Chapter 10
Livestock Production Systems

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Abstract Rangelands, 50 % of the earth's land surface, produce a renewable resource of cellulose in plant biomass that is uniquely converted by ruminant livestock into animal protein for human consumption. Sustainably increasing global animal production for human consumption by 2050 is needed while reducing the environmental footprint of livestock production. To accomplish this, livestock producers can interseed legumes and use bioenergy protein by-products for increased dietary protein, develop forage "hot spots" on the landscape, use adaptive grazing management in response to a changing climate, incorporate integrated livestock-crop production systems, improve fertility to increase birth rates, and reduce livestock losses due to disease and pest pressure. Conceptual advances in livestock production systems have expanded the utility of livestock in conservation-oriented approaches that include (1) efforts to "engineer ecosystems" by altering vegetation structure for increased habitat and species diversity, and structural heterogeneity; (2) use of targeted grazing to reduce invasive annual grasses and invasive weeds, and fuel reduction to decrease wildfires; and (3) improvement of the distribution of livestock grazing across the landscape. Livestock production systems need to increase output of animal protein by implementation of knowledge and technology, but this production must

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be sustainable and society needs to have confidence that animals were raised in a humane and environmentally acceptable manner such that the quality and safety of the animal protein are acceptable for consumers.

Keywords Adaptations for increasing climatic variability • Adaptive grazing management • Flexible stocking rate strategies • Forage hot spots on landscape • Ruminant livestock • Sustainable intensification

10.1 Introduction

10.1.1 Goals and Objectives

Livestock production systems utilizing global rangelands provide the ability for humans to effectively harvest animal protein from plants. These systems, which occur on six of the seven continents (Antarctica is the exception), are highly diverse, ranging from low-input, pastoral production systems located in arid and semiarid environments on communally owned lands to highly intensive production systems in more mesic environments which can integrate livestock-crop-forage systems to improve feed efficiency and reduce time from birth to harvest. The goals of this chapter are to review the important conceptual and technological advances in livestock production systems of the past 25 years, and look forward to the key opportunities that will influence global livestock production in the next 25 years.

For the retrospective look back 25 years, our objectives are to (1) showcase global trends that have occurred for ruminant livestock; (2) demonstrate, using the USA as an example, the economics of livestock production; (3) review the contributions of technological advances; (4) exhibit the shifts in management strategy toward increased emphasis on livestock in conservation-oriented approaches for land managers; (5) address environmental considerations of livestock production with an emphasis on greenhouse gas emissions; and (6) examine the changes in livestock production systems of South America's largest beef producer, Brazil.

For the prospective look forward 25 years, our overall objective is to demonstrate the significant influence of increasing global population and a rising middle class on increasing demand for animal protein. Here, we address (1) sustainable intensification of livestock production systems, including options in Australia; (2) adaptations to climatic variability; (3) customer influence on livestock production systems; (4) the need for increased feed efficiency and fertility; (5) reducing losses to disease; and (6) the importance of genetics and genomics, including rapidly emerging DNA and RNA genetic tools, and conclude with (7) an emerging integrated livestock-crop production system involving pasture, crops, and forestry.

10.1.2 Global Significance of Ruminant Livestock

Ruminant livestock, by hosting specialized microbes in their digestive system, serve as energy brokers between cellulose in plant biomass and energy and protein available for human consumption. Worldwide, rangelands provide 70 % of the forage for ruminant livestock (Holechek 2013) as domesticated livestock graze about 50 % of the world's land surface (Holechek et al. 2011), primarily occurring on lands which are ill suited for crop production (Steinfeld et al. 2006; Fig. 10.1). Furthermore, livestock can enhance efficiency of crop production through consumption of plant residues and increased rates of nutrient cycling.

10.1.3 Global Livestock Production

Globally, numbers of cattle, goats, and sheep increased from 1979 to 2009, with percentage increases of 14 % (cattle), 93 % (goats), and 1 % (sheep) observed (Fig. 10.2, FAO 2011). The continents of Africa and Asia experienced the largest percentage increases in cattle numbers, whereas Europe had the largest percentage decrease. In Africa, Asia, North America, and Oceania the numbers of goats at least doubled; only Europe had a decline in goat numbers. Sheep numbers were about 50 % higher in 2009 for Africa, Asia, and Central America/Caribbean, but about 50 % lower for

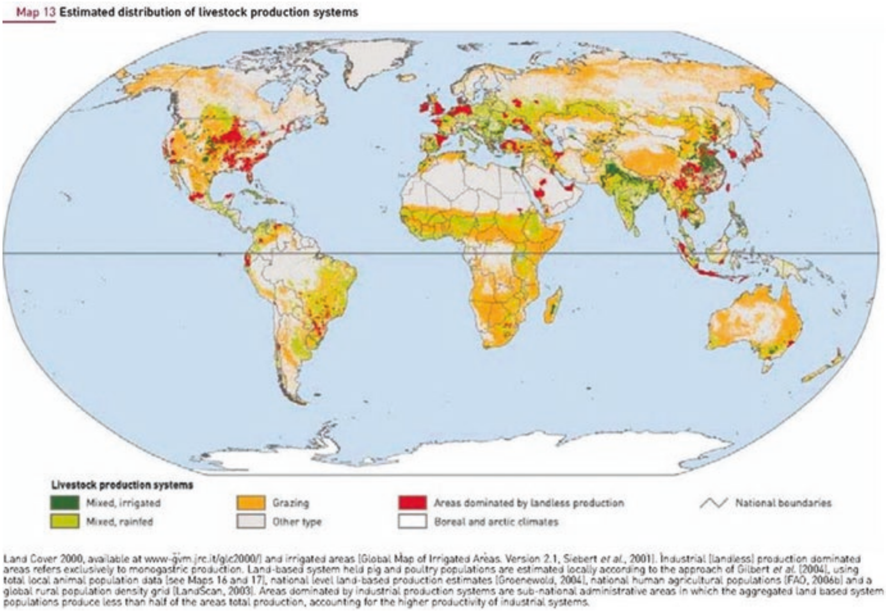

Fig. 10.1 Distribution of livestock production systems (FAO)

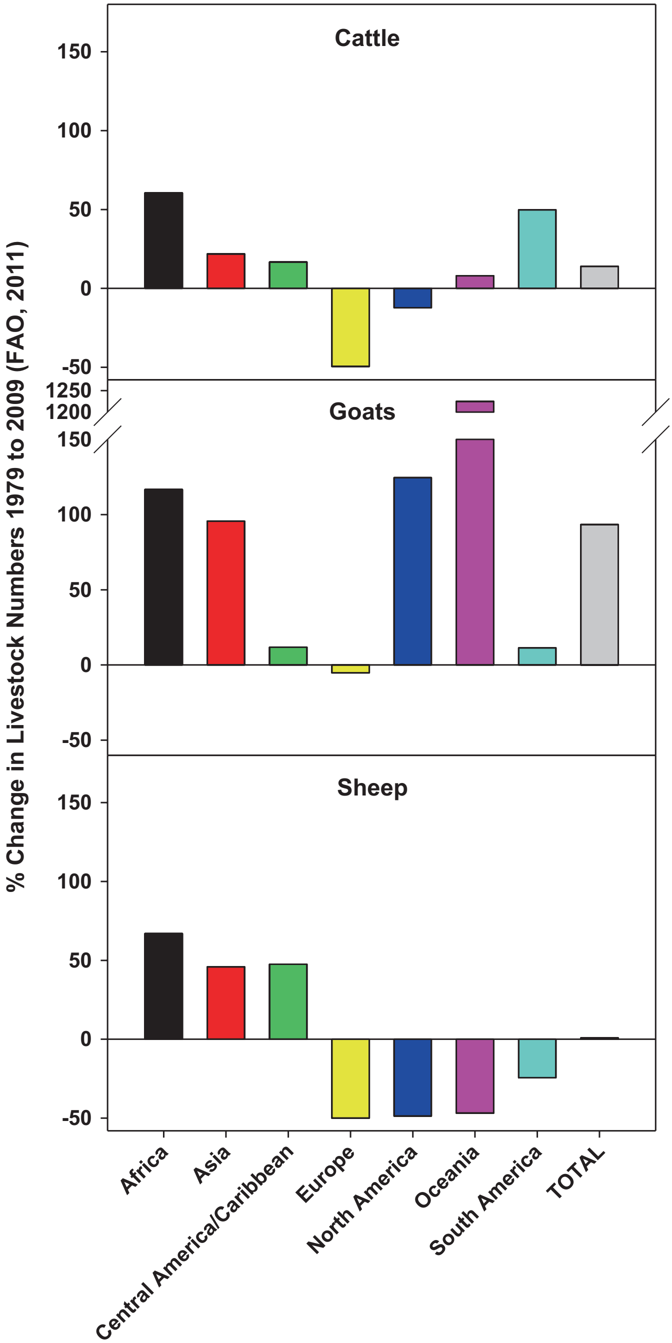

Fig. 10.2 Percentage change in livestock numbers from 1979 to 2009 (FAO 2011)

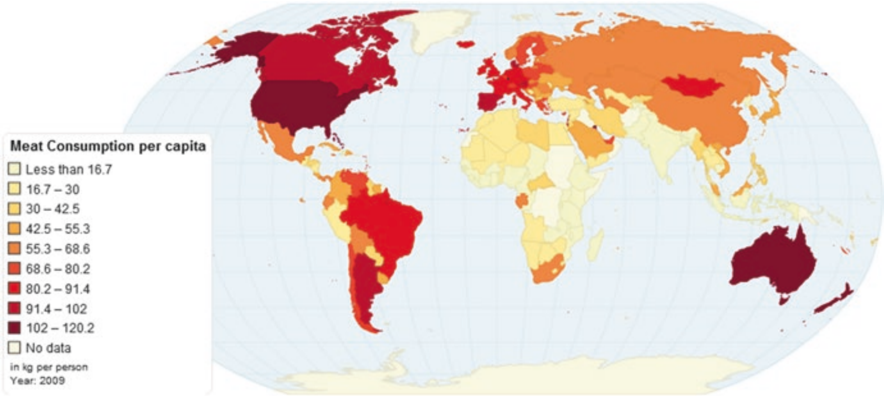

Fig. 10.3 Worldwide annual meat consumption per capita (FAO 2013). Current Worldwide Annual Meat Consumption per capita, Livestock and Fish Primary Equivalent, Food and Agriculture Organization of the United Nations, viewed 31st March, 2013

Europe, North America, and Oceania and 25 % lower for South America (Fig. 10.2). Increasing incomes in emerging economies of Africa and Asia, as well as increased urbanization on these continents, are driving these changes in global patterns of livestock production due to greater amounts of animal protein in human diets.

Annual growth rates in meat production over the past three decades for beef, sheep, and goats were 3–4 % in developing countries compared to slightly negative rates in developed countries[1]. Beef production is expanding globally. For example, breeding cattle (primarily the Angus breed) are being purchased by Russia[2] as well as former Soviet Republics (e.g., Kazakhstan[3]), and Brazil (see below), through direct purchases from the USA and Australia. Worldwide meat consumption per capita is highest in North America and Australia, and lowest in Africa (Fig. 10.3, FAO 2013). Beef and African buffalo contribute about one-fourth of the worldwide meat production (Table 10.1). Areas of the world with more than half of their total meat production from beef and buffalo are eastern Africa, central Asia, and Australia and New Zealand. Sheep and goat production contributes about 5 % of the worldwide meat production, with western Africa, central Asia, and Australia and New Zealand having 20 % or more of their total meat production from sheep and goats. Total meat imports across the world increased by about 60 % from 2000 to 2010, with percentage increases highest for southern and central Asia, and western Africa (Table 10.2). Cattle density is highest in India, the eastern Great Plains of the USA, western Europe, and southeastern South America (Fig. 10.4). Sheep density is highest in the Mediterranean region, and southwestern and southeastern Australia (Fig. 10.4), while density of goats is highest in India and the tropical region of Africa (Fig. 10.4).

[1] http://faostat.fao.org/

[2] http://www.businessweek.com/articles/2012-06-21/beef-the-new-opiate-of-the-russian-masses

[3] http://www.themeatsite.com/meatnews/22375/kazakhstan-to-grow-beef-herd

Table 10.1 Global meat production (1000 tons) in 2010 (FAO 2013 Stats)

		Beef and buffalo		Sheep and goat			
Groups of countries	Total	Production	% of total	Production	% of total	Pig	Poultry
World	296,107	67,776	22.9	13,459	4.5	109,370	99,050
Africa	17,309	6684	38.6	2872	16.6	1239	4769
Eastern	3595	1808	50.3	522	14.5	408	503
Middle	1189	413	34.7	143	12.0	153	118
Northern	5977	2504	41.9	1098	18.4	1	2059
Southern	3075	955	31.1	208	6.8	322	1507
Western	3473	1004	28.9	901	25.9	354	582
Latin America/ Caribbean	46,253	17,386	37.6	438	0.9	6553	21,310
North America	46,626	13,318	28.6	92	0.2	12,112	20,800
Asia	123,501	16,623	13.5	7716	6.2	62,054	34,858
Central	2323	1346	57.9	472	20.3	246	155
Eastern	86,904	7386	8.5	4136	4.8	54,194	19,447
South-eastern	15,948	1737	10.9	221	1.4	7164	6760
Southern	12,342	4853	39.3	1941	15.7	352	4951
Western	5984	1300	21.7	947	15.8	98	3545
Europe	56,628	11,001	19.4	1287	2.3	26,939	16,222
Eastern	16,825	3166	18.8	302	1.8	6639	6222
Northern	8099	1978	24.4	369	4.6	3399	2305
Southern	11,881	2091	17.6	417	3.5	6004	2964
Western	19,823	3766	19.0	200	1.0	10,897	4731
Oceania	5789	2764	47.7	1053	18.2	474	1092
Australia and New Zealand	5297	2744	51.8	1053	19.9	383	1065
Melanesia	478	18	3.8	0	0.0	80	24
Micronesia	3	0	0.0	0	0.0	2	1
Polynesia	12	2	16.7	0	0.0	8	2

10.1.4 Economics of Livestock Production: The US Cattle Example

The cattle production industry in the USA has become increasingly specialized, with individual sectors focusing on calf production, yearlings (mostly backgrounding on forages—e.g., wheat or grasslands/rangelands/pasture), feedlots for finishing, processors, packers, and retail marketers. For all sectors, risk management is key. For example, cow-calf producers in highly variable environments often employ conservative stocking rates as a strategy across years to reduce risk (Torell et al. 2010). Generally, low-input producers utilize conservative stocking, minimization of debt, and enterprise and income diversification to maintain economic sustainability (Kachergis et al. 2014; Roche et al. 2015). Producers having access to

Table 10.2 Volume (1000 tons) of total meat imports and exports in 2000 and 2010 and net importer or exporter status in 2000 and 2010 (FAO 2013 Stats)

	Imports		Exports		Net importer/exporter	
Groups of countries	2000	2010	2000	2010	2000	2010
World	23,441	37,239	24,359	39,530	Exporter	Exporter
Africa	778	1753	118	189	Importer	Importer
Eastern	29	74	23	19	Importer	Importer
Middle	181	533	0	0	Importer	Importer
Northern	235	428	10	8	Importer	Importer
Southern	217	322	84	105	Importer	Importer
Western	117	396	2	57	Importer	Importer
Latin America/ Caribbean	1858	3266	2424	7840	Exporter	Exporter
North America	2320	2197	5881	8029	Exporter	Exporter
Asia	7650	11,820	2568	3736	Importer	Importer
Central	89	347	1	1	Importer	Importer
Eastern	5856	6823	1701	1898	Importer	Importer
South-eastern	598	1581	501	753	Importer	Importer
Southern	37	343	312	742	Exporter	Exporter
Western	1070	2725	52	341	Importer	Importer
Europe	10,642	17,849	10,909	17,212	Exporter	Importer
Eastern	1680	4519	794	2187	Importer	Importer
Northern	2090	3455	2872	3416	Exporter	Importer
Southern	2875	3453	1072	2187	Importer	Importer
Western	3998	6422	6172	9422	Exporter	Exporter
Oceania	193	354	2459	2523	Exporter	Exporter
Australia and New Zealand	80	229	2456	2521	Exporter	Exporter
Melanesia	63	70	2	2	Importer	Importer
Micronesia	7	1	0	0	Importer	Importer
Polynesia	43	55	0	0	Importer	Importer

additional forage (e.g., irrigated pastures), crop residues, and grazing of cover crops can utilize higher input strategies to optimize economic returns. Relatively cheap grains and growth of the feedlot industry since the 1960s have encouraged many cow-calf producers to sell calves rather than carry yearlings as costs of gain in feed-lots have historically been cheaper than cost of gain on forage. Feedlots sell finished animals into the packer-processor market where animals are harvested and moved into the wholesale market. From here, beef is dispersed into the retail market. Cow herd numbers in the USA have decreased over 30 % since the 1970s, and are at their lowest levels since the end of World War II (Fig. 10.5), leading to record high cattle prices in 2014 and 2015. Production outputs such as weaning weights have increased due to implementation of multiple technologies (Ash et al. 2015).

In 1970, there were over three feeder cattle outside feedlots for every animal in a feedlot; currently this value is less than two animals as comparatively cheap grains

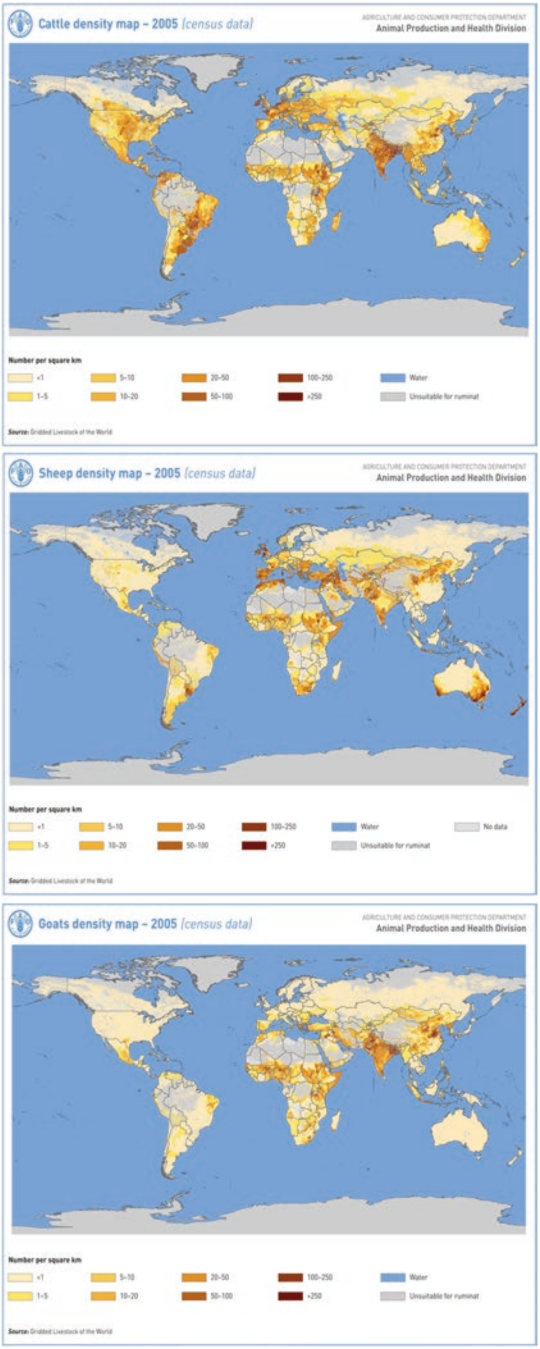

Fig. 10.4 World density maps in 2005 (numbers of animal km^{-2}) for cattle (*top*), sheep (*middle*), and goats (*bottom*) (FAO)

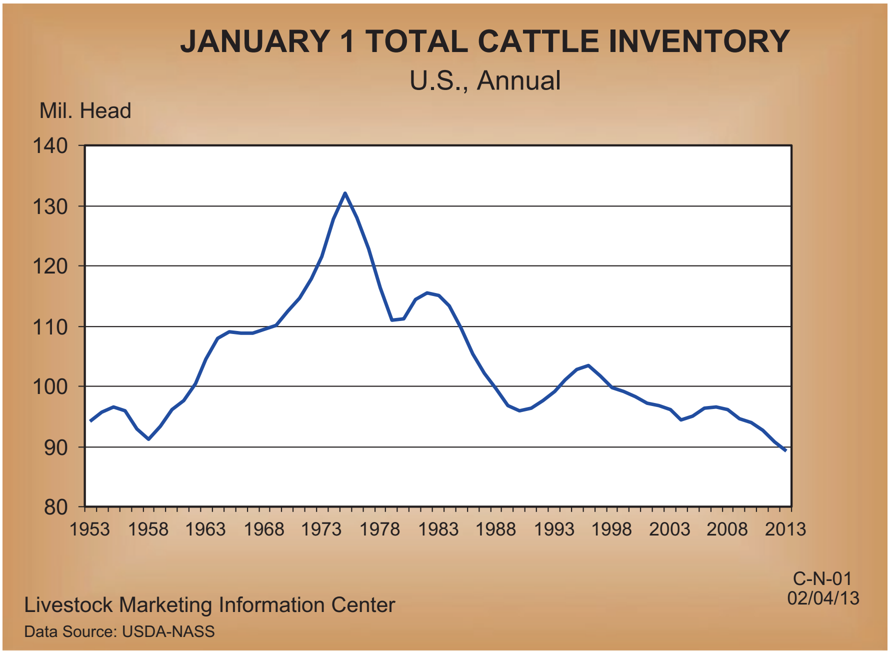

Fig. 10.5 US total cattle inventory (1953–2013) (USDA-NASS)

have increased the reliance on feedlot gains for cattle. The vast majority of feedlots in the USA are located in the Great Plains where most of the corn is produced. In addition, most of the biofuel (e.g., ethanol) refineries are located in this same region, which provides a large supply of by-products for use in feedlots. Feedlots having capacity for greater than 32,000 head market around 40 % of fed cattle, and greater feedlot operation size, have been shown to significantly reduce costs of production. Genetic selection for animals with greater gains kg of feed^{-1} has increased carcass weights. Residual feed intake is garnering attention as a tool that allows producers to select for efficiency while accounting for body weight and a wide range of factors above and beyond simply total feed consumption and total animal gain (Herd et al. 2003; Herd and Arthur 2009). Successful technological advances that increase feed efficiency to enhance productivity (e.g., improved feeding and management), and structural shifts in the livestock sector to reduce adverse environmental impacts, can increase profitability and sustainability of livestock production systems (Herrero et al. 2013).

Feedlot operators are increasingly turning to formula and grid markets, where prices are determined on actual carcass qualities instead of the traditional markets that base price on live or dressed weights. Grid-based prices rely on USDA quality and yield grades to impact prices through premiums for those carcasses with desirable grades, while many formulas also include premiums for branded beef (e.g., Certified Angus Beef) and discounts for characteristics such as injection-site blemishes and hide damage. Cattle price on grids has increased from 14 % in 1996 to

50 % in 2001, and to 75 % by 2012. The grid system can be a benefit to the cattle industry as it sends clear signals to feeders of changing consumer preferences. For example, premiums occur for branded products that meet customer preferences for reduced used of antibiotics and hormones (e.g., natural beef).

10.2 Looking Back: Livestock Production—The Previous 25 Years

10.2.1 Technological Advances

Technological advances and implementation of management practices derived from experimental research in the past 25 years have focused on increasing the efficiency of livestock production and reducing environmental impacts. Technological advances include (1) use of artificial insemination for breeding livestock with superior genetic traits, (2) crossbreeding to achieve heterosis (hybrid vigor), (3) emerging use of DNA and RNA technology for advances in genetic trait selection, (4) use of grains for improved gain efficiency to finish livestock for harvest, and (5) use of growth hormones to shorten the time from birth to harvest leading to increased efficiency. Associated with this increased production efficiency has been a reduction in greenhouse gas emissions kg beef^{-1} (Capper and Hayes 2012). Other technological advances have included additional water developments—water systems, pipelines, spring developments, and installation of ponds—which improve livestock distribution and utilization of available forage, and dietary supplements (e.g., urea, phosphorus, minerals) to overcome seasonal deficiencies in forage quality, especially in tropical and subtropical rangelands. Grazing strategies across the globe are quite diverse from low-intensity management of pastoral and communal approaches to high-intensity management facilitated by infrastructure developments (Roche et al. 2015). Key management practices that have been developed include (1) the application of sustainable stocking rates to maintain or improve the health of rangelands, including riparian habitats (Briske et al. 2011), as well as associated optimization of net income (Holechek 2013; Kemp et al. 2013), and (2) matching of calving season to the prevailing environment to reduce associated harvested feed costs (Grings et al. 2005; Griffin et al. 2012).

10.2.2 Shifts in Production Strategies

Within the first decade of the twenty-first century, livestock production strategies have increased emphasis on livestock in conservation-oriented approaches to include (1) efforts to "engineer ecosystems" by altering vegetation structure for increased habitat and species diversity, and structural heterogeneity to achieve desired contemporary outcomes (Derner et al. 2009, 2013); (2) use of targeted grazing involving application of a specific kind of livestock at a determined season, duration, and intensity to accomplish defined vegetation or landscape goals (Launchbaugh and Walker 2006), to reduce invasive annual grasses (Diamond et al. 2010) and invasive weeds (Goehring et al. 2010), as well as fuel reduction efforts (Davison 1996; Clark et al. 2013); and (3) improvement of the distribution of livestock grazing across the landscape through the use of low-stress stockmanship methods using herding, strategic location of low-moisture supplement blocks (Bailey et al. 2008), patch burn grazing in mesic (Fuhlendorf and Engle 2004) and semiarid (Augustine and Derner 2014) ecosystems, and foraging and learning through past experiences that increase the likelihood of animals learning to eat different plants (e.g., Provenza et al. 2003). These ecological benefits from conservation-management applications have been attained without negatively impacting livestock production (Limb et al. 2011; Augustine and Derner 2014).

10.2.3 Environmental Considerations: Beef Production and Greenhouse Gas Emissions

Greenhouse gas emissions kg beef^{-1} produced between 9.9 kg CO_2-eq (carbon dioxide equivalent) and 36.4 CO_2-eq in intensive systems, and from 12.0 to 44.0 kg CO_2-eq kg^{-1} beef in extensive systems (Pelletier et al. 2010; Capper 2012). These differences in GHG emissions may be attributed to differences in assessment methodology in addition to the direct consequence of different production systems. Assessment methodology differences include variation in the system boundaries and underlying assumptions and model complexity that may have a considerable effect upon the results of environmental impact assessments (Bertrand and Barnett 2011). Until a global analysis of environmental impact from beef production is conducted, with similar methodology for each region, it is difficult to draw firm conclusions as to the variation within and between global regions. The study by Herrero et al. (2013) is a first approximation to spatially disaggregate a global livestock dataset to assist in determinations of greenhouse gas emissions at regional to local scales. Most of the developed countries have low greenhouse gas emission intensities due to improved and intensive feeding practices, and higher feed quality; conversely, sub-Saharan Africa is a hot spot for high greenhouse gas emission intensities as a result of low-quality feeds and animals with low productive potential animal^{-1} (Herrero et al. 2013).

Adverse environmental effects are minimized by improving productivity in the metrics of carcass weight and growth rate (Capper and Hayes 2012; White and Capper 2013). As productivity increases, the proportion of daily energy allocated to maintenance decreases and maintenance requirements of the total animal population decreases. Improvement in growth rate reduces time from birth to harvest and increases the total production of meat yield in a shorter time frame without affecting herd numbers (Capper 2011a; Capper and Hayes 2012; White and Capper 2013). With increasing intensity of a production system, corresponding improvements in productivity and efficiency are usually exhibited resulting in "more intensive"-type production systems tending to use fewer resources and having lower greenhouse gas emissions than "less intensive" or "extensive" systems (Capper 2011b).

Efficiency in the US beef industry markedly increased between 1977 and 2007 with growth rates (kg head^{-1} day^{-1}) increasing by 64 %, harvest weights increasing by 30 %, and days from birth to harvest decreasing by 20 % (Capper 2011a). These advances over the 30 years were attributed to improvements in genetics, nutrition, and management, as well as use of fossil fuels and irrigation water development. As a result, 12–33 % less land, water, and feed were needed, and greenhouse gas emissions kg beef^{-1} decreased by 16 % (Capper 2011a). Greenhouse gas emissions unit beef^{-1} were 67 % greater in pasture-finished systems than in feedlot systems (Capper 2012). To maintain current US beef production (11.8 billion kg) from an entirely pasture-based system would require an additional 52 million ha of land (Capper 2012). If such conversion did occur, the increase in carbon emissions from these extensive systems would be equal to adding 25.2 million automobiles to the road year^{-1} (Capper 2012). Questions remain for feedlot systems with respect to long-term availability and cost of quantity and quality of water, as well as fossil fuels for associated crop production to maintain the current advantage in greenhouse gas emissions for these systems.

10.2.4 Beef Production: A Brazilian Example

Beef production in South America is primarily confined to pastures compromised of introduced forage species that vary with regional environmental characteristics. For example, temperate species of grasses and legumes dominate pastures in southern Brazil, while the remainder of Brazil has mostly tropical species. Brazil has approximately 200 million head of cattle. Increases in the numbers of cattle in Brazil are occurring in spite of a decrease in total pasture area (Martha et al. 2012). This is a result of production intensification and increased efficiency that supports higher stocking rates. In addition, age to harvest has decreased, as has the age at the beginning of reproduction. The quality of carcasses produced has markedly improved as a result of better animal and forage genetics, better management practices—financial, nutrition, reproduction, and health—and organization of the beef supply chain. For example, beef production increased only 0.3 % year^{-1} from 1950 to 1975, but increased to 3.6 % year^{-1} from 1975 to 1996, and then further increases to 6.6 % year^{-1} were observed from 1996 to 2006 (Martha et al. 2012). Key beef production metrics for Brazil increased from 1994 to 2007 (Table 10.3). For example, over these 13 years, harvest rate (13 %), numbers of cattle harvested (73 %), beef production (77 %), consumption per capita (13 %), domestic consumption (37 %), and the amount (540 %) and value (694 %) of beef exports increased, whereas the amount of beef imported decreased by almost half.

Table 10.3 Key metrics of beef production in Brazil (1994–2007)

	1994	1998	2002	2006	2007
Harvest rate (%)	16.4	19.1	19.8	21.7	21.7
Harvest (millions of head)	26.0	30.2	35.5	44.4	45.0
Beef production (1000 tons of carcass)	5200	6040	7300	8950	9200
Consumption per capita (kg of carcass)	32.6	35.8	36.6	36.6	36.7
Domestic consumption (1000 tons of carcass)	5017	5797	6395	6780	6880
Export (1000 tons of carcass)	378.4	377.6	1006.0	2200.0	2420.0
Import (1000 tons of carcass)	195.9	135.1	100.7	30.0	100.0
Export (US$ million)	573	589	1107	3800	4552
Import (US$ million)	230.5	220.0	84.0	63.0	210.0

Source: Adapted from CNPC. Available at http://www.cnpc.org.br/site/Balanco.xls

For livestock production in Brazil, improvements in forage management involving combinations of new grass and legume cultivars developed by breeding programs, and associated grazing systems adapted to regional-specific conditions can increase livestock production, with the caution that mineral supplementation is necessary due to the weathered soils (Ferraz and de Felicio 2010). Greater understanding of soil-plant-animal interactions in both temperate and tropical areas will result in better pasture management, as well as improved livestock production efficiency. The seasonality of forage production in tropical regions can limit sustainability of livestock production as forage limitations in dry seasons reduce animal gains. Intensifying management in these regions remains a challenge, but opportunities exist for (1) adapting stocking rates for seasonal differences in forage production, (2) irrigating pastures where water is available and it is recommended, (3) stockpiling of forage for dry season, (4) use of diet supplementation, (5) increased use of feedlots as a strategy to finish animals, (6) improved animal breeding, and (7) a combination of two or more of these strategies. Intensifying management provides important co-benefits such as reducing the pressure for clearing new areas for pasture and lessening deforestation impacts, decreasing costs of beef production by keeping the production systems closer to the infrastructure system of roads and industries already in place, and contributing to decreases in total greenhouse gas emissions since intensification shortens the time to harvest.

10.3 Looking Ahead: Livestock Production in the Next 25 Years

The global livestock production industry faces a significant challenge in producing sufficient animal protein to supply an increasing population, including an expanding middle class. Predictions are that animal production will need to increase by 70 % by 2050 to accommodate an additional two billion humans (from seven to nine billion

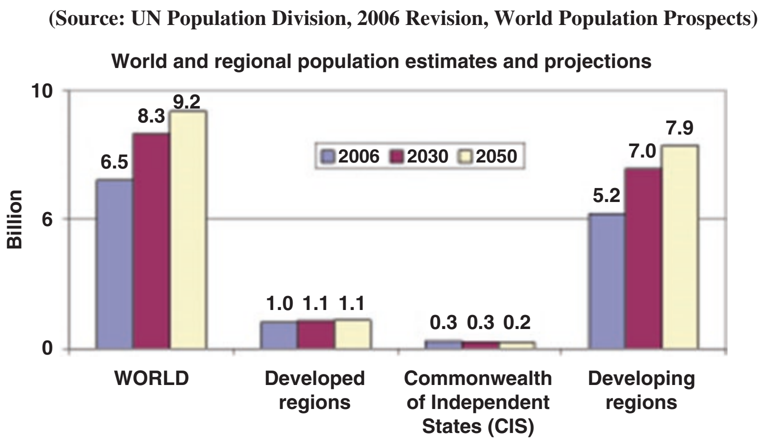

Fig. 10.6 World and regional population estimates and projections. Source: UN Population Division, 2006 Revision, World Population Prospects

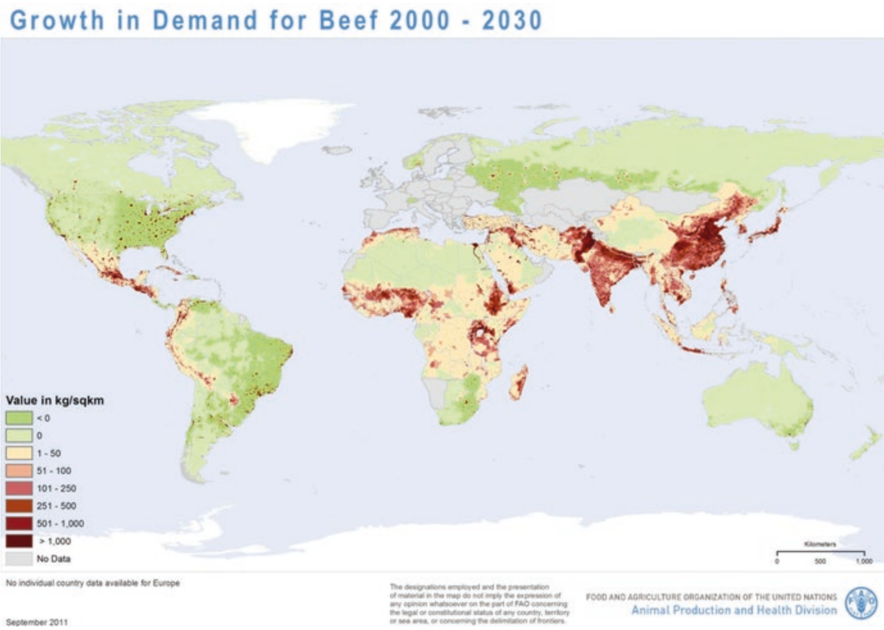

Fig. 10.7 Growth in demand for beef (2000–2030) (FAO)

plus) and a rise in the global middle class (FAO 2009, 2011; Fig. 10.6). Growth in demand for animal protein through 2030 will be largely concentrated in the tropical regions of Asia (e.g., India and China), Africa, and Latin America (Fig. 10.7). As a result, livestock production will need to employ sustainable intensification in terms of management to increase production while having neutral environmental effects.

The feasibility of sustainable intensification will largely depend on the ability of managers to adaptively match forage production, forage demand, and forage quality with increasing weather and climatic variability. The flexibility of operational structure such as cows and calves with yearlings provides substantial economic outcomes with adaptive management, but is dependent on high quality and accurate seasonal climate forecasts that are not currently available (Torell et al. 2010). Forage quality concerns of reduced crude protein concentrations and forage digestibility are predicted to offset greater forage production associated with increases in atmospheric CO_2 concentration (e.g., Milchunas et al. 2005; Craine et al. 2010).

Intensification of livestock production will largely occur in mesic, rather than xeric, environments. In drier environments, management emphasis will encompass resiliency, risk reduction, avoidance of debt and degradation of natural resources, and low input for sustainability. Livestock production intensification in more mesic environments will be determined by four variables and external forces (Euclides Filho 1996). First, improvement of efficiency and economic viability of livestock production enterprises is dependent on effectively managing available natural resources and efficiently utilizing available technologies, including the potential risks and adoption rates of best management practices by producers. Second, market-driven competitiveness and achieving consumer expectations will require a capacity to consistently provide high-quality products with reliable taste and tenderness within price ranges affordable for society. For example, value-added products with unique niche markets could be associated with traceability and certification systems to document origin of the livestock for the consumer. Third, recognition of constraints in land-use decisions related to coexistence of food, feed, fiber, and energy production from lands will require increasing integration of these production systems. Fourth, emphasis on economic, social, and environmental benefits, including greater improved distribution of livestock profits among segments of the supply chain, and an increased concern about the collective and individual well-being of both humans and animals. In summary, livestock production systems must intensify their activities by introducing knowledge and technology that not only assures sustainable production, but also demonstrates transparency for the general public that will increase confidence in the quality of animal protein for consumers, as well as humane treatment of animals and environmental impacts of livestock production.

10.3.1 Sustainable Intensification: An Australian Example

Sustainable intensification options in Australia include oversowing native perennial grass pastures with legumes, the development of "mosaic" irrigation for forage "hot spots" on the landscape where limited areas of suitable soil on large properties are developed with irrigation to produce high-value forages to enable animals to be finished for market, and potential on-farm production of low-cost supplements such as high-protein algal-based supplements using technology from the biofuel industry. While the technology may not yet be in place to support all these developments, and the economics may not be positive in all cases, these options do indicate that there is potential to increase livestock production by 2 % annually over a 20-year time frame (Ash et al. 2015). Other developments such as genetic improvements for feed conversion efficiency, improvement in veterinary care, and increased use of supplements can also have an important role in boosting productivity (Ash et al. 2015).

However, most intensification options require greater managerial commitment and capital infrastructure costs, and are often associated with increased risk. The economic risk is generally high, because of the large capital costs associated with intensification options and frequency and duration of drought which reduces the value of livestock due to excess market supply (Coppock et al. 2009; Ash et al. 2015). Livestock enterprises will also need to adapt to a low-carbon operating environment as societal pressure increases to reduce carbon emissions while enhancing carbon sequestration. The potential benefits of various intensification options for livestock production and environmental sustainability require greater consideration on rangelands.

10.3.2 Adaptations for Increasing Climactic Variability

Climatic variability is an area of considerable concern for livestock production (Polley et al. 2013; Reeves et al. 2013). A high degree of climatic variability is a key feature of arid and semiarid rangelands worldwide as droughts are a major cause of land degradation and economic loss (Stafford Smith et al. 2007; Coppock 2011). Preparedness of land managers for such events and their responses are crucial to minimizing negative effects on natural resources as well as the financial consequences for the production enterprise (Kachergis et al. 2014). A high degree of reliance on emergency government financial assistance to support drought-affected properties has encouraged land managers to maintain current stocking rates with consequential land degradation. Adverse effects of poor drought management on other rangeland values such as biodiversity and water resources are also of increasing concern.

The use of diverse management strategies is often necessary to manage risk associated with climate variability (McAllister 2012). Options include adaptation strategies associated with flexible herd management, alternative livestock types and breeds, modified enterprise structures, and geographic relocation (Joyce et al. 2013). The main livestock management options range from the use of conservative stocking rates (Hunt 2008) to adopting a flexible stocking rate strategy in which livestock numbers are varied in response to changing and seasonal forage availability (Ritten et al. 2010; Torell et al. 2010). Incorporation of a yearling enterprise in addition to cow-calf operations can increase flexibility by providing (1) extra grazing animals during periods of high forage availability, (2) readily marketable animals during drought periods, and (3) ability to preserve herd genetics by selling yearlings, rather than the base cow herd. Challenges to adding this second enterprise include increased managerial effort and skills, contacts in the industry for the supply and sale of yearling animals or other classes of animals, and additional financial outlay, cash flow, and marketing. For example, obtaining yearling animals during favorable times and having somewhere to send these animals as forage conditions deteriorate can present challenges for land managers under a flexible strategy. For more remote areas distant from markets, a flexible strategy can present challenges due to logistical difficulties and costs of transporting animals. Transporting livestock from a property with a forage deficit to another property with a forage surplus (agistment), where the livestock owner leases the land for grazing the livestock, is an important management option in Australia (McAllister et al. 2006). Benefits to the livestock owner can include (1) an avoided forced sale of livestock with depressed prices, (2) a more rapid vegetation recovery following the end of drought by reducing degradation due to drought, and (3) maintaining a core breeding herd. A risk is prolonged drought and the leased property also running out of forage, potentially forcing the eventual sale of the livestock. Agistment is less common outside of Australia, although in the USA there was a substantial movement of cattle from Texas and California to the Northern Great Plains during recent droughts. Nomadism and transhumance are practiced in some African and Asian rangelands as a means of buffering the effects of climate variability, but this mobility is rapidly being lost (Chap. 17, this volume).

Provision of supplementary feed as a drought management strategy is problematic in many rangelands because of the conflict between drought policies and economics of purchasing supplemental feed. The cost of purchase and transport of supplemental feed can be considerable, particularly for remote regions and extensive enterprises with large herds or flocks typical of many rangelands, and in the case of multiyear droughts (Kachergis et al. 2014). Maintaining livestock on rangelands by means of supplementary forage can degrade natural resources, including vegetation and soils. Providing supplementary feed can only be justified for maintaining a limited number of animals, such as valuable core breeding stock. For example, placing cows in drylots for calving and breeding may be advantageous for both cow and subsequent calf performance compared to supplementing cows on pastures during these periods, due to controlling rations for protein, energy, and fat content (Wilson et al. 2015). In shrub-dominated rangelands experiencing drought, livestock will increase use of shrubs (Estell et al. 2012).

10.3.3 Customer-Driven Demand for Livestock Quality and Products

Consumers of animal protein and fiber products are becoming increasingly concerned about the nature of livestock production systems, the welfare of animals, and the effects of livestock production on the environment. Consumers expect these products to be produced using humane methods in largely natural environments and without adverse environmental consequences, and this affects their buying habits (Grandin 2007). There has also been a trend toward the development of "low-stress" stockmanship methods of livestock handling and production, and land managers are increasingly adopting such techniques. Adoption of these methods can have an added benefit as there is increasing evidence that productivity and profitability of livestock enterprises are improved (Cote 2004; Grandin 2007). Although survey data overwhelmingly concludes that price, taste, convenience, and nutrition are the major factors affecting purchasing decisions (Vermeir and Verbeke 2006; Simmons 2009), these are still dependent on the product being morally or ethically acceptable to the consumer. Furthermore, legislative efforts could potentially dictate production practices for livestock production.

10.3.4 Improving Feed Efficiency

The poultry and swine industries have made significant gains in improving feed efficiency over the past several decades, and considerable interest currently exists within the beef industry to select cattle for improved feed efficiency. This may be achieved through an improvement in residual feed intake (RFI), defined as reduced feed consumption required to support maintenance and production compared to the predicted or average quantity (Archer et al. 1999). Steers selected for high efficiency (low RFI) consumed less feed over the finishing period compared to low-efficiency (high RFI) cohorts in a large-scale feedlot study while maintaining harvest weight and exhibiting a greater dressing percentage (Herd et al. 2009). Furthermore, Angus steers selected for low RFI had reduced methane emissions consistent with reduced dry matter intake (Hegarty et al. 2007). If productivity can be maintained with reduced dry matter intake, then resource use, greenhouse gas emissions, and feed costs would also be predicted to decrease unit production output^{-1}. National research programs[4] are evaluating genetic improvements for feed efficiency in beef cattle to reduce feed resources, increase production of animal protein without additional feed inputs, and reduce greenhouse gas emissions of beef production systems.

10.3.5 Improving Fertility

Livestock fertility is arguably the major factor by which global livestock producers could improve the sustainability of animal protein. For example, within the USA, 89 % of cows bear a live calf each year (USDA 2009), but this number declines to 50–60 % in South American countries (e.g., Brazil, Argentina, and Chile). Cow-calf operations contribute up to 80 % of greenhouse gas emissions unit beef^{-1} (Beauchemin et al. 2010) and productivity improvements post-calving cannot compensate for the resource use and greenhouse gas emissions associated with maintaining a nonproductive cow. Management practices and technologies that improve birth rates offer significant opportunities to reduce land and water use, greenhouse gas emissions, and feed costs (Capper 2013a).

[4] http://www.beefefficiency.org/

10.3.6 Reducing Losses to Disease

Globally averaged livestock losses due to disease are more than 20 %; thus considerable gains could be made through treating diseases or conditions that have a negative impact upon livestock performance. For example, prudent use of parasiticides in beef cattle improves performance, with associated positive environmental and economic impacts (Lawrence and Ibarburu 2007; Capper 2013c). To date, effects of many of the less tangible productivity losses within livestock systems such as male fertility, clinical and subclinical morbidity, and growth of replacement animals have yet to be quantified. Development of new vaccines provides opportunities for targeted protection from losses associated with livestock viruses, including bovine viral diarrhea, BVD; bovine respiratory syncytial virus, BRSV; infectious bovine rhinotracheitis, IBR; and parainfluenza 3 virus, PI3[5].

10.3.7 Hormone Use and Sustainability

Consumer aversion to the use of chemicals in food production is often cited as a retailer rationale for removing technologies such as hormones, beta agonists, or antibiotics from the food supply chain. The market share for organic, natural, or local foods is small, but growing. Technologies such as ionophores, steroid implants, and beta agonists have had significant roles in reducing environmental impacts of ruminant production in those regions where they are registered for use (Capper 2013b). For example, steroid implants and beta agonists improve growth rates and harvest weights which reduce land and water use, as well as greenhouse gas emissions unit beef^{-1} (Capper 2013b). Removing these production enhancement technologies from US beef production would increase land and water use, and global greenhouse gas emissions, while also resulting in increased imports from countries will less efficient production systems (Capper and Hayes 2012).

10.3.8 Genetics and Genomics

Current selection efforts in livestock production, especially beef, have resulted in animals with increased growth and carcass qualities. As a result of these selection efforts, animals now have a larger mature size with greater maintenance requirements, which increase production costs (Williams et al. 2009). However, genetic improvement in reproductive performance has not occurred (Garrick 2011). This may be attributable to low selection accuracy in traits such as longevity, lifetime

[5] http://purduephil.wordpress.com/2013/10/10/usda-approves-first-combination-mlv-vaccine-to-provide-targeted-protection-against-bvd-1b/

reproductive performance, and fertility (Garrick 2011). Advances in breeding programs and best management agricultural practices have produced linear gains in global food production equal to 32 million metric tons year^{-1} (Tester and Langridge 2010). However, this rate will need to be increased to 44 million metric tons year^{-1} to accommodate predicted global food production needs by 2050. Completion of the Genome Sequencing for cattle (Zimin et al. 2010), goats (Dong et al. 2013), and sheep (The International Sheep Genomics Consortium 2009) provides the genetic template for using DNA and RNA technologies to improve production efficiency of these species. Use of genetic markers for determination of parentage has been commercialized with costs of DNA sequencing precipitously decreasing from 1990 to 2012 (Eggen 2012). Genomic selection has been put forward as a new breeding paradigm (Meuwissen et al. 2001; Eggen 2012), with use of molecular breeding values being combined with traditional expected progeny differences as indexes for traits. Fundamental to livestock producers will be the combination of new genomic information with traditional pedigree and performance data, but the genomic information needs to be cost effective and have a high accuracy (Johnston et al. 2012). It is anticipated that rapidly emerging DNA and RNA genetic tools (Johnston et al. 2012) will permit the advancement of genomic selection programs for individual and multiple traits simultaneously. New genetic tools may also allow selection for traits that are difficult to measure, such as adaptability and grazing distribution (Bailey et al. 2015). In addition, newly emergent genetic field such as epigenetics, which is the study of cellular and physiological traits that are heritable and not caused by changes in the DNA sequence where inheritance patterns differ even when DNA sequences are the same, provides opportunities to turn on or off different sets of genes (e.g., Rada-Iglesias and Wysocka 2011). Here for example, hair coat color could be modified to adapt to seasonal environmental stresses, with hair color darker during the colder months and lighter during the hotter months.

10.3.9 Integrated Livestock-Crop Production Systems

Integrated livestock-crop production systems (Sulc and Franzluebbers 2014) are an emergent management strategy. Integrated livestock-crop production systems can reduce enterprise risk, restore degraded land, increase productivity, diversify production, and enhance resiliency of the land (Palmer 2014). In addition, by integrating livestock with crops as well as with forests, manure from livestock can be used as fertilizer to improve soil nutrient status and soil organic matter (Sulc and Franzluebbers 2014). Combining crops, livestock, and forestry might be done in rotation to capitalize on synergies among the ecosystem components by improving physical and chemical characteristics of soils which results in decreasing the need of new areas for increased production.

10.4 Future Perspectives

Livestock production enters a period of opportunity to address increasing efficiencies for the provision of animal protein as well as reducing environmental footprints. First, the incorporation of adaptive grazing management, with monitoring-informed decision making, to optimize forage demand with available forage will increase efficiency of livestock weight gain on rangelands while providing additional economic benefits for producers. This will concurrently reduce negative environmental impacts associated with improper stocking rate during dry periods and drought, and capture additional livestock gain during wet periods for increased net economic returns. Second, increasing availability and reliability of transportation infrastructure in developed and developing countries provide capacity to more efficiently move animals to feed which (1) reduces GHG emissions with transportation of feed to animals, (2) reduces land degradation associated with drought, and (3) increases animal weight gains due to removing constraints in systems that are characterized by extended dry seasons where animals typically lose weight. Third, continued advances in genetics for feed efficiency and carcass quality provide opportunities to capture additional economic income from value-added niche markets for the delivery of animal protein products in highly transparent manner to society with concomitant reductions in the GHG footprint of livestock production due to shortened times from birth to harvest. Fourth, improvements in birth and weaning rates and reductions in losses to disease and pest provide inherent efficiencies to global livestock production to increase provision of animal protein without any increase in land area, thereby again reducing environmental footprints.

With an additional two billion humans and a rise in the middle class by 2050, animal protein production will need to increase by 70 % to meet global demand. This growth, largely concentrated in the tropical regions of Asia, Africa, and Latin America, will require sustainable intensification of livestock production systems. Two possible strategies to meet this demand are (1) further increases in "more intensive" production systems that incorporate grains in countries like Brazil to increase gain efficiency, reduce time from birth to harvest, and reduce greenhouse gas emissions, and (2) intensification of rangeland systems by interseeding legumes and use of bioenergy protein by-products for increased dietary protein, and development of forage "hot spots" on the landscape. Further, livestock production efficiencies can be increased through (1) adopting a flexible stocking rate strategy to vary livestock numbers on rangelands in response to changing seasonal forage availability, (2) selecting animals for improved feed efficiency, (3) improving fertility to increase birth rates, and (4) reducing livestock losses due to disease and pest pressure. Rapidly emerging DNA and RNA genetic tools, combined with completion of genomic sequencing for livestock, provide capacity for advancement of genomic selection programs for individual and multiple traits simultaneously as well as mitigation and adaptation to a changing climate and environmental stresses. In summary, livestock production systems must intensify their activities by introducing knowledge and technology that not only assures sustainable production, but also improves transparency for increased confidence in the quality of animal protein.

10.5 Summary

Ruminant livestock uniquely convert the high cellulose biomass of grasses, forbs, and woody plants produced on rangelands, which occupy about 50 % of the world's land surface, as a renewable dietary source of energy and animal protein for human consumption. Globally, increasing incomes in emerging economies of Africa and Asia, as well as increased urbanization on these continents, are driving increasing livestock numbers and changes in global patterns of livestock production due to greater levels of animal protein in human diets. Although livestock production systems have already benefited from fossil fuel inputs and many technological and conceptual advances, sustainably increasing global animal protein production for human consumption by 2050 is needed while also reducing the environmental footprint of livestock production. Genetic improvement technology involving artificial insemination for breeding to increase superior genetic traits, crossbreeding to achieve heterosis or hybrid vigor, and emerging use of DNA and RNA technologies combined with the completion of genomic sequencing for livestock provide capacity for advancement of genomic selection programs through transparent efforts that increase societal confidence in the quality of animal protein for consumers, as well as increasing production efficiency and reducing land and water use, and greenhouse gas emissions per unit beef. Further, increasing abundance of "more intensive"-type production systems that incorporate grains, growth hormones, and dietary supplements for improved gain efficiency to finish livestock for harvest use fewer resources and have lower greenhouse gas emissions per unit animal protein than "less intensive" or "extensive" systems. Livestock producers can interseed legumes and use bioenergy protein by-products for increased dietary protein, develop forage "hot spots" on the landscape, use adaptive grazing management in response to a changing climate, incorporate integrated livestock-crop production systems, improve fertility to increase birth rates, and reduce livestock losses due to disease and pest pressure. These management strategies can be used in an effort to (1) improve gain efficiency facilitating finishing livestock for harvest using fewer resources, (2) reduce time from birth to harvest, and (3) have lower greenhouse gas emissions per unit animal protein. Economics of livestock sales for harvest are increasingly turning to formula and grid markets, where prices are determined on actual carcass qualities instead of the traditional markets that base price on live or dressed weights; premiums are paid for carcasses that meet customer demands, whereas discounts are associated with less desirable carcasses. Conceptual advances in livestock production systems have expanded the utility of livestock in conservation-oriented approaches to include (1) efforts to "engineer ecosystems" by altering vegetation structure for increased habitat and species diversity, and structural heterogeneity); (2) use of targeted grazing to reduce invasive annual grasses and invasive weeds, and fuel reduction to decrease wildfires; and (3) improvement of the distribution of livestock grazing across the landscape. Livestock production systems need to increase their output of animal protein by implementation of knowledge and technology, but this production must be sustainable and society needs to have confidence that animals were raised in a humane and environmentally acceptable manner such that the quality and safety of the animal protein are acceptable for consumers.

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