began to be applied around the teat.

Mode of action of milking machines

The expression of milk from the teat can be achieved by two means: squeezing and sucking. Squeezing is the main method used by the calf and during hand milking. Pressure is applied to the base of the teat, either by the calf's tongue pressing the teat against its upper palate or by the milker's fingers, and this pressure is passed down the teat, causing evacuation of the teat cistern. Milking machines, however, rely on evacuating a closed area around the teat at regular intervals (about once per second). The calf also applies some vacuum by enclosing the teat in its mouth. The maintenance of the correct pulsation rate (number of cycles per minute) and pulsation ratio (ratio of vacuum level to atmospheric level) is important in minimizing teat damage and optimizing milking efficiency.

Closure of the teat canal at the end of a cycle is achieved by the pressure exerted by the collapsing teatcup liner. It is important for teat condition that the milk glands are not overmilked, that the full vacuum is achieved for at least 15% of the cycle and that a sufficiently low pressure is achieved, i.e. not above 50 kPa (Mein, 1992).

Milking machine components

The milking machine includes: (i) the milking cluster, which comprises four teat cups that apply the vacuum around the teats; (ii) the vacuum system, which includes the vacuum pump and line, connected to the teat cups; (iii) the pulsator, which alternates the applied vacuum with atmospheric pressure to prevent the teat being damaged; and (iv) the transport pipeline to take the milk to be cooled and stored (Fig. 8.13).

The vacuum system is protected by: (i) an interceptor jar, which prevents liquid entering the pump; (ii) a sanitary trap (in pipeline systems), which prevents contamination of the vacuum system with milk; (iii) a regulator, which maintains a steady vacuum; and (iv) a vacuum gauge, which allows the efficient running of the vacuum to be monitored.

The milking cluster, which comprises four teat cups with soft liners, usually of synthetic material, is connected by short milk tubes to a clawpiece that collects the milk. The clawpiece admits air to break up the milk column for easier transfer. It also acts as a weight to keep the four teat cups in the correct position. Milk is transferred from the four teat cups by a long, flexible milk tube to a fixed pipeline for transfer to a bulk milk tank. It may alternatively pass via a recorder jar, which allows milk yield to be recorded at each milking, or through flowmeters, which are inserted into the long milk tube with the same purpose.

Milking systems

Tie stalls

Cows that are kept permanently tethered in stalls (tie stalls) are usually milked by bringing milking units to them. The milk is either collected into a can suspended under the cow's body or into a churn that is wheeled down the cowshed passageway. In some of the more advanced systems, the milk is taken from the cow by a milking machine that travels down a gantry running the length of the passageway. As in a parlour, milk passes to a pipeline that conveys it under vacuum to a bulk tank. More labour is required to milk tethered cows than those that walk to a parlour, because of the need to move the milking machine between cows.

Parlours

Some of the first milking units to be introduced did not rely on moving the cows to a parlour for milking, but on taking the milking system to cows at pasture (Fig. 8.14). However, as more farms were established with a central set of buildings and good access to the farm's grazing by tracks, static milking parlours were developed. Initially, six to eight cows were arranged side by side in stalls (called an abreast parlour, often on a raised platform, with cows leaving the stall by the front, thus allowing the next cow to enter from behind). However, milking a large number of cows in this way was slow, and hard work for the milker because of the constant bending down that was necessary to access the cow's udder.

After this the tandem parlour was developed (Fig. 8.15), where cows enter and leave the stalls either side of a pit, which enabled the milker to attach and remove clusters while standing upright. In modern tandem parlours, exit and entry gates can be automatically opened after the cluster has been removed, allowing one cow to leave and the next one to enter. This allows cows to sort out their own order of entry into

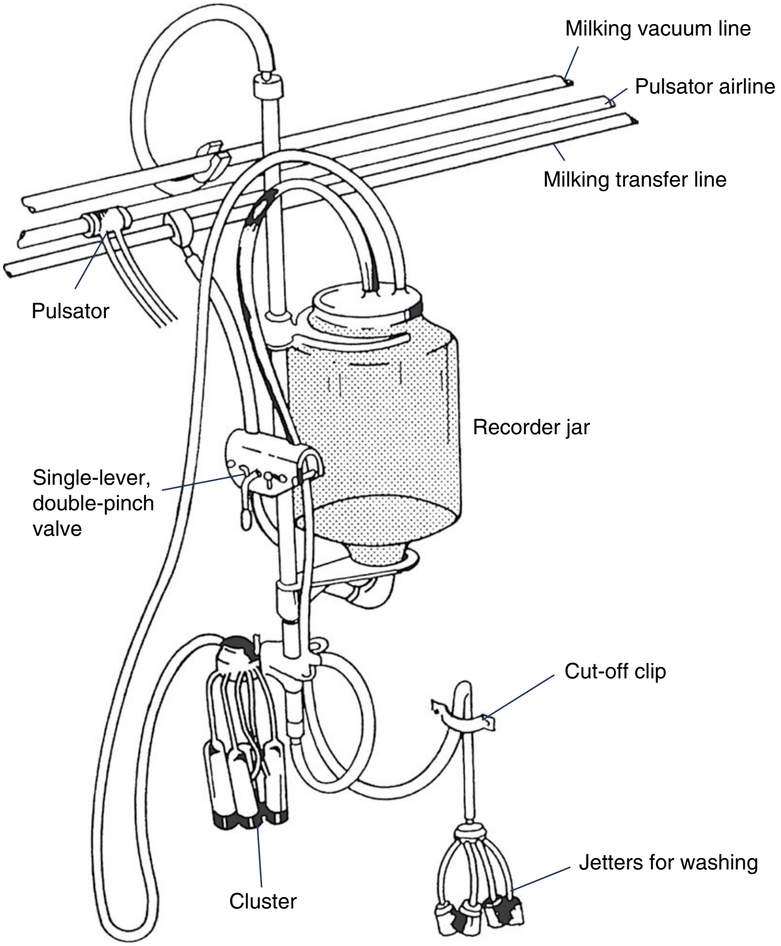


Fig. 8.13. Milking unit showing cluster and jetters, recorder jar and milk and vacuum transfer lines. (From Whipp, 1992, reproduced by courtesy of Insight Books, Reading, UK.)

Fig. 8.14. Milking cows at pasture in the mountains of France.

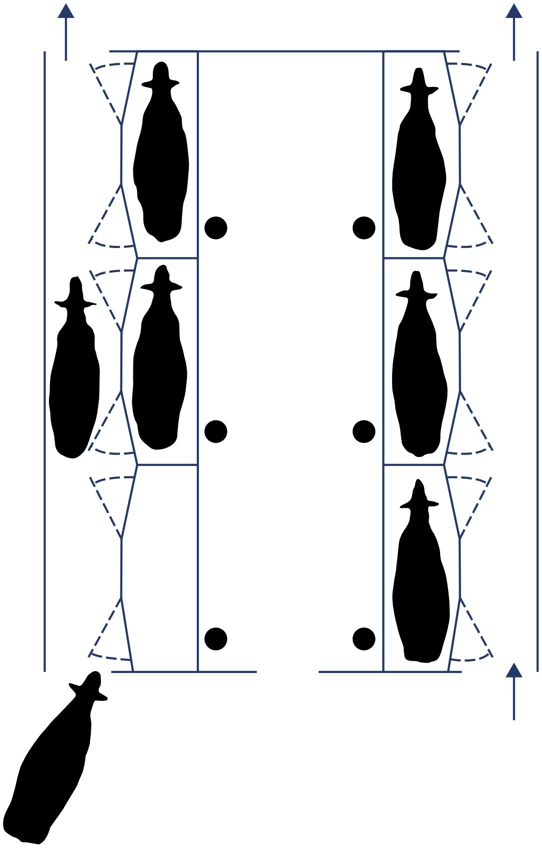


Fig. 8.15. The tandem milking parlour. • = milking unit. (From Whipp, 1992, reproduced by courtesy of Insight Books, Reading, UK.)

the stalls, leading to cows being more contented during the milking process.

The major drawback of large tandem parlours for modern dairy herds is that the milker must walk long distances if there are many stalls. Thus, a tandem parlour does not normally have more than three or four stalls either side of the pit, which limits the use of this type of parlour to herds of 100 cows or fewer. The greater the number of milking units, the faster the herd will be milked, provided that the milker can use the extra units effectively.

Before the development of automatic entry and exit gates, a modification of the tandem parlour, the chute parlour (Fig. 8.16), was developed, which allowed cows to enter and exit each side of the parlour as a single group; this saved building space. The design was further developed to allow cows to stand at an angle of 30–35 degrees to the side wall, reducing the distance between cows' udders and therefore walking by the milker. This popular design, called a herringbone parlour, could be extended at either end, sometimes putting additional milkers in the pit. The largest herringbone parlours have 48 units in two rows of 24, with two people milking.

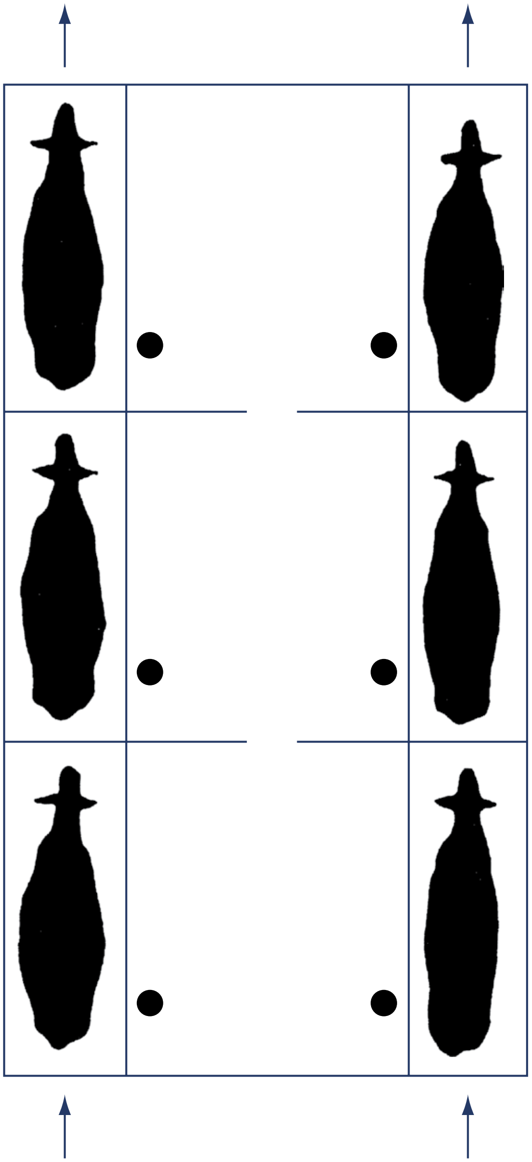


Fig. 8.16. The chute milking parlour. • = milking unit. (From Whipp, 1992, reproduced by courtesy of Insight Books, Reading, UK.)

Initially, milking units were shared between the cows on either side of the central pit and were passed from one side to the other after the first cow had finished being milked. Although this allowed for efficient use of the milking units, milkers were often standing idle waiting for cows to finish being milked. Most parlours now have a milking unit for each cow place. The limiting factor for milking speed is not availability of a milking unit but cows that are slow to release their milk. Large parlour units with long lines of cows suffer most.

Later trigon and polygon parlours were developed for large herds, where blocks of four to six cows stand in lines at an angle of 35 degrees to the wall in a triangular (trigon) or diamond (polygon) configuration (Fig. 8.17). This system allows each line to have its own entry and exit passage. Such units provide large pits for a comfortable working environment but they cannot be extended if a herd increases in size. An alternative to cows leaving by the end of the passage where they are standing to be milked is for the side wall or barrier to lift up, called a 'rapid exit parlour'. The disadvantage of such a parlour is the large exit floor area that has to be cleaned but it can avoid cows having to be hurried down the milking passage at the end of milking to allow the next row to enter.

On large farms, an alternative to static milking parlours is for cows to walk on to a raised turntable, which transports them past the milker, who therefore has little walking to do (Fig. 8.18). These rotating or rotary parlours, as they are known, also offer the potential for having a small number of automation units, such as concentrate feed delivery units, which can be activated when the turntable passes a certain point. Rotary parlours inherently have many moving parts and breakdown causes an inability to milk cows, which reduces their welfare. Some rotary parlours are designed so that the turntable floats on water, thereby reducing the mechanical requirements and increasing reliability.

Cows may be reluctant to enter and leave a moving turntable, especially if they have to move backwards. Rotary herringbones are better than rotary tandem parlours because cows mainly move forwards. In the tandem and herringbone rotary parlours the clusters are attached from inside the turntable, whereas in the rotary abreast they are attached from outside. This allows the milker to encourage any reluctant cows to step on to the turntable, whereas the rotary tandem and herringbone may require two people, one inside and one outside the turntable. A disadvantage of the rotary abreast parlour is that cows disappear from view after the initial stages of milking.

The development of new milking parlour designs has been accompanied by the introduction of automated operations concerned with milking. The following have been the most significant.

MILK YIELD RECORDING. In early parlours the milk yield of individual cows was recorded by collecting the milk in a jar, which was read by an operator working alongside the milker. Later, developments focused on the recording of either a proportion of total milk entering a meter and scaling it up to give total yield, or measuring the force generated to change the direction of flow of the milk as it passed: a continuous flowmeter. Meters recording a proportion of the total yield may measure either the weight or volume of the sample taken. Despite the large variety of yield recording methods, they are usually accurate to within 2% of total yield, or 0.25 kg if the yield is less than 10 kg.

MASTITIS DETECTION. Cows with mastitis produce milk with the enzyme lactate dehydrogenase (LDH), with somatic cells and with more sodium and chloride. All of these can be detected in milk automatically, either at the quarter or whole udder level. Sodium increases the conductivity of the milk and can be detected by a pair of electrodes placed in the cluster or short milk tube. The resulting conductivity measurement correlates closely with the somatic cell count (SCC). Handheld devices are also available. Milkers can get advance warning of an incidence of mastitis using this method, and antibiotic treatment will be more effective if given before the infection is properly established. However, mild cases often recover spontaneously and, in the light of increasing concern about the development of antibiotic resistance, care must be exercised when deciding whether to treat with antibiotics. Mild cases can be isolated and milked last, to stop the infection spreading, or treated by means other than antibiotics. Mastitis can also be detected by filters placed in a transparent container that is inserted into the long milk tube. Clots collect on the filter and the milker can then be alerted not to allow the milk to pass into the collection tank.

COW IDENTIFICATION. Cows can be individually identified electronically from radio signals emitted at unique wavelengths as they enter the parlour through an archway that generates an electromagnetic field. Ultrahigh-frequency signals can be quickly read from 10 m or more

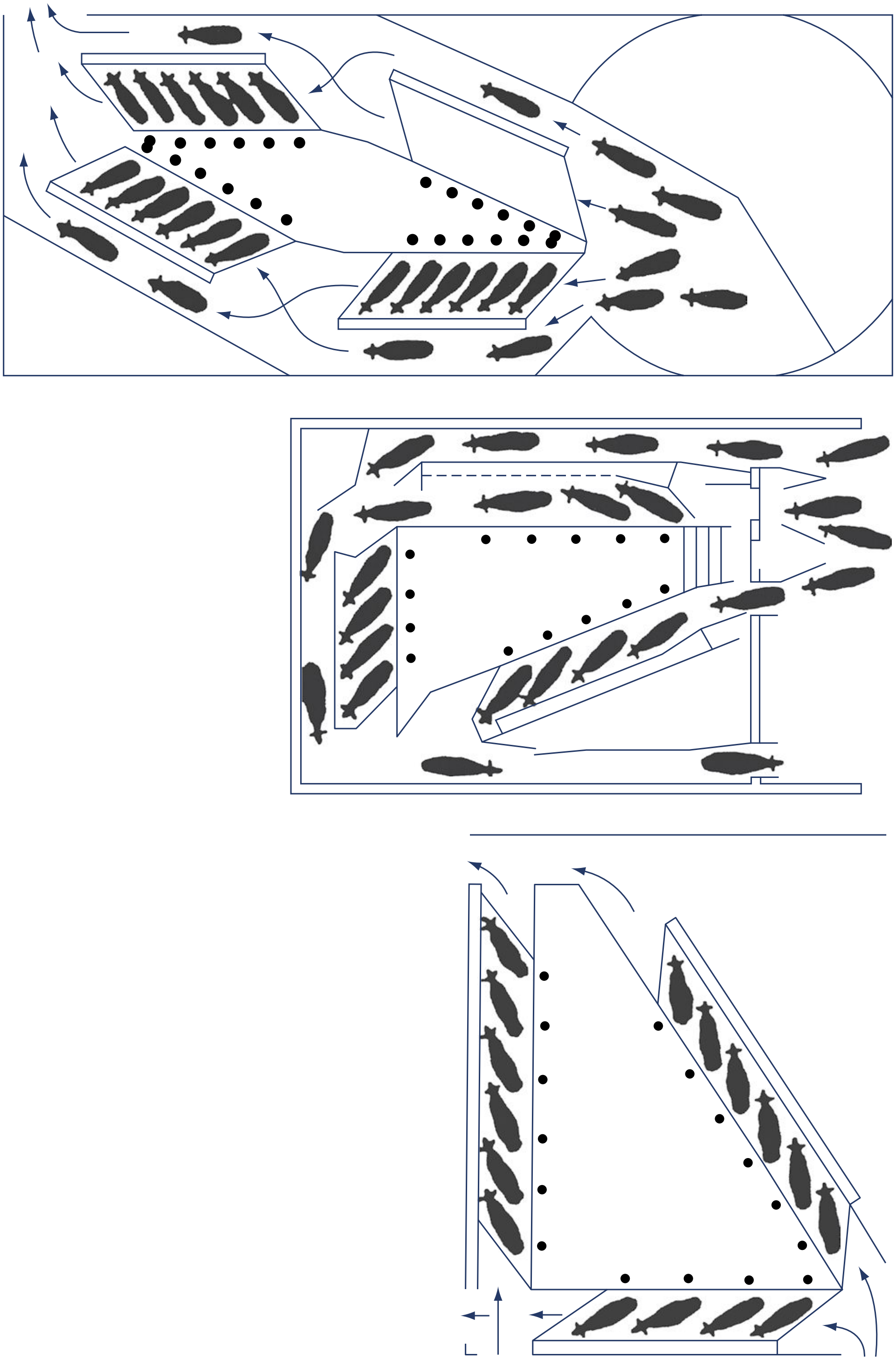


Fig. 8.17. Variations on the herringbone parlour: a polygon parlour (top) and a trigon parlour (middle, bottom). • = milking unit. (From Whipp, 1992, reproduced by courtesy of Insight Books, Reading, UK.)

Fig. 8.18. Rotary parlour, with cows on a turntable that rotates once for each cow.

away. Once the cow has been accurately identified, a feeder can be activated to deliver a pre-programmed amount of feed, or information can be downloaded from an identification unit on her leg to indicate how far she has walked since the last milking, which will increase during oestrus. The system can also be used to automatically sort and/or weigh cows after milking and can be linked to a GPS position, health records and measuring devices for milk yield.

ACTIVITY MONITORS. Activity monitors, or pedometers, record the number of steps taken by a cow by means of piezoelectric sensors or mercury switches connected to a real-time microchip and individual identification unit. This can be attached to the cow's leg or suspended around her neck. Because the increase in activity during oestrus is proportionately greater and more consistent than changes in other parameters, such as milk temperatures, yield and vaginal mucus conductivity, the pedometer offers the best potential to automate oestrus detection. Theoretically, 100% accuracy in detecting oestrous cows can be achieved, with no false positives, but errors may be made if cows change their physical environment, e.g. from housing to pasture, or become ill, especially if they are lame. Activity increases by a factor of about 350% on the day of oestrus and an algorithm can be used to distinguish this increase from other non-oestrous variation. The information may be relayed to a control processor at milking time, along with cow identification, or it can be used to signal directly to the herdsperson that the cow is in oestrus, using flashing lights.

CONCENTRATE FEEDERS. Cows that are fed concentrates in the parlour are easier to collect from the field but they are more excited during the milking process. The widespread adoption of out-of-parlour feeders and total mixed rations (complete diets) has discouraged farmers from feeding their cows in the parlour. This can create difficulties if a farmer wants to feed concentrates to individual high-yielding cows. Cows are now kept more in large herds and treated as a group, with less focus on managing individual animals than previously.

Conventional parlour feeders rely upon the milker entering the cows' identification numbers as they enter the parlour, and a pre-programmed computer instructs the release of individual concentrate rations to feed troughs in each milking stall. The feed delivery devices have to be calibrated regularly to ensure accurate allocations to each cow. The maximum speed of eating for adult cows is approximately 0.4 kg/min, and rather less than this for heifers. This limits the total daily intake to 8–10 kg, which is insufficient for some high-yielding cows.

TEAT CLEANING AND DISINFECTION. Simple but effective teat cleaning can be achieved by the provision of a hosepipe in the parlour, which the milker can use to spray warm water on to the cow's udder. Using a bucket of water and a cloth is not advisable, because it can transmit bacteria between cows. In hot, dry countries, cleaning can be assisted by automatic spray units set into the floor of the collecting yard, which cool the cows as they come in. After washing it is beneficial to dry the cow's teats to prevent water, which may contain bacteria, contaminating the milk.

Teat disinfection post-milking is important to control the contagious pathogens *Staphylococcus aureus* and *Streptococcus agalactiae*. It is usually achieved by spraying with a disinfectant germicide after the cluster of teat cups has been removed from the cow. Alternatively, the milker can dip each teat in a cup of the disinfectant but this takes longer. Disinfection can be automated by fitting a floor-mounted spray line in the floor of the exit passage, triggered by cows interrupting a beam of light. Chlorine-based disinfectants can be used outside the parlour and effective teat coverage ensured. Whatever method is used, complete teat coverage should be the aim and not just the teat ends, because the contact with the barrel of the milking cups extends over the whole teat. At least 20 ml per cow is required for effective coverage. In cold weather the udders should be allowed to dry before cows are turned outside.

In future the effective control of mastitis may include effective disinfection of the teat cups after each cow has used them. This is particularly important after a cow with mastitis has been milked, and these cows should be left until last to try to minimize spread of the bacteria.

AUTOMATIC CLUSTER REMOVAL (ACR). Sensors detect when the milk flow rate falls below about 0.25 kg/min. This activates a piston that pulls a nylon cord attached to the cluster and removes it from the cow.

By adopting these automations in the parlour, farmers can increase their processing time from about 50 cows/h per person to about 110 cows/h per person (Table 8.2), which many had achieved by the end of the 20th century. However, milking could not be fully automated until automatic cluster attachment became possible.

Fully automatic or robotic milking

In the late 20th century the high profitability from dairy farming and the expensive cost of labour for milking cows, together with an ageing labour force that did not want to be tied to a daily milking schedule, provided the impetus for scientists to design a fully automatic milking system. The development of the technology was assisted by the rapid progress in developing robots for a variety of functions in factories.

Systems used today include a computer memory of the position of the teats in each cow. Following location of the teats, a robotic arm attaches the cluster from the side of the cow or it emerges from a false floor. The arm remains under the cow during milking and removes the teat cups when milk flow has declined.

The cow must be restrained in an individual stall for a fully automated system, with voluntary entry, rather than under the supervision of the milker. High-yielding cows will visit three or four times each day, which increases milk yield compared with a conventional twice-a-day supervised milking. It also therefore increases efficiency in the use of feed for milk production, because the maintenance requirement for the cow is diluted by a higher output. However, a higher-quality diet is likely to be required for increased output. A system must be in place to prevent the milk of cows with mastitis from entering the bulk tank. Cleaning of the unit between cows limits the spread of mastitis better than conventional parlours.

Using the automations of the milking process outlined above, cows can now be milked automatically, using a milking robot to attach and remove the cluster. The opportunity for cows to present themselves for milking voluntarily offers more frequent relief of udder pressure, reduced udder weight and less contact with the herdsperson. Being milked by a machine is an unnatural process and may be viewed as frightening by a nervous cow, but is a positive development for the cow if the herdsperson instils fear in the animals. A good herdsperson will help the cows to overcome their fear of milking machinery but rejection rates are greater for fully automated plants than for conventional parlours. For the farm owner and herdsperson, the time saving with automatic milking is attractive and may ultimately prove essential if the farm is to remain competitive.

Cows should be able to visit two to three times per day, which may be difficult in some grazing systems.

Table 8.2. The effect of automation on cow milking routine time (min per cow) in the parlour.

	Basic routine	Semi-automatic system
Let cow in	0.25	–
Foremilk	0.10	0.10
Wash and dry udder	0.2	0.2
Attach cluster	0.2	0.2
Remove cluster	0.1	–
Disinfect teats	0.1	–
Let cow out	0.2	–
Safety margin	0.05	0.05
Total	1.2	0.55
Cows/h per person	50	110

Cows may need to be encouraged to visit by providing concentrates at milking. Automatic milking technology is most likely to be adopted on farms with elderly owners, or those unwilling to milk daily, or large farms that can afford the high investment cost. However, the saving in labour should not be achieved at the expense of routine care of the cows.

Managing Cattle in Extreme Climates

Ruminant cattle produce considerable amounts of endogenous heat caused mainly by the microbial digestion in their rumen, and they are therefore more prone to heat stress and less to cold stress than other farm animals. In common with other homeothermic animals, cattle increase evaporative heat loss (sweating, panting, etc.) as the ambient temperature increases and the sensible heat loss decreases (convection, conduction and radiation) (Fig. 8.19).

Below the lower and above the upper critical temperatures (LCT and UCT[1]) cattle invoke physiological mechanisms to maintain core body temperature (38.2°C), so heat production increases and the efficiency of milk production or growth is reduced. Milk production can be reduced by up to 5 l/day in extreme high temperatures. Between the LCT and UCT is the zone of thermoneutrality, or comfort zone, and in a controlled environment the most economic temperature for housed cattle is just above the LCT, where the artificial heat provision is at a point where there is minimum heat loss from the animals. Most cattle are not kept in controlled environments and so this would only apply to calves that are kept in environmentally controlled buildings in cooler regions.

The zone of thermoneutrality in adult cattle is from approximately −20°C to +26°C, depending on the environment and animal factors that influence the critical temperatures. One of the most important of these for young cattle is the rate of air movement, as draughts remove the temperature shells surrounding a calf's body and rapidly chill it. For adult cattle that tend to be more prone to heat stress than young stock, the productivity of the animal is most important, since a high-producing dairy cow produces a much greater heat output, because of increased digestion, compared with a beef cow at maintenance.

In cold environments the neonatal calf is particularly at risk of cold stress, even though it has reserves of brown adipose tissue (BAT) to produce heat (non-shivering thermogenesis). Reserves of BAT are proportionately greater than in lambs, and piglets have very little BAT, but are usually delivered into an environment where the temperature is close to that of the womb. Hence, neonatal mortality in the calf as a result of hypothermia is

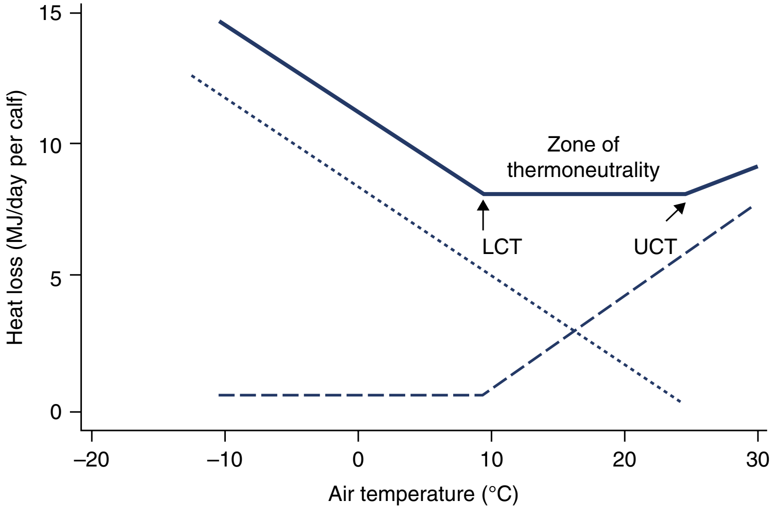


Fig. 8.19. Changes in evaporative (— —), sensible (····) and total (———) heat losses of a calf with changes in air temperature. LCT, lower critical temperature; UCT, upper critical temperature.

less common than with lambs. The relatively large body mass of calves in comparison with lambs, and the lower surface area:volume ratio, helps them to preserve body heat. BAT is laid down in the latter stages of pregnancy and rapidly metabolized after birth to help to overcome the large temperature differential, perhaps 30°C, between the cow's womb and the environment. Born into a cool, temperate environment, this would give a calf about 50 h to live if no feed is consumed, compared with lambs and pigs, both of which would have only 10–15 h in that environment.

A calf must suckle well before 50 h if it is to absorb adequate immunoglobulins from the mother's colostrum, preferably within 6 h. The ease with which a calf suckles depends on both the mother and the calf. The vigour of one or both may have been challenged by a prolonged (dystocial) calving and in extreme cases of hypoxia the calf may be severely weakened and unable to stand to suckle. In such cases, the drop in rectal temperature can last for 10 h or more (Fig. 8.20). One of the mother's first tasks is to stimulate the calf to suckle by massaging it and orienting it to her udder. This helps to produce energy to counteract cold conditions and is achieved by licking the calf's anus, which helps to expel the waste products that have accumulated in the calf's gut during pregnancy. Primiparous cows may not intuitively show these behaviours, especially after a difficult calving, and assistance may be necessary. In cold conditions, the calf may lack the strength to suckle but, fortunately, the time period over which immunoglobulins are absorbed from the gut is extended in such conditions.

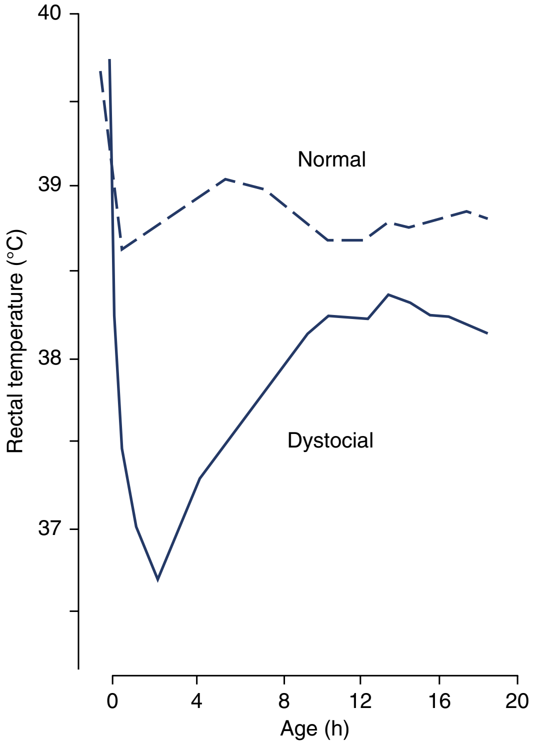


Fig. 8.20. Variation in rectal temperature of normal (eutocial) and dystocial calves in the first 20 h of life, when maintained at an ambient temperature of 10°C.

Apart from air movement, other environmental factors will influence the susceptibility of cattle to temperature stress. On cloudless nights, outdoor cattle will lose most heat by radiation and, conversely, on a sunny, cloudless day they gain a considerable amount of radiant heat. High humidity reduces the ability of cattle to lose heat by evaporative means, and any evaluation of the susceptibility of dairy cows to temperature stress should take account of this (Fig. 8.21). The temperature–humidity index is a valuable simple heat stress indicator but it does not take account of radiant or conductive heat exchange or evaporative heat loss, for example in windy conditions. In extreme cases, heat stress can be diagnosed from elevated core body temperature, detected in the rectum. Infrared thermography can measure core body temperature in the eyes of cattle, which are hotter than the surrounding body parts. Respiration rate is another key indicator but after a certain level, perhaps 120 breaths/min, it reverts to deep slow panting, because very rapid panting itself generates body heat.

The thermal properties of the floor are important for heat loss, since this is the point of direct contact for the animal with the ground, to which heat is conducted. Dry bedding in cubicles acts as an insulator, as well as cushioning the impact of cows lying down and absorbing urine. In cold climates, such as in Canada, the concrete bases of cubicles may be laid over an insulating layer and rubber matting used on top of the cubicle for extra insulation and comfort.

Drinking-water temperature is important in relation to the internal thermal environment of cattle. At high temperatures, careful positioning of supply pipes underground and insulating them above ground will provide cool drinking water for cattle. Running water pipes under the ceiling to the troughs will warm the water and exacerbate heat stress. In cold climates, pipes

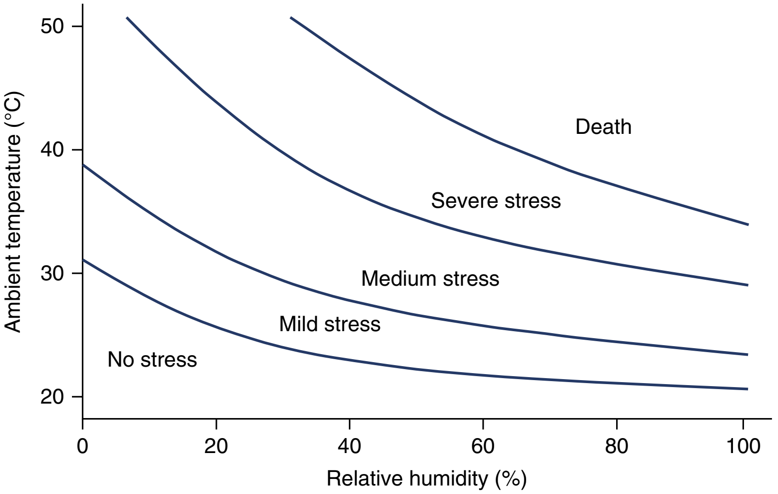


Fig. 8.21. Temperature–humidity index to estimate heat stress in dairy cows.

must be well insulated to ensure that the water supply does not freeze, which would cause a rapid reduction in milk production. Calves are particularly prone to chilling and are reluctant to take milk replacer when it is too cold.

At high ambient temperatures, feed and water intake are adjusted to reduce heat stress. As temperature increases so does water intake, to replenish body water that is lost during sweating and by respiratory means. Feed intake decreases, beginning at temperatures as low as 26°C, particularly that of fibrous forages, to reduce the heat of fermentation in the rumen. In particular, rumination (which generates heat) and fibre digestion decline, reducing acetate production in the rumen and hence milk fat output, this being largely a product of acetate absorption. Milk protein content may also decline, but not as much as milk fat, which may decrease by 40%. Increased respiratory rate and sweating will increase the loss of fluid and salts. It is therefore preferable to feed a concentrated diet to cows at risk of heat stress and to include more sodium and potassium salts to replace those lost in sweating. For example, in Israel, a diet of 70% concentrates and 30% roughages is commonly fed to dairy cows to minimize the heat load. Increased respiration predisposes cows to respiratory alkalosis as a result of increased carbon dioxide (CO_2) expiration. Most investigations of the impact of heat stress on dairy cows have been conducted in the hot arid regions of the world, such as Israel and California. However, in recent years there has been increasing recognition that cooler maritime conditions may pose problems of heat stress for dairy cows, for example in New Zealand and Canada. The irregular patterns of exposure to heat in these regions and warmer night-time temperatures prevent cattle adapting to heat stress in the long and short term, respectively, making them susceptible to heat stress. Global warming, estimated to be between 4°C and 7°C by the end of the century in many cattle-producing regions, will only increase their susceptibility to heat stress and increase the cost of providing cooled environments. Increased climate variability will further reduce the ability of cattle to adapt to consistently high temperatures.

At the other extreme, at low ambient temperatures, failing to allow *ad libitum* feed intake can seriously reduce the ability of cattle to cope with the cold, as they cannot increase their nutrient intake to cater for increased maintenance demands. In cold-stressed cattle, gut motility increases to allow for extra feed intake, which slightly reduces feed digestibility. Even in the temperate environment of the northern UK, outwintered cattle will eat more than those indoors to meet the extra demands for maintenance but milk production will not be reduced if adequate feed of reasonable quality is available. Sick cattle are most at risk of cold stress as they have low intakes and often low mobility, reducing their heat generation.

Different cattle genotypes have different susceptibilities to temperature stress. In particular, the type of hair and its length will affect the insulation value of body coverings. In hot climates cattle develop short, shiny coats that reflect the sun's rays and transmit body heat effectively. The best coat colour is white for maximum reflection, but dark skin is valuable as the melanocytes protect against skin cancer. In cold climates the coats of cattle become long and dull-looking, reducing heat reflection and maximizing the insulatory value and protection from the rain.

Other morphological features have developed over generations to combat temperature stress. In hot climates cattle have developed long legs and loose skin, which increases the surface area from which heat can be lost. *Bos indicus* cattle, living in the hot conditions of the Indian subcontinent, have many adaptations to heat, including pronounced dewlaps and preputial sheaths, large ears and long legs (see Chapter 7, Figs 7.9 and 7.10). Their fat stores are concentrated into a hump to minimize the subcutaneous fat layer over the rest of their body that would restrict heat losses. *B. indicus* cattle are predominantly white, but the variety of colorations of cattle in hot climates suggests that this is not of major benefit. Apart from affecting heat loss, coat colour may influence the ability of insect parasites to locate a new host. In male *B. indicus* cattle, the scrotum is extended to ensure that the testes are held as far away from the body heat as possible, while still being shaded from direct heat by the animal's torso. Spermatogenesis is impaired if conducted at core body temperature.

In the female, oestrus is short and usually restricted to cooler parts of the day. As a result, it is important to look for cows in oestrus at these times, which is best achieved by overnight observation if labour is available. Feeding may also be concentrated into the cooler parts of the day, particularly by grazing cows exposed to extreme heat without shade. The UCT of dairy cows (normally approximately 26°C) is reduced for high-yielding cows. It is therefore not surprising that, even in cool temperate climates, cows may have to seek shade in summer months. The circadian variation in temperature is important, as in arid areas the hot days are often counterbalanced by cold nights, when the cattle lose the heat gained during the day. Heat stress can also cause embryo loss, with reduced growth and function of the dominant follicle and impaired oocyte function and embryonic development. This, combined with the difficulties in observing oestrus, results in extended calving intervals in hot conditions, often well over 400 days. Gestation length is reduced by hot conditions, resulting in small calves with few BAT reserves for the neonatal period.

If there is a risk of heat stress, shade must be provided from either trees or artificial structures. Nevertheless, it is often not provided for cattle in small feedlots and extreme heat events kill cattle in Queensland, Australia, for example. If shade is provided, radiant heat load from the sun is avoided. The roof is normally oriented east–west so that more ground is permanently shaded and therefore cool for the cattle to lie on. If the roof is oriented north–south, there is a greater movement of the shade because of the sun's movement, which will help to keep the lying area clean and dry. Orienting a cattle building north–south will allow more sunlight to enter, increasing radiant heat load on the animals. Regular movement of the shade may be possible in some small-scale installations to help avoid any badly soiled areas. This is especially important for dairy cows, which are at risk of environmental mastitis if they lie in dirty conditions. Stocking densities in heat-stressed conditions should be reduced to maximize the air turbulence around each animal: at least 8–9 m^2 and preferably 12–15 m^2 per animal is best for permanent housing of lactating cows. Free-lying areas, rather than cubicles, are used so that each cow can have plenty of free air space around her. A small area of hard-standing, say 3 m^2 per cow, is usually provided to allow adequate space and a good footing for cows in oestrus to mount each other. In feedlot conditions, 2–6 m^2 of shaded area per animal is usually provided.

The material to provide the shade is often synthetic, such as iron or aluminium roofing sheets or shade-cloth (a plastic mesh). Metal sheets are good conductors of heat, compared with natural materials, and can create a hotter temperature under the shade than the ambient temperature, if the roof is low. Shade-cloth allows some radiant heat to penetrate to the animals below but it also allows airflow. It is inexpensive to erect but is likely to last for only 3–5 years. Natural materials, such as straw and leaves, have the advantage that they tend to be poor transmitters of heat, but they can also provide a suitable environment for vermin to live in. Artificial materials can be painted white to reflect the heat. If the roof is low a double skin or adding roof insulation can provide a better heat protection, but light structures with metal sheets or shade-cloth at a height of 4 m above ground level and with no central supports are best. Tall roofs minimize airflow impedance. Offsetting the two spans of the roof so that one is higher than the other at a central ridge will encourage airflow by the Venturi effect (increased air speed when air is passed through a constriction).

In extreme conditions, shade may be combined with sprinklers, in the collecting yard of lactating cows for example (Fig. 8.22), or in the feeding passage. The improved comfort of the cows if they are sprayed before milking will help to encourage milk let-down. Milking cows can be brought into the collecting yard on one or two extra occasions per day to be cooled. Sprinklers can be sited both over the cows' heads and at floor level, the latter also serving to wash the cows' udders before milking. Droplet size is important: if too small, it will evaporate from the hair surface rather than penetrating through to the animal's skin, and if too large it may run off on to the floor.

Misters may be used in the housed area for dairy cows to provide a regular increase in moisture content of the air to aid evaporative cooling but adequate drainage must be provided. Fans may be installed as well to further reduce the heat load (see Fig. 8.11). Misters are usually installed in the collecting yard for milking (Fig 8.22) or over the feeding passage, and cows are then encouraged to feed when the misters are working. Often this would be after milking, to stop the cows lying down and possibly contracting mastitis.

Fig. 8.22. Spraying in the collecting yard before cows enter the milking parlour (beyond the vertical bars of the electronic backing gate). Note the white tube providing cold air to cows in the parlour.

Air-conditioning of barns and milking parlours (Fig. 8.22) is gaining increasing popularity in intensive production systems, despite the high cost. A cheaper option, passing air over evaporative cooling pads made of fibrous material through which cool water passes, can reduce the air temperature by 8–10°C but humidity is increased, therefore reducing the cooling effect. Air may be distributed around the barn through plastic tunnels. Careful consideration of airflow in barns is important and fans can be installed to correct poor designs. These can be sited overhead or at one side of a barn to draw air across the cows. Barns now usually have much taller roofs than when the first lean-to constructions were introduced, to allow good airflow at cow level and to avoid dark, humid conditions. Bedding is rarely considered when it comes to alleviation of heat stress, but sand allows much better heat loss than wood shavings. In many dairy systems in developing countries, such as India, no bedding is used and cows lie on earth floors, which assists heat loss but hinders cleaning and control of pathogens causing mastitis.

Reproductive failure can be a problem for dairy cows in hot conditions. In Israel and the southern USA, conception rates decrease from the normal values of 50–60% in winter to 20–25% in summer if the cows are not adequately cooled. The reduction in conception rate is mainly as a result of hyperthermia in sensitive reproductive tissues but also partly because of reduced feed intake and consequent malnutrition, and the failure of cows in oestrus to exhibit the normal behavioural signs, at least during the daytime. Hyperthermia in the ovarian tissues reduces the supremacy of the first dominant follicle, with reduced oestradiol secretion. After ovulation, the luteal cells of the corpus luteum produce less progesterone. Low conception rates persist into autumn, after temperatures have declined, probably because pre-ovulatory follicles in the ovary have been adversely affected during the summer. Several months after hot summer temperatures have subsided, the ability of the theca cells of the corpus luteum to produce oestradiol is still impaired, resulting in reduced steroidogenic capacity of the ovarian follicles.

To conclude, the ability of farmers to effectively manage dairy and beef cattle in some of the most extreme temperatures on the globe is testament to both the human ability to modify the environment effectively and the adaptability of cattle in their thermoregulation. Cattle are now profitably and successfully kept in the hottest parts of the world. Nevertheless, it is important to be aware that hot conditions can easily reduce the welfare of cattle, and heatwaves in regions such as Australia regularly result in cattle mortalities if the necessary precautions of providing shade have not been taken. In extreme-cold regions, it is not the inability of cattle to survive that limits their population, but the shortage of fodder, which often makes it uneconomical to keep them in large numbers.

Conclusions

Housed cattle are kept in an unnatural environment and attention to their welfare requires special consideration. Different classes of cattle have different requirements for space, light and other resources and it is important that stockpeople understand the needs of animals within their care. Extremes of temperature must be allowed for and all animals within a group must be suitably accommodated, not just animals of average size. Particular care must be taken with isolated cattle, such as young calves or bulls.

Note

[1] The temperature threshold at which cattle have to increase their metabolism to cool the body.

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9 Disease and Herd Health Management

Introduction

The health of cattle is an important part of the ethical acceptability of any cattle production enterprise. There has been increasing criticism of the health and welfare of intensively kept cattle in the past decade or so, whereas the concerns of the public were previously focused on the welfare of pigs and poultry. This has been due to a growing realization that, even though the dairy cow may have access to pasture, presenting that apparently tranquil and natural scene, she is confronted with serious challenges to her metabolic and physiological well-being during lactations that have been engineered to produce considerably more milk than she would produce naturally for a calf. Because of this she readily succumbs to disease or fails to reproduce and, as a result, is unlikely to last more than about 3 years in a lactating herd.

Health is essentially governed by the interaction between the animals, their environment and disease-causing organisms. As gregarious animals, cattle should be considered not only as individuals but as a group, and the health of any one animal that differs markedly from that of the group should be noted and acted upon. Bringing a group of cattle indoors presents one of the most severe challenges to their health, as the contact between animals is increased by close proximity and disease organisms are better able to survive in the more constant and generally benign environment populated with many hosts, compared with outdoors, where the environment is usually harsher and the lower stocking density of the cattle makes disease transmission less likely. However, the nutrition of a high-yielding cow may be better controlled indoors and the animal's ability to rid itself of pathogens may be greater than if it were permanently at pasture, as the immune system functions best in a well-nourished animal.

The advent of widespread use of antibiotics in the latter half of the 20th century heralded a low incidence of infectious bacterial diseases for most cattle, especially dairy cows, which are often treated annually at the end of lactation, as well as routinely when there is any evidence of bacterial infection. In the long term, antibiotics will have restricted use as the ability of bacteria to mutate and produce new pathogenic forms is greater than our ability to find new antibiotics. Resistance is spread through livestock products, flies and other secondary hosts, including people living close to livestock facilities that spread excreta on the land. Of particular concern is methicillin-resistant *Staphylococcus aureus* infection. *Staph. aureus* infection is one of the most common causes of mastitis in cows and also of wounds in humans. It is of particular concern that methicillin-resistant *Staph. aureus* infection is apparently transmissible from cows to humans and is being found in the milk of dairy cows. Antibiotic use in dairy cows needs to be more effectively restricted to ensure maximum effectiveness of antibiotics for humans and it may eventually be banned. Farmers must therefore be prepared to use more prophylactic measures, such as reducing the stocking density of cattle and keeping them cleaner, to prevent disease transfer. Good nutrition, limiting milk output, use of probiotics and fostering a healthy immune system will all assume a new importance in the future when antibiotic use is restricted or perhaps totally forbidden on cattle farms.

Farm size has increased considerably in most cattle production systems in industrialized countries since the late 1950s, as enterprises expand and small family farms are amalgamated into larger units. Cattle are also more likely to be housed, often to the detriment of their welfare. These changes herald more difficult conditions in which to control disease spread. Most disease organisms affecting cattle were controlled in the past through careful husbandry; for example, the measures taken to prevent the spread of rinderpest more than 150 years ago included the following.

- The byres of infected animals had to be washed and left empty for 2 months.
- People attending sick animals were prohibited from going near healthy stock.
- The sale of sick cattle was prohibited.
- Sick cattle were slaughtered and buried.
- All cases of the disease had to be reported.

Such simple biosecurity measures restricted the transmission of the disease and eventually led to its eradication. Nowadays, there is much greater long-distance movement of cattle and this reduces their effective immunity, which develops for a range of pathogens in a specific area. Effective disease control will involve restricting movement and encouraging the development of immunity to the principal diseases in the area.

An alternative method of controlling disease is to reduce the stocking density of the cattle and hence the contact between animals. Extensive cattle ranches rarely suffer the outbreaks of diseases typical of some unprotected, housed cattle herds. However, any reduction in output per unit area can only be justified if product prices are increased or farmers are in some way compensated for economic losses. Some reduction in cattle stocking density can be achieved through mixed farming systems, for example with sheep, since pathogens find it difficult (but not impossible) to infect stock of more than one species. However, the increased mechanization of farms has encouraged the adoption of intensive farming systems, usually relying on the farming of single species of animals and crops (monocultures). It is a technological challenge for the future to design mixed farming systems that minimize disease risks but are still efficient users of land, labour and capital.

The following is not an exhaustive list of cattle diseases, but rather descriptions of some of the most important challenges (in particular, mastitis and lameness), some of the new ones, such as *Escherichia coli* O157:H7, and some that illustrate important principles of disease management, especially those surrounding the BSE outbreak at the end of the last century. This illustrates the range of disease issues that may confront cattle farmers in the future.

Calf Diseases

The newborn calf is relatively unprotected as a result of the naivety of its immune system in responding to environmental challenges. In addition, the calf is growing rapidly relative to its size, so it requires a high level of nutrition. If this is not provided, it will impair the immune system. There is a temptation to reduce costs by limiting milk supply to just a few weeks after birth but calves in the wild would naturally suckle their mother for at least 6 months. The health status of many, if not most, of the calves that are weaned early is generally acknowledged to be worse than that of suckled calves. On many units isolation of calves in individual crates limits cross-infection during the first few weeks, but it also prevents the development of normal interactive and locomotive behaviour and in the long term reduces their ability to socialize with other animals.

An important feature of successful calf rearing is careful observation and treatment, which minimizes the disease prevalence. This tends to be easier with isolated calves than groups. A sick calf is inactive and often lies down for long periods with its head extended. Its eyes may be sunken and lacrimating and its nose and lips inflamed. Its coat is dull and may be soiled with diarrhoea. Stockpeople responsible for calves should be trained to recognize these symptoms, especially when calves are moved away from their place of birth on to other farms. Many male calves from dairy cows are currently transported at just a few days of age to be slaughtered as ‘bobby calves’ for veal production, being surplus to requirements in countries using specialized dairy and beef breeds. In countries where the dairy and beef industries are integrated, it is unusual for calves to be slaughtered so young.

Calf diarrhoea

Calves suffer from two major forms of diarrhoea, otherwise known as scours: (i) viral diarrhoea, which damages the ability of the intestinal villi to absorb nutrients; and (ii) bacterial (usually *E. coli*) or white scours, which does not. It can also result from incorrect feeding of milk powder: either too much in each feed or inadequate quality, particularly protein. Early introduction of solid feed will help to reduce such problems with milk feeding. The risk of scours is increased if calves are subjected to stress, for example by movement or following a sudden change of diet. Calf scours might occur at any time up to 4 weeks of age, by which time the rumen is sufficiently inoculated with benign bacteria to prevent it being colonized by bacterial pathogens. Calves can be vaccinated against certain forms of *E. coli* scours but the most important means of protection is ensuring that the calf has an adequate intake of colostrum in its first 6 h of life.

The major viral pathogens are rotavirus and coronavirus. Calves with viral diarrhoea are not able to adequately reabsorb water from the gut, because of villi damage, so dehydration is the major problem. This can be averted by recognizing the symptoms early and providing oral rehydration therapy. It should be accompanied by alkalinizing therapy with sodium bicarbonate, as the diarrhoea is usually accompanied by acidosis, caused by poor renal excretion of hydrogen ions. Reduced nutrient absorption accompanies a severe acidosis, and milk should be withdrawn and replaced with a glucose solution for energy. Probiotics, particularly those containing *Lactobacillus acidophilus*, have also been shown to reduce the incidence of scouring in calves in some trials (for more information on probiotics, see below).

Calf pneumonia

This infection of the lungs is caused by several types of viruses, mycoplasmas or occasionally bacteria. The conditions in which a calf is kept will determine the impact of the disease, in particular whether there are adequate ventilation and dry conditions, including the calf's bedding, both of which are essential to minimize the spread and severity of the disease. Traditional enclosed calf houses with little ventilation and overcrowded conditions are often the cause of an outbreak, whereas modern portal-framed buildings with plenty of air for each calf and sufficient air changes to reduce pathogen load will rarely produce outbreaks. Moving calves from well-ventilated individual pens to damp, poorly ventilated group housing after terminating their milk supply often triggers an outbreak of pneumonia, not least because the challenges faced by the animals when they are grouped together is accompanied by the stress of weaning.

The chief clinical signs are a chesty cough, loss of appetite, sweating and sometimes an ocular discharge. An elevated temperature will provide confirmation of the diagnosis. The entire group of cattle should be treated with antibiotics to prevent secondary infections and because inhalation of just a few bacteria can cause the primary infection.

Other calf diseases

Other common calf diseases include bacterial infections of the navel, often caused by calves lying on wet ground, and ringworm. Bacterial infections entering via the navel may remain localized there (navel ill) or circulate around the body and infect other parts, such the leg joints (joint ill), or can create a serious blood poisoning in the form of septicaemia with *E. coli* infections. The internal organs, such as the liver, may become infected. Ringworm is an unsightly skin infection of older calves by the fungus *Trichophyton verrucosum*, which can also be transmitted to humans.

Treatment of calf diseases with probiotics

Probiotics are feed supplements that are added to the diet to improve the intestinal microbial balance. They offer an alternative to antibiotics, particularly in controlling the diseases of the gastrointestinal tract of young calves. Calves are prone to stress from weaning, routine procedures such as dehorning, and lack of companionship, all of which may increase the susceptibility of the immature gut microbiome to enteropathogen colonization. Probiotics are more effective in calves than in older cattle, as there is no complication of the ruminal microflora. The colonization of the intestine by benign bacteria may confer protection against pathogenic bacteria. This is not only by competitive exclusion – they can limit the adhesion of some bacteria to the intestinal wall and some actually improve the immunocompetence of the host animals. Some probiotics, particularly the lactobacilli, can neutralize *E. coli* enterotoxins and others, notably *L. acidophilus*, produce large quantities of lactic acid that reduce pH and prevent the growth of some pH-sensitive bacterial strains.

The initial colonization of the small intestine is from the dam's micoflora and the immediate surroundings and usually includes streptococci, *E. coli* and *Clostridium welchii*. When milk feeding commences, the lactobacilli become the predominant bacteria present. Calf probiotics contain benign lactobacilli or streptococci and are likely to be valuable only when given to calves that have suffered stress or have been treated with antibiotics that will have destroyed the natural microflora. Addition of probiotics to the diet produces variable benefits, depending on whether the calves are in poor health. It is difficult to determine which bacterial species would be beneficial in each circumstance but experience may provide this information.

Adult Cattle Diseases

Lameness

Lameness is a departure from normal gait, caused by injury or disease in a part of the limbs or trunk. It mainly afflicts dairy cows (Fig. 9.1). This is not only one of the most costly diseases to the dairy industry, it also causes significant pain and distress to many cows. The costs arise chiefly from lost milk production, veterinary treatment, mortality and impaired reproductive performance. It is a problem that has increased as the dairy industry has intensified in many countries, and in intensive dairy systems about 20% of cows in a herd develop an incidence of lameness each year (e.g. Macrae and Esslemont, 2015). It is particularly associated with high-yielding cows in cubicle housing. In the traditional systems operating in the UK in the 1950s, when most dairy cows were individually housed in byres and were fed a hay-based diet with only a small amount of concentrate, the incidence was usually less than 5% of cows per year.

Caution in interpretation is necessary, as different recording methods have been used, making it difficult to determine the increase in lameness over time accurately. Early studies relied mostly on veterinary records but recent studies take into account the records of foot trimmers, the herdsperson and sometimes locomotion scores of cattle by researchers. A 5-point scale is most commonly used: 1 – perfect locomotion; 2 – some abnormality of gait; 3 – slight lameness, not affecting behaviour; 4 – obvious lameness, behaviour affected; and 5 – difficulty in getting up and walking. Despite improved recording methods, it can only be concluded that lameness is now an extremely serious problem for the dairy industry.

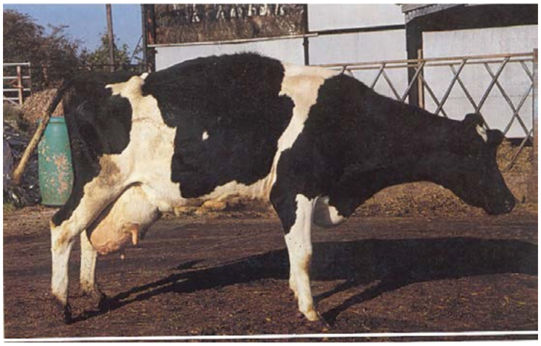

Fig. 9.1. Lameness in dairy cows is a common result of poor welfare, causing an arching of the back and reluctance to put the affected limb on the ground.

Most lameness occurs in the hind feet of dairy cows, especially the outer claws. It is actually a number of different disorders, the most common of which are sole ulcers, white line lesions, laminitis, digital dermatitis and interdigital infections, each of which is briefly described below.

Sole ulcer

A sole ulcer is manifested as a haemorrhage, most often in the lateral claw of the hind feet. It arises through the pinching of the corium by pressure from the pedal bone, which provides an entry route for bacteria (Fig. 9.2). Often, the ulceration is hidden by a thin sliver of horn tissue, but paring this away reveals the haemorrhaging. Sole ulcers are one of the most common forms of lesion. Predisposing factors include lack of exercise, subclinical laminitis and wet conditions.

White line lesion

The junction between the horn of the hoof wall and the sole is called the white line (Fig. 9.2), which cements the two structures together with immature, unpigmented horn tissue. This is weaker than older, more highly keratinized horn tissue and is therefore prone to entry of foreign bodies, which may be forced upwards towards the corium by the pressure of the cow walking on an injured site. In this case an abscess is likely to form; pus then accumulates within the hoof and has to be drained out. When cows walk on stony ground, foreign bodies can puncture the sole and cause pus formation, which has to be drained out by a veterinarian or professional foot trimmer. White line lesions are particularly common in wet conditions.

Laminitis

This is an inflammation of the laminae of horn tissue that are produced from the modified corium or papillae, just below the coronary band. The inflammation is a common condition in lactating cows housed on concrete and fed silage and concentrates but the aetiology is

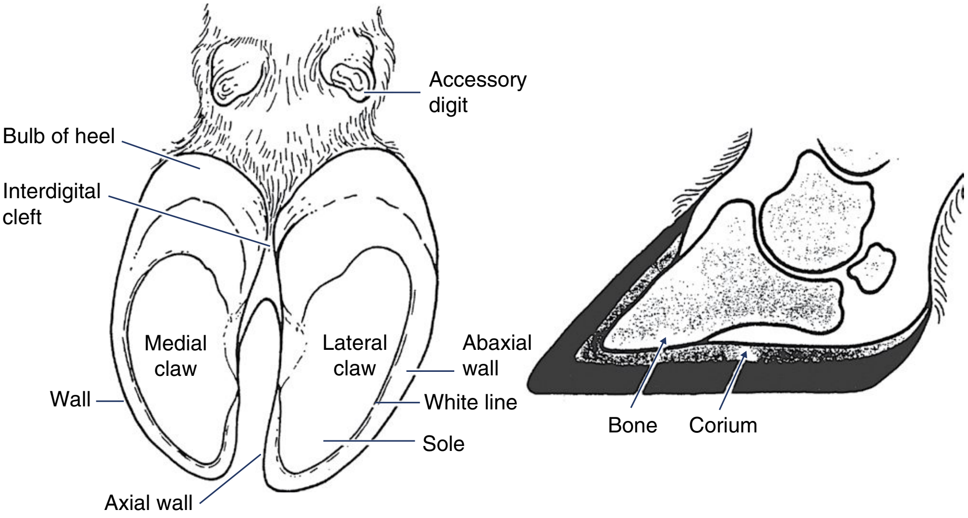

Fig. 9.2. A diagram of the right hind foot viewed from below (left) and from the side (right). (Reproduced by courtesy of Farming Press Books Ltd, Ipswich, UK.)

not yet well understood. The principal influence of concrete is the high impact that it inflicts on the hoof, causing a sinking of the bone (the pedal bone) (Fig. 9.2) within the claw capsule and putting pressure on the corium.

However, also important is the release of substances (perhaps bacterial endotoxins) in the corium that cause vasodilation and anoxia, leading to the failure of the laminae to support the weight of the animal. This is probably a consequence of the feeding regimes that cows are given in modern dairying systems. Excessive concentrate feeding or grazing on lush pasture causes a low and widely fluctuating pH of ruminal fluid, inducing transient subclinical acidosis events and consequent release of endotoxins. During ruminal acidosis the release of histamine is also stimulated and both endotoxins and histamine can damage blood vessels, restricting blood flow in the hoof and the supply of nutrients to the hoof corium. Weak hoof tissue ensues, which is susceptible to injury and infection. The disease results in painful haemorrhage of the hoof laminae and a predisposition of the hoof to other disorders, leading to the possibility of a common aetiology of several hoof disorders arising from the housing and feeding system currently used for high-producing dairy cows.

Digital dermatitis and related diseases

Digital dermatitis is a disease that has only recently emerged but has rapidly become a major cause of lameness in dairy cows. It is associated with housed cows fed large amounts of concentrates and is exacerbated by wet conditions. The symptom is a painful skin lesion, usually at the back of the foot between the heel bulbs and adjacent to the coronet. It is caused by bacteria, often *Treponema* spirochaetes or *Bacteroides* species, and readily responds to antibiotics. It is highly contagious if not treated. Footbaths are sometimes used for treatment, with formalin, copper and zinc sulfates in solution. Cleaning soap and rock salt are alternatives to clean the feet. New solution is needed every 250 cow passes, approximately. Antibiotics are sometimes used in outbreak situations but may be inactivated by the zinc and copper compounds used in the footbath solutions. Antimicrobials are also rapidly neutralized if there is a large amount of organic matter in the footbath. The best remedy is to keep cows' hooves clean and dry.

Many regard interdigital dermatitis as of the same aetiology as digital dermatitis, since the most commonly isolated organism is *Bacteriodes nodosus*. The same is true for slurry heel, though laminitis is a strong predisposing factor in this disease. The erosion of the heel bulb caused by bacteria is often prevalent throughout the older animals in a herd. It does not itself cause lameness but predisposes to other hoof disorders and may be considered to be part of the general hoof condition caused by the management system usually adopted for high-yielding housed dairy cows.

Interdigital necrobacillosis

Otherwise known as foul in the foot, this disease is caused by an infection with the bacterium *Fusiformis necrophorum*, which commonly inhabits the environment of livestock and can survive in the soil for 10 months. This bacterium penetrates the interdigital skin tissue only if there is damage by stones, sticks, etc., in which case it invades the underlying tissues and causes skin lesions. It causes a pronounced and no doubt painful swelling and acute lameness, but is not fatal. Regular cleaning of the hooves by walking cows through a formalin footbath will help to prevent this disease.

The influences of housing and cow tracks on lameness

The type of housing is a dominant influence on the incidence of the common disorders of the legs of cattle. Concrete wears the hooves away more than earth, but the constant wetting of the foot in cubicle passageways covered in deep slurry can also erode the soft heel bulb. This predisposes the cow to laminitis and sometimes leads to the toes losing contact with the ground and unchecked growth (slipper foot). Excessive walking on concrete stretches the white line and wears the sole, thus weakening the bond between the wall and the sole. In straw yards the abrasion on the hoof is minimal, leading to increases in toe length until the cows are out at pasture. Interdigital infections are more common than in cubicle houses, as straw may be pushed up between the claws, causing a lesion that is open to infection, often by *Phlegmona interdigitalis*. Excessive growth may close up the interdigital space, trapping dirt and causing infection. Long digits are also common in modern cattle units as a result of two additional factors: (i) excessive growth arising from the high nutrient density of the diet; and (ii) inadequate wear on a smooth concrete floor or soft straw and low levels of activity.

Slipping can be a significant problem in cattle accommodation and slaughterhouses, especially around water troughs, or where cattle are moved rapidly and are turning sharp corners. The hooves may be trimmed to correct the hoof conformation, which will increase the area of the hoof in contact with the floor and reduce the chance of a cow slipping. Trimming reduces load bearing by the heel, improves locomotion in cattle and reduces the hardness of the sole and abaxial wall. It is normally performed by the following method, first developed by Dutch cattle farmers.

1. An incision to the wall of the medial claw is made at the toe end with hoof clippers, perpendicular to the sole and 75 mm from the periople line (the hairline). The sole is then pared with a knife to remove any overgrowth, reducing the original cut to the digit to 7 mm and exposing the white line.
2. Using the medial claw as a template, the lateral claw is cut to the correct length and the sole pared to the same depth.
3. The non-weight-bearing axial surfaces of the sole of both digits (the area surrounding the interdigital cleft) are hollowed out.
4. Irregularities in the sole are excavated and corrected.
5. Heels are trimmed to remove loose horn and reduce any furrows.
6. The soles are levelled off using a rasp.

The condition of cow tracks can influence the prevalence of lameness in a herd. Stony, muddy tracks provide an uneven surface that can stress the sole and lead to lameness and poor welfare. The ideal surface is absorbent and provides a firm surface for walking on; bark chippings are recommended but need constant care. They should be laid over a porous membrane and aggregate for good drainage. Concrete is very durable and is better than stony tracks, but not as comfortable for the cows as bark chippings. However, a concrete track can be used by both cows and vehicles, whereas if bark chippings are used separate tracks are required for each as a vehicle's wheels will create ruts that would make comfortable walking difficult for the cows. Cows should never be hurried down a track by a herdsperson using a dog or motorbike.

Mastitis

Mastitis is an opportunistic infection of the mammary gland, the severity of which is mainly dependent on the delay in inflammatory response to the infection. It is not one disease, but a wide range of possible infections by up to 100 possible pathogens, each with different predisposing factors, making it a multifactorial disorder.

Mastitis causes a major reduction in the welfare of the cow because of the fever that it induces, the localized pain in the mammary gland and the possible stress of isolation and treatment. The cost to the farmer is considerable, with losses arising for a number of reasons:

- penalties imposed by the dairy purchasing the milk because it has a high somatic cell count (SCC);

- reduction in milk yield from the infected gland, which may persist into the subsequent lactation;
- withholding of the milk from sale after antibiotics have been administered;
- drug and veterinary costs;
- reduced value of the affected cow;
- replacement costs;
- increased labour for managing the sick cow; and
- cost of associated diseases, in particular reproductive failure.

Mastitis also presents risks to human health, as milk containing antibiotics that is drunk by humans may encourage the development of bacterial resistance, or the consumption of unpasteurized milk contaminated with bacteria could lead to the consumer acquiring a zoonotic infection. There are penalties in most countries for dairy farmers supplying milk contaminated with antibiotics and insurance against this possibility is now available in some. Not only is milk that is contaminated with antibiotics unfit for human or calf consumption, it is also unsuitable for cheese or yoghurt production, as the antibiotics prevent the fermentation from proceeding. Dairy cows that contract mastitis before pregnancy is established have a delay in the interval to first service, on average about 3 weeks, and an average of one extra service is required for each conception.

Signs of mastitis

Chronic infections are most common and often affect 20–25% of cows annually. It is useful to recognize these cows in the early stages of infection, so that they can be milked after the cows that are free of infection, thus reducing transfer to these cows. In chronic mastitis, some abnormal secretions are likely to be the only sign, but in acute cases the gland is swollen, hot and full of clotted milk and the cow suffers from a potentially fatal fever. Dairy cows on organic farms have a particularly high incidence of subclinical mastitis but many of these recover spontaneously. Mastitis can be detected by various means: (i) expressing the first milk into a cup and looking for clots and flakes of milk; (ii) using detectors in the milk pipeline that show the clots on gauze or that measure physiological parameters that change in the milk of cows with mastitis, such as electrical conductivity; and (iii) palpating the udder and detecting its hot, swollen appearance. The California Mastitis Test (CMT) and other similar cow-side tests rely on a reagent that clots when added to milk containing DNA from somatic cells.

Defence mechanisms

The external surface of the mammary gland is designed to minimize the adherence of bacteria, being without sweat or sebaceous glands and with a limited amount of hair. The teat is the primary line of defence against mastitis, with its skin possessing a thick layer of stratified squamous epithelial cells. The surface contains much dead, keratinized tissue, in which it is difficult for bacteria to grow. Keratin has antibacterial properties, being a waxy substance that limits moisture availability to colonizing bacteria. At the end of the teat is an 8–12 mm canal surrounded by a sphincter that closes within 20–30 min of milking because of the pressure of milk on the Furstenberg's rosette (a ring of muscle around the top of the canal). This prevents the ingression of bacteria into the teat cistern. It is therefore best to prevent cows from lying down for 30 min after milking, especially housed cows, which have a greater chance that pathogenic bacteria will enter the teat canal than grazing cows. This is usually achieved by restricting them to the feeding area. Cows are often fed in the morning but it is good practice also to offer some feed during afternoon milking so that cows spend time feeding on returning to their housing.

Some of the keratinized epithelial tissue lining the cistern is sloughed off during milking and enters the milk, preventing adherence of foreign material to the gland. Bacteria may contaminate the teat end from a number of sources, including the milker's hands, the environment (particularly bedding material), udder cloths and residual milk from the previous cow to be milked. In high-yielding cows, there can be considerable shedding of keratinized epithelial cells into the teat canal, which reduces its protective properties between milkings.

Other non-specific defence mechanisms include the lactoperoxidase complex in milk (lactoperoxidase, thiocyanate and hydrogen peroxidase), which is bactericidal and inhibits the growth of viruses, moulds, yeasts, mycoplasmas and protozoa. Lactoferrin in milk provides a second biochemical defence mechanism; it is an iron chelator that depletes milk of the available iron that is required by bacteria. Similarly, the increase in milk sodium during mastitis is probably toxic to some mastitogenic bacteria, particularly *Staph. aureus*. Also in milk are complement proteins and immunoglobulins, both of which are bacteriostatic or bactericidal.

The specific defence systems that are used to protect against bacterial colonization of the gland centre on the polymorphonuclear leucocyte (PMN) response to macrophage recognition and destruction of invading bacteria. This inflammatory response can increase cell counts very rapidly because of the logarithmic increase of PMN numbers when lysosomal breakdown products are liberated into the gland. Of particular importance is the rate of arrival of neutrophils at the mammary gland, which is often 2–4 h after the first appearance of endotoxins in the gland. Neutrophils in the milk have less phagocytic activity than blood neutrophils. Adequate zinc, selenium and vitamin E dietary levels are particularly important for neutrophil function around calving and early lactation.

During the infection, the paracellular junctions in the secretory tissue become more permeable and sodium leaks into the milk, giving it an unpleasant taste. This can be detected by the change in electrical conductivity of the milk, providing a parlour test for both clinical and subclinical mastitis detection. However, even if detection is possible for subclinically infected cows, therapeutic measures are restricted and probably limited to minimizing the possibility of transfer to uninfected cows. This can be done, for example, by milking the infected cows last in the herd. Routine antibiotic use in subclinically infected cows is inadvisable because of the risk of antibiotic resistance developing, especially since many cases recover spontaneously.

Somatic cell counts and other milk quality measures

The somatic or body cells present in milk are mostly macrophages, which reside in the teat cistern. Samples are usually taken monthly to be analysed for somatic cell count (otherwise known as bulk milk cell count, BMCC). In normal (non-mastitic) milk produced in mid-lactation they typically comprise approximately 65% vacuolated macrophages, 14% non-vacuolated macrophages, 16% lymphocytes, 3% PMNs and 2% duct cells. The macrophages recognize invading bacteria and invoke the production of PMNs to phagocytose invading bacteria. The duct cells are epithelial and alveolar cells that apoptose and are excreted in milk. These represent the basal level of somatic cells in milk, which is usually referred to as the somatic cell count (SCC). The SCC in clinically infected cows is usually above 250,000 cells/ml, and in uninfected cows usually less than 100,000 cells/ml. SCC naturally increases as cows age; in their first lactation mean SCC is on average about 150,000 cells/ml, as long as cows are uninfected, but in subsequent lactations SCC usually increases and is likely to be up to 300,000 cells/ml (Laevens *et al.*, 1998). Since milk can be purchased from an EU farm only if the SCC is less than 400,000 cells/ml, it is imperative that the incidence of mastitis be kept to a minimum.

There are three main disadvantages to high milk SCCs.

1. Milk yield is reduced because of damage to the secretory tissue, by about 2.5% for each 100,000 cells/ml above 200,000 cells/ml (Blowey and Edmondson, 2010), indicating that an additional 10% of the herd is infected at any one time.
2. The milk has increased lipase content and the lipid breakdown products give it a rancid taste.
3. The milk has a low casein content, leading to reduced cheese yield.

In 1992, a legal limit for SCC in cows' milk for human consumption of 400,000 cells/ml was included in the EU's Hygiene Directive. These standards are now starting to have an impact in countries wishing to export to the EU, including the USA and Australia, even though under US standards the upper limit is 750,000 cells/ml. The mean SCC in many EU countries is now well below 250,000 cells/ml. At a herd level or over a long period of time, the SCC is an indicator of the level of bacterial infection in the mammary gland. However, for an individual cow, an increase in SCC may not coincide with an acute bacterial infection, since the SCC can take 2 weeks to decline after treatment (Laevens *et al.*, 1998).

National levels of SCC can be decreased considerably if incentive payments and penalty schemes are introduced. This was evidenced in the UK as SCCs declined from 750,000 cells/ml in 1968 to 180,000 cells/ml by 1996, after an incentive payment scheme had been introduced, and has remained at approximately that level until the present day. Most of the decrease in SCC was because farmers became more aware of the need to prevent milk from cows with a mastitic infection entering the saleable milk in the bulk tank. Mastitis incidence has generally not declined in parallel with this and remains at approximately 35–45 cases of mastitis in one quarter of the udder per 100 cows per year, and 20–25% of cows affected in each herd each year.

The SCC increases only when the udder's defences have failed to prevent bacterial colonization of a gland. The CMT gives an approximate guide to the SCC, by testing for the amount of DNA from somatic cells in a milk sample. The CMT values range from 0 (< 200,000 SCC/ml) to 3 (> 5,000,000 SCC/ml). It can be a good screening test for large numbers of cows in a problem herd; any samples with test values of 1 or more indicate that a more detailed bacteriology test should be conducted.

In addition to SCC, there are direct measures of bacterial contamination of milk that are routinely conducted. The total bacterial count (TBC) was traditionally assessed by culturing bacterial colonies to determine the number of bacteria in a sample. This method has been replaced in most many countries by an automatic scanner, which dyes and counts individual bacteria automatically in raw milk. This measures all bacteria, including thermoduric bacteria, psychotrophs (bacteria capable of growing in cold conditions), coliform bacteria, etc. The value derived is usually approximately four to five times the conventional TBC value obtained from cultures.

The TBC increases in milk from cows with mastitis but it is also increased by inadequate refrigeration or by dirty milking procedures or cows' teats. If it is suspected that mastitis is not the cause of the problem, it may be possible to identify a source of outside contamination. For example, a coliform bacteria count of more than 20–25/ml indicates that the cows have dirty teats or that cows are being washed but not dried, which conveys the bacteria into the liner and then into the milk. A high count of thermoduric bacteria (indicated by a laboratory pasteurized count of more than 175/ml) suggests inadequate washing, since the thermoduric bacteria multiply in the film of milk that remains in the milking machinery after inadequate washing of the plant. This could be because of a boiler failure, insufficient washing solution or blockages in the washing system.

The pathogens causing mastitis

Mastitogenic pathogens are highly specific to each geographical region and even to each farm. They can be divided into those that are contagious and are passed from cow to cow, often via the milking cluster, and those that are contracted from the environment, particularly dirty, moist bedding, laneways and passageways. Since the late 1970s, there has been a reduction in contagious pathogens through the widespread use of prophylactic antibiotics, while environmental mastitis forms have increased.

The most common contagious organism is *Staph. aureus*, which is usually spread between cows at milking through the milking machine or by the milker and is persistent once established. The most effective control is good parlour hygiene and dry cow therapy. *Staph. aureus* produces toxins that bind to the epithelial membrane of the secretory tissue, opening transmembrane pores that cause the leakage of ions from blood into the milk. Eventually, secretory tissue is destroyed and there is an accumulation of fibrous tissue that inhibits antibiotic activity. The bacteria are also particularly resistant to antibiotic therapy because they attach to milk fat globules, which encapsulate and protect them.

One of the best control measures against such mastitis is regularly to extract as much milk as possible from the affected glands, perhaps by hand stripping or allowing a calf to suckle. This helps to extract the fat globules, which are not easily expressed from the milk tubules into the collecting ducts. At the end of lactation, infrequent milking may lead to accumulation of milk in the glands. If it is evident that this is accompanied by disease, the lactation should be terminated and treatment given.

Other contagious mastitogenic pathogens include: (i) *Streptococcus dysgalactiae*, which can exist in extramammary reservoirs, most notably the tonsils; (ii) *Streptococcus agalactiae*, which exists in bedding and milking equipment and causes large increases in bulk tank SCC; (iii) mycoplasma; and (iv) *Corynebacterium bovis*. *Strep. agalactiae* is spread easily between cows at milking time. However, it survives only in the mammary gland and is susceptible to antibiotics. *C. bovis* dramatically increases SCCs but often with limited infection. It exists mainly in the mammary gland and reproductive tract.

The major environmental pathogens are: (i) *E. coli*, which is present in the intestinal tract and therefore contact is spread via faeces; (ii) *Streptococcus uberis*, present on external surfaces of the cow and in some orifices, causing large increases in milk SCC; and (iii) *Klebsiella* spp., which are particularly common in damp sawdust. *E. coli* infection is particularly prevalent at the onset of lactation in high-yielding cows and shortly after the cessation of lactation. It is more pathogenic than *Strep. uberis*, producing toxins that rapidly induce loss of appetite, fever, depression and a rapid reduction in milk yield, perhaps by 60% within 2 days. It is the most likely of the mastitogenic pathogens to cause an acute, and sometimes fatal, mastitis.

Mastitis is most prevalent in the immediate postpartum period because of the suppression of immunocompetence, which lasts for about 1–2 weeks before and after calving. This periparturient immunosuppression is believed to occur partly because of the preparation for and onset of lactation, partly because of changes in the environment and greater bacterial challenge in early lactation, and probably partly because of the rapidly escalating nutritional deficit at this time.

Another important mastitogenic pathogen is *Actinomyces pyogenes* (*Trueperella pyogenes*), which is both infectious and of environmental origin. It is also resistant to antibiotics. This is the main cause of summer mastitis that infects dry cows and heifers but rarely lactating cows. It is transmitted by the headfly, *Hydrotaea irritans*, and is best addressed by fly control with impregnated ear tags or sprays.

Surveys indicate that the proportion of mastitis incidents is typically distributed among the bacteria as follows: *E. coli*, 27%; *Strep. uberis*, 21%; *Staph. aureus*, 19%; *Strep. dysgalactiae*, 6%; *Strep. agalactiae*, 2%; and other bacteria, 25%. Previously, *Staph. aureus* was a more common cause of mastitis, but the widespread use of intramammary antibiotics and better milking hygiene has reduced its prevalence, with *E. coli* increasing in its place.

Current control measures

Measures to address mastitis include good hygiene and regular use of antimicrobial chemicals and antibiotic drugs. These have been well established for many years and, if correctly implemented, should enable a dairy herd to have a satisfactory standard of mastitis control for economic production and supply of milk to retailers or manufacturers; that is, an SCC count of 100,000–150,000 cells/ml for milk in the bulk tank, fewer than 20 cases of mastitis per 100 cows in a 305-day lactation, less than 12% of the herd infected at any one time and a recurrence rate of less than 6%. Fewer than five doses of antibiotics should be used for each case of clinical mastitis. The indiscriminate use of antibiotics has led to residues being found in milk and to resistant bacteria evolving. Furthermore these targets, although attainable, are not particularly helpful for milk-purchasing companies to regulate contamination and they may in future devise species-specific penalties/incentive payments in the regulation of individual bacteria species.

The successful treatment of mastitis will require researchers to continue to develop advanced control measures, since the bacteria will mutate and develop resistance to the current range of antibiotics. So far, resistance has been observed in response only to *Staph. aureus* infections when these are treated with penicillin or when cloxacillin is used for dry cow therapy. *Staph. aureus* infections during lactation are best controlled by clavulanate/amoxycillin and cloxacillin is still the best antibiotic to use for dry cow infections. Most other infections can be controlled with penicillin, but clavulanate/amoxycillin is best for *E. coli* infections.

Despite evidence of pathogen resistance to antibiotics becoming available soon after these were first used in cattle, there is little evidence yet of emerging or widespread resistance in the common pathogens, but our knowledge of pathogen developments suggests that this will happen eventually. Careful and limited use of antibiotics is essential. When choosing an antibiotic, note should be made of the period of time that milk should be withdrawn from the farm's supply to the retailer (from the time of insertion of the last tube). When using antibiotic therapy on dry cows, the persistence should be noted, which ranges from 7 days for ampicillin to 42 days for cloxacillin. Some products are a combination of antibiotics. Withdrawn milk should not be used for feeding to other stock, such as calves, and must be carefully discarded with consideration for the potential for environmental pollution. It must not be used for human consumption. Pasteurization is an important process to ensure that milk does not contain active bacteria and the use of antibiotics in dairy cows could endanger their effectiveness in humans if raw milk is drunk.

The level of mastitis has not declined significantly since the late 1970s despite widespread development and adoption of control measures. In future, farmers will have to concentrate on maintaining their cows in very clean conditions, and especially on controlling environmental pathogens, which have become more common as the infectious pathogens have been brought under control by antibiotics. Slurry disposal will need to be carefully planned and greater attention paid to fly control and ventilation of buildings. Modern portal-framed buildings facilitate such improvements in cleanliness.

Heifers are particularly vulnerable to mastitis, as their defences are not well developed and they sometimes demonstrate twice the incidence of mastitis found in older cows. Infection chains from older cows to the heifers are common where bacterial infections are transmitted in the milking parlour. One reason why mastitis incidence has not declined relates to the increase in milk yield of most cows, in response to genetic selection and improved feeding. High-yielding cows tend to have wide teat canals, so the ingress of bacteria into the teat cistern is facilitated. Increasing milk yields through the injection of the growth hormone analogue (bovine somatotrophin or bST) also increases mastitis levels. The analogue bST can stimulate the immune system in the mammary gland but the extra mobilization of body tissues to support increased milk production can depress the immune function, leading to an increased mastitis frequency. The current recommendations for controlling mastitis are presented in a five-point plan (Box 9.1), but these may have to be modified as antibiotic resistance reduces the effectiveness of antibiotics in combating new strains of bacteria.

Future control measures

In future, control will have to rely to a much greater extent on prophylactic measures than on the use of antibiotics. The following are some of the measures that farmers will have to consider carefully with their veterinarian.

1. Minimize contact between the cow and slurry/faeces.
2. Avoid muddy pastures and cow tracks.
3. Cull cows that lie in passageways rather than in cubicles (free stalls) or strawed yards.
4. Improve cubicle design to encourage cows to use them.
5. Train cows to use cubicles.
6. Clean cubicles regularly and improve bedding provision to reduce bacterial contamination of the bed.
7. Clean the cluster between cows during milking.

Displaced abomasum

Cows in late pregnancy have an enlarged uterus, which gradually puts pressure on the caudal end of the rumen. This causes the abomasum, which usually sits adjacent to the diaphragm, to slide under the rumen, hopefully to return after calving. However, in a small proportion of cows (about 3%) the abomasum takes up residence between the rumen and the body wall. In 80–90% of cases this is on the left side. Predisposing factors are low-fibre diets, concurrent milk fever or ketosis (which reduce ruminal and abomasal motility), overconditioning of transition cows and deep-chested cows (which have ample room for the abomasum to displace to the left side of the body). This condition illustrates the interplay between genetics, nutrition and management that underpins many diseases in high-producing dairy cows. Transition cow management is crucial in preparing the cow adequately for lactation.

Bovine spongiform encephalopathy (BSE)

The emergence of BSE in cattle in the UK in the late 1980s and early 1990s had a considerable impact on livestock farmers, government, veterinary practices and even the British tourist industry. The first believed case of BSE occurred in Sussex, England, on 22 December 1984. The animal was misdiagnosed as having worms or mercury poisoning and died 3 months later. Until then, the UK had been considered relatively free of infectious diseases, aided by its island geographical state. In 1986, the disease was eventually confirmed as a spongiform encephalopathy by the UK Ministry of Agriculture, Fisheries and Food (MAFF), but the diagnosis was suppressed for 18 months. It was originally believed to be one of a few isolated incidents caused by toxic material; however, by the end of 1986 there were seven confirmed cases. The new disease was a fatal and transmissible neurological condition, with the infective material being detected in the brain, retina, spinal cord, ileum, some ganglia and the bone marrow of affected animals.

The confidence that Europe had in its cattle industry was then shattered in 1987 when it became apparent that the UK had become the centre of a major new epidemic: a transmissible spongiform encephalopathy (TSE) (Donnelly *et al.*, 1999). TSEs were known in other species but there was no known cure or even preventive measure, other than the certain knowledge that there was a strong environmental component. Slaughtering sheep flocks with ovine TSE, termed scrapie, and restocking had not eliminated the disease, which had remained at a low level in some sheep flocks for many years. Because of this, the suspicion arose that the recycling of meat and bone meal from sheep had caused the TSE to transfer into cattle. This association was strengthened by the observation that the brain tissue of cattle with BSE contained scrapie-associated fibrils made of prion protein. In particular, it was suspected that an infective agent had been delivered to farms, because of the sudden and widespread appearance of the

Box 9.1. The five Cs for control of mastitis.

1. Clean cows. Use a teat dip or spray to disinfect all teats after every milking. Clean cows' teats before milking with hot water and dry with individual paper towels. Dirty bedding contains *Strep. uberis*, *E. coli* and other coliforms. Outside areas where cows lie down overnight can become soiled and harbour *Strep. uberis*. In the parlour, all cows should be washed on entry to their stalls if their teats are visibly dirty, and then dried with individual paper towels. A communal cloth used for many cows spreads infection. If the teats are not visibly dirty, they should be just wiped with a dry paper towel. Cows' teats may be either sprayed or dipped in a disinfecting solution, usually based on iodine, together with an emollient to stop the skin dehydrating and chapping. These reduce the rate of new infections by *Staph. aureus* and *Strep. agalactiae* by about 50 % but are ineffective against *E. coli*. Alternatively, hypochlorite solutions are effective but sometimes irritate the skin. Spraying is quicker but dipping ensures a better coverage of the teat. Before milking, the udder should be washed with a sprayline and individual paper towels used to dry the udder, with the milker wearing disposable gloves to prevent bacteria on their hands contacting the udder. This will help to limit the invasion of the udder by contagious pathogens, whereas post-milking teat dipping largely controls the environmental pathogens.

2. Correct equipment. Ensure that the milking machine is tested regularly and faults are promptly corrected. Maintain the parlour in a clean state and clean the equipment thoroughly on a daily basis. Machine maintenance is essential at least once a year to ensure that the teats are not excessively stressed by the milking machine. This will always be difficult to achieve, as the sucking action of the machine inevitably puts more pressure on the teat blood vessels than does the calf, which essentially squeezes the milk out of the teat with its tongue. Rapid build-up to a maximum vacuum and return to atmospheric pressure are important. The vacuum should be maintained for at least one-third of the cycle and fluctuation in pressure within the open phase avoided. Valves can be inserted into the claw to prevent transfer of milk from one teat to the other. Liners should be designed to minimize slipping down the teat and should be replaced every 1000 milkings or 6 months. Aged liners harbour bacteria in cracks, as well as increasing vacuum fluctuations, which reduces milk flow rate.

3. Cull persistently infected cows. Cull animals with persistent and recurring cases: break the infection chains. In some jurisdictions, in particular the EU, the low limit for SCC in milk should encourage farmers to cull high-SCC cows regularly. As SCC increases with lactation number, older cows will naturally be a target. Farmers should remember that SCCs are lower in mid-lactation, when yields are greatest, than at the beginning or end of the lactation. However, it may be unwise to breed cows selectively with very low SCCs, since these cows may be more at risk of developing mastitis, particularly from the environmental organisms such as *E. coli* or *Strep. uberis*. The colonization of a gland by minor pathogens, which increase SCC but do not cause clinical mastitis, reduces the risk of contracting a severe environmental mastitis. The speed of reaction of the immune system is potentially more important than the SCC but currently this cannot be included in any widespread breeding programme.

4. Clinical cases treated. Treat all clinical cases promptly with the recommended intramammary antibiotic and record the cases accurately. Treatment should be given to the cow according to the severity of the disease. Milking cows should be treated with intramammary tubes for 3 days, administered by the farmer. If the mastitis is severe, a veterinarian may be needed to administer high-dose injectable antibiotics, as well as intramammary treatment. Hypertonic saline solution fluid therapy may be given if the case is particularly severe. This should be given intravenously and will be beneficial in counteracting the dehydration that accompanies acute mastitis.

Continued

Box 9.1. Continued.

5. Cows treated at drying off. Traditionally this was with a long-lasting dry cow intramammary antibiotic, applied to each quarter, but this is now undesirable because of the potential to develop and spread antibiotic resistance. Teat seals accelerate the natural plugging of the teat canal after cows have been dried off. Internal seals are as effective as antibiotics and last throughout the non-lactating period. They should be carefully inserted after drying off and removed by stripping out each cow when she starts her new lactation and avoid putting milk into the bulk tank from the first eight to ten milkings after calving. A failure to remove teat sealants can lead to blemishes in cheese produced from milk extracted at the start of the lactation.

Some bacteria, such as *Staph. aureus* and *Streptococcus* spp., may be active from one lactation to the next, in which case there is justification for the use of an antibiotic intramammary infusion at drying off to prevent recurrent inflammation of the gland. The cure rate will depend on the level and duration of the infection, the number of quarters that are infected and the age of the cow. Old cows are most difficult to cure, partly because they develop resistance to antibiotics, in particular penicillin. Cure rates vary from about 90 % for a 3-year-old cow with one infected quarter to about 35 % for an 8-year-old cow with three infected quarters. The spontaneous cure rate is normally 10–15 %.

Routine use of antibiotics for the control of contagious mastitogenic pathogens, particularly at drying off, is also probably partly responsible for the recent increase in environmental pathogens. As the contagious pathogens are treated and eliminated, the mammary gland is left susceptible to novel pathogens, in particular those normally present in the environment. Alternative treatment methods must now be used, and more emphasis focused on prevention. As an interim stage in the progression towards eliminating routine antibiotics at drying off farmers may choose to use them only on cows with persistently high cell counts.

disease (sheep also develop scrapie through infection, not as a spontaneously generated disease).

Investigations revealed that the UK rendering industry had recently revised its practices, under the guidance of the relevant government ministry (MAFF), through the removal of acetone from the process of fat extraction from the carcass and a reduction in the temperature at which the extraction took place. These measures were introduced in order to reduce both energy costs and risks to abattoir workers. Although there have been anomalous situations in which cattle presenting with BSE appear not to have been fed meat and bone, this is now assumed to be the true origin of the disease, because the prion glycoforms were identical for the two diseases. Most cattle presenting with the disease in the initial outbreak were probably infected as calves in 1981/82. Another change in the cattle industry that took place at this time was the widespread use of systemically active organophosphates that were poured on to the backs of cattle to eradicate warble fly, which probably predisposed cattle to the transmission of the disease from sheep.

In 1988 the MAFF made BSE a notifiable disease and prohibited the feeding of any ruminant protein to ruminants. It is now questionable whether this was a sufficient reaction to the threat of widespread transmission of the disease, because it was known at the time that many species could become infected with TSEs from other species, albeit less easily than the transmission of infection within a species. Meat and bone meal had been used in the cattle feed industry for about 40 years and in the late 1980s about 13,000 t of meat meal and 5000 t of bone meal were exported annually by the British rendering industry. As a result, the disease made sporadic appearances in other countries, but the reporting of these was limited because of the obvious damage that such cases could do to a country's cattle industry.

Nowhere was the damage been more acutely felt than in the UK. In fact, the disease threatened the survival of the government in power at the time, which had to negotiate a delicate path between on the one hand an extreme reaction involving destruction of the country's cattle industry and on the other taking adequate steps to safeguard the population from acquiring the disease. Repeatedly, the government of the day tried to allay public suspicions by claiming that there was no risk associated with eating beef. When it became apparent that public suspicion was not satisfied by these pronouncements, the government authorized, in 1989, the removal of specified offal and nervous tissue in abattoirs and these items were effectively removed from the human food chain. Several senior scientists warned that this was not enough and in the same year the EU voted to ban imports of beef from the UK, believing that some infective material was still reaching the human food chain. The offal ban was extended to intestines and thymus in 1994, after infective agents had been found in calves following oral infection. A selective cull was started in 1996, with over 60,000 animals over 30 months of age being slaughtered out of a total of 160,000 cattle that were believed to be infected. This operation was far more expensive than if the government had introduced greater controls at the start of the crisis, because of some vertical transmission of cases and spread of the disease to the majority of farms in the UK.

In the same year a new variant of the related Creutzfeldt–Jakob disease (nv-CJD, a rare spongiform encephalopathy affecting the human population) was described in the UK, and several scientists linked its emergence to the BSE epidemic when similar patterns of glycosylation and behaviour were observed in mouse bioassays for the two diseases. There were almost 200 human cases of nv-CJD, though it is unclear whether these people had particularly short incubation periods, were more susceptible or consumed a greater infective dose than the rest of the population. It is currently estimated that one in 2000 people in the UK is a carrier of nv-CJD but it is unknown if they will develop the disease.

The belief that the disease could transmit to humans led to ever more stringent measures to try to control its spread. In 1988, the government banned the use of ruminant protein in ruminant diets; in 1994 this was extended to all mammalian protein; and in 1996 the ban was applied to all farm animals, not just ruminants. In the meantime, scientists had determined that BSE could be experimentally transmitted to many other mammals by injection into the brain, and to some mammals (other cattle, sheep, goats, mink and mice) by oral ingestion of infective agents. As little as 1 g of infected bovine brain material could cause development of the disease via the oral route, and considerably less in sheep and goats. Natural transmission occurred to domestic cats, captive wild ruminants and carnivores. The epidemic lasted from 1987 to 1998 and many of the control measures can be seen, with the benefit of hindsight, to have been inadequate and too late.

One lesson from the BSE outbreak for those involved in the cattle industry is that disease outbreaks are a constant threat to their livelihood. At any time, a major disease outbreak can leave a cattle farmer unsupported by government, the enemy of the public and without a market for their product. The impact on the livestock industry in the UK was long lasting and very significant, resulting in an ultimate loss of confidence and support from government.

Other countries, such as Japan, Canada and the USA, which had just one or two cases, suffered major reductions in beef sales and export restrictions, costing billions of dollars and having a significant impact on many nations' economies. A single case in the USA in 2003 cost cattle farmers a reduction of between 5% and 8% of their income over the subsequent 4 years. Following the outbreak many countries have introduced compulsory individual identification of animals – traceability schemes – so that the origin of meat stocks in retailers can be determined and random testing for the disease in slaughter plants. The extent of the loss of confidence of the public in cattle as food producers may never fully be known. Not only did people almost immediately reduce their consumption of beef, in some countries by 50%, but they were also made aware of the widespread nature of livestock products, such as tallow and gelatin, throughout the food industry, leading to further concerns and revision of eating habits.

New cases are still appearing worldwide but in much smaller numbers. The disease is worthy of detailed study because it represented a new major disease challenge to the cattle industry that had major impact on worldwide trade, public confidence and cattle and human health.

Escherichia coli O157:H7

E. coli O157:H7 is an example of an evolving bovine pathogen, which emerged at the beginning of the 1980s when a prophage enabling the bacterium to produce shiga-like toxins entered the bacterium. These toxins attack the small blood vessels in the kidney, brain or large intestine. Renal failure may result and is the most common cause of death, which occurs in 3–5% of cases. A haemorrhagic diarrhoea is also a common symptom. The organism is resident in the faeces of some cattle and, although it does not cause any disease in ruminants, it is a potent zoonotic agent that is transmitted in meat and milk through contamination of the coat and udder with faeces. In liquid milk it is transmitted only if pasteurizing processes are absent or inadequate but it can also be transmitted in milk products such as cheese. Risks of food contamination with *E. coli* O157:H7 can be reduced by adding probiotics to the feed, particularly those containing *L. acidophilus.*

Feedlot cattle are particularly at risk and studies in US feedlots have indicated that about 13% of cattle have the organism in their faeces. Ensuring that cattle are kept clean and clipping off contaminated hair before they are sent to slaughter will limit the spread of the organism to humans. A dirty animal may have 10–12 kg of manure on its hide, which reduces the value of the pelt as well as creating a health risk to people handling and consuming the meat of the animal. Such animals should be rejected at the abattoir and returned to the farm of origin. Clipping to remove faeces from the pelt may present a risk to people doing the clipping unless adequate precautions are taken.

Prevention can also be achieved by better microbiological training of food preparation staff, including farmers with milk-processing plants on their farm. Part of the reason for the organism's success is its ability to survive in harsh conditions. Laboratory tests show that it can survive for several days on dry stainless steel. It also survives in soil, from which it can cross-contaminate stock that are lying down outside. It is usually acquired from surface contamination of carcasses with faeces, or contamination of the muscle tissue with intestinal contents. During preparation of the meat, knives allow entry of the bacteria into muscle tissue. In the grinding of beef to make hamburgers the bacteria are spread throughout the food item and, if insufficiently cooked, the presence of just a few bacteria can readily transmit the disease to the human consumer. In beef steaks this is less likely to occur as the bacteria reside only on the surface, which is usually subjected to sufficiently high temperatures to kill the bacteria.

The worst outbreak so far occurred towards the end of the 20th century in Lanarkshire, Scotland, when 21 people died as a result of having eaten steak-and-kidney pies produced from a contaminated side of beef. The speed with which the organism spread is a major concern in attempting to guard against future outbreaks. In this case the authorities closed the shop selling the infected meat within 10 days of it entering the premises, where inadequate hygiene and disinfection procedures had allowed the organism to spread. Rapid recognition of the problem and treatment of infected individuals is essential in such outbreaks, and the young, old and infirm are most likely to die. As with other zoonotic diseases the public tends to see the risk as disproportionately high, because it is outside their control. The incidence has gradually increased since about 1990 and is consistently greater in Scotland than the other UK principalities, with an average of approximately five cases per 100,000.

Bovine tuberculosis

This bacterial disease usually causes localized infections (tubercles) in the lymph nodes of cattle, especially in the respiratory tract. It can spread to other parts of the body, such as the mammary gland, if it remains undetected. It is occasionally found in the gastrointestinal lymph nodes, where the infective dose is much greater than for respiratory infection, in which case a single organism delivered to the right place may suffice.

The responsible organism is *Mycobacterium bovis*, which used to be responsible for many human deaths, especially children who drank the milk of infected cattle. In the 20th century, the widespread adoption of pasteurization of milk restricted infection in humans to those who came into direct contact with infected cattle. In addition, a programme of regular tuberculin testing of cattle for *M. bovis* reactivity was begun in the 1930s in the UK following the development of the cervical skin test, which compares the skin inflammatory response to *M. bovis* with that to *Mycobacterium avium*. It has since been adopted in all high-prevalence regions and is normally followed by the slaughter of positive reactors. In the UK the scheme was introduced initially on a voluntary basis but in 1950 a compulsory programme was introduced that has continued to this day. This reduced the number of outbreaks to less than 0.1% of herds by 1970 but since then the prevalence has been increasing, particularly in recent times, demonstrating the difficulty in completely eradicating the disease.

The number of herds testing positive has increased rapidly since the late 1980s, so that there are now many more animals proving positive than in the early 20th century, when the disease was recognized as the most significant health problem in cattle, a status that it may yet regain. The recent increase is attributed to greater movement of cattle, especially during restocking of herds after the 2001 foot-and-mouth disease outbreak in the UK, and the growth in population of an intermediary host, the badger, which used to be controlled by game wardens. Increased use of maize silage and complete diets on dairy farms may also have increased the badger population. Many cattle probably contract the disease by sniffing dead or dying badgers, or infected faeces or urine patches in the fields.

Pre-movement testing and the separation of cattle and badgers now seem to be the main hopes for controlling the disease. Compulsory pre-movement testing of cattle was introduced in areas of high prevalence of the disease in the EU in 2005–2006. Separation can be achieved by fencing off badger sets, avoiding heavy grazing in areas occupied by badgers (to prevent cattle having to graze close to their excreta) and preventing badgers from feeding at cattle feed stores. Culling badgers has dubious efficacy and was initially rejected by government as being too unpopular with the public. However, it has been undertaken on several occasions by either cage trapping and shooting, or free shooting. The maintenance of a high level of biosecurity on cattle farms is now a major priority in high-risk areas, such as in the UK and Ireland.

The new threat to the cattle population comes at a time when the public is sensitive to the use of snares or gassing to cull badgers. An animal indigenous to the UK, the badger arouses considerable passion in conservation groups, in contrast to the intermediate TB host in New Zealand, the possum, which is not native and can be destroyed with impunity. Hence, the emphasis in Europe was until recently on improved husbandry and the development of a vaccine, rather than on badger culls. In addition, frequent testing of cattle in susceptible herds is advocated, with elimination of reactors. The sensitivity of the tuberculin skin test is about 90% and its specificity even greater. It is unlikely that an increased frequency of testing would reduce the prevalence of the disease, but a blood test using gamma interferon can help to detect the 10% of cases that might escape detection by the tuberculin test.

Cattle-to-cattle transmission is limited by any test and slaughter policy, since this prevents the disease reaching the fulminating stage where cattle become highly infectious. The incubation period is usually about 6 months, though some excretion occurs in the early stages of infection. Cattle-to-cattle transmission is particularly common following cattle movement and in contiguous herds. There is a particularly high risk of transmission from purchased bulls, which may relate to the stress that they suffer during transport. Some countries, such as Australia, have had considerable success in eradicating bovine tuberculosis by adopting a rigorous test and slaughter policy, though the success of this policy would be reduced by the presence of a widespread intermediate host. The last case in the main intermediate host, the water buffalo (*Bubalus bubalis*), was in 2002.

Bovine tuberculosis and other mycobacterial diseases of cattle, such as Johne's disease, are more likely to emerge when housing conditions are poor and cattle are stressed. Cattle faeces are an important means of transmission, especially in scraped-floor housing systems and following slurry spreading in fields. The spread of such diseases may ultimately require farmers to find ways of separating cattle from their faeces, such as slatted floors or regular automated scraping of passageways.

Finally, as with many cattle diseases, there is a genetic component to susceptibility. Certain family lines are particularly susceptible and a breeding programme could reduce the susceptibility of cattle and help to control the disease in a manner that the public finds more acceptable than eliminating the supposed intermediary host (Phillips *et al.*, 2000b).

Bovine respiratory disease (BRD)

Also known as shipping fever, this complex of infections of the bovine respiratory tract is most common in animals stressed by transport or those in feedlots. A variety of agents are responsible, including both viruses and bacteria. Stresses most likely to reduce the animal's immune system and create conditions favourable for BRD include wide environmental fluctuations and mixing with other cattle. Exposed to such stresses, the normally benign microorganisms in the upper respiratory tract extend their activities to the lower respiratory tract, resulting in pneumonia and sometimes leading to death. BRD is the commonest form of death in feedlots. The signs are easily observed: coughing, nasal and ocular discharge, depressed appetite, noisy and laboured breathing and a lethargic disposition.

Prevention is usually by adopting best industry practice in moving cattle or keeping them in feedlots. Hurried movement (especially soon after weaning), hot conditions, overcrowded pens, repeated use of the electronic goad, dust and mud will all stress cattle. Common viral forms of the disease include infectious bovine rhinotracheitis (IBR), parainfluenza-3 virus, bovine viral diarrhoea (BVD) and bovine respiratory syncytial virus (BRSV). Common bacterial forms include *Pasteurella multocida* and *Haemophilus somnus*. Vaccines are being developed that protect against some of these but the best and most humane method of treatment is to remove affected cattle, treat them with antimicrobials and reduce their exposure to stress.

Trypanosomiasis

Trypanosomiasis is a disease caused by the trypanosome parasite that is transmitted by the tsetse fly, which inhabits most of central Africa. The parasite causes intermittent fever, listlessness, progressive emaciation and eventually death. The distribution of the tsetse fly controls the distribution of livestock breeds in Africa, with only wild game and trypanotolerant cattle breeds inhabiting the heavily infected areas, such as wet, swampy regions. In the open savannah, the tsetse flies prefer to feed on wild game but, increasingly, these have been replaced by cattle, which are more valuable for food production. The desirability of controlling cattle trypanosomiasis has led to an extensive search for means of controlling the tsetse fly.

The disease is a particular constraint to the productivity of recently imported exotic cattle in Africa. Over several thousands of years breeds of local cattle, such as the N'Dama and West African Shorthorn, evolved their own resistance, but these are not as productive as modern European cattle. Wildlife are carriers and do not suffer severe clinical symptoms but they do provide a constant reservoir of disease organisms, rendering eradication of the disease impossible. The potential exists to transfer the resistance of the local cattle to more productive European cattle. If quantitative trait loci (QTLs) for trypanotolerance can be identified, it should be possible to transfer the relevant regions of the genome and produce novel genotypes with favourable disease resistance and production characteristics. The major challenge is to understand the physiological basis for trypanotolerance, because only then can the virulence of the disease be reduced in the long term. Clearly, the trypanosome haemoprotozoans are capable of commensal relationships in some cattle and wild animal genotypes, and this should be the objective of current breeding programmes for more productive cattle. Reliance on trypanocidal drugs and vector control has ever-diminishing effectiveness, which is prompting considerable interest in breeding disease-resistant stock.

Herd Health Assurance Schemes

There is a growing recognition among the public that farm conditions are sometimes unsatisfactory for the health and welfare of cattle, which rivals their concern about food quality and environmental impact. Herd health assurance schemes may be part of approved standards that many concerned members of the public are prepared to pay for. Standards for specific diseases, e.g. enzootic bovine leukosis, may be set by animal welfare organizations, veterinary associations or major retailers, such as the international supermarket chains, and by governments. Membership of assurance schemes may be required by the major retailing chains. Such standards will usually focus on the health of herd members but also on related issues, such as hygiene on the farm, the quality of housing, plant and equipment, feedstuff and water storage facilities, stockmanship and the ability of a farm to manage an emergency.

Monitoring should be conducted on a regular basis and may be by veterinarians or, more usually, by staff specifically trained for the task, who have a checklist to examine different parts of the farm to assess their adequacy. There is an increasing emphasis on outcome measures, which rely on cattle measurements or observations, rather than on input measures, which rely on environmental parameters. The former are seen as providing more flexibility in production systems to achieve the desired outcome – good animal health. However, outcome measures are not always possible on large groups of animals moving rapidly through a system, for example cattle travelling by trucks or exported by ships, and in such circumstances recorders may have to rely on input measures, such as environmental temperature, stocking densities, etc., while acknowledging that the relationship to welfare and disease status is less direct. Measuring environmental variables in herd health assurance schemes should ensure that the cattle have:

- adequate space, in particular to allow for sufficient exercise indoors;
- freedom from aggression by other cattle, e.g. by providing adequate feeding and drinking facilities;
- adequate floors to walk on;
- a comfortable and clean bedded area;
- regular veterinary care;
- competent supervision by stockpeople; and
- adequate transportation away from the farm where necessary.

Herd health assurance schemes are useful not only to monitor disease frequency and enable comparisons to be made with acceptable standards but also to determine risk factors contributing to disease and to implement control measures to improve performance.

Notifiable Cattle Diseases and Legislation Concerning Cattle Health and Disease

When diseases are of occasional occurrence, centralized action may be justified to contain the spread of the disease and prevent it becoming established as endemic in the population or even developing into an epidemic. An important part of this process is to notify the disease to the World Organization of Animal Health (OIE – historically the *Office International des Epizooties*). The OIE has some responsibility for livestock health in its 181 member countries and is the only international body with responsibility for developing worldwide welfare standards for livestock. Diseases that primarily affect cattle and must be notified to the OIE are:

- Bovine anaplasmosis
- Bovine babesiosis
- Bovine genital campylobacteriosis
- Bovine spongiform encephalopathy
- Bovine tuberculosis
- Bovine viral diarrhoea
- Enzootic bovine leukosis
- Haemorrhagic septicaemia
- Infectious bovine rhinotracheitis/infectious pustular vulvovaginitis
- Infection with *Mycoplasma mycoides* ssp. *mycoides* SC (contagious bovine pleuropneumonia)
- Lumpy skin disease
- Theileriosis
- Trichomonosis
- Trypanosomosis (tsetse-transmitted).

Others affect multiple species and must also be notified, including foot-and-mouth disease, anthrax, bluetongue, brucellosis, rinderpest, paratuberculosis and Q fever.

Action is also usually taken by individual countries' government authorities, in part to restrict spread of the disease and to mitigate any possible risk to the public in relation to zoonotic diseases or threats to food security. For example, in the UK there is compulsory notification of 14 major cattle diseases:

- Anthrax
- BSE
- Bluetongue
- *Brucella abortus*
- Contagious bovine pleuropneumonia
- Enzootic bovine leukosis
- Foot-and-mouth disease
- Lumpy skin disease
- Rabies
- Rift Valley fever
- Rinderpest
- Tuberculosis (bovine)
- Vesicular stomatitis.

The action taken may include compulsory slaughter, isolation of the site where the disease was found and action to contain the disease within the vicinity. Many countries have specially trained teams of veterinarians capable of recognizing exotic diseases and these are involved in statutory surveillance. Some routine monitoring programmes exist in abattoirs for high-risk diseases in high-risk areas, for example BSE. In developed countries there are often systems to compensate farmers if their cattle are found to have notifiable diseases. The management of cattle diseases is controlled in some countries by law, and regulations in EU member countries are increasingly applied across the entire region.

At the end of the 20th century, the desire for further improvement in the disease status of cattle and limitation of the spread of disease, particularly zoonoses, led to the widespread introduction of cattle-tracing systems. These were mandated in the EU member states from the year 2000. Under the system operating in the UK, cattle are required to have 'passports', which contain details of each animal's breed and sex, its date of birth and, eventually, its death; its dam's number; any movements that the animal makes during its life; and any government financial support that has been received for the animal. The scheme enables government authorities to trace cattle easily if there is a disease outbreak and to assure members of the public that the authorities have control of cattle movements. The system is managed centrally by the British Cattle Movement Service (BCMS) and paid for by the industry through a passport fee. The passport must include details of all of an animal's movements and BCMS must be notified either electronically or by post within 7 days each time an animal moves. When the animal is slaughtered, the passport is returned by the abattoir to the BCMS.

Conclusions on Controlling Disease Challenges

The selection of cattle diseases described in this chapter is by no means exhaustive but it demonstrates the importance of managing the environment, nutrition and genetics of cattle herds to develop a sustainable health management system. Biosecurity must be the key consideration in all intensive cattle production systems, in which disease transmission has to be contained in animals in close proximity. It is usually in these systems that the greatest challenges to the health of cattle occur. Bacterial infections will be increasingly hard to control, as primary and secondary infections, if antibiotic resistance continues to grow. New methods must be used to control these infections, often based on hygienic practices and alternative treatments. In extensive systems, infectious agents must also be brought under control and the environment managed to limit conditions supporting diseases.

The biggest threats to cattle farming are posed by new diseases, such as BSE, especially if they are zoonotic, since the consumer's purchasing habits will have far-reaching effects on the profitability of cattle farms. As with BSE, new diseases often emerge as a result of relaxation of biosecurity measures. However, significant threats are also posed by many traditional diseases, such as mastitis or bovine tuberculosis. This is most likely to occur if a disease mutates to a more pathogenic form, such as *E. coli* O157:H7, or if it becomes resistant to antibiotics used to treat it, or if social pressures prevent traditional control measures being adopted, for example slaughter of wildlife as intermediate hosts. In these situations breeding of resistant stock is one long-term solution and it replicates natural selection. However, it is costly and time consuming and there is often no guarantee of success.

In addition to the infectious diseases, there is an emerging challenge from production diseases, associated with high-output production systems. A high prevalence of these diseases is even less likely to be tolerated by the public than infectious diseases, as they are seen as anthropogenic and a product of over-intensive systems of production that are a product of human greed. Subclinical acidosis is a prime example but new treatment methods with probiotics are helping to stabilize rumen pH, particularly using lactate-metabolizing bacteria. Most of the production diseases relate to the nutrition of the lactating or rapidly growing animal.

Never before have cattle diseases received so much attention from the public, the veterinary profession and farmers as during the early years of the 21st century. In some countries the cattle industry has been criticized for failing to provide a healthy product for consumption and governments have been accused of not safeguarding human health and of not acting on scientific advice. From the difficulties that have been encountered, there is emerging a system of cattle monitoring and health care that should ensure a significant reduction in the risk to consumers, provided that the production system takes account of the risk of infectious disease transmission in overcrowded, dirty systems of production. Systems that have been put in place in countries recently affected by transmissible diseases, such as cattle movement and farm assurance schemes, serve as models to other countries wishing to increase the safety of their beef and dairy products and to assure consumers that adequate systems are in place to safeguard their health.

Further Reading: Blowey, R.W. (2009) *Mastitis Control in Dairy Herds*, 2nd edn. CAB International, Wallingford, UK.

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10

Cattle Welfare

Introduction

The welfare of cattle has been the subject of much debate and scientific research over the last 50 years and the concept of animal welfare and methods of assessment are now well established. In this chapter the welfare impact of practices that cattle are exposed to when they are raised to be killed for food and when they are kept as dairy cows or as sport animals is considered. The numbers kept worldwide are very large, almost 1 billion, of which two-thirds are in just three rapidly developing countries: India, Brazil and China. Although attitudes to their welfare differ enormously between these countries, this chapter attempts not to justify what is or is not done to cattle but to describe the major welfare problems worldwide and suggest how these can be assessed. Armed with that knowledge we can then look at the morality of what is done to cattle. Exercises (Boxes 10.1 and 10.2) are included in the chapter to assist in that process.

What is Cattle Welfare?

An animal's welfare refers to whether it is in a good or bad state, determined largely by its experiences, its situation and most importantly its feelings. It can be scientifically measured on a continuum from very bad to very good. Although people may differ in their assessment of the ethics of keeping cattle for various purposes, a welfare assessment should be able to be agreed by all, provided that they have the right information and tools to make the evaluation. Early measurement techniques focused on avoidance of negative feelings – hunger, thirst, discomfort, pain and fear in particular. Today, it is recognized that we must also assess whether cattle have positive feelings, during play for example, or by giving them good nutrition and making them comfortable.

Welfare fundamentally relates to whether cattle can thrive well in their environment and how they feel: contented, in pain, satiated, excited, etc. Their experiences are governed by whether they have access to the necessary resources or 'freedoms' that are recommended for any animals managed by humans:

1. Freedom from hunger and thirst
2. Freedom from discomfort
3. Freedom from pain, injury and disease
4. Freedom to express most normal behaviour
5. Freedom from fear and distress

Feelings cannot usually be measured sufficiently well to make deductions about welfare, so biological indicators are normally used. These include behaviour, disease incidence and severity, physiological indicators, production rate, life expectancy and reproductive rate. Physiological indicators include immune status measures, stress hormones and homeostasis mechanisms, for example pain regulators. These indicators of welfare status are not ideal, in part because they interact with each other, and something that appears directly to increase one indicator of welfare may decrease another either directly or indirectly (Table 10.1). For example, breeding for increased milk production or reproductive rate could have negative effects on longevity. This illustrates the need for caution in interpreting measures of cattle production and reproduction as indicators of the animals' welfare state. There is also difficulty in equating different welfare measures; for example, is an environment that prevents cattle from performing normal behaviour as harmful as one that induces diseases such as lameness or mastitis?

We can speculate that there is a continuum from good to bad welfare, which suggests that an objective assessment may eventually be possible (Fig. 10.1).

Box 10.1. Classroom exercise: Role playing a cattle welfare issue

A well-known cattle farmer in …… [your area], Boss Indicus, has a 230-cow dairy herd and has an ice cream manufacturing business using the milk from the farm. His business relies on his good reputation in the area. However, he has recently been criticized publicly for his management of bobby calves (male calves that are slaughtered at a few days of age as they are unwanted for meat production). Activists from a well-known animal advocacy organization, Animals International, have taken footage on Boss's farm of them being forcibly removed from their mothers in an inhumane way, without sensitivity for the plight of mother and calf during the separation. They also filmed them waiting in the hot sun without food or water before being loaded on to trucks without the necessary due care and attention. The activists were then able to film them being offloaded cruelly by throwing them into a pile and brutally clubbed to death. Release of the footage to the media has sparked a vigorous debate about whether dairy farming is ethical if it is associated with such cruelty. Animals International then takes Boss to court for infringement of the national 'protection of animals' law. At this stage Boss's bank manager reconsiders his significant loan, which is jeopardized by the possible consumer backlash following negative publicity for Boss's ice cream manufacturing business.

Divide the class so that they can role play the different interested parties that would get involved. These are:

- The farmer, Boss
- Boss's spouse, who provides emotional and logistical support to Boss
- Boss's veterinarian
- Boss's bank manager
- The representative of the food outlet, McHappy, that Boss supplies ice cream to
- The media reporter, who interviews Boss and the CEO of Animals International
- The chief executive officer of Animals International
- The Animals International chief scientist
- The national dairy farming federation representative
- The head of the state animal welfare advisory organization, who provides advice to the government minister for agriculture.

And in the court case:

- Boss's lawyer
- The expert witness for the defence (a well-known local dairy farmer)
- Animals International lawyer
- Animals International expert witness (a scientist).

Depending on the time available, the teacher may like to introduce and briefly discuss these roles. Using internet resources, slides could present pictures purporting to be of the farming family, the animal abuse exposed, media reports of animal abuse, interviews with representatives of the animal advocacy organization and the dairy industry organization representative, an interview with a dairy farmer defending his industry, media reporting of an abuse court case, the involvement of animal standards officers working for government, the animal welfare standards developed by the retail industry, and finally the possible involvement of veterinarians in providing a cattle welfare monitoring programme for the farm in future. The task for the class is to consider the role of each party and, in a play directed by the teacher, act out a scenario in which the relevant players each prepare and work through a script as follows.

Continued

Box 10.1. Continued.

- Directions for students: Take 10 minutes to prepare a 2–3 min talk on your role in the Boss Indicus cattle abuse case.
- Describe:
    - what your role is;
    - what your objectives are;
    - how you will achieve them; and
    - problems you are likely to encounter.

The teacher then concludes with a short summary, explaining the importance of considering the welfare issue from the perspectives of all the different parties.

Box 10.2. An ethical dilemma: What should an accompanying veterinarian do when the welfare of cattle exported by ship deteriorates significantly?

Aims and objectives

This scenario will help you consider the complexities of being a vet charged with upholding animal welfare in the face of commercial considerations and your own personal interests.

Time

Working through this scenario and writing your response to the final learning activity (but excluding the assessment task) should take around 1 hour.

Background

Thousands of cattle are sent from Australia to the Middle East each year, a journey of some 10–14 days. En route the animals will face challenges of heat stress, ammonia accumulation, lack of feed and overcrowding. Exporter companies are required to employ a veterinarian to accompany long-haul shipments of cattle. The vet should meet with the captain of the ship regularly to discuss the animals' welfare and they should also complete a voyage report, which identifies the mortality and documents any problems during the voyage. If mortality exceeds a threshold of 0.2 % for cattle, there is a government investigation. Government theoretically has the power to stop shipments of animals by any exporter.

For background information, read an activist, industry and government perspective on live export; available at these websites:

- Activist: https://www.voiceless.org.au/the-issues/live-export
- Government: http://www.agriculture.gov.au/animal/welfare/export-trade/
- Industry: http://www.livecorp.com.au/industry-information/an-overview

The scenario

You are employed by a live export company, the Cattle Courier Company (CCC), as a veterinarian to accompany cattle on long haul shipments to Egypt. The ship is loaded in Fremantle in August with 500 Angus steers, which have been trucked from Victoria, held overnight and loaded first thing in the morning. Up until the equator the voyage goes well, but as you approach the Persian Gulf the wind

Continued

Box 10.2. Continued.

drops and the temperatures climb to over 40°C. With limited ventilation capacity on the vessel, the cattle close to the engine room are obviously stressed by the heat, with open-mouthed panting and copious salivation. You arrange for some hosing of the cattle with seawater but, given the risk of extra humidity further increasing heat stress, when their condition does not improve after a short period you desist from this activity. You advise the captain not to enter the Gulf until the temperatures have dropped. He answers that he has a schedule to keep to and must continue.

The next day as you approach the Suez Canal you find three cattle dead and you notice that the internal temperature on the ship is 46°C. You advise the captain not to enter the Canal, but to wait out in the Gulf where there is a breeze. He insists on continuing and does not accept your report, which includes the mortalities. By the end of the voyage, ten cattle have died and relationships between yourself and the captain are even more strained. You are aware that any complaints to the company may jeopardize your position.

Preparing your response

The veterinarian has special obligations or duties in this case by virtue of their specific role on the ship, as well as broader professional duties to fulfil. Even if it may be difficult and compromise their ongoing work with the company, the vet must make the report to government, as required by his position, that mortality has exceeded 0.2 % . This will trigger an investigation. The company is likely to be unhappy but the right thing to do is to make the report.

Your response

You first advise the captain that your duty to the animals, to your profession and to the company as ship's veterinarian requires you to report the high mortality, and that you are not wanting to impair what has otherwise been a cordial relationship. You then contact the CCC Chief Executive and advise that there was high cattle mortality on the voyage that you accompanied. You further advise that you believe that some deaths would have been avoidable if you had waited at the entrance to the Gulf and even more if the ship had not entered the Suez Canal. You advise that the continuation of the voyage was contrary to your advice and that the Australian Standards for the Export of Livestock requires an advance weather report to be obtained that, had it been obtained, might have averted the disaster. You indicate that there will now be an Australian Government investigation of the causes of the mortality and ways of preventing it in future, which will consider your report. You end by stating that you are concerned by the many impacts of these journeys on the animals and that you would like to meet him to explain these, and help develop alternatives as soon as possible.

To consider: if someone made the following argument for what the veterinarian should do in response to this scenario, what view would they be espousing?

Veterinarians also have broader professional duties which align with making the report irrespective of the consequences. In many countries vets swear an oath that commits them to 'use my scientific knowledge and skills for the benefit of society through the protection of animal health, the relief of animal suffering' and 'the promotion of public health'. Concern for the cattle and their suffering must override any considerations to do with personal interest.

Question:

Is this a rights-based or utilitarian view?

Answer:

This aligns most closely with a utilitarian perspective of animal ethics. It does not say that animals cannot be used for this purpose, but that the welfare of animals must be a focus of attention. Veterinarians usually

Continued

Box 10.2. Continued.

adopt this perspective but others, including philosophers and animal rights groups, are more likely to adopt a fundamental animal rights perspective that animals should never be used for this purpose.

Your assigned assessment task

Write a short paper on whether live export of cattle should continue and if so whether any changes are required. In your paper you should briefly state the arguments an animal activist group is likely to make, as opposed to those that industry would make. Assess these positions. Which position do you think is superior and why?

Your paper should be 800–900 words.

Table 10.1. Matrix analysis of the interactions between different indicators of cattle welfare (from Phillips, 1997).

			Impact on other welfare indicators[a]			
Welfare indicator	**Behaviour**	**Disease status**	**Mental satisfaction**	**Production rate**	**Longevity**	**Reproductive rate**
Behaviour		N	++	N or +	N or +	N or +
Disease status	+		++	+	+	+
Mental satisfaction	+	+		N or +	N or +	N
Production rate	N or -	N or -	-		-	+, N or -
Longevity	N or -	++	N or +	-		-
Reproductive rate	N	+	-, N or +	+	-	

[a] N indicates a neutral impact on welfare, + indicates a positive impact, - indicates a negative impact.

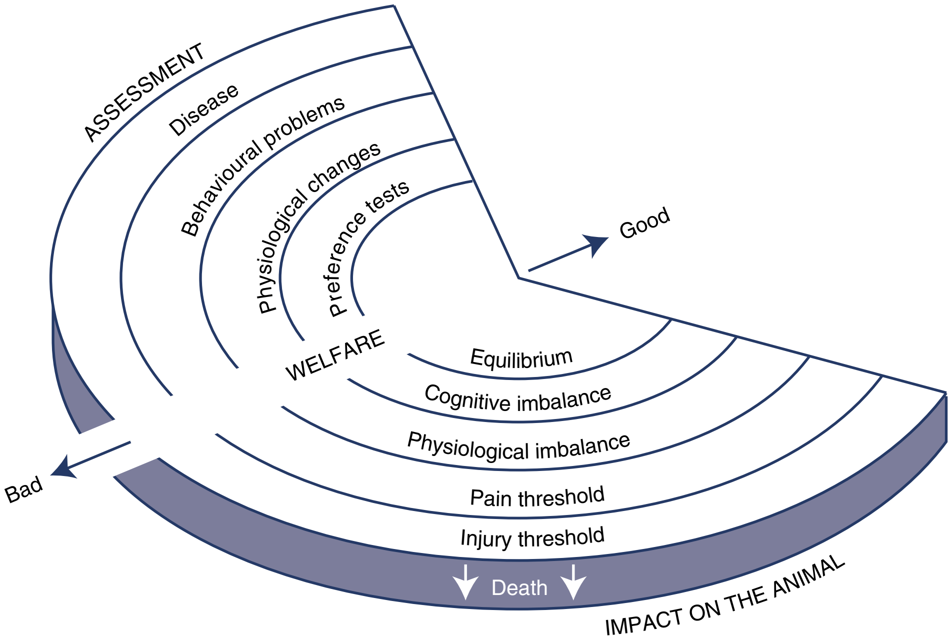

Fig. 10.1. The impact of good and bad welfare on cattle, and means of assessing their state of welfare.

A cow in a state of good welfare will be in perfect equilibrium and in a state of contentment; if welfare is reduced she will initially have adverse feelings and then, as homeostatic mechanisms break down, her physiology will be affected. Pain will be perceived, perhaps in association with, or followed by, injury and finally, if corrective action is not forthcoming, death may ensue. The assessment of the cow's state is difficult. Preference tests may inform whether the cow prefers to be in a different state or environment, and her desire for self-administration of analgesics could be investigated to indicate whether she is in pain. As welfare deteriorates, physiological changes become evident and, in particular, stress responses. Behavioural changes may become evident, which when severe can indicate the presence of disease – for example, withholding a leg from contact with the floor in severe lameness.

How Can Welfare Be Assessed?

Modern on-farm assessment techniques include measures of resources, such as the number and length of feeding and drinking places, the floor surface, the softness of bedding in the lying areas, and measures of characteristics of the animals themselves. The latter includes measures of production, longevity and direct measures from the animal: body condition; cleanliness of the various body parts that are in contact with the floor; and evidence of disease, such as a mammary gland infected with mastitis, or a cow with lameness in one hoof. The Welfare Quality® protocol developed in the European Union (EU) (Welfare Quality®, 2009), is becoming one of the best known systems of welfare appraisal and it aims to optimize the feeding, health, housing and behaviour of the cattle, recognizing that the most important parameters include hunger, thirst, resting and thermal comfort, ease of movement, absence of pain, injury and disease, ability to express social and other behaviours, relationship with humans and a positive emotional state. For dairy cows the protocol bases the assessment on cattle comfort, disease status, production levels and cleanliness parameters. Methods of assessment in any region need to be tailored to the systems utilized for dairy farming. For example, a simple assessment scheme that has been used to assess welfare of cows kept in small-scale dairy production systems in Bangladesh, based on the Welfare Quality® protocol, is contained in Table 10.2.

Examples of Cattle Welfare Issues

Cattle used for food production

Body mutilations

Cattle are often mutilated to make them easier to manage, to stop aggression between entire males, to prevent breeding and to remove what to some people are troublesome appendages, like the tail. The ethics of body mutilations of this nature are questioned, as it interferes with the integrity of the animal, but if they are not done the welfare implications for the animals can be very serious. Other more minor mutilations include a nose ring for leading cattle and nose plate to prevent adult cows from suckling, a habit that they learn as calves.

CASTRATION. In beef production systems, male cattle, and in some rangeland systems females, are usually desexed to make the system easier to manage, even though the procedure is known to cause significant pain and distress to the animals involved. The unnecessary complication of female pregnancies in young growing beef heifers is avoided and the cattle are calmer and more docile.

In males, castration reduces unwanted aggressive and sexual behaviour and makes them easier to handle; in females, it prevents unwanted pregnancies in cows when they could not support the offspring because the grazing is of low quality. The procedure in males is usually achieved by surgical removal of the testicles, application of a rubber band around the neck of the scrotum (elastration) to cut off the blood supply to the testicles, or the application of a set of clamps (an emasculator) that crush the blood vessels and nerves leading to the testicles. All three methods cause pain, but prolonged pain is greatest following elastration and it carries a risk of the calf getting tetanus. Surgical castration carries the risk of severe inflammatory responses if infection sets in. The usual behavioural responses are struggling, kicking, swishing of the tail, walking with a stilted gait and standing with a hunched posture. Heart rate is elevated and it is clear that intense pain is felt, but immediate pain is less after elastration. Castrated males have abnormal behaviour and lose their appetite for a few weeks and may show less interest in their dam, the result being that weight gain is usually reduced. Signs of pain and physiological stress are reduced in young calves but that does not necessarily mean that they cannot feel it. Immediate pain responses can be reduced by administering a local anaesthetic

Table 10.2. Parameters measured and methods of data collection for the assessment of the welfare of dairy cows in smallholder systems in Bangladesh, based on animal and management parameters used in the Welfare Quality® assessment protocol (Welfare Quality®, 2009) (personal communication, Ariful Islam *et al*., 2017).

Parameters	Typical raw data	Measure
Milk yield	Farm records or farmer recollection	Average milk yield (l)/cow/day
Body condition score (BCS)	Animal-based measure; direct observation	Visual and tactile appraisal of individual BCS using a four point scale (0 = very thin, 1 = thin, 2 = fat and 3 = very fat, scored to whole units).
House management	House-based measures; questionnaire and direct observation	Flooring type (concrete, soil, brick); frequency of faeces removal from the house (< 1×/day, 1×/day or 2×/day) and floor cleanliness (1 = clean to 4 = very dirty)
Clinical examination	Animal-based measure; direct observation and physical examination	General appearance (alert/dull/depressed); mucous membrane of eye conjunctiva (moist and pink/moist and pale pink/dry and white); teat condition (deformed/cracked/dry), rumen condition (distended, hollow or normal).
Cleanliness	Animal-based measure; direct close observation	The hindquarter, lower hind leg (hock), flank, udder, and teats inspected to assess cleanliness. Cows classified as clean if there is no or only minor contamination (< 15 cm²) with either soil or manure, otherwise classified as dirty.
Lameness	Animal-based measure; direct close observation	Cows assessed from behind and from the side when walking on a surface on which they normally walked. A 3-point scoring system can be used (Breuer *et al*., 2000) 0 = not lame, timing of steps and weight-bearing equal on all 4 feet; 1 = lame, imperfect temporal rhythm in stride, creating a limp; and 2 = severely lame, strong reluctance to bear weight on one limb, or more than one limb affected.
Skin lesions	Animal-based measure; direct observation	Six body regions of cows (neck, brisket, carpal and tarsal joint, flank and tuber coxae) evaluated on one side (randomly chosen). In each region, the number of cows with hairless patches and lesions/swellings of > 15 cm² should be recorded.
Presence or absence of diseases:	All animal-based measures; direct observations/ clinical examinations are needed but without touching the animal	
– Nasal discharge		Scale: 0: Little or no evidence of discharge 1: Evidence of clearly visible flow/discharge from the nostrils; transparent to yellow/green and often of thick consistency
– Ocular discharge		Scale: 0: Little or no evidence of discharge, or 1: Evidence of clearly visible flow/discharge (wet or dry) from the eye, at least 3 cm long
– Vulval discharge		Scale: 0: Little or no evidence of discharge 1: Evidence of purulent effluent from the vulva, including on the underside of the tail
– Laboured respiration		Scale: 0: No evidence of abnormal respiration 1: Evidence of deep and laboured respiration; expiration usually accompanied by pronounced sound

Continued

Table 10.2. Continued.

Parameters	Typical raw data	Measure
– Diarrhoea		Scale: 0: Little or no evidence of abnormal consistency of faeces 1: Evidence of loose watery faeces around the tail
Ectoparasitic infestation	Animal-based measure	Close inspection, including with a hair comb to find any mites or ticks
Mastitis incidence	Farm records or farmer recollection	Number of cows with an udder infection during the last 12 months
Dystocia incidence	Farm records or farmer recollection	Proportion of cows requiring major assistance during the last 12 months.
Vaccination schedule	Farm records or farmer recollection	Use of vaccines against important diseases (e.g. foot-and-mouth disease, anthrax, black quarter); classified as never used, occasionally used, or routinely used
Deworming schedule	Farm records or farmer recollection	Use of anthelmintics; classified as 1, 2 or 3 times/year

(such as lidocaine) before castration and this is mandatory in some countries. Application of an analgesic at the time is also recommended and will reduce longer-term pain, but few operators use such pain relief, because of the cost, or availability of suitable approved drugs, and because they are not aware of, or do not see, the pain experienced by the cattle after castration. In the case of cattle on extensive rangeland that are mustered annually, anaesthetic administration prior to conducting the procedures on the cattle would require passing them twice through the handling system, which is in itself stressful.

Females are spayed by either a flank incision, or increasingly by ovariectomy per vagina, which is faster, cheaper and safer. Anaesthetic is not usually used and there is a significant risk of haemorrhaging and mortality, depending on the skill of the operator.

DEHORNING AND DISBUDDING. Cattle evolved horns to protect themselves but in modern husbandry systems it is necessary to remove them because of the risk of injury to handlers or other cattle. This may be done by using genetically polled breeds of cattle, such as the Aberdeen Angus, Red Poll, Galloway and some Herefords. *Bos indicus* cattle are nearly all horned. In *Bos taurus* cattle the gene for this trait is autosomally recessive, with the polled gene being dominant, but in *Bos indicus* cattle the inheritance is more complex.

If naturally polled breeds are not used, a method of physically removing the horns is often necessary. Horned cattle are more aggressive, need more space during transport and can inflict open wounds in other cattle, sometimes leading to fly strike. Bruising is also more common in carcasses from horned cattle. Removal of horns by either disbudding (before the horn tissue adheres to the skull) or dehorning (after adherence to the skull) therefore occurs in over half of all cattle, and in the extensive rangeland beef industries in the USA, Canada, Australia and New Zealand this is usually dehorning without anaesthetic. As with castration of males, application of an anaesthetic would require passing cattle twice through the race, which would potentially stress them more than the benefit they would receive. In European systems cattle are usually housed at an early age and hence it not difficult to require the use of anaesthesia, for example for cattle over 1 week of age in the UK. This is usually by a hot iron, which removes the horn bud and cauterizes the wound. Dehorning requires the use of an amputation device, most commonly a sharp knife for young cattle, but also cups, scoops or opposing metal blades, such as guillotine shears, for older cattle. The pain associated with dehorning is believed to be intense, because the region is highly innervated, including into the horn tissue itself (Sinclair, 2011). Haemorrhage, the inflicting of burns and/or infection are quite common. Observed behavioural responses include kicking, foot stamping, tail wagging, head jerks and rearing up. Older cattle have an increased risk of significant blood loss and injury. A separate muster for dehorning is often not justified on extensive rangelands, so the operation is conducted in one common handling operation, along with identification by tagging and branding, castration and injection of mineral boluses into the rumen. Dehorning itself has a risk of introducing fly strike, and weight gain is reduced for up to 100 days, compared with cattle that have not been dehorned, particularly when the operation is performed on older cattle.

TAIL DOCKING. A particularly contentious body modification in dairy cows is to remove their tail. This prevents it becoming covered in faeces, which is a hygiene problem, and also potentially hurting milking staff if it hits them when they are milking. The operation is usually done by applying a rubber ring about 12 cm below the level of the vulva and is still common in parts of the USA, Ireland, Australia and New Zealand. It is banned in Denmark, Germany and the UK. The welfare impact of the operation includes pain to the cow post-surgery, an inability to remove flies from their hindquarters and loss of an important signalling device to other cows.

IDENTIFICATION. Cattle are usually identified by tagging or tattooing one of their ears as calves and/or fire- or freeze-branding on their side at a later age. Older animals need to be run through a chute for adequate restraint and use of a head bail is advised. Visibility of ear tags at a distance is limited but they can be coded by colours. They may have radio frequency identification incorporated. Good-quality tags have a 'female' and 'male' component either side of the ear that are united in the tagging process and are then freely rotating. Paint branding may be used for temporary identification but may cause a localized reaction. The purpose of identification is to indicate who the owner is or the type and/or individual identity of the animal. Additionally, health status and records of treatment may be included. Identities are usually unique to the animal but beef cattle may have one or more notches removed from their ears to signify ownership. The negative consequences of identification are not just to the welfare of the animals; their hide may be down-valued and there is a risk of injury to handlers. Attaching an ear tag is not a simple procedure and adverse welfare consequences and loss of the tag usually occur when inexperienced operators are doing the job, for example putting it in the wrong place in the ear. The right place is in the centre of the ear, identified by drawing two imaginary lines across the four corners of the ear and seeing where they bisect. This is the point of minimum risk of the tag being removed when, for example, the animal enters a thicket. Other adverse welfare consequences include an infestation of the site with myiasis, which if the risk is high is best avoided by making the hole in the ear early in a calf's life.

Fire-branding is usually on the flanks or face of the animal, both extremely sensitive parts of the body. The aim is to destroy the hair follicles but leave the hide of the animal undamaged. From an animal welfare perspective, fire-branding is the most harmful method but it is still commonly used and without anaesthetics. Some countries advise against its use or recommend use of anaesthetics and/or analgesics. Cattle have an extremely adverse reaction to the procedure and may become reluctant to enter handling races afterwards. The welfare impact is reduced with small brands of no more than 8–10 cm, but these may be difficult to see at a distance. The branding iron should be at the right temperature, hot enough to achieve an effective brand but not so hot that a deep injury is possible. Freeze-branding damages the pigment-producing cells (melanocytes). It has a less severe welfare impact and coolants (liquid nitrogen or dry ice/alcohol) are used to chill the branding iron.

Performance enhancement in dairy cows by injection of chemicals

Although some would argue that genetic modification has equivalent welfare impact, the promotion of high milk yields by daily injections of bovine somatotrophin (BST) or oxytocin has the additional welfare issue of daily injections and the risk of a localized reaction. The use of oxytocin is mainly in developing countries with little animal welfare regulation, such as Pakistan and Mexico, but BST is also used in some advanced dairy systems, such as in the USA. BST works by increasing milk synthesis, and oxytocin probably by both milk synthesis and milk release from the mammary gland, thereby reducing milk available for calves if the cows are dual purpose, as is common in developing countries. Cows are stressed by these daily injections, which are usually into the thigh, which seem unethical as both practices increase milk yield by only a few litres each day.

Inadequate nutrition of cattle

Undernutrition is the result of a prolonged inadequate supply of the nutrients needed to sustain good health or, in the case of immature and underweight cattle, growth potential, where 'prolonged' implies that a steady state has been reached. It is more common in beef than dairy cattle, because the former have fewer nutritional requirements and can survive in lower-rainfall and hotter areas where nutrition is poor. However, these areas also have a more variable rainfall and are prone to drought and flood. Drought is a common source of welfare distress to cattle in inland continental zones, in Australia in particular, and may lead to significant mortality. It is often seen as being outside of human control, whereas in reality stocking densities are often too high and the risks elevated.

It is hard to determine the exact welfare impact on cattle that are progressively starved but it is likely that initial hunger results in stress that eventually causes desperation and a depraved appetite (pica). Risks at this time are that cattle will eat unsuitable things in an attempt to find nutrition, such as animal bones (potentially harbouring botulism). Carcasses of dead cattle should be removed from the paddocks to prevent this (see Chapter 4, Fig. 4.4). Failure to find nutrients will cause frustration and eventually, if continued attempts are not successful, lethargy, as the animal attempts to conserve energy. If no feed is obtainable, exhaustion and death ensue.

Malnutrition, which is often associated with undernutrition, is when cattle experience a deficit, imbalance or excess of nutrients with consequential adverse effects on the normal functioning of the animal, including behaviour, physiology, reproduction, health and growth potential. They may eat weed plants, or soil with excess heavy metals – in particular lead, by accessing old car batteries or ordnance on former munitions dumps. Plastic consumption is a major problem in India, where street cattle search for feed after being abandoned by their owners when their productivity declines (slaughter is illegal in many states). Post-mortem inspection of cattle that die of natural causes often finds large quantities of plastic in the rumen (up to 140 kg in one case), preventing feeds being properly digested there by the microorganisms. Knowledge of the critical live weight of various breeds, below which an animal cannot walk, graze or safely obtain drinking water, will help to classify animals as malnourished or not for the purpose of lawsuits.

Undernutrition and malnutrition are often accompanied by poor immunity to disease, particularly if protein intake is low. Dietary amino acids regulate antibody titres and lymphocyte and macrophage activation; energy supply is less important. Good protein nutrition is particularly important to combat gastrointestinal parasitism. An adequate supply of the minerals zinc, iron, selenium and molybdenum and vitamins A and E is also important for a healthy immune response. Plant secondary metabolites, e.g. condensed tannins, can also reduce nematode parasitism.

Cattle in exhibition and sporting events

Rodeo

Rodeo evolved as a test of cowboys' cattle-handling skills in the second half of the 19th century, initially in the USA and now also in Australia and New Zealand. It attracts large crowds and has a social function of bringing together young men and women from remote rangeland properties. The skills used are no longer needed for management of the cattle, even in the most remote properties, but present a physical challenge, especially as most are undertaken against the clock. Recorded injuries are rare but there should always be a veterinarian, or at least a veterinary nurse, present to attend to these if needed.

One of the biggest attractions is bull riding, in which cowboys are lowered on to the back of a bull, which bucks to remove the rider. Bucking is encouraged by a tight strap around the girth of the animal and by spurs on the back of the cowboy's boots, which are dug into the sides of the animal. The spurs should be worn smooth before use and not sharpened to injure the animal. There are reports of electric prodders being used to stimulate the bulls whilst they are in the chute.

Calf roping involves holding a calf in a chute, then releasing it, after which it is pursued by a cowboy on horseback who lassoes it. There are reports of calves being provoked within the chute before release. Calves should not be dragged backwards by horses but should be held up by a taut rope between horse and calf, until the cowboy has dismounted and tied the calf. The lassoing results in a sudden halt to the calf, which may be lessened by a 'Roper's Mate' device attached to the lasso to act as a spring to reduce any jerking of the calf to a halt. The cowboy then dismounts, lifts the calf from the ground and drops it on to its side on the floor, then ties three of its legs and signals their completion of the task to the rodeo official. Calves are usually 4–8 months of age, around 115 kg and of the Spanish Longhorn type. Maximum use of the calves in Australia under the professional association's code is three times per day or four times in 2 days, used for 2 months at the rate of one rodeo per fortnight. They may appear to accept the practice but it is still naturally stressful to them (Sinclair *et al.*, 2016).

Calf scruffing is a similar practice but with older cattle, around 200 kg, compared with the lighter animals used for roping. In scruffing, the cattle are wrestled to the ground by one or two handlers, usually by twisting the neck. Catching the cattle by anything other than the neck or body should not be allowed.

Steer wrestling involves the cowboy leaping from his horse to grab the horns and twist the neck to cause the animal to fall to the ground. Other rodeo events using cattle include steer tripping or 'busting', with the aim being to trip, roll and drag a steer using a rope around the horns. As with calf roping, stunning the animal with a sudden fall aids roping the legs together, signalling the end of the event.

The preparation of the rodeo cattle involves practising with them and getting them used to the procedures, and in particular the exit and entry points for the ring. This probably has a major effect on their welfare. Docile breeds should be used to minimize aggressive confrontation between humans and the cattle but this may not result in a good show that the public attending the event want to see. Reuse of animals should be discouraged, or at least minimized, and records should be kept of any injuries to the animals or mortalities. Usually registered events have low injury rates but some unregistered events may attract entrants who are less careful and may be under the influence of alcohol. Veterinarians should be available to treat injured animals at such events if possible or, failing this, veterinary nurses can do this under remote monitoring by a veterinarian. This should include euthanasia where necessary.

Camp drafting

Camp drafting is a separate local event to rodeo, in which a young animal is released from a pen and chased across an arena by a mounted rider, who has to manoeuvre it through obstacles within a time period (see Chapter 2, Figure 2.3). Such cattle-handling events attract large numbers of spectators in countries where there was, and usually still is, a major cattle industry, in particular the USA and Australia.

Bullfighting

The close but conflicting relationship between cattle and humans is exemplified in the practice of bullfighting. Our reverence for their strength and fertility has been evident for thousands of years, and pitching man against beast in the form of a bullfight serves to demonstrate that in some societies it is expected that the best of their young men, armed only with lances, barbs and swords, will be able to demonstrate that they can exceed the skill of the bull in fighting.

The welfare impact on the bulls needs no description, as lances and a sword are thrust into their flesh. Its justification is solely on cultural grounds and the sport has been legalized in the Europe Union, which is otherwise a bastion of animal welfare concern, by special exemption from slaughter regulations on the grounds of cultural heritage. The greatest following is in Spain, where about 4000 bulls are killed per year in 1000 bull rings. Bullfights also take place elsewhere, in Portugal and south-west France for example; however, the bull is not usually killed in the ring, but soon after. In South America bulls are killed in the ring. The bulls are bred and reared to be aggressive and females are selected for breeding these bulls from the strength of their charge at a horse when provoked with a lance. As well as those killed as a result of a public fight, less aggressive bulls are used for practice fights. The glamorous spectacle is popular with older members of society, both live and on television, but younger people often dislike the sport. There are concerns about the viewing of televised fights by minors.

A typical Spanish fight lasts for about 20 min, with two matadors, each fighting two bulls. The matador has assistance from two picadors (horsemen), carrying long lances with 10 cm steel tips, and three bandilleros, who use decorated wooden sticks with a barbed harpoon to further weaken the bull. The fight begins when the picadors jab the lances two or three times into the bull's shoulder muscle as he charges, to weaken his tossing ability. Then the bandilleros stab their harpoons into the bull's back. A good bull does not cry out when they are inserted and indeed shows no signs of pain throughout the event. Then the matador taunts the bull by tempting it to charge a large piece of cloth, coloured fuchsia and yellow, held outside his body. The movement of the cloth takes the bull's attention away from the matador. This taunting continues until the matador has complete control of the charging bull, which may take about 20 charges. During this period the bull may also charge the matador. Then, with his sword in his right hand, he attracts a final charge at a small bright red cape held directly in front of his body with his left hand. As the bull charges, the sword is plunged between the shoulder blades, which if correctly positioned causes instant collapse and death. If the bull does not die, the matador will lance the neck with a short sword, causing immediate death. A bull is considered to be more courageous and honourable if it dies with its mouth closed.

Bull-running

Another practice involving bulls in a small number of Hispanic communities is running them through a town, behind a group of young men who have to escape. Although obviously less of a welfare problem to the bulls than bullfighting, the bulls are severely stressed and may suffer injury. Following the bull-running, bulls may be used in a fight, as in the town of Pamplona in Spain.

Ritual slaughter

Ritual slaughter of bulls was described in ancient texts of the Middle East and eastern Europe and the ritual lives on in the traditional societies of some Asian and African tribes. In Asia, mithun cattle (*Bos frontalis*) are raised for ritual sacrifice during religious, social and community feasts. Slaughter techniques are often barbaric and involve taunting the animal before slaughter and may include cutting flesh off the live animal. Repeated spearing is another method practised in Bangladesh but some tribes use methods that are less painful for the animal, such as cutting its throat, or blows to the back of the head. The methods may have evolved partly because they result in major bloodletting, thereby helping to preserve the meat, but could be considered to be just as damaging to the animal's welfare as bullfighting. In South Africa, Zulu tribesmen kill a bull each year in the Ukweshwama ceremony with their bare hands. Usually the bull is wrestled to the ground by large numbers of men, and its head twisted to break its neck, together with many other cruel practices on its various appendages.

Cattle used for work

Oxen are still used for tillage and other work in many developing parts of the world, by virtue of their greater strength relative to other domesticated herbivores, horses, sheep and goats. Often they are required to work for 8 h per day, during which time they cannot eat or ruminate. Sometimes, like many cattle in Africa (Fig. 10.2), they are corralled into a boma (enclosure) at night without access to food, further depleting the time available to eat the necessary high levels of energy, in particular for their work. Depending on the nature of the work, there is a major risk of injury, especially sores, lesions and accidental broken bones. Excessive work can make the cattle prone to infectious diseases. Nutritional requirements are high and the risk of undernutrition is severe. Water and sodium requirements are especially high, due to their high sweating rate. Overwork is the most common welfare problem for these oxen, leading to poor condition, exhaustion and high risk of disease acquisition.

Cattle Marketing and Transport

Many cattle are still sold through live auction markets but an increasing proportion go direct to an abattoir or are sold through an 'electronic auction', where the vendor and prospective purchasers do not meet but communicate via the telephone or internet. Some farmers cooperate to send cattle in groups to abattoirs, thereby increasing their ability to control the price. The risk to a farmer of sending cattle direct to an abattoir is that if they achieve a low price, which may occur if the carcass receives a low grade for fatness or conformation, the animals cannot be returned to the farm for further fattening. During a drought farmers frequently delay sending cattle to market, in the hope that conditions will improve, and when they are eventually sent they are very thin (see Chapter 2, Fig. 2.6). Prices are preset for the carcasses in abattoirs, in comparison with cattle sold in live auctions which receive a price for the live animal on the day. If a producer sells to an abattoir, which then sells direct to a supermarket chain, the supply chain is shortened compared with selling through a market and this assists in tracking the animal through the marketing chain. At auction markets the competitive bidding

Fig. 10.2. In Africa, cattle are often corralled in a boma (fenced area) at night for safety.

between purchasers may increase the price of the cattle. Purchasers buy cattle per unit of weight and the bidders are given a guide to an animal's weight. Auctions also give farmers an opportunity to exchange information on latest developments in their industry, weather patterns, stock prices, etc.

Electronic auctions prevent the stress to the cattle involved in the transport to and from live markets, and possible mistreatment in the market itself, but they still offer opportunities for purchasers to compete for the sale and for the buyer to withdraw the animal from sale if the price is inadequate. The difficulty is the grading of the animal, and some electronic auctions sell the animal subject to abattoir grading.

The welfare of cattle at markets may be compromised by several factors, including the stress caused by an unnatural environment, the presence of unfamiliar animals and people, and disruption to their normal routine. Stress before slaughter leads to the production of meat that is dark, firm and dry (DFD), particularly in bulls that are liable to fight when mixed. The meat is dark because the glycogen has been utilized in fighting between cattle before slaughter and in movement during transport. Post-mortem the muscle tissue still remains active, but if there is inadequate glycogen for the energy requirements, the levels of lactic acid in the meat (one of the end-products) are low.

It then becomes dark instead of its normal bright red colour and has a high water-holding capacity. Such 'dark cutters' are invariably downgraded. This typically affects 1–2% of slaughtered cattle but the proportion can be much higher in some groups, such as tired old bulls. Meat with this defect will have a short shelf-life and poor palatability.

There may also be physical damage caused by forcing cattle to move, particularly when this is done with the aid of electronic goads or sticks. When cattle slip or fall, bruising occurs that will reduce the value of the carcass. New standards in markets are now enabling the welfare of cattle to be improved. Cattle are less likely to be penned with strange animals and there is greater recognition that they must be loaded and unloaded from trucks in an unhurried manner. Their physical requirements are better catered for, with non-slip floors, water provided in the pens, feed and bedding provided if the cattle are accommodated overnight. Market personnel should be instructed in how to move animals, and sticks, flags and other implements are recommended for use only as extensions of the handler's arms, not to beat animals. Animals should not be moved by twisting their tails or, in the case of calves, thrown or moved by lifting their back legs off the ground.

One of the reasons for improving welfare standards is that moving cattle to and from markets or to an abattoir may result in a reduction in their value. Weight loss occurs during most journeys and is mostly fluids. During transport, cattle are subjected to dehydration, feed deprivation, physical exertion, noise, vibration, strange surroundings, odours, motion sickness, hypothermia and hyperthermia, overcrowding or sometimes isolation; all potentially contribute to stress and weight loss. For some of these potential stressors, such as feed and water deprivation, the welfare impact can be minimized by good practice. Cattle should not be taken off feed and water before transport, even though it is a common practice in Australia to do this for up to 1 day to attempt to limit contamination of the carcasses and vehicles with excreta. Not only does this practice reduce the animal's welfare, it also creates a risk that pathogens colonize the rumen and then contaminate the carcass at the abattoir. Thus although the contamination risk is reduced, it is more likely to be by pathogenic bacteria, which has led in the past to significant human illness and even mortality. However, for other potential stressors there is insufficient knowledge currently to make recommendations about their impact on welfare.

The livestock vehicle or vessel should have good ventilation, with the exhaust fumes ducted well away from the animals, good access for humans and an inspection light. Cattle transported in road 'trains' (Fig. 10.3) often experience hot, dusty conditions, particularly those in the rear sections (Fig. 10.4). The internal partitions should be adjustable and there should be no internal projections and adequate headroom. Stocking density should be sufficient for the cattle to lie down with ease. Overstocking causes bruising, aggression between the cattle and cattle that are afraid to lie down because others will crowd over them, preventing them from getting up again (Fig. 10.5). When loading, the route to the vehicle should be clear and preferably without shadows or pools of water. Cattle prefer to move from a dark area to light. Solid walls and curved raceways are best, but moveable gates are an acceptable alternative. The loading ramp should have side-gates and a slope of less than 4 in 7 (see Chapter 8, Fig. 8.12) and cattle should not have to step up more than about 20 cm. The ramp should have battens for the cattle to get a grip and the floor of the ramp and the inside of the vehicle should be non-slip. Adequate staffing is essential for moving cattle and they should be moved slowly and preferably without the use

Fig. 10.3. Offloading cattle from a road train at a northern Australian cattle station.

Fig. 10.4. On unmade roads cattle trucks produce a lot of dust, affecting those cattle in the rear carriages most.

Fig. 10.5. A heavily stocked cattle truck being transported on a ship.

of goads. Staff should be calm, confident and able to predict the animals' behaviour. As with market personnel, sticks or flags can provide a useful means of extending the arm to accelerate movement, using persuasion rather than aggression, but these should not be used to hit the animals with unnecessary force.

On the road, the vehicle should be driven with extra care, avoiding fast cornering and excessive braking. The animals should be checked on long journeys and in hot conditions a rest can be provided by parking the vehicle in the shade. Once at the destination, it must be recognized that the cattle will be tired. Offloading should not be done in a hurry and preferably without the use of an electronic goad (Fig. 10.3). A purpose-built bay should be used if possible for offloading, with the same characteristics as for loading. Providing access to feed and water will help to reduce the stress of transport.

The EU has introduced the strictest standards worldwide for journeys involving transport of cattle. Calves less than 10 days of age can travel up to 100 km, but only if their navels have healed. Those of 10–14 days of age can travel for 8 h. Calves of 15–41 days of age can travel for 9 h initially, after which they must be given 1 h of rest with liquid and, if necessary, feed provided. After that they may travel for a further 9 h and, if their destination is still not reached, they must spend 24 h in an EU-approved control post before further travel. Travelling times for older cattle are increased from 9 h to 14 h. Journeys can only be extended beyond 8 h if the vehicle has a roof, bedding to allow absorption of excreta, sufficient ventilation to maintain internal temperatures between 5°C and 30°C, and a temperature recording and warning system that will be activated if it exceeds these limits. Elsewhere standards are more liberal and somewhat dependent on what is easily achieved, rather than being set based on scientific standards. The Australian standards allow transport of mature cattle for up to 48 h, provided that they are travelling well and the journey can be completed within that time. The duration is set by the maximum time without water, so if water access is restricted pre-transport the maximum time on the vehicle is reduced.

Cattle Slaughter

Cattle slaughter is a difficult process, given the size of the animals and their ability to resist the attempts of humans to kill them. Effective inspection and regulation of the process is essential for good standards but not present universally. Sometimes the responsibility is given to the industry itself but such self-regulation is rarely effective and the process becomes shrouded in uncertainty. Often the work is done by people with little control over the process and limited knowledge of animal welfare standards, and the speed of the processing line may be too fast to allow for humane treatment of all the animals.

At the slaughter plant, cattle are initially offloaded and held in lairage, often overnight ready to start being slaughtered early the next morning. This helps them to recover from the journey, depending on how good the facilities are. Bulls, however, should be slaughtered immediately on arrival as any delays cause dark cutting. In lairage, the provision of feed and water is important at this time to reduce stress, which will help to preserve meat quality. Mixing different cattle types on the truck or in the abattoir should be prevented if at all possible as this may cause mounting and fighting, particularly in bulls, which will reduce meat quality by increasing bruising and dark cutting after just a few hours (Warren *et al.*, 2010).

Cattle are usually isolated from conspecifics for the slaughter process in modern plants. However, in many developing countries cattle are still killed in the presence of others and the fear responses of animals being slaughtered are likely to be perceived by the others. The first part of the process is usually to stun them, which is necessary for good welfare as cattle take up to 2 min to lose consciousness following the cutting of their throat. This is achieved in most developing countries with a blunt instrument that delivers a sharp blow to the head, which should be positioned at 90 degrees to the forehead. In old cattle, especially bulls, it can be difficult to achieve an adequate stun with the percussive bolt because of the thickness of the skull. The need for a second or third blow to the head is common. In modern abattoirs the percussive force is usually delivered to cattle by a non-penetrative retractable captive bolt delivered to the head. Although effective in well-trained hands in a high-quality plant, it can have a high failure rate, usually recorded as 1–3%, but with some animals, particularly bulls, failure rates can be much higher. An alternative is electrical stunning, achieved by passing an electrical current across the head, which potentially causes a reversible suspension of consciousness for 30–40 seconds. However, in cattle there is an alternative blood supply to the brain in the vertebral arteries, and blood loss through the cut carotids may be limited by clotting at the severed ends or arterial contraction, with the result that the brain remains conscious after the electrical stun. Normally, the electrical stun triggers a seizure in the animal, as a result of the hyper-synchronized electrical activity of central neurons and associated muscle contractions, which may cause blood splashing, or ecchymosis, reducing the value of the meat. Any delay in 'sticking' the thoracic cavity causes paddling and kicking of the legs, head shaking, return of reflexes and high incidence of ecchymosis. The rapid movement of the animal's legs may endanger workers and is sometimes controlled by electrical immobilization of the animal, in which case any sensory responses are likely to be undetectable. A particularly high-voltage stun is being developed that overcomes many of these problems and appears reversible, to satisfy the Islamic authorities. Unconsciousness is profound and lasts a few minutes but the high current used would not be safe to apply in many abattoirs in developing countries.

In halal slaughter the force used in percussive stunning may be reduced to ensure that the process is reversible and the skull is not damaged, but this can reduce the efficacy. Sometimes stunning is not allowed in halal jurisdictions. Halal slaughter is strictly controlled by Islamic organizations worldwide but the interpretation of exactly what is required by the primary sources of Islamic law, the Holy Quran and the Hadith, is variable. Generally the slaughterer and abattoir inspector must be practising adult Muslims who are mentally sound, the knife used must be sharp and clean, the cut to the throat must sever the trachea, oesophagus, carotid arteries and jugular veins and the animal must be confirmed dead before processing ensues. Stunning is only accepted by some jurisdictions if it is reversible and does not cause permanent injury to the animal, and is monitored as above. Hence only non-penetrative captive bolt use is permitted, if at all. In some parts of the world it is believed that stunning reduces the meat quality, for which there is some evidence in electrical but not percussive stunning. In some jurisdictions, e.g. Australia, cattle must be stunned but this is after the throat is cut.

Shechita slaughter, which produces kosher meat for consumption by Jews, has similar restrictions on the method of slaughter to halal slaughter. However, it permits stunning only if carried out at the same time as, or just after, the throat is cut. Much emphasis is placed on the training of suitable slaughterers to make a correct cut to the throat and having a suitably long and sharp knife for this purpose. It can only be carried out by those authorized by the Jewish authorities.

Stunning, if applied, is followed by severing the trachea, oesophagus, carotid arteries and jugular veins with a knife or sharp stick, a process that is aided if the animal can be hoisted by its back legs, exposing the neck for exsanguination. Blood is lost via the cut carotids at high pressure as the heart beats rapidly under the influence of adrenaline and noradrenaline released. The animal is experiencing a 'grand mal' seizure, in which consciousness is rapidly lost and abnormal signals across the brain cause rhythmical and violent muscle contractions. Death should be confirmed by testing for brainstem reflexes in the form of breathing and corneal and palpebral reflexes.

If the animals are not being stunned, effective severance of the carotid arteries requires the animal to be cast to the ground and then restrained forcibly. This is usually achieved by tethering the animal, tripping it, often aided by wetting the floor, or forcing it into a box where the procedure can be done more safely. This process is likely to be dangerous for the slaughterers and it may be accompanied by some appalling experiences for the animals if they are large, relatively untamed cattle, stressed by a long journey and therefore difficult to handle. Such a situation exists in the export of cattle from the north of Australia, where they are rarely handled before transport, to Asia, where workers find them very difficult to restrain. Some have resorted to cutting the tendons on their legs, gouging out their eyes and breaking their tails. Sometimes animals are held in a crate that is subsequently inverted for an easier knife cut, a procedure likely to cause severe stress.

Conclusions

Cattle are used for food production worldwide, about 1 billion at any one time, and most are in developing countries where the welfare of the human population itself is often not assured. The welfare of these cattle cannot be assured. Cattle industries in many countries have now intensified in the face of growing demand for their products in developing countries. Breeders have changed the genetics of cattle so that they have the potential to grow faster and produce more milk than ever before, but this requires large quantities of high-quality feed. In the face of growing human populations this is often not available locally and has to be imported. Diet has a major impact on welfare when insufficient feed or feed of the wrong type for the cow's digestive system is fed. High-yielding dairy cows present a serious conundrum: they are unable to eat sufficient high-quality feed in early lactation and lose large amounts of weight, predisposing them to metabolic problems. Grazing cattle increasingly find themselves competing with settled agriculture; and in more extreme climatic regions, global warming is rendering their environment ever more marginal for cattle farming. In intensive milk and meat production systems cattle have to be mutilated in order to survive, procedures that are often carried out without anaesthetic. This chapter has described many other welfare problems in cattle used for other purposes, such as sport, entertainment and work. Finally, welfare problems involved in transport and slaughter of cattle have been highlighted, which may apply to cattle used for any of the described purposes.

If cattle systems are to survive, the welfare problems outlined here have to be addressed. Our relationship with cattle has to become much more symbiotic, providing benefit to both. The chapter does not contain an exhaustive list of welfare concerns but illustrates some of the major ones that should be addressed first.

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11

Cattle Production and the Environment

Introduction

The cattle industry has been the subject of criticism with respect to its impact on the environment for several decades. In South America, the destruction of large areas of rainforest to create grassland for cattle grazing has been held partly responsible for global warming. In North America and parts of Europe, the imbalance between waste production by the animals and the availability of land on which to spread the waste contributes to pollution of water supplies. In parts of Africa, cattle are accused of being a major cause of overgrazing, and the treading and removal of plant cover in hill regions causes soil erosion. Even a typical British family farm of 100 dairy cows has a potential pollution load equivalent to that from a human population of 1000 people.

At the same time, cattle are acknowledged to perform a useful function in effectively commuting fibrous grasses into food for human consumption in areas where crops for direct human consumption cannot be grown. They also produce valuable manure to fertilize the land or to be burned as fuel, saving trees from destruction for firewood. In desert reclamation programmes, the installation of cattle farms may be the first action to be taken, as their manure will stabilize the sandy soil and increase water retention capacity. This represents significant potential for soil carbon gain, an important benefit in considering the impact of livestock on climate change. However, utilization of the potential to sequester carbon in soil would only be of benefit if cattle management practices did not contribute to climate change negatively, for example by using fossil fuel to produce cattle feed. The cattle industry should be carbon neutral at least, and preferably positive to offset other industrial activities and benefit regions that are unable to establish carbon neutrality.

In the grazing situation, cattle are often preferable to sheep or goats on marginal land, as they are less destructive of trees and cannot graze as close to the ground, thereby leaving a greater plant cover. They are less particular in their grazing habits because of their broad muzzle, so that they cannot selectively consume valuable species in the sward, which would deplete them by overgrazing. They are still a major source of traction in developing countries, reducing the reliance on mechanized traction and hence fossil fuels. A quarter of a century ago it was estimated that about half of the cultivation in developing countries was by animal traction, but this has declined substantially with rapid mechanization in countries such as China and India following industrial development (Steinfeld *et al.*, 2006). Using cattle improves food security in smallholder farming systems; they are cheap to maintain and can access all terrains. They may also be used to lift water, transport goods to market and for logging and milling, all in place of machines that may pollute the environment through their use of fossil fuel. Women and children may be saved from tedious and hard work by the use of cattle on the farm. However, the human health benefits of cattle products are mixed. Meat and milk from cattle are high-quality human foods due to the high digestibility and suitable composition of nutrients, rendering them particularly valuable for those humans experiencing food shortages. In considering whether cattle products should be sought for alleviating the plight of the rural poor, the efficiency of utilization of resources to produce livestock products will probably be the governing factor in future.

A new emphasis on sustainable agricultural systems is emerging in many regions of the world, which aims to ensure that the systems of cattle production practised are those that allow the food production benefits to outweigh the environmental, human health and animal welfare risks. Some governments are helping these changes, with assistance for farmers who wish to practise cattle production in ways that are not as profitable as intensive farming but are more beneficial for the environment. The assistance for organic farmers in Europe is one example of this. Although in some regions there would not be enough land for all people to eat organic cattle products, many consider that it is still justifiable for farmers to receive a subsidy for managing it in a manner that both improves the environment and produces cattle products in a safe and sustainable way.

Controlling Emissions and Land Degradation

Intensification of the cattle production industry has mainly been possible because of large inputs of fossil fuel reserves, principally in fertilizers and fuel use for mechanized management of the systems, which allow food production from the land to be increased and a larger number of cattle to be kept on small land areas. In addition, considerable quantities of concentrates are purchased from arable farms, which further intensifies the production from livestock areas. This intensification, while being generally advantageous in terms of labour use and other economies of scale, may produce problems with waste disposal. For example, there are several hundred thousand dairy cows on less than 20 square miles (52 km^2) of land in the greater Los Angeles metropolitan area of Chino-Ontario. Here the ability of the disposal sink, such as the soil or the groundwater, to detoxify and utilize the wastes is easily overloaded and emissions may escape into the public water supply or the atmosphere.

In many highly stocked pasture-based systems the areas around outside water and feed troughs where cattle congregate suffer treading damage, destroying the grass:soil interface. In mountainous areas, slopes and hillsides can become denuded of vegetation, particularly in the gullies, as a result of cattle treading. These gullies should be fenced off and, if necessary, levelled and planted with stabilizing trees to prevent cattle causing further damage. Troughs should be situated on flat ground if possible. Burning land adjacent to an eroded area can be used to draw cattle to young grass shoots that rapidly emerge after fire.

About 20% of the world's pastures and rangelands are degraded (Niamir-Fuller, 2016). High stocking densities of cattle on grazing land lead to low levels of plant cover and soil losses in the form of nutrient runoff and erosion. For example, an increase in pasture use from 25% to 35% can increase annual soil loss from 0.5 t/ha to 2.0 t/ha. Reducing plant cover adversely affects the ability of rangeland to recover. Climate change may exacerbate this problem, since higher transpiration rates at elevated temperatures and lower rainfall will reduce pasture growth in areas denuded by overstocking. Poor profitability as a result of reduced stocking rates may be offset by carbon credits, which will enable retention of carbon in soil to be rewarded financially. As rangelands are lost to urban development, mineral extraction, biofuel production and conservation, grazing pressure on the remaining rangelands increases. At the same time as rangelands are lost to industrial activities in some parts of the world, in others, in particular South America, new pastures are created in felled rainforest areas.

Managing input–output balances on cattle farms

Both carbon and nitrogen compounds are important greenhouse gases, principally carbon dioxide, methane, nitrous oxides and ammonia. Phosphorus is also of serious concern in relation to: energy, nitrogen, and phosphorus and other minerals.

Energy

Carbon dioxide is one of the most important greenhouse gases in the industrial sphere, with significant emissions from the use of fossil fuels on cattle farms, but carbon balances are difficult to measure on farms and hence they are often excluded from proposed carbon trading schemes. The carbon emissions that contribute to global warming are much higher from ruminant meat production, and in particular cattle, compared with other sources of food protein production (Tilman and Clark, 2014) (Table 11.1). Vegetable production produces a very small fraction of the greenhouse gas output of ruminant livestock systems, much less than 10%. This is mainly because cattle ferment their feed in their rumen with the aid of microorganisms that liberate methane in the process, which is voided to the atmosphere via their mouths.

Since more carbon exists in the soil than in the atmosphere, farming systems that sequester more carbon in the soil should be encouraged. One such system is the rotation of livestock in a long-term cycle, allowing grass to grow tall and then be trodden into the soil, increasing its carbon content. This mimics grazing by wild ungulates. However, if this is adopted to control greenhouse gas emissions, the feed available would not meet the nutritional demands of cattle selected for high

Table 11.1. Carbon emissions efficiency of major animals and plants used for human foods (Tilman and Clark, 2014).

Human food	Carbon emissions (g/g edible animal protein produced)
Ruminant meat	62
Mutton and goat	15
Pork	10
Poultry	10
Milk	9
Trout	4
Maize	1
Rice	6
Legumes	0.2

production of milk or meat. Cattle may then only be used if they are part of a low-output stocking system kept on land that cannot be used to grow crops for human food production, if carbon sequestration becomes a major reason for keeping them. Reduced tillage, silvopastoralism (mixed tree-and-pasture farms) and less feedlot finishing of cattle are other likely consequences of any carbon trading scheme that includes cattle farms.

Methane is a natural carbon compound, a by-product of the digestion of plant material by cattle, and it removes hydrogen from the rumen. It is one of the most potent greenhouse gases, producing 23 times as much global warming per unit as carbon dioxide. In countries with large populations of ruminant livestock, such as New Zealand and Australia, methane output contributes up to one-third of the total greenhouse gas emissions. Because of their smaller feed intake beef cattle generate less methane per animal – about 80 l/day – than dairy cattle, which produce about 120 l/day. However, the total greenhouse gas emissions[1] per kilogram of food product are much greater for beef, at 20 kg, than for any other food, including lamb (13 kg), butter and cheese (both 13 kg), chicken and olive oil (both 4 kg), processed cereals and nuts (both 3 kg), fresh fruit and vegetables (< 1 kg). Milk is comparable, at approximately 1 kg/l, with other drinks such as fruit juices.

There is a growing realization that methane emissions must be brought under control. It is emitted from both eructation of waste gases from the rumen and microbial degradation of faecal waste. Methane output from excreta is most easily controlled since it can be stored and used as a fuel, for cooking or heating. Control of eructated gases is more difficult but potentially achievable by a variety of methods, including changes in the feeding, genetics of cattle and consideration of alternative species for meat production, such as the kangaroo in Australia, which produces substantially less methane. Control of methane emissions by feeding a more concentrated diet reduces methanogenesis in the rumen and promotes propiogenesis, but the increase in the use of cereals and other high-energy feeds required to be imported on to the farm could increase fossil fuel use and reduce the health of the cattle if inadequate fibre is consumed. Similar reductions in methanogenesis could be achieved by adding ionophores to the diet but there are concerns over residues, especially in milk. In future it may be possible to immunize cattle against methanogens, introduce probiotics to manipulate the ruminal microflora or breed cattle that are inherently low methane producers. Commercial yeast products are one particular type of probiotic that has been found to be effective.

The problems do not end when cattle products leave the farm. Inputs of fossil energy, relative to home-grown energy, are high for cattle products once the animal has left the farm, with considerable energy costs for long-distance transport, abattoir management and food processing and transport. Transport energy costs should not be used as the sole indicator of energy efficiency, as demonstrated by the fact that milk solids produced in New Zealand for consumption in the UK can have less carbon cost than milk solids produced in the UK, in spite of the long distance that they have to be transported. This is because UK dairy systems rely on nitrogen fertilizer to sustain high grass production; they also employ winter housing and feeding of conserved forage because grass production is limited to about 6 months of the year. However, it is still environmentally desirable for all primary producing nations to sell their produce as close as possible to the place of production, to reduce carbon costs of transport.

Nitrogen

On dairy farms the efficiency of nitrogen utilization for productive purposes (milk, pregnancy and growth) is typically only 25% (Kristensen and Halberg, 1997), with 75% of consumed nitrogen being excreted. Most of this is in urine, after which it is readily volatilized as ammonia into the atmosphere. Reducing cows' dietary crude protein concentration from 20% to 15% would have little penalty in milk production and could cut nitrogen in excreta by 50%.

In many intensive dairy production systems, nitrogen efficiency has decreased with the increase in use of nitrogen fertilizer. With high nitrogen inputs emissions may be lost, not just from the transient pool of a nutrient but also from the very substantial reservoir of the nutrient in the source. For example, the flux of nitrogen into leached water may be 300–400 kg/ha in an intensive dairy farm, i.e. 80% of the amount of nitrogen applied. Some of the release of nitrates into groundwater comes not from nitrogen applied as fertilizer but from the soil's organically bound nitrogen pool, which typically contains N at 7000 kg/ha. The very best dairy farms can have nitrogen surpluses as low as 75 kg N/ha, but even on farms applying relatively low amounts of nitrogen fertilizer accumulation it is typically about 225 kg/ha/year (Fig. 11.1) (Kristensen and Halberg, 1997). Ultimately, accumulating nitrogen must be lost somewhere: into the groundwater, volatilized or removed in a crop or pasture.

Changing from applying nitrogen as fertilizer to manures releases mineralized nitrogen from the soil, but not in the early years, and hence production can only be maintained with artificial nitrogen fertilizer. In later years the mineralized nitrogen release allows nitrogen recovery in the crop to increase to 60% for pasture and 80% for forage and silage. Most nitrogen fertilizer is produced from natural gas and its main use globally is for the purpose of increasing yields of feeds for livestock, especially maize and grain crops such as barley and sorghum. Production of fertilizer requires about 40 GJ energy/t of ammonia (Steinfeld *et al.*, 2006), which has to be provided by burning fossil fuel. On many farms even greater amounts of energy are required for other aspects of the growing of cattle feed: seed production, herbicides/pesticides, diesel for mechanized land preparation, feed harvesting and processing, transport and irrigation.

Some nitrate leaching is inevitable, but good practices can still be adopted that will help to minimize it. Most important is the timing of nitrogen applications to avoid periods of heavy rainfall and low plant growth, when nitrogen uptake is reduced. Following the application of nitrogen fertilizer, immediate loss can occur in the form of nutrient runoff from the surface of the field, usually into watercourses. This is most likely after large applications or when the soil is waterlogged or frozen. Sloping ground will increase the risk of nitrogen runoff.

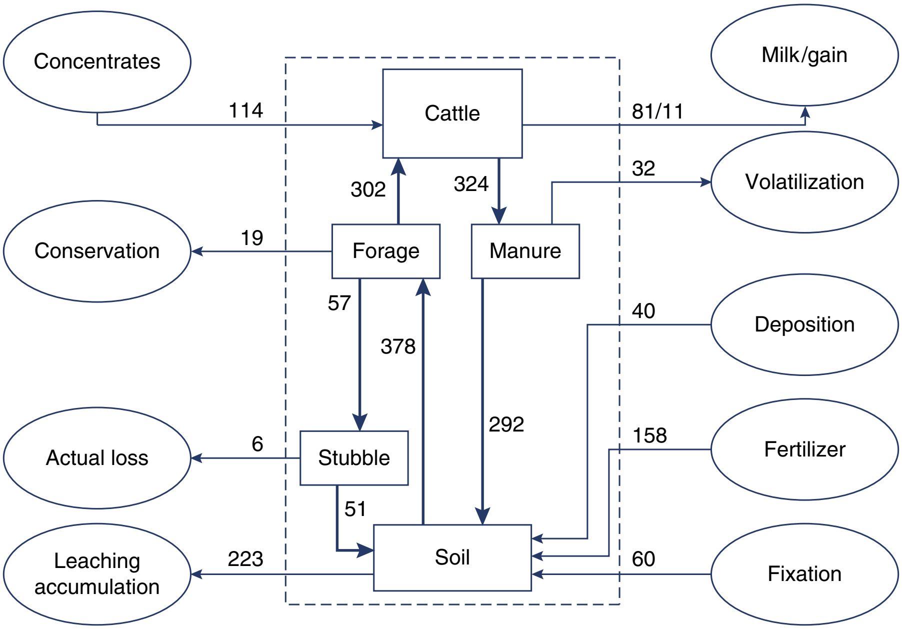

Fig. 11.1. Nitrogen flux (kg/ha) in a low-intensity dairy farm, showing inputs from concentrates, fertilizer, aerial deposition and fixation by soil microbes and losses through volatilization, conservation processes and from the herbage stubble to the soil and the air. The remainder is accounted for by output in the form of milk production or live weight gain and leaching or accumulation in the soil reservoir. (From van Bruchem *et al.*, 1999.)

Nitrogen can also be volatilized to ammonia before it is absorbed into the soil. Once in the soil, nitrogen is prone to leaching losses, which is most likely when the rainfall is high. If the nutrients are leached to below the rooting zone of the grass plants, they will never be absorbed by the plant. Typically about three-quarters of the nitrogen applied as slurry in autumn will be lost by leaching, runoff and to the atmosphere, while for a winter application this is likely to be reduced to one-half, and for a spring application one-quarter. However, a large store is required to keep all the slurry produced by a dairy herd during the winter months. Overflowing slurry stores are another significant cause of watercourse pollution. Ploughing increases nitrate leaching, so permanent grassland is likely to have lower losses than temporary grass leys or arable crops. Maintaining a crop cover for as much of the year as possible is important, especially in countries such as Ireland and New Zealand where the rainfall is significant, unpredictable and not strongly seasonal.

The intensive cattle industries of the world, for example in the Netherlands and the USA, have most difficulty in pollution control. Such industries are usually concentrated in areas of the country where cereal feeds are readily available. However, importation of nutrients on to the farms enables stocking densities to be increased to levels producing more waste products than the land area can safely absorb. Excreta often have to be removed from the area, usually by mechanized transport, though pipelines offer a more efficient and cheaper alternative. There is increasing legislative emphasis on developing systems that reduce emissions, particularly of nitrogen and phosphorus. In the Netherlands these must be reduced to below 180 kg and 8.7 kg/ha/year, respectively. Intensive dairy systems commonly have losses of 400–500 kg N/ha/year but this can be reduced to about 200–250 kg N/ha/year by reducing inputs of nitrogen fertilizer and adopting environmentally friendly practices. The opportunities for improvements in nitrogen efficiency are exemplified by a comparison of an intensive dairy farm in the Netherlands with a mountain dairy farm in Italy producing milk for Parmigiano–Reggiano cheese under local regulations (Table 11.2).

Table 11.2. Nitrogen balances of an intensive dairy farm in the Netherlands and a mountain farm in Italy producing milk for the production of specialist cheese under local regulations that control the farming methods (from de Roest, 1997).

	Netherlands intensive dairy farm		Italian specialist dairy farm	
	kg/ha	%	kg/ha	%
Inputs				
Cattle purchases	4	0.7	1	0.2
Straw	1	0.2	7	2.2
Fertilizers	346	62	36	11
Organic manure purchased	3	0.5	22	7
Nitrogen deposition	42	8	18	5
Nitrogen fixation	4	0.7	22	7
Roughage purchased	45	8	85	26
Concentrates purchased	114	20	132	41
Milk powder	1	0.2	1	0.4
Total inputs	560	100	324	100
Outputs				
Cattle	16	19	8	10
Milk	64	76	54	65
Manure	3	4	9	10
Others	1	1	13	15
Total outputs	84	100	84	100
Balance	476		240	

In the Italian system the feeding of silage, industrial by-products and a range of feed ingredients is prohibited, because of adverse effects on cheese quality. Milk is collected from farms twice a day and is processed under strict conditions. The nitrogen balances show that, although milk in relation to other useful outputs (cattle and manure) is greater in the Dutch farm, the balance or accumulation of nitrogen on each hectare of the farm is nearly double that of the Italian mountain farm. Mountain farms have a greater input of labour per cow but much of this is family labour. At normal labour rates, the production cost of the milk output is high but this may be compensated by the greater product value, as can be seen in a comparison of extensive mountain and intensive lowland dairy production in Italy (Table 11.3).

Hence, the mountain farm provides employment in a marginal economic region, as well as preserving the environment for future generations. However, mountain farms have to rely more on purchased concentrates than lowland farms, which can grow forages more easily. For the production of high-quality foods, the type and amount of concentrate used are strictly regulated.

Forage production on a low-input farm can be maintained by making better use of cattle excreta and mixing it with straw to make manure before spreading on the land. Farmyard manure has slow nitrogen-release characteristics but also contains useful amounts of phosphorus, calcium, magnesium, sulfur and trace elements, all differing from the supply in fertilizers by their long period of availability in the soil. Urine is particularly rich in nitrogen and potassium. Growing legumes will reduce the need for additional nitrogen inputs but forage crude protein contents above 180 g/kg dry matter (DM) are likely to result in the farm exceeding emission limits, as well as potentially reducing reproductive rates of the cows. Improving the efficiency of nitrogen utilization by cattle, for example by matching the energy supply to the protein breakdown, will have some impact, but not as much as reducing nitrogen inputs to the farm.

Excreted nitrogen deposited on bare feedlot pens is largely lost through volatilization as ammonia. Feedlot managers still often supply excess nitrogen in the diet so that growth is not limited by this nutrient, even though the knowledge to ration nitrogen effectively is now very advanced.

Phosphorus and other minerals

Phosphorus (P) emissions are more difficult to control than nitrogen and need to be tackled by managing farmyard manure properly, minimizing phosphorus fertilizer use and reducing purchased concentrate use. The main problem is surface runoff from farmyard manures (Fig. 11.2), which ends up in watercourses and causes eutrophication[2] in lakes. This is most probably caused by phosphorus runoff from manures spread on the land or stored near a watercourse, but it can also be caused by nitrogen deposition from volatilized ammonia. Phosphorus fertilizers also have to be carefully controlled both because they are diminishing in supply and

Table 11.3. A comparison of the technical and economic efficiency of mountain dairy farms for the production of Parmigiano–Reggiano cheese and intensive lowland dairy farms producing milk for liquid consumption in northern Italy (from de Roest, 1997).

	Mountain dairy farm	Intensive lowland dairy farm
Number of cows	25	70
Cultivated area (ha)	27	35
Cows per ha forage crops	1.1	2.5
Milk yield per cow (kg/year)	4800	6200
Concentrates per cow (kg/year)	2100	1700
Working units (people/year)	2.4	3.5
Costs per kg milk (€)[a]		
Concentrates	0.11	0.08
Family labour	0.20	0.06
Hired labour	0.0005	0.0210
Total production cost	0.47	0.28

[a] Originally in Italian lire; conversion rate, €1 = 1936 lire.

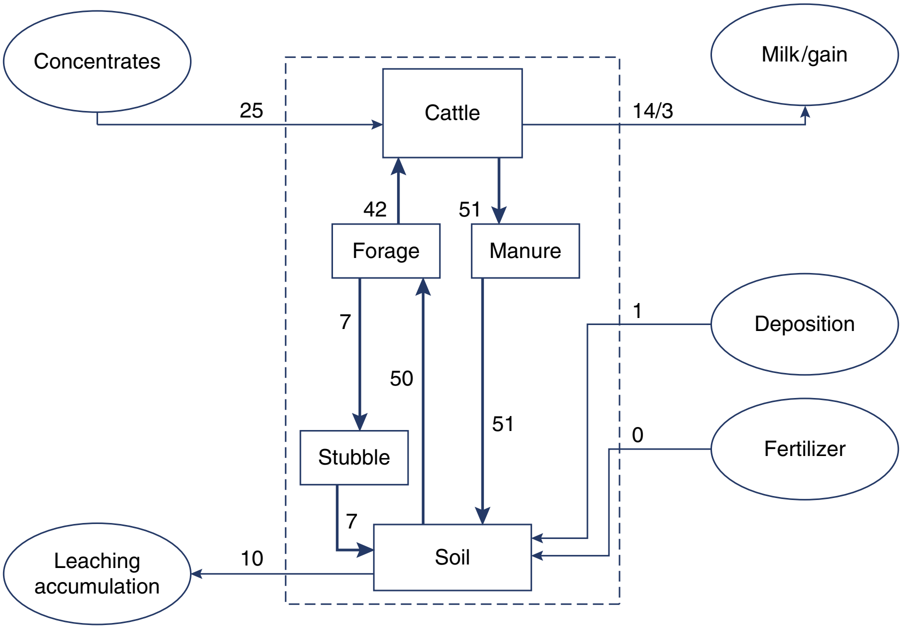

Fig. 11.2. Phosphorus flux (kg/ha) in a low-intensity dairy farm that applies no phosphorus fertilizer, showing input from concentrate and aerial deposition, and output as milk production, live weight gain or leaching or accumulation in the soil reservoir. (From van Bruchem *et al.*, 1997.)

because they sometimes have a high cadmium (Cd) content. This varies considerably but may be as high as 150 mg Cd/kg P, in which case regular application could increase herbage cadmium content above the European Union (EU) legal limit of 1 mg/kg herbage DM.

Efficient fertilizing of cattle grassland

Fifty per cent of fertilizer applied to agricultural land is for animal feed production but with wide variation globally (Niamir-Fuller, 2016). The application of fertilizers can be made more efficient by applying the optimum compounds at the correct rates to each area of land, taking into account the soil type, crop type and weather. This requires detailed and up-to-date soil maps for each field on the farm, precision application and knowledge of past and forecast weather patterns. The benefit of such high-technology inputs into fertilizer application is that growth can be optimized with the minimum of inputs. It will be more difficult for mixed crops, such as grass/clover mixtures, where the requirements of the species are different at the various stages of the growing season. Fertilizers that are mixed for optimum growth of the crop at each stage in its production cycle are likely to contain more than just nitrogen, phosphorus and potassium – the three nutrients most commonly applied. Sulfur may be co-limiting with nitrogen and sodium, but sulfur applications should be restricted, as high concentrations in herbage reduce palatability and milk fat concentrations.

Although sodium does not greatly enhance grass growth in most temperate conditions, it will increase the palatability of the grass and cattle intake. Its use can replace some potassium fertilizer, which is required more by the plant than the animal, with the benefit that the animal's needs for sodium are more effectively met.

An efficient fertilizing strategy should aim to reduce fertilizer application and to tailor specific fertilizers to the requirements of each field. Some nutrient return is essential, because, as long as crops are removed from the land, there will be a net drain of minerals from the system. Many agricultural systems have failed in the past because the land becomes exhausted and nutrient deficient. Although nutrient release from faeces is slow, urine contributes to significant localized losses of nitrogen as it is deposited in small, concentrated areas, contributing to leaching of nitrogen at these points. However, in terms of environmental risk, the nitrate leaching from permanent grassland is not a major cause for concern, since it is less than from ploughed fields. The major concerns with excessive nitrogen fertilizer use in grassland systems, relative to the nitrogen output, are the losses of nitrogen to the atmosphere through denitrification and the fossil fuel use during the fertilizer manufacturing process. In relation to phosphorus, the world relies on limited supplies and there are no simple replacements for phosphorus fertilizer; more judicious use is warranted if food production is to continue to be boosted by its use.

Global Warming and Cattle Production: Addressing the Challenges

Global warming, which is due in part to the emissions from cattle production units, is predicted to increase global temperatures over the next 100 years by between 1.5°C and 4.5°C. The temperature increase is expected to be greater in the mid- to high latitudes, including the subtropical savannah and temperate zones that are extensively used for cattle production. In equatorial zones the temperature increase will be smaller but there is much less cattle production in these regions. However, the clearing of equatorial rainforest in South America for pasture for cattle production is one of the most significant contributors to climate change, through loss of carbon to the atmosphere during clearing and burning, depletion of soil carbon reserves and reduced carbon sequestration by pasture compared with native forest. Such developments are likely to be increasingly seriously challenged on a political as well as an economic front.

As well as increasing temperatures, climate change over the 21st century is expected to include more extreme weather patterns, bigger storms, longer droughts and more frequent heat waves. More frequent periods of high temperature will have a significant effect on cattle in feedlots, if this system of intensive finishing prevails. Stock in many feedlot systems do not have the opportunity to seek shade, with the result that periods of high temperatures, in particular those in excess of 40°C, already cause significant mortality and distress to cattle in Australian feedlots. With an upper critical temperature of just 27°C, all cattle are prone to heat stress, but particularly those that are growing fast and eating large amounts of feed, with a consequent heat increment in the body arising from the digestive processes. With rising temperatures, reduced conception rates and shorter pregnancy periods are expected, producing offspring that are born earlier as a result of heat stress on the mother. This might lead to less calving difficulty but would also result in reduced calf viability.

Increasing carbon dioxide concentrations in the atmosphere are predicted to increase growth rates of C3 crops, such as wheat, rice and soybean, which are largely grown at mid- to high latitudes. The C4 crops, such as maize, sorghum and pasture grasses, will not increase in growth rate as much; and since these are largely the crops used currently for cattle feeding, in contrast with the C_3 crops that are largely used for human food production, then it is unlikely that the increased carbon dioxide concentrations will have major effects on feed availability for cattle. Rising sea levels are expected to inundate many coastal regions and increase the exposure of agricultural crops to salinity. Crops such as sugarbeet (*Beta vulgaris*) thrive in these regions, being more resistant to salinity than pasture grass.

The cumulative effects of climate change on cattle production were predicted early this century to be a lengthening of the time to finish beef cattle and a reduction in dairy production by about 1–2% by the year 2030 and 5% by the year 2090 (Khalifa, 2003). In addition to direct effects on cattle production, there will be indirect effects of food shortages for the human population, putting pressure on the production of feed for cattle, which suggests that there could be further reductions in the output of cattle as a result of reduced use of concentrate feeds. Furthermore, ethical concerns about the use of land for growing feed for cattle, when a growing sector of the human population is likely to be undernourished – as well as the varying impacts of intensive systems of production on the welfare of cattle – render it likely that cattle production will be confined to areas of land that cannot be used for the production of human food. Depending on how effectively human population growth is brought under control and human food production is increased sustainably, the classification of land as capable of producing food for humans will be more or less stringent.

In the worst-case scenario, with significant human populations underfed, it is likely that even the rangelands used extensively for cattle production today will be converted for human food production. In drought-prone regions, agroforestry, with trees providing edible crops interspersed with the leguminous bushes producing high-quality protein for synthesized human food, could be used more efficiently than grasslands for cattle to feed a human population. Similarly, the cool temperate zones of northern Europe could be converted from grassland production of cattle and sheep to agroforestry systems with trees producing a harvest of fruit and nuts and intercropped with cereals such as rye, which tolerates cool temperatures well, or a green manure crop to enrich the soil and lock up carbon, perhaps with the aid of cattle as agents to incorporate carbon into the soil by treading and excretion. Conversion of extensive rangelands to agroforestry systems will help to counteract global warming by carbon sequestration in the trees and in the soil. Such systems, however, take many decades to develop and must be further tested experimentally or through models. Given the uncertainty about the role of cattle production systems in the future, it is imperative that consideration be given to the long-term future of rangeland areas as quickly as possible. It is often assumed that they can only be used to rear cattle and sheep, whereas in reality they have often been used for this purpose because of the ease of establishment and maintenance of livestock systems compared with intensive agriculture.

An alternative scenario is of human population growth being brought rapidly under control, which has already happened in developed countries, and human food production being expanded sustainably through use of genetically modified (GM) crops, especially through the development of crops with nitrogen-fixing capabilities, to be used as a component of sustainable land management systems. These are still likely to focus on agroforestry systems, because of their inherent sustainability, and are unlikely to include intensive fattening of cattle in feedlots, unless the concentration of production into a small area becomes regionally essential to release land for the maintenance of native flora and fauna. The uncertainty surrounding the future of cattle production systems can only truly be addressed through effective modelling of the various types of system available, predicted changes in climate and demand for cattle products and human food. Such models need to be constructed to take into account predicted changes over the next 100–200 years, not just 30–50 years, and should include the impact of cattle on climate, water use, soil structure, nutrient balances and human health.

Global climate change will also bring about significant water shortages in drought-prone regions, as high temperatures lead to increased transpiration rates and more extreme weather events lead to more prolonged dry periods. The high rates of utilization of water by cattle, compared with agricultural crops, will restrict their use in the many drought-prone regions that are currently used for cattle production. Similarly, the high processing and transport costs of some cattle products to be converted into human food will increasingly become a disadvantage, compared with the use of agricultural crops directly for human food.

Climate change also influences disease profiles of cattle and potentially zoonotic diseases. Cattle products may harbour diseases such as bovine spongiform encephalopathy (BSE), as well as tuberculosis and a host of other diseases potentially transmissible to humans. Most of these are currently destroyed during processing, for example by pasteurization of milk. However, novel genotypes of pathogens develop rapidly and may be able to survive processing. Climate change will introduce new opportunities for disease organisms to expand their geographical spread, with those in middle latitudes (45–60 degrees) estimated to move about 250 km towards the equator for every 1°C of warming (Khalifa, 2003).

The public cannot necessarily be relied upon to understand the complexities of climate change and how it interacts with livestock production systems. Climate change is not a primary factor influencing food choice. Consumers are remarkably resilient to changing their diet based on evidence from scientists on climate change. Fortunately those in countries with rapid meat consumption growth (China, Brazil and India) are most receptive to such changes (Bailey *et al.*, 2014).

Waste Management

A dairy cow produces approximately 60 l of excreta (principally faeces and urine) per day, or 0.06 m^3. This is usually collected into a semi-solid mixture, or slurry, which contains not only excreta, but also wastewater, for example from washing cattle yards, and stored in a tank. Some dilution is necessary for efficient storage, handling and spreading on the land, and a winter rainfall of 500 mm on a 0.5 ha farmstead will produce 2500 m^3 to be stored, i.e. a volume roughly equivalent to the slurry produced by a 320-cow dairy herd during this time. For this size of herd, the rainfall will produce a suitable degree of dilution for handling purposes. For the most part the slurry flows under gravity, a physical characteristic that is used to collect it into a central pit, from which it is pumped into the storage unit. In a well-designed system, there is minimum manual or mechanized movement. Most dairy farms with loose housing of their cows now produce slurry rather than farmyard manure (excreta mixed with straw), because the former is more easily handled mechanically.

Slurry is scraped out of cubicle passageways either by a tractor with a rubber blade mounted on the back or by automatic scrapers attached to a chain that passes down the passageway approximately every hour. Scraping with a tractor should be done at least twice a day, usually at milking times, otherwise slurry accumulates in the passages, the cattle become dirty and their movement is hindered. After scraping it out of the building, the slurry is scraped by tractor to a pit, from where it may be pumped to an above-ground store. High-quality storage of cattle excreta is often required in regions prone to pollution of watercourses. Traditional slurry stores had gaps in between the 'weeping' wall panels, through which the more liquid component of the slurry could emerge and be absorbed into the soil. Nowadays, storage tanks mostly have sealed walls and may be covered to prevent excessive rainwater entering and the release of gases. It is stirred regularly to reduce crust formation and to stimulate aerobic fermentation, which will also reduce the odour and the biochemical oxygen demand (BOD) (Table 11.4). Apart from sealing the store, gaseous losses can be reduced by adding nitrification inhibitors. The most common nitrification inhibitor is dicyandiamide, which acts for 2–6 months to prevent nitrification. When added in cold climates, it has produced reductions in nitrogen losses.

In uncovered stores, stirring will increase loss of nitrogen in the form of ammonia and nitrogen gas after denitrification, with the nitrogen content reduced by one-third during storage. When urea in urine is catalysed by the enzyme urease, naturally present in the animals' faeces, ammonia is formed. The liberated ammonia will enter the atmosphere but this amount is small in comparison with ammonia emitted from the cowshed before slurry is removed and emitted from excreta applied to the land. Cattle sheds are usually open to the atmosphere on at least one side, preventing gaseous emissions being cleaned in the way that they sometimes are from fully enclosed pig and poultry buildings. Hence in countries with major cattle industries, such as Germany, more than 50% of ammonia from agriculture is from cattle (Rösemann *et al.*, 2015). Although ammonia is not a greenhouse gas, when slurry is applied to the land ammonia can indirectly contribute to nitrous oxide emissions, following conversion by soil bacteria. Nitrous oxide has a global warming potential almost 300 times that of carbon dioxide (IPCC, 2007). Nitrification of the ammonium in poorly buffered soils acidifies them. Nitrification is also responsible for nitrogen losses from the soil, where NH_4 ions, which are not readily leached as they are adsorbed to clay particles, are converted into nitrates, which are readily leached. A further concern in hilly areas is that the returned nitrogen fertilizes trees and encourages growth, making them more susceptible to disease.

Table 11.4. The biochemical oxygen demand (BOD) of substances produced on cattle farms.

Substance	BOD (mg/l)
Dirty water (dairy parlour and yard washings)	1,000–2,000
Liquid wastes draining from slurry stores	1,000–12,000
Cattle slurry	10,000–20,000
Silage effluent	30,000–80,000
Milk	140,000

If slurry is spread near watercourses and has a high BOD (Table 11.4), it will deplete the water's oxygen content, making it difficult for fish and other aquatic organisms to survive. Most old dairy farms were sited near water sources, often springs, so that water was available for the farming operations and the farmer's household. The risk of these farms (which have usually increased considerably in size) polluting the water supply is today often considerable. Runoff control can be achieved by constructing a drainage ditch around the farm, which diverts runoff into a holding pond. Periodically, and especially after a period of high rainfall, the water from the holding pond should be spread on to the land. The pond should have the capacity to hold a rainfall incident equivalent to the largest incident experienced over the previous 10 years.

Waste disposal opportunities must be a paramount consideration in choosing a site for a cattle farm nowadays. The soil type, local climate, surrounding crops and proximity of human population should all be investigated. Sandy soils are more susceptible to leaching losses than clay soils or loams. In mixed grazing and housing systems in temperate regions, consideration should be given to the possibilities for spreading slurry during the housed period. If there are no suitable days when the ground is frozen to allow slurry tankers to spread on to the land, a large store will be needed to hold the slurry produced during the winter. The length of the grazing season also needs to be assessed so that winter storage requirements can be determined. Crop nitrogen requirements should be considered and their ability to absorb different slurry applications. For permanent grassland, a slurry application in spring can cause capping on the grass and loss of sward-production potential. Applications to any crop in the autumn should be avoided because of the high leaching risk during the winter, when uptake by the crop will be negligible. The high potassium content of slurry can be a risk on grassland as it inhibits the plants' uptake of magnesium, potentially causing hypomagnesaemia in cows that are grazing lush pasture.

Spreading of slurry releases noxious odours and should be restricted in highly populated areas. Odour spread is exacerbated by the use of slurry tankers fitted with a discharge nozzle delivering to a splash-plate, spreading the slurry in a wide arc behind the tanker. This creates a small droplet size that increases volatilization of compounds into the atmosphere. Pathogenic microbes, such as *Mycobacterium bovis*, may be spread several hundred metres and could potentially infect humans or livestock. Slurry injectors deliver it directly into the soil at a depth of about 150 mm, via a series of hollow tines fitted with wings to aid dispersal of the slurry beneath the ground. After each tine has created the injection slot and the slurry has been injected, a wheel or roller passes over to close the slot. About 70% of the odour is eliminated but grass yield may also be reduced because of the damage to the sward. Tractor power requirements are increased, leading to increased fuel use and more carbon dioxide emissions. In addition, slurry injection is not possible in stony soils or in hilly terrain. Shallow injection, to a depth of 60 mm, has lower tractor power requirements and gives an adequate reduction in odours of about 50%, making it the best option for many grassland applications. In the Netherlands, injection is the only permitted method of slurry disposal on farmland, which is possible because the soils are predominantly reclaimed land that is flat and without stones.

Anaerobic digestion of slurry

Slurry can be effectively digested anaerobically by bacteria to produce methane gas, an odourless liquid and a friable solid material. The gas can be used for cooking (though it not as pure as natural gas); the liquid can be pumped on to the land via an umbilical cord; and the solid material can be put into bags and sold as garden compost. Such a digestion produces a 40% reduction in the chemical oxygen demand – not enough to allow it to enter watercourses, but it enables the liquid waste product to be easily applied on the surrounding farmland via a pipeline. The pipeline can be connected to a tractor or an irrigation system. The greatest difficulty is keeping the digestion process at a suitable temperature for bacterial growth, which requires protecting it from variation in environmental temperature. Digestion systems are therefore most popular in hot countries where natural fuels are expensive, in China for example. In cold climates the digestion chamber needs to be heated, which can utilize the methane gas from the bacterial fermentation. It can be difficult to have a continuous system from which the solid residue can be extracted, and continuous-flow systems that use sealed polythene chambers set in the ground often have a short life. Some governments have subsidized the installation of anaerobic fermentation plants on the grounds that they reduce emissions.

Slurry separation

An alternative treatment method for slurry is separation, which produces a friable solid material for sale as compost or fertilizer and a liquid product for spreading on the land. Separation is achieved with varying degrees of efficiency by vibrating or rotary screens, or presses using belts or rollers.

Using sewage sludge on cattle farms

In highly populated countries, human sewage sludge is increasingly disposed of on farmland, including cattle farms, rather than dumped at sea where it creates pollution problems. On land there are potential benefits to crop growth but also problems of nitrogen overload, public nuisance, pathogen transmission and soil contamination with heavy metals. Sludge nitrogen, being in the ammoniacal or organically bound form, is not leached as readily as nitrogen fertilizer, and the sludge has to be combusted if there are insufficient suitable farm sites. Contamination of agricultural land with heavy metals from sludge, particularly zinc, copper, lead and cadmium, is becoming less of a problem in many developed countries as industry reduces its emissions of toxic metals into industrial effluent. Pathogens can be minimized by chemical, biological or heat treatment but this is more applicable to situations in which the crop is directly consumed by humans, such as fruit and vegetable production, rather than to cattle farms.

Water Use by Cattle

Cattle production systems use prodigious amounts of water, to clean buildings, irrigate crops, provide drinking water for the animals and cool them in hot climates. The quantity used is much greater in intensive cattle production systems than in grazing systems (712 m^3 versus 243 m^3/t of beef produced) (Mekonnen and Hoekstra, 2011). Water may be piped to cattle from central supplies or the animals may be expected to take water directly from flowing streams and rivers. The latter is often restricted, e.g. in Europe, due to damage to the riparian zones and potential to pollute the water with excreta.

Intensive and semi-intensive cattle production systems are criticized for using large quantities of water and farmers do not pay the full cost. As a result, water usage is much greater for livestock farming than cereal production; for example, that required for beef production is over 16 times the quantity required to produce the same weight of maize. In addition, farmers rarely pay the full cost of the water that they use; the construction of dams, provision of irrigation services and management of water services are usually covered by local or national government. At the same time the public are facing increasing water charges due to shortages as a result of the growing use by agriculture, so they are subsidizing livestock farmers. Increasing variation in rainfall as a result of climate change is putting further pressure on water resources and requirements for long-term storage.

Silage Effluent

More silage is produced for cattle than dried forages in industrialized cattle production systems, because advanced technology is now available that will make and feed silage automatically to cattle, and because it is of higher energy value, resulting in higher milk yields or faster growth. Increased use of nitrogen fertilizer on grass has produced a crop with lush growth and low dry matter content. The tendency to minimize the wilting period for silages for rapid conservation and low field losses increases the harvested yield but also effluent production (Table 11.5).

Table 11.5. Typical losses (% DM) from grass silage that is either wilted in the field for 36 h or ensiled directly, both under conditions of good management (from Wilkinson, 1981).

	Direct cut	Wilted
In field		
Respiration	0	2
Mechanical loss	1	4
During storage		
Respiration	0	1
Fermentation	5	5
Effluent	6	0
Surface waste	4	6
During removal from clamp	3	3
Total	19	21

Greater reliance on silage and growing farm size have increased the potential for pollution incidents associated with silage effluent and in England and Wales it is the third most common source of pollution from farms, with over 40 incidents per year. In some jurisdictions government grants for construction of above-ground stores have helped to reduce these. As well as government penalties, there are often prosecutions by angling associations for the damage to fish stocks following pollution of watercourses. The threat to watercourses from silage effluent is even greater than that from slurry – despite more slurry being produced – because of the high BOD of the effluent (Table 11.4). Silage effluent allowed to seep from silage clamps unchecked can end up in watercourses, where it represents a high risk for eutrophication of the water. The necessity of collecting the effluent from silage clamps is becoming more generally accepted and in some countries is legally required. The output (l/t herbage) of effluent from fresh grass being ensiled can be calculated from the herbage dry matter (DM) content (g DM/kg fresh weight) using the following equation:

$$\text{Effluent output} = 800 - 5H + 0.009H^2$$

where H is herbage dry matter content.

Most of the effluent is produced in the first 10 days after ensiling, so the effluent tank must have sufficient capacity for this volume, as well as any rainwater that falls on uncovered clamps. A 1000 t clamp will need a tank of at least 25 m^3, or larger if very wet silage is conserved. The effluent is acidic (normally pH 4) and will etch the concrete of the clamp. Following collection, it can be either spread on the land as a fertilizer or fed to cattle or other stock. However, spreading effluent on the land may scorch crops because of its acidity. A maximum of 10 m^3/ha should be spread, or 20 m^3/ha if it is diluted with water at 1:1, and applications should not be repeated within 3 weeks as the soil microflora will not have had time to break it down. The fertilizer value of effluent is similar to that of farmyard manure. The crude protein content is about 250–350 g/kg DM, most of which is amino acid nitrogen, making it a suitable feed for cattle in limited quantities. The DM content varies from 40 g/kg to 100 g/kg, with a mean of 60 g/kg.

When feeding effluent to cattle it should be preserved by adding formalin, at 3 l/t, or weak acids if its pH value is greater than 4. Its feeding value is about 1/20th that of barley on a fresh matter basis. It is rich in minerals, particularly potassium, and also contains ethanol. Antibacterial preservatives should be used cautiously as they may inhibit ruminal fermentation if too much is consumed. There is no problem with palatability, unless the effluent has been allowed to spoil, but cattle should be offered an alternative water source. The greatest difficulty lies in the rapid production of the effluent and the cost of storing and feeding it.

An alternative to collecting the effluent as it is produced by the clamped crop is to reduce effluent from the crop by adding absorbent material at the time of ensiling. The absorbent material can be of lower nutritional value than the ensiled herbage, such as chopped straw. Straw bales can be laid at the bottom of the clamp but are not very effective in absorbing the effluent. If straw is added, the feeding value of the final product will be reduced and also more variable, with some cattle rejecting effluent-soaked straw if *ad libitum* silage is available. Alternatively, cereal grains can be added, which will increase the quality of the finished product. These are also not particularly absorbent and the starch in the grains will not assist the fermentation of the grass, as most bacteria cannot use it as a substrate. The absorbency of the grains can be increased by grinding them and, if they can be added evenly as the grass is ensiled, a total mixed ration or complete diet can effectively be made in the clamp. A third possibility is to add shredded beet pulp to the ensiled crop. This is highly absorbent and will reduce the effluent production by one-half when added at about 50 kg/t. Although absorbents are effective in reducing effluent production, they are difficult to apply and may be lost in the feeding process.

Contamination of the Environment with Weeds

Another potential pollutant of the environment from cattle farms is the transmission of weed seeds. The transport of cattle to other farms or to slaughter can disperse weed seeds and result in unwanted infestations and even weeds becoming endemic. In addition, cattle introduction into recently colonized lands has often been accompanied by plants thought to be suitable for fodder production in their new territory. These plants may outcompete the native flora in some years but can be less resistant to extremes of climate that native plants have become adapted to over many centuries. Biodiversity, which safeguards against changes in climate and economic circumstances, might be reduced by replacement of native flora with introduced species.

Seeds may be transported on the coats of cattle or in their hooves but most commonly in their gastrointestinal tract. Droving of cattle along traditional stock routes provided an opportunity for weed seeds to be dispersed along the route, especially at feeding and watering points. Vehicular transport also gives an opportunity for dispersal over large distances, primarily in the excreta that are removed from vehicles at the end of the journey. Ideally, cattle should be fed on seed-free forages for least 3–4 days before transport. Failing this, the plant species fed should be ones that are common in the destination region. A strict washing routine for vehicles and transfer of cattle to a quarantine area, where faeces can be deposited and safely removed, will help to contain weed seed dispersal. For cattle transported by ship, the pens are usually washed out at sea, with little likelihood that seeds will remain viable.

The effect on seed viability when seeds are passed through the digestive tract, or are composted or ensiled, depends on many factors. Foremost of these is the hardness of the seed, with soft seeds hydrating rapidly with consequent exposure to attack by microbes. Also important are the period of exposure and the extent of mastication. Grazing weeds with livestock and preventing them from flowering minimizes seed dispersal. Cattle have a limited selection of preferred plant species and are therefore better at controlling weeds than other livestock species.

Environmental Risks of Intensive Beef Production

The concentration of cattle into a small area of 15–20 m^2/head in feedlots produces a significant risk of water and air pollution. However, this must be weighed against the alternative of producing cattle at pasture, where they occupy a much larger area and have a potential impact on native flora and fauna, possibly damaging the soil with their hard hooves, causing nutrient runoff and groundwater pollution. Hence it is often argued that the best way to reduce the environmental impact of beef production is to intensify the production methods, so that less land is utilized. This can include adoption of improved crops or more fertilizer application. The logical conclusion to this trend is that beef will be produced *in vitro*, with methods already developed to grow meat in nutrient media in the laboratory. Although many potential consumers have concerns about the naturalness of this process, the parallel with similar concerns around genetically modified crops suggests that eventually this will not be an impediment to consumption.

For the present, intensification of beef production means expansion of the feedlotting systems. Many feedlots are relatively small, carrying fewer than 500 animals, but there are also large company feedlots, licensed to carry over 100,000 animals (see Chapter 2, Fig. 2.8). Reducing the pollution risk is not simply a matter of providing more space, since at lower stocking densities dust can contaminate the atmosphere, whereas at higher densities the ground may become poached and boggy.

Feedlots should be sited away from watercourses, rocky ground and natural springs, preferably on the side of a hill to aid drainage (Fig. 11.3). The risks of water contamination can be reduced by having a sedimentation system draining into a holding pond, both with an impermeable base. Sandy soils are not suited to feedlot development, because of their high permeability. If the clay content of the soil is inadequate, synthetic liners or imported clay will be needed to protect the groundwater. Each pen should drain directly to the sedimentation system, which separates the solid and liquid fractions of the excreta, rather than through other pens, and should have a slope of 2.5–4.0%. If the slope is steeper than this, there may be manure contamination of runoff during major rainfalls. The site should be surrounded by drains channelled to the holding pond. Feed and manure storage areas should be sited with a view to directing effluent to the sedimentation area. Lanes and gateways should be wide enough to prevent the ground becoming boggy and the crossing over of laneways should be avoided. The environmental impact of a feedlot can be assessed by regular sampling of soil, effluent, manure, sludge, surface water and groundwater.

Markets for the manure, preferably a cropping or pasture area nearby, should be determined in advance. Spreading rates for the manure can be determined by the N, P or salt additions that the land can utilize. As a guide the manure should be applied at no more than the following rates (Skerman, 2000):

- dry land pasture for grazing: 5 t/ha
- dry land pasture for cutting: 10 t/ha
- irrigated pasture for cutting: 15 t/ha
- dry land cropping: 15 t/ha
- irrigated cropping: 20 t/ha.

Fig. 11.3. Cattle feedlot built into the side of a hill to aid drainage.

Proximity of the feedlot to nearby houses and prevailing winds should be considered at the planning stage, since offensive odours may be generated. The stocking density of the cattle is crucial, as wet pads (outwintering areas) produce 50–100 times more odours than dry pads. The recommended separation distance from sensitive areas can be calculated from the number of cattle at the feedlot, the stocking density, drainage and land surface characteristics (Skerman, 2000). Disposal of carcasses of casualty stock should be prompt and into sealed pits that will not allow the watercourse to be contaminated. Consideration should be given to a mass carcass disposal site, should it be needed.

Environmental Toxins and Anti-nutritive Agents

Cattle may be either directly affected by environmental toxins or they may be carriers of toxins in the human food chain. Some compounds also have anti-nutritive properties, i.e. they reduce the nutritional value of the diet but are not toxic. Here, a description is given of some of the most significant toxic agents. Knowledge in this field is rapidly advancing and other, more potent toxic elements consumed at low levels may yet be discovered.

Lead

Lead is ubiquitous in the anthropogenic environment, because of its numerous uses. When consumed by cattle it is toxic at relatively low concentrations compared with those for other livestock: about 2 mg/kg live weight, or approximately 60–100 mg/kg feed DM. It is still the most common form of poisoning of any farm livestock, with about 200 cases in cattle annually in the UK alone, most arising as a result of accidental consumption. Housed cattle often become poisoned when they lick old paint, containing lead, in their stalls; ensuring that a suitable diet is available will help to control paint consumption. Cattle at pasture that become poisoned usually have licked or chewed discarded lead batteries. These may even make their way into a complete diet if picked up by a forage harvester. In developing countries cattle often graze close to the road and lead, formerly added to petrol to prevent the engine knocking, can spread up to 10 m from the road. This lead has toxic effects on ruminal bacteria but cattle learn to avoid lead-contaminated herbage if given the opportunity. Once the lead has been washed off the plant leaves, it remains in the topsoil and may still be consumed, since grazing cattle may consume up to 10% soil in their diet. The uptake by plants is low, with some entering the roots, but very little reaches the plant parts above ground. However, little of the lead will leach from the soil and it presents an almost permanent threat to grazing cattle, unless the topsoil is removed.

In lead-mining regions the heaps of spoil present a threat to cattle, as lead contents remain dangerously high and will also be a threat indefinitely unless remedial action is taken. Removal of the topsoil is the best way to allow such areas to be grazed safely. The areas surrounding old munitions works present a similar threat, which may only become evident during a drought, when cattle consume a significant quantity of soil with short herbage. Clay pigeon shooting may also leave lead on fields, which cattle can ingest during dry weather.

Lead has a particular affinity for bones and causes osteoporosis; it also enters the liver and kidneys. It interferes with both iron metabolism, causing anaemia, and cadmium metabolism, causing nephrotoxicity. It typically causes a blue line at the junction of the gums and teeth, and grey faeces. Most of the symptoms relate to the neurotoxicity of lead. Affected cattle may charge around and press their heads against a wall, and later develop ataxia.

Fluorine

Fluorine (F) is involved in bone and tooth formation. There are some areas of the world where fluorine concentrations are naturally high in deep well waters but most fluorine toxicity arises from exposure to emissions from the processing of rock phosphates high in fluorine. Aluminium, bricks, tiles, steel and rock phosphate quarries can all produce high fluorine emissions and the degree of exposure will depend on the prevailing winds and height of the emission source. The inclusion of phosphates in mineral supplements will add significantly to fluorine intake unless defluorinated phosphates are used.

Cattle are the most susceptible of farm livestock to fluorine toxicity, and especially dairy heifers, as their bones and teeth are actively growing. Mottled and malformed teeth and misshapen bones are the usual symptoms of fluorine toxicity, if concentrations in the feed reach 30–40 mg F/kg feed DM. Cattle become lame, milk production can be reduced and fertility impaired at high exposure levels (> 50 mg F/kg feed DM). Deposition of the fluorine in bone tissue provides cattle with some protection from the toxic effects; however, once bone fluorine content reaches 30–40 times its normal level, the excess fluorine invades the soft tissues. The kidneys can excrete a certain amount but once this is exceeded a severe anorexia ensues and death may follow.

Cadmium

Cadmium is a cause for concern both at point sources, particularly around metal smelting works, and because of the gradual accumulation in many pastures. It is deposited in cattle grazing mainly from phosphate fertilizers and sewage sludge and may also be consumed by cattle in mineral supplements with high phosphorus contents. The cadmium content of some soils is naturally high but most of the potential problems are the result of human activity. The problems are not so much in its toxicity to cattle as to humans consuming cattle kidneys and, to a lesser extent, livers that have accumulated cadmium over their life. Only a very small part of the ingested cadmium is absorbed, this being dependent largely on the animal's zinc status. Following absorption, cadmium is complexed with metallothioneins in the liver and gradually released to the kidney, where it is liberated by the lysosome system. It is this liberated cadmium that can cause damage to the proximal tubules. The long half-life of cadmium means that this is normally only a problem with older animals. Ingested cadmium does not readily transfer to cows' milk.

Dioxins

This term is commonly used for polychlorinated dibenzo-para-dioxins, dibenzofurans and polychlorinated biphenyls, though it should strictly be reserved for the compound 2,3,7,8-tetrachlorodibenzo-para-dioxin. Dioxins are used in industrial chlorination processes, incineration of municipal wastes and herbicide production. There is a significant concentration in sewage sludge, which is increasingly used on the land or burned to replace disposal at sea. Both of these methods of disposal could contaminate cattle products. The health risks are principally their carcinogenic, immunomodulatory and teratogenic properties, which have been demonstrated in rodents but not yet conclusively in humans. Concern arises for humans consuming cattle products, such as milk, after cattle have absorbed the chemicals directly or indirectly. This may occur in, for example, cattle lying on or eating newspapers, eating contaminated concentrate feed, or surface contamination of herbage in industrial zones. Milk products are particularly implicated because of the lipophilic nature of dioxins and the high fat content of most milk products.

Mycotoxins

Mycotoxins are sometimes present in purchased milk but, as with other contaminants, they have to survive the processing and the animal's detoxifying mechanism. The main mycotoxin capable of entering milk is aflatoxin B_1, which is often present in cattle feed grains. Aflatoxins can be hepatotoxic, mutagenic, immunosuppressive and carcinogenic and there is an increase in bacterial infections of cows consuming aflatoxin. Zeolites may be used to reduce the toxicity by tight binding of the aflatoxins in the gastrointestinal tract. In Europe, the legal limit of aflatoxin B_1 in cattle feed may result in a limited amount of aflatoxin in milk, even above the legal limit in infant formula. To ensure that the legal limit for infant milk is not exceeded, the concentration of aflatoxin B_1 in cattle feed should not exceed 2 μg/kg.

Conclusions

The relationship between cattle production systems and the environment should be a primary consideration in all units and particularly when new units are being planned. Projected budgets should take into account a greater control of pollution from cattle units in future and the anticipated requirement that emissions are reduced. It is likely that small units will be favoured, because of the difficulty of disposing the large volumes of waste from big units on to small areas of land. Large units are, however, most often able to spend the necessary capital to control emissions by such methods as slurry injection, separation, or fermentation to produce biogas, or slurry effluent capture. Cattle farmers must be ready to take action to control the emissions of substances that are known to be harmful, and should be made aware of the action required if new threats to the environment of intensive cattle farming practices are discovered.

Notes

[1] Includes all emissions from production and manufacturing, CO_2 from fossil fuel energy inputs, methane and nitrous oxides from agriculture.

[2] Eutrophication is the depletion of oxygen reserves in the upper warm water regions of a lake (the epilimnion) as a result of excessive plant growth and organic matter decay.

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12

The Future Role and Practice of Cattle Farming

Introduction

Cattle have been domesticated for at least 8000 years and have been one of the major food providers for humans for approximately 7000 years. Although these are long durations in terms of human civilization, they are only brief periods in human evolution. Despite their relatively long history in human civilization, cattle production systems are now being challenged on many fronts, including:

- their inefficient use of land and water resources to produce human food, compared with other food animals and agricultural crops;
- their contribution to greenhouse gas emissions, both through direct emissions of methane from the cattle and release of carbon locked up in forests when they are felled to produce grazing land;
- overgrazing of fragile land, increasing the risk of desertification;
- difficulties in disposal of excreta from intensive units;
- unsuitability of their products in contributing to a healthy human diet;
- their susceptibility to host diseases, particularly in intensive systems of production, which may transmit to humans, such as tuberculosis and BSE;
- the poor welfare status of many animals; and
- their contribution to the development of antimicrobial resistance.

These challenges are anticipated to change, in alignment with global trends. Human population growth will require more effective use of resources, especially those that are rapidly diminishing and non-renewable, such as phosphorus fertilizers and fossil fuels. Water will become an increasingly scarce resource; and agricultural systems, such as cattle production, which use large amounts of water will need to become more efficient. Food will become more expensive, relative to income, and waste will need to be better controlled.

Diet will change. In an ageing society, foods will need to be increasingly functional to maintain healthy humans. As medical advances remove the other impediments to a long, healthy life, there will be increasing avoidance of foods presenting a health risk, with wearable devices to provide real-time supporting measures (e.g. of blood pressure); these ‘risks’ might include foods with high concentrations of saturated fats and sugars. Food storage life will need to increase for those older people losing their mobility who are unable to shop regularly. Conversely, for younger people the replacement of jobs with robots and artificial intelligence will give them more leisure time, including to travel and prepare foods from exotic locations that they have visited.

Maintenance of cattle (and human) health will change. The close connection between livestock and humans is fostering the development of diseases that threaten our species. This is not entirely new: one of the first examples was rinderpest in cattle, from which measles developed, a common infection in children in developing countries. In the intensive livestock production units that have developed in the past 50 years, the increased risk of diseases has often been managed by regular administration of antibiotics, often in the animals’ feed. However, antibiotic resistance is now developing rapidly, to make the antibiotics ineffective not only in the animals but also in humans. Scientists are hurriedly searching for alternatives but any new antibacterial agents will eventually produce the same resistance in bacteria in such intensive livestock conditions. Thus we have to change the way we keep our animals, not attempt to medicate our way out of the problem. Increasingly, the diminishing availability of effective antimicrobials will require a focus on maintenance of a healthy gut flora to prevent gastrointestinal disorders.

This may include use of lactobacilli as probiotics, for humans as well as calves.

In relation to the efficiency of land use, Chapter 5 showed that beef cattle are inherently less efficient converters of feed to food, i.e. meat. The land area to produce protein (1 g) for different animal and plant species is as follows: beef cattle 1.02 m^2, pork 0.13 m^2, poultry 0.08 m^2, eggs 0.05 m^2, dairy cattle 0.04 m^2, wheat 0.04 m^2, rice 0.02 m^2, maize and pulses 0.01 m^2 (Roser and Ritchie, 2017). Even if we take a broader perspective, with efficiency calculated as energy out/energy in (the latter being labour, fertilizer and other artificial inputs, but not sunlight), the ratio is much lower for dairy cattle, at approximately 0.36, than for cereal production at 1.9 (Leech, 1976). However, when the energy cost of making the bread from a cereal, such as wheat, is included, efficiency falls to 0.53, which is not much better than milk production from dairy cows. Not all vegetable production is efficient in energy terms: lettuce production, for example, has an energy efficiency of 0.002. Energy efficiency is also easily modified by the distance that food has to travel before it is consumed. For example, long-distance air transport of 1 kg of organic meat has roughly the same environmental impact as the primary production of the meat itself (Reijnders and Soret, 2003). Deep-freezing of the product can have an even greater additional impact. The energy required post-slaughter for processing meat can be low, compared with vegetable products. Foods from cereal grains and oilseeds often require considerable energy expenditure during processing and cooking if, for example, the grains are crushed and the starch is fermented into a loaf of bread, sliced, frozen for storage and toasted before consumption. Any perceived inefficiency of land utilization for meat production must therefore consider the additional energy requirement for processing and cooking. Clearly, meat production cannot be dismissed as inefficient, particularly if it utilizes land that cannot easily be used for agronomy. It must be compared with other foods in terms of total resource use and pollution potential. The requirements for different resources must be considered in the light of the scarcity of the resource in different regions. Usually energy efficiency is not much considered when deciding which agricultural systems should be perpetuated, as extensive subsistence farming has energy efficiency values ranging from 10 to 60, i.e. there is vastly more energy in the output than is used in the production of the crop, but that is of course explained by the use of natural resources, especially sunlight for producing the crops.

Nevertheless, as developing countries emerge from times when malnutrition and poverty were rife in human society, their desire to consume more high-quality protein is increasing demand for cattle products. An increasing proportion of the world's beef production is in developing countries, as was predicted at the end of the last century (Delgado *et al.*, 1999). Consumption patterns are also changing rapidly, though beef consumption is still much greater in developed countries. It is increasing in developing countries, albeit not as fast as other meats, particularly chicken. Part of the change in demand from developed to developing countries is due to increased affluence in the latter and the fact that meat is increasingly perceived to be a staple commodity. At incomes of US$1000–10,000, every 1% increase in income increases beef consumption by 2%, whereas at incomes above this level it is increased only by 1%.

Part of this change is due to urbanization. In Indian cities vegetarianism is considered old-fashioned and associated with the ruling classes, therefore city dwellers are more likely to diversify their diet into meat (but not beef) and milk products than are rural dwellers. The growing middle classes like to eat meat to distinguish themselves from their forebears. In developed countries where meat-eating is more traditional, vegetarianism and veganism are growing amongst the youth, who are conscious of the detrimental impact of meat consumption on the environment, animal welfare and, most importantly to them, their own health.

As well as increasing per capita consumption, populations are still expanding in developing countries, on average by about 1.5% annually. Urban growth rates are about double this value, leading to rapidly escalating demand for livestock products. Much of the increased demand for meat is being met by increased production in developing countries, while milk production is still focused in developed countries; beef consumption can be a status symbol in the former.

Although industrial-scale production is largely confined to the poultry and pig sectors, which have grown more rapidly than for beef and sheep, some intensive cattle production systems have been established in Asia and South America. In most of Africa cattle remain in traditional grazing systems, with little intensification (Fig. 12.1).

The apparent incongruity of increasing criticism of cattle production systems in the developed countries and rising demand for cattle products in developing

Fig. 12.1. Cattle farming is traditional in sub-Saharan Africa, as in this village in Ghana. Note hand milking of the cow in the foreground.

countries is leading to a shift in production to the latter. However, cattle farming is a long-term commitment and, as such, is usually regarded as an inelastic business. Cattle farmers cannot react rapidly to changing demand, because of long production cycles and the high level of investment required to provide the necessary resources, especially for milk production. Occasionally, cattle production systems have been forced to change rapidly, such as in response to political revolutions in the former Eastern Bloc countries, or as a result of new diseases, such as following the outbreak of BSE in the UK, which had major effects on consumer confidence in the safety of cattle products and hence demand. Sudden changes in demand can precipitate improvement of the systems, which otherwise would take place slowly over several decades.

Such instances can also result in instability in cattle production systems, with businesses failing and sometimes even the social structure of the region being affected. More gradual change results from technical developments. Reliable long-term forecasts of the requirements for cattle products will enable changes to be made most efficiently. This chapter describes the changes that are taking place in these requirements and the effect that these are having on the way in which cattle businesses are managed in the rural environment.

Ethical Considerations in Cattle Production

The ethical implications of cattle production are broad-reaching and could have a major influence on the economies of many countries in the world. Not only are there concerns about the welfare of cattle, especially in intensive production systems, but also many people hold a respect or even reverence for cattle, which leads to concerns when their basic rights are violated. For example, people may have concerns about the extent to which we should manipulate the genotype of this species for our own benefit and the impact that this has on the form and function of the animals concerned.

Welfare concerns are focused on the impact of intensive management systems on the health of cattle and their ability to perform natural behaviour. The high prevalence of lameness and mastitis in housed cattle is directly attributable to the environment in which they live. Production diseases, such as hypercalcaemia or hypomagnesaemia, are attributable to the imbalance between the genetic potential for production, especially milk, and the level of nutrient supply. Offering cattle feeds that have been harvested and processed mechanically allows cattle to consume them very rapidly, for example when they are being milked, with the net result that their motivation to search for and consume grasses or browse material is not satisfied and they develop abnormal feeding behaviours, such as repeated licking, tongue rolling or feed tossing.

Processed concentrated feed often relies on bypassing the ruminal fermentation to be digested and absorbed post-ruminally, allowing absorption of nutrients in excess of those that the ruminal microorganisms can supply. However, providing nutrients that bypass the ruminal fermentation process can overload an animal's ability to utilize them, with the net result that excess nutrients, such as lipids, accumulate in the body, particularly in the liver where they may cause damage. The natural grazing behaviour of cattle may be generally considered unable to reliably provide sufficient nutrients for high-producing cattle and is avoided by feeding cattle on conserved nutrient-rich feeds.

Other welfare concerns relate to the various amputations that are deemed necessary for cattle to be kept in economic and labour-efficient farming systems (see Chapter 10). Removal of their horns, sometimes when fully developed and without anaesthetic or analgesic, is still normal practice in extensive rangeland farms. It is possible to breed cattle that are naturally polled, i.e. without horns, but so far there has been insufficient incentive to do so. Tail docking is still commonly practised in some intensive dairying regions to eliminate the need for the herdsperson to keep the tails clean and free from faeces. Castration of male calves to reduce aggression is normal in most cattle systems. Hot-iron branding is used in extensive cattle farms rather than freeze-branding, even though it is more painful. Surgical deviation of the penis of bulls to prevent them serving but allow them to identify oestrous cows is unnecessary, but still conducted in parts of the world.

Breeding objectives are under scrutiny, in particular to examine whether they have distorted the animals' form and function and introduced welfare problems. Breeding dairy cows to produce large quantities of milk requires them to eat more and there is a significant risk that they cannot consume enough feed, with resulting weight loss. This tends to be self-rectifying since thin cows do not reproduce, though there is an increasing trend to administer the reproductive hormones artificially to enable them to conceive. Breeding for high muscularity in beef cattle has led to excessive weight being placed on the joints of the limbs, with resulting lameness problems, just as were found to occur when the broiler industry bred for excessive muscularity. In cattle it brings the added problem of calving difficulties, with many having to be born by caesarean section.

Another ethical concern is the removal of calves from their mothers at a very early age, often at 12–24 h. Early weaning prevents the natural learning process, whereby calves develop an understanding of what to graze, what dangers exist, social behaviour in the herd, etc. Separating calves from their mother makes them learn more from their peers and the herdsperson, which can still be effective but is not as easy or natural as occurs through the mother–offspring bond.

People have ethical concerns about depriving cattle of their life at an early age, particularly in Eastern countries, where there are religious traditions concerning slaughter practices. The killing of male calves from dairy cows at just a few weeks of age represents to many people the waste of a life but is still commonplace in countries where the beef industry utilizes breeds selected for rapid muscle growth and tender meat. Male dairy calves essentially have no role in such cattle production systems. Ethical concerns are most extreme in countries with a strong Hindu tradition, with cattle being used only for production of milk or dung and not eaten for meat. There are also restrictions on cattle-handling practices in Muslim countries, most notably the restriction on stunning cattle during halal slaughter (see Chapter 10).

The Relationship between Cattle Production Systems and the Environment

As the world population of farm animals increases to cater for the increased human population and their increasing desire for meat, the livestock's effect on, and interaction with, the environment becomes of major significance. Sustainable systems, where the environment is not adversely affected in the long or short term, may not initially be economically viable, particularly if labour costs are high. External support may be provided from governments as encouragement, such as when it has been provided for conversion to organic systems. The direction of these grants will depend on the public need to maintain different systems of animal production. In regions of the world with a long history of settled agriculture there is a reluctance to see traditional, extensive systems of cattle farming disappear. Grants that were originally provided to support high production levels are increasingly being diverted from direct support for food products to provide support for maintaining traditional systems or features of environmental value in the countryside. This may include old cattle buildings, traditional systems of forage conservation (usually in the form of hay, rather than silage) and even support for the maintenance of traditional cattle breeds. Support may also be provided to maintain farmer income when natural disasters affect the industry, in particular during drought, flood, outbreaks of disease or collapse in public confidence, and this will preserve stability in the cattle industry. Stability is further enhanced by making changes in support gradually but sometimes new governments may bring about rapid changes that damage the industry. Rapid withdrawal of governmental support for dairy farmers in New Zealand in the 1980s took farmers several years to adapt their systems and find new markets. The period while farmers adapt to new political directives can be destabilizing and may lead to long-term damage to the production system that has taken many years to establish.

This happened in the former Eastern Bloc countries, where not only was much of the government support and control rapidly withdrawn but also there was enforced land redistribution, as state and collective farms were returned to those who had been their owners before the land was collectivized, which was often at least 50 years ago. Alternatively, the land was distributed between the farm workers. In addition to these difficulties, there was a marked loss of purchasing power for cattle products, which are expensive compared with other staple foods. As a result of escalating costs of animal production and reduced prices for the products, many of the new owners were unable to operate a viable farming system and land changed ownership several times. A significant proportion of the land was initially returned to systems of production requiring fewer resources than cattle farming, such as sheep production.

In the developing regions of the world, expanding populations and increasing demand for cattle products create a need for sustainable and efficient systems of production that use the most appropriate technology. In the latter part of the 20th century many developing countries, such as Mali, relied on surplus milk powder from the subsidized dairy industry in the EU to support their infant-feeding programmes. Now that dairy surpluses in the EU have been brought under control and there is a growing urban population and therefore demand for milk products, many developing countries are expanding their dairy farming industry. The new dairy systems are often based in peri-urban districts, with the major difficulty being lack of suitable fodder for the cattle. It would be preferable for long-term sustainability of the human population to confine dairy production to marginal land, where cattle fodder can be grown easily. Other land can then be maintained for the production of more demanding crops – food crops, fuel (e.g. oil crops) and raw materials (e.g. fibre crops). Additional land may be kept in its indigenous vegetation to attract tourists, maintain a gene pool of diverse biological material and provide credits in a carbon trading scheme. These multiple land-use systems are evolving as a result of market forces in some less developed regions of the world, where government support for the land-based industries has traditionally been limited. It might evolve faster under the combined influence of market forces and strategic support from developed regions to prevent environmental damage and over-exploitation of natural resources. This must be carefully considered; for example, sending a cow to Africa can undermine local enterprise, create health and welfare problems for the cow and introduce reliance on Western aid. Alternatively, support from developed nations has sometimes been limited, as they do not always take a sufficiently long-term view of the benefits of collaborating with developing nations.

In future, land for cattle production will face increasing competition from other potential users, because cattle products can be replaced by foods produced more efficiently, and it is likely that sustainable forms of fuel and raw material production will require more land in future. Cattle have been an easy means of producing food from land but, as land becomes scarcer, their use will be increasingly challenged by alternative land users.

The Future Market for Cattle Products

No consideration of the future role of cattle in the countryside is complete without exploring the future demand for cattle products, as this will largely determine the economic climate in which farmers will operate. This must be put in the context of a world population living in either industrialized regions that have low or zero population growth, or countries that are trying to develop but are hindered by rapidly expanding populations, debt repayment obligations and a limited export market as a result of the industrialized countries protecting their market. The issue of freedom of trade is of vital importance to the future demand for cattle products in the developing world (Phillips, 2015). Tariffs restrict the access of developing countries to markets in the developed world, where the demand for high-priced cattle products is strong. Greater trade would be possible if these tariffs were abolished and there would be greater uptake of the technological developments that allow cattle products to be safely stored and transported. International trade is criticized on account of the significant environmental costs of transport, but if cattle products cannot be produced in an environmentally efficient manner in the country levying the tariffs, abolition of the tariffs could actually reduce the environmental impact, as for example in the New Zealand trade in dairy products to Europe (see Chapter 11).

The potential exists for developing countries to trade sustainably with developed nations in cattle products, providing the revenue to improve production systems and increase output for their increasing share of the world's population. Africa, for example, is predicted to double its share of the world's population by 2052 (from 12% to 24%). However, the Western-style market economies are fostering an increase in the rich–poor divide and may take the responsibility for environmental protection out of central control. The dissolution of the large state and cooperative farms in Eastern Europe produced a return to extensive farming methods, at least temporarily until the new land owners could accrue the capital to invest in their businesses. Extensive grazing systems were utilized and, in some cases, tractors were even replaced by animal traction.

The development of a sustainable cattle farming industry may benefit from a certain degree of central support, otherwise some cattle farmers will overuse land resources for short-term profit. However, any central control has to be for the long-term benefit of the farming system and not to increase the productivity of the land at the expense of its long-term sustainability. Both the 5-year plans of the Communist era and the product support of the Western European governments can be criticized on this account. Former successful agricultural systems used centrally managed insurance policies, such as resting the land periodically or creating stores of food reserves to guard against the extreme adverse conditions that occasionally afflict farming systems. Land fertility will decline unless account is taken of the need to return to the soil the resources that are removed by farming. Recent discussion on support for carbon sequestration in the soil, using cattle as agents to tread it in, offers hope that the vital importance of soil fertility will be recognized.

The globalization of the world's agricultural industries, often with central control by big multinational companies, has affected beef cattle production, directing it down the path of large feedlot-based production. The dairy industry has been influenced also, with the major dairy companies advancing an intensive form of production in many parts of the world.

The demand for beef

In many industrialized nations the increased affluence of the past 50 years has stimulated an increase in meat consumption, which now stands at about 50 million tonnes worldwide each year. Meat consumption is particularly dependent on income, increasing continuously up to $20,000 GDP per capita (Tilman and Clark, 2014). Rapidly escalating demand for beef and other meats is increasing the demand for agricultural land worldwide, which if provided by land clearing would further increase greenhouse gas emissions. A transition to a more sustainable diet and land-use pattern is essential if we are to maintain food supply through to 2050 (Tilman and Clark, 2014).

In Europe, a post-war policy of increasing agricultural production was successful up to the 1980s. Coupled with an increase in disposable income, this led to an increase in beef meat consumption from 16 kg/head per year in the 1960s to approximately 25 kg/head per year by the end of the 1980s, after which it gradually declined back to about 15 kg/head per year in the face of competition from other products. This is still considerably less than consumption in the USA, which averages 36 kg/head per year. Beef meat consumption has begun to decline in some of the most advanced Western nations, such as Germany, Hungary and Switzerland, particularly for the younger members of the population, who usually indicate future trends in consumer demand. There are three main reasons for this: human health concerns; animal welfare; and competition from vegetable-based foods.

Human health concerns

There have been many assertions that eating meat, particularly red meat, is detrimental to human health – specifically that it raises blood cholesterol and increases the risk of heart disease, stroke, diabetes and some cancers. Beef from cattle fed on grain and stored forage is more likely to promote these diseases, compared with beef from grass-fed cattle. Fresh grass has an improved lipid profile rich in linolenic and linoleic acids, resulting in omega-3 and conjugated linoleic acids in the meat. These are essential fatty acids with beneficial effects on human health.

Both advantages and disadvantages of eating beef have been demonstrated. In developing countries protein consumption is often inadequate: meat is rich in this nutrient. Iron-deficiency anaemia is also commonplace: meat is a good source of iron of high availability and a good source of B vitamins.

In the industrialized world, an additional risk of meat consumption relates to the excessive nutrient intake of a large proportion of the population. Increasingly sedentary lifestyles in Western countries have reduced nutrient requirements. Meat-eating is associated with increased risk of breast, prostate and colon cancer, partly because it stimulates steroid hormone production and partly because meat lacks the protective effects of fibre and antioxidants. Another major risk is that nutrients, and in particular saturated fat consumption on a high-meat diet, will be excessive and obesity will ensue, which places increased demands on the cardiovascular system. Meals with high carbohydrate content lead to a greater feeling of satiation than isoenergetic meals with high fat content. This is particularly true for structural carbohydrates (fibrous products) and there is a corresponding reduction in appetite. In relation to mineral supply, cereals and other high-fibre products consumed in Western countries are often fortified with minerals and vitamins to ensure adequate intake, though deficiency problems are more often seen in developing countries as total intakes are low.

Animal welfare

The intensification of cattle production systems has heightened awareness of the welfare of the animals, with many people citing animal cruelty as the main reason for non-consumption or low consumption of meat. Intensification is often believed to lead to a reduction in animal welfare. Many of the fundamental questions remain unanswered and often unconsidered. Do cattle prefer a short, happy life to a long one in poor conditions? What are their needs for mental stimulation and how do these interact with physical requirements, of which we have a better knowledge? Is an anthropomorphic evaluation of cattle needs, so often used by the public to judge production systems, a useful guide or an unnecessary irrelevance? How does the animal's perception of its well-being change during its lifetime?

In the EU, intensification has been most evident in the pig and poultry industries, yet it is the consumption of these meats that has increased, while that of beef is declining. This anomaly suggests that other factors than welfare concerns are also influential for changing meat consumption habits. Relative cost is one of these, with the beef industry failing to reduce prices through the use of modern technology to the same extent that the white meat industries have done.

Competition from vegetable-based foods

The rapid development of the food industry, particularly in industrialized regions of the world, has produced increased competition from other staple foods, with meat often appearing relatively less attractive. The food manufacturers have developed non-meat foods that appeal strongly to all our senses. Consider, for example, the growth of the breakfast cereal market, which has replaced the traditional meat-and-eggs cooked breakfast. Cereals are ultra heat-treated to improve digestibility and coated with a large variety of sweet, nutty or aromatic substances to stimulate the gustatory senses. The food-processing industry has largely concentrated its efforts on non-meat foods, because meat with its high raw material cost has less potential than, for example, cereals for added value. The visual appeal of non-meat foods has also been exploited to the full, and the full range of colours of breakfast cereals is instantly attractive to a child's visual palate.

By contrast, the visual and gustatory attractions of meat are increasingly less obvious to many consumers. The appeal of strong-flavoured meat, with its complex volatile flavour compounds, is acquired during childhood. Children are conditioned to enjoy the taste of strongly flavoured meat, in the same way as the enjoyment of spiced, mouldy and smoked foods can be learned. It is possible that animals developed the pheromones that produce volatile meat flavours partly to prevent them from being eaten: a prey animal's equivalent of plant toxins. Indeed it would be surprising if animals had not developed such adverse flavour compounds during the long course of predator/prey evolution. The experience of zookeepers suggests that the consumption of red meats that are highly flavoured, such as the meat of male goats, is an acquired taste for many predators.

These are some of the issues that explain the decline in beef meat consumption by young people in many developed countries. In developing countries, the increases in population and affluence are leading to an increased demand for meat products. In developed countries, even if people have no ethical beliefs encouraging them to refrain from meat eating, it is highly likely that red meat consumption will continue to decline in the face of increasing competition from plant-derived foods that have been flavour-enhanced or modified in other ways. There is already an increased demand for meat with low fat content or fats that are protective against heart and circulatory diseases, such as the omega-3 fatty acids. The intensive methods of beef cattle fattening, with high-energy diets and lack of exercise, lead to rapid rates of fattening, with the deposition of saturated fat in the muscle tissue. In future, discerning meat consumers may require meat from extensive production systems, with a return to grazing systems, and they may pay more for the products, which will have smaller amounts of intramuscular fat that is less saturated. This would help to satisfy demands for the animals to be raised in high welfare conditions, as it would be viewed as more natural than indoor fattening.

Vegetarianism and the avoidance of cattle products

Most vegetarians do not accept the consumption of other animals on health and ethical grounds. The health benefits of a vegetarian diet are mainly a reduction in diabetes, coronary heart disease and certain types of cancer (Tilman and Clark, 2014). For a small minority the concept of 'exploiting' captive animals for meat production is unacceptable. We do not yet know enough about the relative importance of the loss of certain freedoms to determine accurately whether the life of cattle is satisfactory to most consumers.

However, the systems are most often criticized for not offering cattle basic resources that we would value for our own mental and physical health, such as adequate space, companionship and 'natural' surroundings – reflecting our own highly complex human social requirements. In relation to space, we are all captive to a certain extent, humans and cattle, in the biological system in which we function. For humans, this may involve spending most daylight hours in an office, or for farm livestock in a stable. We all function in a hierarchical structure, which is the basis of a complex society, and we welcome the existence of distinct territorial boundaries (personal space) as increasing our security. Some cattle, but not all, suffer stress in close confinement and develop behavioural modifications (e.g. stereotypies) to help them cope. It is difficult to criticize cattle production systems for having inadequate space per animal until we know precisely the requirements that cattle have and their tolerance of space allowances that differ from the optimum. However, at the same time as we attempt to understand the needs of cattle in detail, alternatives to farmed meat are being developed that may rapidly gain acceptance.

Competition from in vitro meat

In vitro meat can be grown using stem cells or adult skeletal muscle satellite cells on a digestible scaffold immersed in a suitable medium, including nutrients and growth factors, all contained in a rotating bioreactor. By this process, beef burgers have been produced. Replication of structured meats, such as steak, is more difficult, as these require a blood supply, fat cells, connective and vascular tissue and a means of exercising the muscle tissue. Scaling up the process to commercial production has not yet been achieved but it may be only a decade or two away. When this happens, assuming it does, many of those eating processed beef meat in the form of burgers may be willing to substitute the *in vitro* meat into their diet. The advantages are partly ethical: no animal welfare problems, no need to kill animals, less use of resources and less waste at a local and global level; and partly health related: manufacturing the product in this way offers the opportunity to manipulate the composition so that it has less or no saturated fat, and mineral or vitamin supplements can be added. If widely adopted this technology could have profound implications for cattle production worldwide, in particular the changes in the landscape and the opportunities for growing more food directly for human consumption. The plight of livestock farmers would need careful management but potentially, if such technology could be used to replace at least some of the intensive beef production, more cattle could have a good life, at pasture, rather than in a feedlot, and more of the world's scarce resources could be utilized for directly producing human food or supporting the conservation of wildlife resources. Livestock farmers could then be viewed as stewards of the land, utilizing the resources they manage to meet market demands. Much will depend on demand; if the price of meat goes up dramatically as a result of increased demand and declining land, water and energy resources to devote to the relatively inefficient method of producing food from cattle, *in vitro* meat may become competitive.

The future demand for milk and milk products

The liquid milk market has declined in recent years due to competition from soft drinks and bottled water. However, in the less developed countries, supplies of liquid milk, recognized as a healthy drink and associated with a Western diet, and milk products (in particular, cheese for pizzas and flavoured milk drinks) have been increasing. For example, whole milk consumption increased from 22 kg/head to 32 kg/head per year from 1977 to 2013 in the least developing countries. In China, increased affluence has led to milk consumption increasing very rapidly, from 4 kg/head to 33 kg/head per day between 1985 and 2013. Because milk spoils easily and is usually traded in the powdered form, most is consumed in the country of origin, leading to a rapid growth in dairy cow production in Asia over recent years.

Milk and milk products were not a natural part of the adult human's diet until cattle became domesticated. Milk solids are naturally high in fats, as a proportion of total solids, which will tend to lead to obesity when consumed in large quantities. Most humans are conditioned to accept cows' milk and milk products as infants.

The major factor governing the maintenance of demand for milk products is the adaptability of the raw material, as it is with cereals. The food-processing industry manipulates the milk constituents in ingenious ways to produce palatable and convenient foods, utilizing all the time our conditioned attraction to dairy fats. As with meat, only small inclusion rates of the fat are actually necessary to impart the necessary flavours, which has led to a profusion of mixed dairy/vegetable fat products, or low-fat dairy products for those conscious of the need to minimize saturated fat intake. Sufficient viscosity to improve handling properties is achieved by adding artificial thickening agents. The availability of palatable alternatives to dairy products gives some reason to be pessimistic about continued demand for dairy products, even those of reduced fat concentration in the industrialized countries. The slaughter of bobby calves is of widespread concern, as is the removal of calves at a very early age. These are fundamental ethical concerns that are difficult to address without changing the system drastically. Doubts about the welfare of dairy cattle kept in intensive units and their environmental impact may strengthen and more research is needed to understand their needs. Intensive production and a high standard of animal welfare are not irreconcilable but there is a problem of human perception in the absence of scientific evidence.

Providing effective information to the public on the environmental, health and welfare consequences of consuming cattle products is assuming increased importance as the urbanization of the human population results in limited contact with production systems. Information is provided by the media, food labels, special interest groups and by influential peer groups. Increasing competition by the food manufacturers for market share is making food labelling a contentious and frequently litigious issue. Associated with this is the need to make consistent progress in the public approval and sustainability of cattle production systems. To do this it is necessary to have accepted protocols for measuring welfare in areas of concern, as well as targets for achieving different status levels and means of monitoring at a farm level.

Alternative uses of cattle

Many pharmaceutical proteins are produced by ruminants but these are usually grown in sheep blood rather than in the blood of cattle, because of the ease of management and handling of sheep. However, cattle are used for harvesting serum from the fetus, because of the special properties that it has to support cell growth. Fetal calf serum, also known as fetal bovine serum, is collected from fetuses at abattoirs to be used in cell and tissue cultures, e.g. for the production of monoclonal antibodies. Although the serum contains no antibodies of its own (because there is no transmission from the mother's blood), it is a valuable source of nutrients, hormones and growth factors for cultures. Worldwide, about 500,000 l of serum is collected annually from between 1 and 2 million fetuses. Calf serum is obtained by removing the uterus from pregnant cows during slaughter and inserting a needle directly into the fetal heart to remove blood under vacuum. Only fetuses over 3 months of age are used, because otherwise the heart is too small to puncture. This blood collection takes place 20–60 min after the mother is slaughtered. The ethics of the process are now under scrutiny: the fetus may be alive during collection, which is actually economically desirable because more blood can be collected from a beating heart.

An alternative procedure involves treating mice to develop tumours and producing ascites (abdominal fluid) as a source of the antibodies but there are major concerns about the welfare of the mice. For some purposes, suitable synthetic protein complexes can be used to replace fetal calf serum, with the added advantage that these are guaranteed to be free from viruses, prions and mycoplasma, which may influence cell growth. After BSE was discovered in European and American cattle, cattle in Australia and New Zealand were the main source of fetal calf serum, which became very expensive. This raised the possibility that, for a brief period while there was a limited source of the serum, farmers in Australia or New Zealand might deliberately send pregnant cows for slaughter because of the high price paid for such animals.

One method of obtaining antibodies from calves that is used commercially in Australia is to immunize pregnant cows close to parturition against human diseases, such as travellers' diarrhoea or shigella, and then collect the colostrum after parturition. This is a mixture of the cow's blood and milk and is rich in antibodies, which is then freeze dried and made into an oral immunization for humans.

Gelatin, a protein extracted from collagen in bones and hides, is another product from slaughtered cattle, used mainly as a thickener in the food industry but also in pharmaceuticals, photography and cosmetic manufacturing.

Genetic insurance

Theoretically, in today's age of rapidly advancing genetic manipulation techniques, cattle could be transformed into meat- and milk-producing 'vegetables', incapable of normal behaviour and with gross distortions of body morphology. To some people, cattle breeding has already gone too far in this respect by, for example, producing cattle breeds with muscular hypertrophy that can result in a dystocia during calving unless caesarean operations are routinely performed. It would be an irony if, at the very time when we are trying to maintain genetic diversity in our wild flora and fauna, we deny cattle their genetic inheritance and diversity. This is their security for future generations, which must be the main priority of all species, wild or domesticated. In this time of very rapidly changing agriculture and countryside management it would be unethical to deny cattle the genetic inheritance necessary for long-term survival. There are three main reasons why the maintenance of genetic diversity in our cattle is important.

1. Loss of environmental adaptability. The rate at which an organism can adapt to meet changing environmental circumstances is dependent on the diversity of its genotype. For example, animals in the genus *Bos* originally had a limited role as grazing species in Asia and, following domestication, the species diversified into a wide range of genotypes to adapt animals to varying environmental conditions in which they were kept. In recent years some of this genetic diversity has been lost, as the Holstein-Friesian has become the dominant genotype for intensive milk production systems. The cows of this breed require feed of high nutrient density; they are more susceptible to hot conditions and often have less disease resistance than cows with lower production potential. Their milk is of low solids content and is therefore relatively expensive to transport and process. In the future, resistance to adverse environmental conditions and low milk transport and processing costs may be more important than a high milk yield per cow, the major benefit of which is to reduce the associated labour requirement. The genotypic information needed to adapt to new demands must be preserved, if production is to be efficient in relation to future resources.

2. Human security. Human manipulation of the environment is far less impressive than the product of millions of years of evolutionary development. Increasingly, people need to complement a stressful working environment, which is often in artificial surroundings, with relaxation in a countryside that contains evidence of natural variation and sustainability, such as exists in some cattle production systems.

3. Product diversity. People's dietary habits change and the need to allow for changes in human dietary requirements necessitates the maintenance of product diversity. Variation in food type is also part of cultural identity and a nation's heritage, without which life would be less unique to individuals and therefore less satisfying.

The maintenance of biodiversity in natural fauna and flora on cattle farms

A range of grazing pressures on grassland need to be provided to create a diverse environment. Further research is needed on the effect of cattle management practices on the flora and fauna in the countryside, but we should not necessarily assume that our dominant farm herbivores, cattle, always create the best environment. Cattle can do considerable damage to shrubs and trees in rangeland when there is insufficient grass, as can natural browsers such as goats and deer. Cattle are unselective grazers, which makes them suitable to maintain a wide variety of pasture species, whereas selective grazers such as sheep can preferentially graze some plant species and reduce their competitiveness.

The main necessities for maintaining a diverse flora, and hence wildlife, are to maintain a diverse range of stocking densities and not to overstock the pastures. Wild or range animals have often been depleted in numbers to make way for single-purpose cattle production systems, at the expense of the environment and biodiversity of the region.

Diverse flora and fauna can be accomplished by maintaining family (matriarchal) groups of cattle, as the animals within a group have different foraging strategies according to their individual needs (or physiological state) and morphology, particularly the shape and size of their mouths. More effective, however, is the mixed or rotational grazing of different livestock species with cattle. Cattle and sheep are often grazed together and graze in similar strata of the herbivory. Cattle are more complementary to the feeding habits of natural browsers, such as goats or deer. Sheep are not only selective in the herbage species they choose but also they are able with their small mouthparts to select only the young leafy vegetation and leave old brown stems. This renders a sward unproductive but it leaves a residue of herbage that cattle will eat if there is nothing else available (foggage). Foggage used to be produced in temperate farming systems as a standing hay crop for winter fodder on free-draining farms. The practice encourages the more erect grass species such as Yorkshire fog (*Holcus lanatus* L.) and cocksfoot (*Dactylis glomerata* L.) and reduces the white clover (*Trifolium repens* L.) content. Cocksfoot is particularly prone to winter frost damage. In the long term, creating foggage (fogging) can open up the sward to invasion by novel species and increased biodiversity. If old mature herbage is thought to be unsightly or wasteful, grazing sheep pastures with cattle will remove much of the dead material. Cattle can be of similar benefit to horse-grazed pastures.

Silvopastoral systems will delay the maturation of herbage but this will also reduce the seed set by plants, resulting in some loss of annuals. A system of cattle grazing among fruit trees has been employed effectively in many temperate regions for centuries, producing high-quality pasture for the animals, fertilizer for pasture and trees and amelioration of the environment for the animals, all of which are more difficult and costly to provide in dedicated single-purpose systems. The value of such a system is obvious, with a high regard for the welfare of the cattle, species diversity and a variety of cattle and plant products that indicates increased self-sufficiency and economic insurance for farmers and their families. Most modern silvopastoral systems use trees for timber rather than for fruit, since the fruit production industry has not yet come under the same sort of pressure for extensification as other agricultural sectors. Also, there continues to be a strong demand for timber for construction worldwide.

The timing of grazing will also have a distinct impact on vegetation diversity and composition. Traditional European hay meadows with their varied flora were maintained for centuries by a precise management regime, which has long since been abandoned by most ‘output-oriented’ farmers. In this management system cattle are overwintered on straw, with the resulting farmyard manure being spread in the spring for a limited but prolonged nutrient release to the pasture. Meadows are grazed by cattle until late spring and then rested until a late hay cut in midsummer, by which time all the annual flowers have produced their seeds. Subsequently, the meadows are lightly grazed by cattle in the autumn and, if available, by sheep in winter. Similar management strategies are available for maintaining other scarce or diminishing systems such as grassland on calcareous soils, water meadows and heather moorland. If the intention is to restore species diversity to ancient meadows, it should initially be cut early, perhaps even in late spring, to prevent seeding of the pasture. Seed of the desired species may then be introduced artificially and the floral diversity subsequently maintained by late or no cutting. Early cutting is damaging to the nesting sites of ground-nesting birds.

The role of cattle in developing countries

In developing countries, the role of cattle will by necessity be different. Governmental or public support is unlikely to be available for preserving traditional cattle production systems (if they exist) in the way described above. There can be little moral justification for expanding the area under cultivation for cattle feed to satisfy the demands of a small minority for meat or foreign capital while food supplies are inadequate, when insufficient fuel supplies, for example for cooking, may be causing considerable deforestation. The same argument applies to the importation of cattle from overseas. The rising population inevitably will mean greater areas under cultivation and perhaps even greater pressure than before to confine cattle production to the marginal areas and to use industrial and other by-products. It is inevitable that cultivation for human food will increase in regions where the human population is increasing and this will reduce the extent of indigenous landscapes.

The role of cattle in arresting environmental degradation

Well-planned cattle production systems can play a useful role in both developed and developing countries in arresting environmental degradation. Silvopastoral systems with cattle are being used to arrest soil loss and encroaching desert in many areas. Dung from the animals adds useful organic matter to the soil, while trees provide shelter for the animals and stability to the soil and also aid water and nutrient cycling. The importance of recycling as much as possible within a cattle farming system is self-evident but is often practised more extensively in developing than in developed countries. Finally, in marginal soil areas, increasing the organic matter content through treading and manure incorporation can increase carbon sequestration to offset anthropogenic emissions.

Drivers of Animal Welfare Standards

Systems of cattle production must adapt in response to new economic and political pressures and changing moral values. Continued intensification is not inevitable: in some regions it is being reversed because of public concern for the effects on the environment and animal welfare; and in others, in particular the Eastern European countries, it was reversed because of the dissolution of large state farms and a lack of capital to finance intensive production systems following the collapse of communist rule. The increase in the consumption of meat in Western countries that occurred in the 20th century is also being reversed in some regions because of concerns over the ethics of intensive animal production, health concerns and increased competition from other, highly processed foods. This trend could accelerate but will be countered overall by rising demand in developing countries. Relative to the consumption of whole milk, that of milk products is increasing because of their adaptability and palatability. Health concerns increasingly require the consumption (and therefore production) of low-fat milk.

One of the biggest duties that consumers have is to think carefully about what they eat and in particular about whether it is an ethical way to eat. Similarly, farmers have to consider carefully the systems of production that they use for their cattle. It is wrong to support unethical animal production practices, which include intensive systems that fail to allow animals a decent life and fail to provide food in a way that does not harm the environment. There are many who have reasons to prevent us from questioning these practices, as they seek to preserve the lucrative animal industries or their passion for meat eating, but we do have to do this for the sake of our own conscience.

Increasingly, there are controls on production methods, both legislative and through voluntary certification, to gain a higher price for the products. Legislative controls will prevent the worst cases of animal and environmental abuse and may be supported by international standards, such as the World Animal Health (OIE) standards for beef and dairy cattle (7.9 and 7.11 in the Terrestrial Animal Health Code) that have to cater for all 180 member countries and an enormous range in production methods. Because of the generalized nature of OIE standards, a toolkit in the form of an International Organization for Standardization (ISO) technical specification (ISO 34700) has been developed to assist in application. However, this only addresses basic requirements and should be gradually revised to take into account better standards for cattle, so that it can be used as a tool in future to improve welfare standards. Improved welfare, environmental and sometimes labour standards are only provided where livestock are accredited in one of numerous schemes developed by interested parties, usually animal welfare advocacy groups. Geographical region of origin is increasingly used as a means of preserving traditional practices and thereby providing some assurance of quality. Food labelling is critical, and increasingly under public and governmental scrutiny, because it bridges the gap between producer and consumer. It is usually in the form of encouraging the consumer to recognize added value, but a confused consumer is more likely to respect warnings on labels, particularly those concerning their health. Advocacy groups are needed to alert consumers to the accuracy of claims by producers and retailers in an unbiased way; however, their need to raise funds for their activities can encourage sensational claims. Through these mechanisms there is no doubt that public consumption of accredited products is gradually driving change in production methods and creating a corporate social responsibility in producers.

Good labour standards recognize that people working with animals in industrial farming systems and processing systems may have low job satisfaction if they are using animals as commodities, not individuals, and they are keeping them in cramped, dirty conditions without the resources they need. Such treatment may be demanded by managers and owners either to serve their own interests or to maintain a profitable farming system. This may distress workers and make their job difficult, unless they train their minds to ignore the plight of animals. Such attitudes may influence the way in which they treat animals and even other people, particularly the less advantaged. In other commodities, such as tea and coffee, use of a Fair Trade label, which recognizes labour standards, is commonplace. This is likely to be required for cattle production systems as they are increasingly based in developing countries.

Cattle enterprises are likely to become increasingly international, with capital from entrepreneurs worldwide supporting the establishment of intensive production systems in developing countries. The demand for sustainably produced commodities is slow to develop in these countries, but if globalization continues as in recent years, eventually sustainability will be recognized as essential.

As well as accrediting organizations, some major food retailers are developing their own standards. Their considerable purchasing power means that these are mainly directed to large-scale producers, which further contributes to the inexorable demise of the small-scale farmer. In China, where demand for milk and milk products has risen very rapidly with the economic development of that country, growth of a dairy industry, almost de novo, has been strongly supported by major international dairy companies. With such rapid expansion comes the need for new standards to regulate production and processing. This was tragically demonstrated in 2008 when six infants died, and another 300,000 became sick, following the addition of melamine to milk products to cover up dilution. In this respect milk is particularly susceptible to fraud, particularly that associated with dilution. Replacement of beef by unwanted horsemeat has also been a problem in recent years and further issues are likely to arise as *in vitro* meat develops as a product in the future.

These trends are associated with corporate domination of the food industries that has arisen in the past 50 years. The corporates are often more in touch with the market and respond to market forces better than small-scale producers but the close connection between managers and their animals, which drives good animal welfare standards, is often lost in the large-scale production systems favoured by the major corporate companies.

The Future Role of Cattle in a Multi-purpose Land-Use Context

From the previous discussion, it is evident that the role of cattle in future will not simply be to provide products for human consumption. In some situations, cattle farmers can be regarded as stewards of the countryside and must meet the public needs for high-welfare systems that maximize environmental protection. The demand for agricultural extensification in industrial countries, and the need to confine cattle to marginal land or as complements to arable enterprises in developing countries, will inevitably change the systems in operation and farmers will need to be flexible to survive within the industry. Above all, sustainability in cattle production systems will only be achieved if adequate attention is paid to social licence, i.e. gaining the approval of the public. This is easier in areas in which cattle production has been an important part of the recent historical development of the country, such as in Australia, New Zealand and much of South and North America. Sustainability needs to be considered for the use of natural resources, animal welfare, efficiency of production, pollution potential, disease transmission potential and management of people within the industry. There have been movements to reduce environmental impact in some major beef production areas, focusing on zero deforestation, responsible packaging and sourcing of products. In other areas sustainability is being addressed by trying to ensure responsible use of antibiotics and growth promoters, as well as an effective monitoring programme across the entire supply chain.

In many areas, tourism is assuming a greater role in dictating land use, even if it is in combination with cattle production systems. In the UK, for example, tourism employs over 500,000 people, equivalent to the total number of people employed in agriculture, but the proportion of the total land area dedicated to tourism is very small.

There must be adequate provision for a high-welfare environment, especially in the short term by manipulating the environment to suit cattle, but in the long term this may include genetically manipulating the animals to suit the environment. However, it is in our interest to maintain a reasonably intact gene pool for future insurance.

Cattle will in future have to play a greater role in complementing and supporting non-food enterprises in the rural environment, particularly tourism, fuel and fibre production and maintaining a suitable carbon balance. Due to pressure on productive land from an increasing population and concerns about pollution from livestock, the animals are increasingly likely to be confined to marginal land. Methods of managing cattle must ensure the maintenance of biodiversity in the rural environment, both in respect of indigenous flora and fauna and in the maintenance of a diverse gene pool in the cattle species to secure their future use in farming or natural habitats.

The future roles of cattle production systems may be summarized as follows.

1. To provide food, fibre and fuel products that maintain and contribute to the health of human users. Cattle may also be used for transport, traction and to improve soils (by incorporation of organic matter to stimulate plant growth and sequester carbon).
2. To provide conditions for cattle that meet their physical and mental needs, as perceived by the general public and in particular the consumer, and supported by scientific research.
3. To create and preserve a countryside that is of high biological and aesthetic value to the human population. This includes the maintenance of diverse flora and fauna, and conservation of natural resources such as farm woodlands.
4. To minimize pollution that could damage the microenvironment of the farm itself, its surroundings or the macro- or global environment. Particular difficulties exist with liquid and gaseous effluents from intensive units.
5. To coexist with and complement alternative land-use systems, e.g. forestry (as in silvopastoral systems), arable production (where by-products may be converted into a product that is of value to humans) or tourism.
6. To preserve the biodiversity of the cattle population, in particular to enable cattle to fulfil a useful function in future, when requirements may change or new disease challenges require certain genotypes within the cattle population.
7. Additional possible minor roles for cattle are the production of pharmaceuticals in milk or blood by transgenic manipulation, and limited use for sport, though sports that are incompatible with point **2** above are increasingly unlikely to be accepted by the public.

This chapter concludes below with a class exercise (Box 12.1) and suggested topics for discussion (Box 12.2).

Box 12.1. Class exercise

Solving an ethical dilemma by use of an ethical evaluation template

Making an ethical decision about a dilemma in the workplace is not easy. It takes an ordered, systematic approach to make the right decision, one that you can justify to others. This ethical evaluation method uses a template (adapted from Verrinder and Phillips, 2017) that has been devised in response to the growing need for a method that respects both life and well-being, not just for the animals but also for other (human) stakeholders in the process. After considering the impact of different actions on each of the stakeholders, you can attribute a score for the extent to which these support the underlying beliefs in: (1) utilitarian ethics (greatest good for the greatest number of individuals); (2) justice as fairness (are the least advantaged treated fairly?); and (3) virtue ethics (what sort of a person do you want to be?). Finally you can add the scores for these three methods of evaluating ethical appropriateness to determine the best course of action.

This sample dilemma is about bobby calf slaughter. It evaluates three alternative strategies for dealing with unwanted male calves in the dairy industry: (i) killing the male calves; (ii) using sexed semen to produce all female calves in the dairy herd; and (iii) using nurse cows to rear the calves until they can be slaughtered for meat. A fourth option, that of rearing the calves for meat without nurse cows, could also be considered. Read through the responses and justification and prepare to complete a blank form for an ethical dilemma – either one of those suggested or one of your own.

Continued

Box 12.1. Continued.

STAKEHOLDERS	Action: Kill bobby calves		Action: Use sexed semen to produce female calves		Action : Use nurse cows to rear the calves until they can be slaughtered for meat	
	Respect Life* √=Benefits, X=Harms	**Respect Welfare** √=Benefits, X=Harms**	**Respect Life* √=Benefits, X=Harms**	**Respect Welfare** √=Benefits, X=Harms**	**Respect Life* √=Benefits, X=Harms**	**Respect Welfare** √=Benefits, X=Harms**
1 Calves	**X** loses life	**X** missed chance to fulfil capacity for good life	**√** calves retain their life	**√** calves have chance to fulfill capacity for good life	**√** calves retain their life	**√√** calves have long suckling period
2 Cows	**X** offspring lose their life	**X** lost ability to nurture calves	–	–	–	**√** cows have opportunity to suckle calves for long period
3 Farmer	**X** may anguish over calf slaughter	**X** distressing to have calves slaughtered	√ more job satisfaction	**√X** not distressed by calf slaughter but may have reduced income	**√** more job satisfaction	**√XX** not distressed by calf slaughter but likely to have reduced income
4 Consumer	–	**√** product cheaper unless consumers concerned about the slaughter		**√X** not distressed by calf slaughter but may pay extra for product	**√** Less likely to anguish over calf slaughter	**√** not distressed by calf slaughter
5 Public non-consumers	**X** likely to anguish over calf slaughter	**X** distressing to have calves slaughtered	**√** Less likely to anguish over calf slaughter	**√** not distressed by calf slaughter	**√** Less likely to anguish over calf slaughter	**√** not distressed by calf slaughter
UTILITARIAN ETHICS Rate Actions 1–5 (1 = Least good for all affected; 5 = Greatest good for all affected)	3		4		5	
JUSTICE AS FAIRNESS Rate Actions 1–5 (1 = Least fair for most disadvantaged; 5 = Most fair for the most disadvantaged)	2		4		4	
VIRTUE ETHICS/INTEGRITY Rate Actions 1–5 (1 = Most virtuous, consistent with values; 5 = Least virtuous, least consistent with values)	2		4		5	
TOTAL SCORE	**7**		**12**		**14**	

*Desire to survive;

**Capacity to enjoy life, fulfil goals and capabilities.

Continued

Box 12.1. Continued.

Sample justification for the decision

- The most fitting ethical decision for an ethic of response is to use nurse cows to rear calves.
- This decision shows respect for all parties' desire for life and well-being (deontological ethics requires duty to universal principles of sentient beings' desire for survival and well-being). It satisfies utilitarian ethics by producing the greatest good for all stakeholders. It satisfies the ethics of justice as fairness, giving most support to the least advantaged – in this case the calves so that they have the capacity to live a happy life. These stakeholder have the most to lose. In comparison, the slaughter of bobby calves is a highly undesirable option. Using nurse cows also satisfies virtue ethics as the farmer is able to show courage and compassion and maintains integrity, showing honesty and consistency with universal ethical principles based on scientific facts that sentient beings value their lives and their well-being.

Now complete the following template for either the live export of cattle to the Middle East by ship or the continued routine use of antibiotic use for cows at drying off in the face of rapidly emerging antibiotic resistance.

STAKEHOLDERS	**Action:**		**Action:**		**Action :**	
	Respect Life*	**Respect Welfare****	**Respect Life***	**Respect Welfare****	**Respect Life***	**Respect Welfare****
1						
2						
3						
4						
5						
UTILITARIAN ETHICS (1–5) 1 = Greatest good						
JUSTICE AS FAIRNESS (1–5) 1 = Greatest benefit to the least advantaged						
VIRTUE ETHICS/INTEGRITY (1–5) 1 = Most virtuous, consistent, 5 = Least virtuous, least consistent with values)						
TOTAL SCORE						

*Desire to survive. **√** = Benefits, **X** = Costs/Harms

Capacity to enjoy life, fulfil goals and capabilities. **√ = Benefits, **X** = Costs/Harms

Box 12.2. Discussion topics

1. Addressing food shortages in the future

It's 2050, and the growth in demand for meat in Asia has left poorer sectors of the population unable to afford basic foods to eat. You are commissioned to advise the Food Governance Ministry in China on the possibilities to regulate meat purchasing to ensure adequate supplies of staple foods for the rural poor.

Continued

Box 12.1. Continued.

- Consider the ethics and practicalities of doing this.
- What alternative courses of action might you advise the Ministry to follow and what are their ethical implications?

2. Investing *in vitro* beef production

Scientists around the world are working on growing 'meat' beef burgers *in vitro*. Using biopsy samples from cattle, it is possible to grow beef burgers using a scaffold on which each burger can grow, when nutrients are added to the biopsied sample.

You are working for a food company seeking to develop a new source of protein that is environmentally sound, safe for consumption and a replacement for traditional meat. They have developed the technique to sufficient proficiency to believe that they can bring an *in vitro* 'burger' to the marketplace within 5 years. However, they need significant investment in facilities for volume production, to grow the capacity to supply to major retailers and keep costs low. They have invited employees to invest in the success of their company.

- How would you decide whether to invest in '*in vitro* beef'?
- How would you promote this to your customers, who have some concerns about the product before they can be persuaded to include it in their diet?
- How would you deal with potential ethical criticisms that it is not natural?

3. Can Ethical Milk live up to its name?

You are working for a large Australian dairy company, Ethical Milk. A group of international investors from Asia have purchased a farm that is supplying milk to Ethical Milk. At a corporate meeting they indicate that, in accordance with their religious beliefs, they will not allow slaughter or be responsible for any deaths of animals sent from the farm.

- Discuss whether a dairy farm could operate within this requirement
- Discuss the ethical and welfare implications of adopting such a policy.

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