8 Livestock Production and Energy Use

Worldwide an estimated 2 billion people live primarily on a meat-based diet while an estimated 4 billion people live primarily on a plant-based diet (Pimentel et al., 1999). The shortage of cropland, freshwater, and energy resources requires that most of the 4 billion people live primarily on a plant-based diet; however, there are serious food shortages worldwide. For instance, the World Health Organization recently reported that more than 3 billion people are malnourished in the world (WHO, 2000). This is the largest number and proportion of malnourished people ever recorded in history. In large measure, the food shortage and malnourishment problem are primarily related to rapid population growth in the world in addition to the declining per capita availability of land, water, and energy resources required for food production (Pimentel and Pimentel, 2003).

Meat, milk, and eggs contribute valuable nutrients to the human diet in the United States and the world. To produce animal protein successfully requires the expenditure of human and fossil energy to supply livestock forage and grain. The land, devoted to grain or forage for livestock production, is exposed to soil erosion which slowly diminishes the fertility of the soil and its productivity (Pimentel, 2006). Additionally, animal production requires large inputs of water for grain and forage crops and, to a lesser extent, directly for animal consumption. All of these factors interact to determine the ultimate success of animal production systems (Pimentel, 1997).

In this chapter, I include an analysis of the quantities of animal products produced; energy, land, and water resource inputs in livestock production; and meat, milk, and egg production.

ANIMAL PRODUCTS CONSUMED IN THE U.S. DIET

In the United States, more than 8 billion livestock are maintained to supply the animal protein consumed annually (USDA, 2001). In addition to the large amount of cultivated forage, the livestock population consumes about seven times as much grain as is consumed directly by the entire American population (Pimentel and Pimentel, 2003).

From the livestock population of more than 8 billion, approximately 7.5 million tons (metric) of animal protein is produced each year (Table 8.1). If distributed equally, it would be sufficient to supply about 75 g of animal protein daily per American. With the addition of 37 g of available plant protein, a total of 112 g of

TABLE 8.1
Number of Livestock in the United States

Livestock and Livestock Products	Number × 10^6
Sheep	7
Dairy	13
Swine	60
Beef cattle	74
Turkeys	273
Broilers	8000
Eggs	77,000

Source: USDA, *Agricultural Statistics*, U.S. Department of Agriculture, Washington, D.C., 2001.

protein is available per capita (Pimentel and Pimentel, 2003). In contrast, the RDA (recommended daily allowance) per adult per day is 56 g of protein for a mixed diet for an adult. Therefore, based on these data, each American is consuming about twice the RDA for protein per day.

About 144 kg of meat, including fish, is eaten per American per year (Pimentel and Pimentel, 2003). In addition, 271 kg of milk and eggs are consumed per capita in the United States per year.

ENERGY INPUTS IN ANIMAL PRODUCT PRODUCTION

Each year an estimated 45 million tons of plant protein are fed to U.S. livestock to produce approximately 7.5 million tons of animal protein for human consumption (USDA, 2001). To produce this animal protein, about 28 million tons of plant protein from grain and 17 million tons of plant protein from forage are fed to the animals (Table 8.2). Thus, for every kilogram of high quality animal protein, livestock are fed nearly 6 kg of plant protein. In the conversion of plant protein into animal protein, there are two principal "costs": (1) the direct costs of production of the harvested animal including the grain and forage and (2) the indirect costs for maintaining the breeding animals (mother and father).

The major fossil energy inputs for grain and forage production include fertilizers, farm machinery, fuel, irrigation, and pesticides (Pimentel et al., 2002). The energy inputs vary according to the particular crop and forage being grown. When these inputs are balanced against their energy and protein content, grains and some legumes like soybeans are produced more efficiently in terms of energy inputs than are fruits, vegetables, and animal products (Pimentel and Pimentel, 1996; Pimentel et al., 2002). In the United States, the average protein yield of the five major grains (plus soybeans) fed to livestock is about 700 kg/ha. To produce a kilogram of plant protein requires about 10 kcal of fossil energy (Pimentel et al., 2002).

Forage can be fed to ruminant animals, such as cattle and sheep, because they can convert forage cellulose into usable nutrients through microbial fermentation.

TABLE 8.2
Grain and Forage Inputs per Kilogram of Animal Product Produced, and Fossil Energy Inputs (kcal) Required to Produce 1 kcal of Animal Protein

Livestock and Livestock Products	Grain (kg)[a]	Forage (kg)[b,c]	kcal Input/kcal Protein
Lamb	21	30	57:1
Beef cattle	13	30	40:1
Eggs	11	—	39:1
Beef cattle	—	200	20:1
Swine	5.9	—	14:1
Dairy (milk)	0.7	1	14:1
Turkeys	3.8	—	10:1
Broilers	2.3	—	4:1

[a] From USDA, *Agricultural Statistics*, U.S. Department of Agriculture, Washington, D.C., 2001.
[b] From Heischmidt, R.K., Short, R.E., and Grings, E.E., *Journal of Animal Science* 74(6), 1395–1405, 1996.
[c] From Morrison, F.B., *Feeds and Feeding*, Ithaca, NY: The Morrison Publishing Company, 1956.

The total plant protein produced on good U.S. pasture and fed to ruminants is 60% of the amount produced by grains (Table 8.2). Current yield of beef protein from productive pastures is about 66 kg/ha, while the energy input per kilogram of animal protein produced is 3500 kcal (Pimentel and Pimentel, 1996). Therefore, animal protein production on good pastures is less expensive in terms of fossil energy inputs than grain protein production (Table 8.2).

Of the livestock systems evaluated in this investigation, chicken-broiler production is the most efficient with an input of 4 kcal of fossil energy per 1 kcal of broiler protein produced (Table 8.2). Broilers are a grain only system. Turkey production, also a grain only system, is next in efficiency with a ratio of 10:1. Milk production based on a mixture of grain and forage also is relatively efficient with a ratio of 14:1 (Table 8.2). Nearly all the feed protein consumed by broilers is grain, whereas for milk production about two-thirds is grain (Table 8.2). Of course, 100% of milk production could be produced on forage. Both pork and egg production also depend upon grain (Table 8.2). Pork has a 14:1 ratio whereas egg production is relatively more costly in terms of feed energy requiring a 39:1 ratio (Table 8.2).

The two livestock systems depending most heavily on forage, but still using significant amounts of grain, are the beef and lamb production systems (Table 8.2). The lamb system with a ratio of 57:1 and the beef system with a ratio of 40:1 are the two highest (Table 8.2). If these animals were fed only on good quality forage, the energy inputs could be reduced by about half depending on the conditions of the pasture-forage as well as the management practices. Note that beef fed 200 kg of forage and no grain had an energy input per kilocalorie protein output ratio of 20:1 (Table 8.2). Rainfall is critical for all productive pasture systems.

Per kilogram of animal product foods, broiler chicken flesh has the largest percentage of protein and milk the lowest (Table 8.3). Beef has the highest calorie

TABLE 8.3
The Calorie, Water, and Protein Availability per Kilogram of Animal Product

Livestock and Livestock Products	Energy (kcal)	Water (%)	Protein (g)
Lamb	2521	47	220
Beef	2565	49	186
Turkey	1193	55	123
Egg	1469	74	116
Pork	2342	57	134
Dairy	647	87	34
Broiler	1357	71	238

Source: Pimentel, D., Canadian Society of Animal Science, Proceedings, Canadian Society of Animal Science, Montreal, Quebec, 1997. With permission.

content because of its high fat content and relatively low water content. Of all the animal products, milk has the highest water content with 87%.

The average fossil energy input for all animal protein production systems studied is about 25 kcal of fossil energy input per kilocalorie of animal protein produced (Table 8.2). This energy input is more than 10 times greater than the average input to output ratio for grain protein production, which was about 2.5 kcal per kilocalorie of protein produced. As food for humans, however, animal protein has about 1.4 times the biological value as food compared with grain protein.

LAND RESOURCES

Livestock production requires a large number of hectares to supply the grains, forages, and pastures for animal feeds. In fact, nearly 300 million ha of land are devoted to producing the feed for the U.S. livestock population. Of this, 262 million ha are pasture and about 30 million ha are for cultivated grains (USDA, 2001). In addition to the large amount of forages and grass that are unsuitable for human consumption and are fed to animals, about 323 million tons of grains—or about 816 kg per American in the United States—are fed to livestock to provide meat, milk, and eggs (Pimentel and Pimentel, 2003).

More than 99.2% of U.S. food is produced on the land, while less than 0.8% comes from oceans and other aquatic ecosystems (FAO, 1998). The continued use and productivity of the land is a growing concern because of the rapid rate of soil erosion and degradation that is taking place throughout the United States and indeed throughout the world. Each year about 90% of U.S. cropland is losing soil at an average rate 13 times above the sustainable rate of 1 t/ha/year (Pimentel and Kounang, 1998). On croplands where most grain is produced, soil loss averages more than 13 t/ha/year from the combined effects of water and wind erosion. Also, our rangelands are losing soil on an average of 13 t/ha/year (Unnevehr et al., 2003). About 60% of United States rangeland is being overgrazed and is subject to accelerated erosion.

The concern about high rates of soil erosion in the United States and in the world is evident when it is understood that it takes approximately 500 years to replace 25 mm (1 in.) of lost soil (Pimentel and Kounang, 1998). Clearly a farmer cannot wait for the replacement of 25 mm of soil. Commercial fertilizers can replace some nutrient loss resulting from soil erosion, but this requires large inputs of fossil energy (Pimentel et al., 2002).

The future of all agricultural production that requires land, including that targeted for livestock, will feel the effects of land degradation, particularly when fossil fuel supplies decline and prices increase. Soil erosion losses, compounded by salinization and waterlogging, are causing the abandonment of nearly 1 million ha of U.S. agricultural land per year (Troeh et al., 1991; Pimentel and Kounang, 1998). Some of the abandoned, degraded cropland may find use as either pasture or forest.

The costs of soil erosion are well illustrated by the loss of rich U.S. soils. Iowa, which has some of the best soils in the world, has lost more than one-half of its topsoil after only 150 years of farming (Risser, 1981; Klee, 1991). Iowa continues to lose topsoil at an alarming rate of about 30 t/ha/year, which is about 30 times faster than the rate of soil formation (USDA, 1989, 1994). The rich Palouse soils of the Northwest United States have similarly lost about 40% of their topsoil in the past century (Pimentel et al., 1995).

Despite the efforts of the USDA Soil Conservation Service, erosion rates in the United States have decreased only slightly during the past 50 years. This is the result of major changes in agricultural production, such as: emphasis on commodity price-support programs; widespread planting of crop monocultures; crop specialization; abandonment of crop rotations; the removal of tree shelter-belts; leaving the soil without protective biomass cover; and the use of heavy farm machinery (Lal and Stewart, 1990; Pimentel et al., 1995). Concurrently these changes have been accompanied by the creation of fewer and larger farms where increased mechanization is a necessity.

Although modern farming practices are contributing to the soil erosion problem, the failure of farmers and governments to recognize and address the soil erosion problem is equally important if soil depletion is to be halted. Erosion often goes unnoticed by some farmers because soil loss is difficult to measure visually. For instance, one night's wind or rain storm could erode 15 t of soil per hectare as a sheet, which would be only 1 mm of soil; the next morning, the farmer might not even notice this loss. This soil loss continues slowly, quietly, year after year, until the land is no longer productive. In addition, governments tend to ignore erosion because of its insidious nature and because it does not seem to be a major environmental crisis like floods or tornadoes.

WATER RESOURCES

Agricultural production, including livestock production, consumes more fresh water than any other human activity (Postel, 1999). Western U.S. agriculture accounts for about 81% of the fresh water consumed after being withdrawn. Growing plants render all water nonrecoverable through evaporation and transpiration. In the United States, about 62% of the water used in agricultural irrigation comes from surface sources and 38% from ground water sources (Pimentel et al., 1997).

TABLE 8.4
Estimated Liters of Water Required to Produce 1 kg of Food and Forage Crops

Livestock and Crop Products	L/kg
Potatoes	500
Wheat	900
Alfalfa	900
Sorghum	1100
Corn	1400
Rice	1900
Soybeans	2000
Broiler	3500
Beef	43,000

Source: Pimentel, D., Houser, J., Preiss, E., White, O., Fang, H., Mesnick, L., Barsky, T., Tariche, S., Schreck, J., and Alpert, J., *BioScience* 47(2), 97–106, 1997. With permission.

The transfer of water to the atmosphere from the terrestrial environment by transpiration through vegetation is estimated to range between 38% and 65% of the rainfall depending on the terrestrial ecosystem (Pimentel et al., 1997). The vital photosynthetic processes and temperature control necessitate that the plants consume enormous amounts of water.

The water required to produce various food and forage crops range from 500 to 2000 L of water per kilogram of plant biomass produced (Table 8.4). For example, a hectare of U.S. corn producing about 8000 kg per year transpires about 5 million L of water during the growing season. Approximately 1000 mm (10 million L per hectare) of rainfall or other sources of water are needed during the growing season for corn production. Even with 800–1000 mm of annual rainfall in the Corn-Belt region, corn usually suffers from some lack of water during the summer growing season (Troeh and Thompson, 1993).

Producing 1 kg of beef requires about 43 times more water than producing 1 kg of grain (Pimentel and Pimentel, 1996). Livestock directly use only 1.3% of the total water used in agriculture. However, when the water required for forage and grain production is included, this dramatically increases the water requirement for livestock production. Producing 1 kg of fresh beef requires about 13 kg of grain and 30 kg of forage (Table 8.2). This much grain and forage requires a total of 43,000 L of water. On rangeland where an animal consumes about 200 kg of forage to produce 1 kg of beef, about 200,000 L of water are needed to produce the 1 kg of beef (Thomas, 1987). With forage and some cereal crops, livestock can be produced in areas with low rainfall ranging from 150 to 200 mm per year (Rees et al., 1990). However, crop production and yields are low under such conditions.

Animals vary in the amounts of water required for their production. In contrast to beef, 1 kg of broiler chicken can be produced with about 2.6 kg of grain requiring approximately 3500 L of water (Table 8.4).

Water shortages are already severe in the western and southern United States. The situation grows worse as the U.S. population and its requirements for water, including for agriculture, rapidly increase (Pimentel et al., 1999).

WORLD FOOD NEEDS

Worldwide, human food needs are rising and will continue to rise with the world population (Pimentel et al., 1999). Currently, there are more than 3 billion who are malnourished based on shortages of calories, protein, vital minerals, and vitamin in their diets (WHO, 2000). Already there are currently 6.2 billion people on Earth and it is projected that the world population will double, to more than 12 billion in less than 50 years, based on the current growth rate (Pimentel et al., 1999). The U.S. population is also increasing rapidly. The U.S. population is currently at 285 million and is expected to double to 570 million in about 70 years (USBC, 2001). Food security becomes at risk as more and more people need food, while the required resources of land, water, and energy decline per person.

Food consumption patterns in the United States and most other developed nations include generous amounts of animal products. More than half of U.S. grain and nearly 40% of world grain are being fed to livestock rather than being consumed directly by humans. Grains provide 80% of the world's food supply. Although grain production is increasing in total, the per capita supply has been decreasing for nearly two decades (Pimentel and Pimentel, 2003). Clearly, there is reason for concern for the future.

If all the 323 million tons of grain currently being fed to livestock were consumed directly by people, the number of people who could be fed would be approximately 1 billion. Also, if this much grain were exported, it would provide approximately $80 billion each year in income—this is sufficient income to pay for our current oil bill of $75 billion per year (USBC, 2001). Of course, exporting all the grain currently fed to livestock would reduce the average protein consumption of Americans from 112 g per day to approximately 73 g per day. Yet this intake would still be greater than the 56 g of protein suggested by the RDA.

Exporting all U.S. grain that is now fed to livestock assumes that livestock production would change to a grass-fed livestock production system. Animal protein in the diet would then decrease from the current level of 75 g to 36 g per day, or about one-half. Again, the diet for the average American would be more than adequate in terms of protein consumption, provided that there was no change in the current level of plant protein consumed. In fact, consuming less meat, milk, and eggs and eating more grains and vegetables would improve the diet of the average American.

CONCLUSION

Meat, milk, and egg production in the United States relies on significant quantities of fossil energy, land, and water resources. Grain-fed livestock systems use large quantities of energy because grain crops are cultivated; in contrast, cattle grazed on pastures use considerably less energy than grain-fed cattle. An average of 25 kcal of fossil energy is required to produce 1 kcal of animal protein and requires approximately

10 times the energy expended to produce 1 kcal of plant protein. However, it should be noted that animal protein is 1.4 times more nutritious for humans than plant protein.

Nearly one-third of the U.S. land area is devoted to livestock production. Of this, about 10% is devoted to grain production and the remainder is used for forage and range land production. The pastureland and range land are marginal in terms of productivity because there is too little rainfall for crop production.

Livestock production is also a major consumer of water because grains and forage consumed by livestock require significant amounts of water for growth and production. To produce 1 kg of grain requires about 1000 L of water. Based on grain and forage consumption, about 43,000 L of water are required to produce 1 kg of beef. In regions where water is already in short supply and where aquifers are currently being mined faster than they can be recharged, major decisions will have to be made concerning all agricultural production, including grain and forage crops for livestock.

As human food needs escalate along with population numbers, serious consideration must be given to the conservation of fossil energy, land, and water resources. The careful stewardship of these resources is vital if livestock production, and indeed agriculture, will be sustainable for future generations. In the end, population growth must be reduced, in the United States and in the world, if we are to achieve a quality life for ourselves and our grandchildren.

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