7 Early Livestock Systems and Animal Power

Throughout history, humans have depended upon animals for food, power, and companionship. Humans have worshipped animals such as the tiger, leopard, and lion. Even today, animals seem to symbolize a special power; one can purchase a Jaguar, Eagle, or Ram automobile. The major role of animals, however, has been to provide food and to supply power to help humans cultivate their crops, build their shelters, and transport their supplies.

All available evidence tends to confirm that humans are omnivores. Humans have the capacity to consume not only a wide variety of plant materials but also animal flesh and milk. The relative proportion of plant to animal food consumed varies with cultural habits, availability of food, and personal preference.

EARLY ANIMAL HERDING

Early civilizations depended upon both animal husbandry and crop culture to supplement hunting and the gathering of wild foods. The first animals kept by humans as a source of food were chickens, ducks, pigs, rabbits, sheep, goats, cattle, camels, donkeys, and llamas. These animals provided meat, fat, milk, and blood for energy and protein and supplied other major nutrients.

Animal husbandry probably began when a hunter carried his prey's young back to camp. There, fed and protected, the animals thrived and could be killed when humans needed additional food. Later on, some of the captive animals were tamed and allowed to reproduce. Eventually, the numbers in captivity were sufficient not only to provide immediate food but also to breed, thus ensuring a continuing, stable food supply.

Herding was more efficient and dependable than hunting because it greatly reduced the time and energy humans spent in pursuit of animal foods. Further, the work involved in herding was easily done by weaker members of the group, thus freeing more able individuals to do other tasks necessary to the survival of the community.

In addition, maintaining herds of sheep, goats, cattle, and camels was a dependable way to store surplus food produced during highly successful crop years. Rather than wasting the surplus, the people could feed it to their animals. In periods of poor environmental conditions, when crop yields were low, the livestock were an available food supply.

The stabilization of the food supply through animal husbandry was even more helpful to those humans who lived in marginal habitats. In severely wet, dry, cold, or mountainous environments, crop production is difficult, unpredictable, and sometimes nearly impossible. Moreover, the tolerant grasses and other types of forage that grow well in many of these habitats are not suitable food for humans. However, these plants are suitable food for livestock, which convert them into meat, milk, and blood that humans can utilize.

The herding carried out by the Dodo tribe of northeast Uganda illustrates the advantages of husbanding livestock in marginal habitats (Deshler, 1965). During the Deshler study, the Dodo tribe numbered about 20,000 and herded about 75,000 head of Zebu cattle over an area of about 780,000 ha, or approximately 10 ha per head of cattle. The human population density was low, about 1 per 39 ha, making the ratio of cattle to people about 3.75:1. Based on a biomass comparison, the cattle outweighed the human population by more than 18 to 1.

The habitat in which the Dodos live is bleak, consisting primarily of thorn scrub and perennial grasses and having an average rainfall of between 450 and 620 mm per year. In addition to herding, the Dodos cultivate sorghum, which has ample yields during good rainfall years. However, low rainfall years also are common in that part of Uganda, making sorghum an unreliable food resource. When the sorghum harvest is poor, the cattle provide the needed food in the form of milk, blood, and meat. In addition, cattle are traded for money, which is used to purchase sorghum when local supplies are inadequate.

The 75,000 cattle yield an estimated 2.5 billion kcal in milk, 2.3 billion kcal in meat, and 630 million kcal in blood annually (Pimentel et al., 1975; Westoby et al., 1979). To produce this total of 5.43 billion kcal of food energy, the Dodos feed the cattle no grain, only pasture forage that is unsuitable for human consumption. Forage consumption is estimated at 8 kg per animal per day (Pimentel et al., 1975; Westoby et al., 1979).

The Dodos use little or no fossil fuel in managing this livestock, and work is done by human power. With the Dodo population estimated at 20,000, and assuming that 40% of the males work 56 h/week and 40% of the females work 7 h/week in herding (totaling 26.2 million hours), the estimate is that 34 human hours per hectare of grazing land per year are invested in managing this livestock population. The annual yield in animal protein is 0.7 kg/ha annually.

The energy input is calculated to be 250 kcal per working hour. Assuming that male herders work 8 h per day with an expenditure of 250 kcal/h, rest 10 h at 45 kcal/h, and spend 6 h at other activities at 100 kcal/h, the daily energy input per herder is 3050 kcal. With an estimated 8000 male herders caring for the cattle, this totals 24.4 million kcal/day, or 8.9 billion kcal/year. The females average only 1 h of herding work per day, spending most of their time caring for the sorghum plots (Deshler, 1965). When the annual female input in herding (730 million kcal) is added to the male input, the total comes to 9.6 billion kcal per year.

With 5.4 billion kcal of animal protein produced and an energy input of 9.6 billion kcal, the output/input ratio is only 0.54:1, or about 2 cal of input per 1 calorie output. Based on the animal protein produced, the Dodo could not maintain themselves only on livestock. However, as mentioned, sorghum is a staple food of the Dodo. Thus, livestock protein is used to supplement the sorghum raised or purchased.

The Dodo tribe illustrates the important role livestock can play in providing food for humans. First, the livestock effectively convert forage growing in the marginal habitat into food suitable for humans. Second, the herds serve as stored food resources. Third, the cattle can be traded for sorghum grain during years of inadequate rainfall and poor crop yields.

ANIMAL POWER AS AN ENERGY SOURCE

For most of the time that humans have inhabited the Earth, their prime source of power has been their own muscle power. They moved about on foot, carried their own goods, tilled their own land, planted, cultivated, and harvested crops through their own labor, ground cereals by hand, hunted animals with arrows and spears, and protected themselves from animal predators and human attackers.

Early additional sources of power included human slaves and domesticated animals. The hunting/gathering societies were helped when an extra food gatherer or hunter could join in the task of securing food. Likewise, the labor intensiveness of primitive agriculture increased both the need for and the usefulness of slave and animal labor.

In hunting, one or two persons could guide wild game to a concealed hunter, and an additional hunter could help in the exhausting task of tracking and killing the wounded prey. Usually the killing of large animals required the efforts of several hunters. Even after the kill, considerable energy was expended in transporting the carcass back to camp, often a long distance away. Thus, additional manpower was a distinct asset both during a hunt and after a successful kill.

The slave or extra hunter, of course, would have to be fed. However, two hunters could kill more than twice as much game as a single hunter could kill alone. In this way, additional labor provided a greater return in energy than the energy input required for its maintenance.

Along with slaves, animals slowly emerged as an additional source of power for humans. Young animals captured in the wild could be tamed and later used to transport goods and people. At first these animals were probably used to carry collected food or animal carcasses back to camp. In addition, nomadic groups used animals to move their belongings to new campsites.

Over time, many kinds of animals have served as beasts of burden. The earliest records of such use show that donkeys served humans in Egypt about 3000 B.C. (Leonard, 1973) and later in Mesopotamia about 1800 B.C. (Zeuner, 1963). Agriculture was already an important activity of these societies, and animals were used to transport the harvest from the field to the village. Gradually, aided by this improved mode of transportation, trade between villages developed.

As early as 2500 B.C., cattle, including oxen and water buffalo, were used to transport people and goods and to draw plows (Leonard, 1973). The use of animal power to cultivate the soil was an immense breakthrough in agricultural production. Tremendous quantities of energy and about 400 h of heavy labor were expended when humans worked alone to turn 1 ha of soil for planting. With 1 h of ox power substituting for 3–5 h of human power, the time and energy requirement was drastically reduced.

The use of horses followed and was a significant improvement over oxen because horses move faster. Best estimates are that horses first inhabited Asia but were probably not domesticated until 3000 B.C. (Lee, 1955). As with oxen, horses were first used to transport goods and people and later to help humans till their fields. Other animals that have been used to carry humans and their goods include camels, llamas, goats, and even dogs.

About 3000 B.C., the invention of the wheel made possible a tremendous increase in the efficiency of transportation (Lee, 1955). The wheel doubled the load of goods that could be transported per unit of energy. The surplus energy was then available for use in other ways and undoubtedly helped humans improve their standard of living.

In addition, the wheel led to improved efficiency in other food-related processes, such as grinding cereals. Grinding grain by hand was slow and tedious. Animals powered the early grinding wheels, but later humans found ways to harness wind and water for power. Of course, wind and water power were significantly more efficient than animal power because they did not require food for maintenance.

Although wind and water power are more efficient than either animal or human power for grinding grain, there are many tasks for which human power is the most efficient energy source. This can be illustrated by analyzing the energy inputs in tilling soil and applying herbicides. A person using a heavy hoe to till 1 ha of soil for planting needs about 400 h, or 40 work days of 10 h each, to complete the task (Lewis, 1951). If we assume that the individual expends 400 kcal/h for this heavy work, this amounts to 4000 kcal expended per 10-h day (though it is doubtful that a person could maintain a 400 kcal/h pace for 10 h). Additional energy is required to maintain the worker for the other 14 h each day. If we assume the worker rests for 10 h at 45 kcal/h and spends the other 4 h involved in miscellaneous light activities requiring an average of 100 kcal/h, the total energy expenditure for one person tilling the soil is 4850 kcal/day. When this daily energy expenditure is multiplied by 40 days of work, the total energy input is about 194,000 kcal (Table 7.1). An added

TABLE 7.1
Comparison of Energy Inputs for Tilling 1 ha of Soil by Human Power, Oxen, 6-HP Tractor, and 50-HP Tractor

Tilling Unit	Required Hours	Machinery Input (kcal)	Petroleum Input (kcal)	Human Power Input (kcal)	Oxen Power Input (kcal)	Total Input (kcal)
Human power	400	6000	0	194,000	—	200,000
Oxen (pair)	65	6000	0	31,525	260,000[a]	297,525
6-HP tractor	25	191,631	237,562[b]	12,125	—	441,318
50-HP tractor	4	245,288	306,303[c]	1940	—	553,531

[a] Each ox is assumed to consume 20,000 kcal of feed per day.

[b] An estimated 23.5 L of gasoline used.

[c] An estimated 30.3 L of gasoline used.

Source: Pimentel, D. and Pimentel, M., *Food, Energy and Society*, Edward Arnold, London, 1979.

6000 kcal input is required for the construction and maintenance of the heavy hoe. Thus, the total energy input to till 1 ha by human labor alone is about 200,000 kcal.

Oxen, small hand tractors, and 50-HP tractors all require a greater total energy expenditure to till the same hectare of land. However, it should be noted that all these other power systems can complete the tilling task in far less time than a human can. For example, two oxen take only 65 h but expend almost 50% more energy than a human tiller does (Table 7.1). The oxen must be fed and need a person to guide them as they work. Likewise, 6-HP and 50-HP tractors take much less time—25 and 4 h, respectively—to till 1 ha than humans. But they use far more energy than either humans or oxen because of the large input of petroleum needed to run the engines.

Considering the current prices of fuel, hay, and labor in all countries, it is generally more economical to till the soil with either machinery or oxen than with human labor alone. If prices of fuels rise, machinery may no longer be quite the energy bargain it is today.

Tilling the soil is an extremely heavy task for both humans and tractors. To keep the relative efficiencies of human labor and tractors in perspective, it is helpful to compare energy inputs involved in applying herbicides. A person takes about 3 h to hand-spray 1 ha with herbicide, expending an estimated 300 kcal/h, plus nonworking inputs, for a total of 1455 kcal. Adding 8 kcal for the construction and maintenance of the hand-sprayer brings the total input for the spraying task to 1463 kcal (Table 7.2).

The 50-HP tractor using a power-driven sprayer requires only 0.7 h to spray 1 ha. The gasoline input is estimated at 3 L, or 30,327 kcal of energy, and the human labor input for 0.7 h is assumed to be 340 kcal. An added 21,463 kcal of energy is expended for the construction and maintenance of both tractor and sprayer. Thus, the total energy input for tractor-spraying is about 52,130 kcal, or about 37 times more than for hand-spraying (Table 7.2). Obviously, using a 50-HP tractor for this task is energy intensive; in fact, the tractor is too highly powered for such light work. The tractor and sprayer weigh 5–6 tons, and a large input of energy is needed to move these weights over the field.

When only the dollar cost is considered, applying herbicide manually would be more economical than employing a tractor. Thus, in a country where farm

TABLE 7.2
Comparison of Energy Inputs for Spraying Herbicide on 1 ha by Human Power and 50-HP Tractor

Spraying Unit	Required Hours	Machinery Input (kcal)	Petroleum Input (kcal)	Human Power Input (kcal)	Total Input (kcal)
Human power	3.0	8	0	1455	1463
50-HP tractor	0.7	21,463	30,327[a]	340	52,130

[a] An estimated 3 L of gasoline used.

Source: Pimentel, D. and Pimentel, M., *Food, Energy and Society*, Edward Arnold, London, 1979.

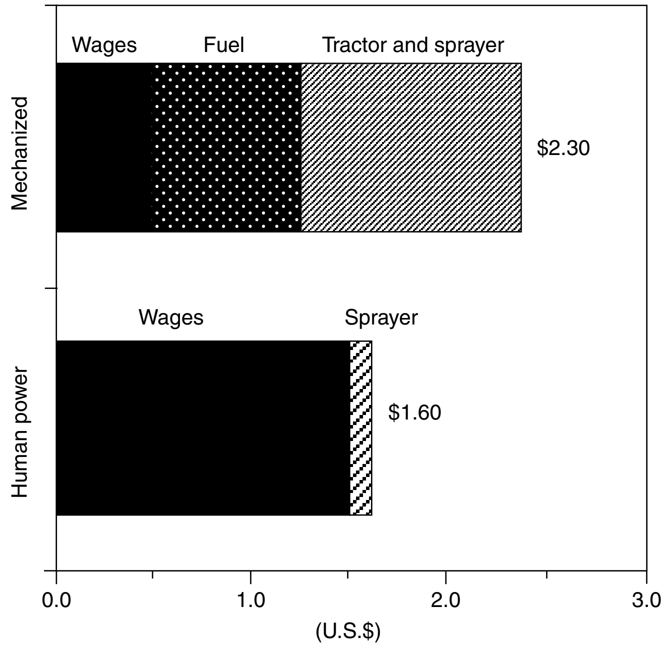

FIGURE 7.1 Economic costs of applying herbicide in a developing country.

wages might be as low as $0.50 per hour, applying herbicide manually would cost an estimated $1.60, whereas using a tractor would cost an estimated $2.30 (Figure 7.1). Hand-spraying becomes increasingly expensive as the hourly wage for labor increases.

In these comparisons, nothing has been said about the type of energy used, and this is a vital factor to consider. Humans need food, the tractor depends on petroleum, and the ox consumes forage, a plant product that humans cannot use for food. In many regions, forage is a free energy source. Forage growing along paths, waterways, and similar areas that do not compete with croplands can be fed to the oxen or other draft animals. Also, straw left after the harvest of rice or similar grain crops can be fed to animals. Hence, the energy cost of maintaining an ox might be minimal to the small farmer. Draft animals have additional advantages because they provide milk and meat as well as power. With animal protein foods at a premium in some developing countries, this supply of milk and meat has great nutritional value.

Many nations have replaced draft animals with tractors and other machinery. For example, when the United States was first settled in 1620, human power was the prime power source for work, but by 1776 an estimated 70% of the power was supplied by animals and only 20% by humans (Cook, 1976). By 1850 animal power had declined to 53% and manpower to 13% (Cook, 1976) (Figure 7.2). By 1950, about 100 years later, animal and human power had declined to only about 1%, and fossil-fuel-powered engines provided 95% of the power. Thus, a dramatic change with far-reaching consequences has taken place, as humans continue to consume ever-increasing quantities of nonrenewable fossil fuels.

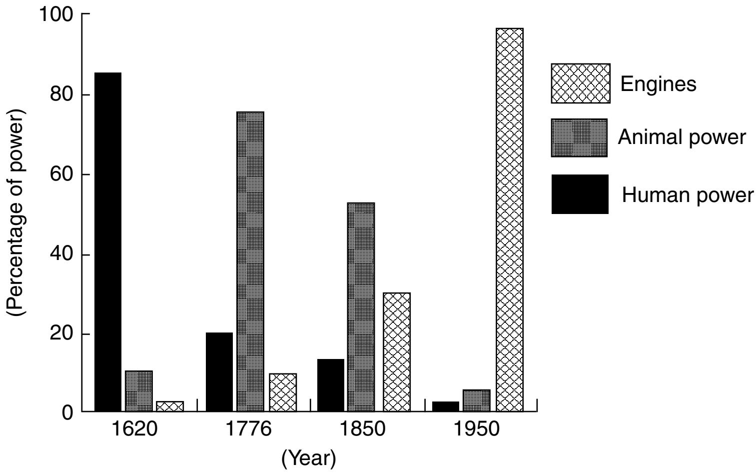

FIGURE 7.2 The percentage of power provided by human power, animal power, and engines during various periods in U.S. history. (*Sources*: 1620, estimated; 1776, 1850, and 1950, from Cook, E., *Man, Energy, Society*, W.H. Freeman, San Francisco, 1976.)

ANIMAL FOOD-CONSUMPTION PATTERNS

Throughout history animals, either hunted or husbanded, have been valued by humans for food. Even so, the majority of humankind has had to depend primarily on plant materials for energy and other nutrients. Even today most of the world's people live on about 2500 kcal per day and obtain most of their food energy and protein from grains and legumes (Worldwatch Institute, 1992).

Historical examples are numerous. One of the unique human diets on record was consumed in Ireland during the nineteenth century. At this time the Irish people relied primarily on potatoes for both calories and protein, consuming about 4.5 kg of potatoes and half a liter of milk each day (Connell, 1950). These two foods provided about 3852 kcal and 64 g of protein per day, of which 45 g were from the potatoes.

Or recall the diet of the New Guinea villagers studied by Rappaport (1968), who consumed primarily plant foods (Figure 6.4). About 99% of their calories came from plant material. A study of 12 rural villages in southern India showed that individuals consumed, on average, between 210 and 330 g of rice and wheat, 140 ml of milk, and 40 g of pulses and beans per day (Tandon et al., 1972). This diet provided about 1500 kcal and 48 g of protein per day, with the major share of both calories and protein coming from plants.

In Central America, laborers commonly consume about 500 g of corn per day (E. Villager, ICAIITI, personal communication, 1975). Along with the corn they eat about 100 g of black beans per day, and together these staples provide about 2118 kcal and 68 g of protein daily. The corn and beans complement each other in providing the essential amino acids that humans need. Additional food energy is obtained from other plant and animal products.

A sharp contrast to all these examples is found in the United States, where the daily protein intake is 112 g, of which 75 g is animal protein. U.S. per capita animal

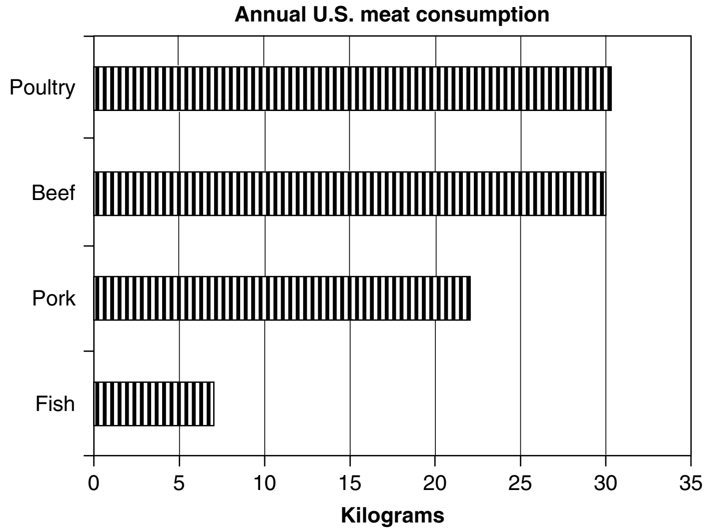

FIGURE 7.3 Annual meat consumption per person in the United States. (From USDA, *Agricultural Statistics 2006*, Government Printing Office, Washington, D.C., 2003.)

and animal protein consumption is among the highest in the world, although similar consumption patterns appear in many highly industrialized nations in Europe (FAO, 1991). In 2006, annual U.S. per capita meat consumption was 92 kg. Poultry is the meat eaten in the largest quantity (Figure 7.3). In addition, annual per capita food consumption includes 14 kg of eggs and about 260 kg of milk and dairy products.

Although mammals and mammal products, such as milk and cheese, dominate the animal products consumed by humans, a great variety of other animal material is also eaten, including many kinds of birds and their eggs, ranging all the way from large ostrich eggs to tiny birds such as the English sparrow. Often the small birds, plucked of feathers and cooked on skewers, are eaten whole, bones and all (Laycock, 1986). Eggs are eaten in a variety of ways: raw, cooked, incubated, preserved, and pickled. Some uniquely prepared eggs are the Chinese, or "century" eggs and the Philippine *balut*. Century eggs are preserved in lime, coated with clay, and buried for long periods of time. As the name implies, century eggs will keep for many years. After the preservation, the white portion of the egg has become black and gelatinous, the yolk a dark green to black color. Balut, a Philippine delicacy, is a duck egg that has been fertilized and incubated for about 17 days. On day 21 a young duckling normally would hatch from the egg, so at day 17 a fairly well-developed young duckling is present within the shell. The egg is boiled and eaten hot or cold.

Fresh and saltwater fishes and their eggs are also favorite foods when supplies are easily accessible and ample. Fish are prepared in many different ways—raw, salted, smoked, dried, boiled, baked, broiled, and by combinations of these processes.

People in many parts of the world eat arthropods, such as shrimp, crayfish, lobster, and their close relatives, the insects. In Europe and the United States, shrimp, crayfish, and lobster are some of the most highly valued and highly priced foods, yet their small insect relatives are considered unacceptable. In fact, the U.S. government has established various regulations to ensure that insects and insect parts are kept to a minimum in food. The small herbivorous insects present in U.S. foods despite the regulations include aphids, thrips, and dipterans. Some large insects that are intentionally used as food include grubs, locusts, and grasshoppers (Pimentel et al., 1993).

Lizards, snakes, snails, and frogs are also eaten by many people. In fact, some cultures consider frogs and snails a delicacy. Lizards and snakes are also eaten and are reported to be excellent food.

NUTRITIONAL QUALITY OF PROTEIN FOODS

One of the important considerations in evaluating the relative value of plant and animal protein sources is their nutritional content. A broad comparison shows, for instance, that one cup of cooked dried beans (190 g) is quite similar to an 85 g serving of cooked ground beef in the amounts of protein, iron, and important B vitamins. Further, the beans contain no fat, no cholesterol, and no vitamin B_{12}.

Although these foods contain similar amounts of protein, the nutritional quality of the protein differs in terms of both the kind and amounts of "nutritionally essential" amino acids. Animal proteins contain the eight essential amino acids in optimum amounts and in forms utilizable by humans for protein synthesis. For this reason, animal proteins are considered high-quality proteins.

By comparison, plant proteins contain lesser amounts of some of the essential amino acids and are judged to be lower in nutritional quality than animal sources. In addition, some plant proteins are deficient in one or more essential amino acids. For example, cereal grains as a group are relatively low in lysine, whereas legumes, such as dried beans and peas, are relatively low in methionine but have ample amounts of lysine. Fortunately, it is possible to combine plant proteins to complement the amino acid deficiencies. Thus, when cereal and legume proteins are eaten together, the combined amino acid supply is of better quality than that provided by either food eaten alone.

More attention and thought must be given to planning a diet that is either limited in or entirely devoid of animal protein. Variety is of prime importance in achieving a nutritionally balanced diet under such constraints. Further, because B_{12}, an essential vitamin, is not found in plant foods, this must be taken as a supplement. The diets of nutritionally vulnerable individuals, such as infants, growing children, and pregnant women, often require additional supplements when a strict plant food regime is undertaken. Individuals in these categories often find it difficult to consume the quantity of plant material necessary to provide such essential nutrients as calcium and iron.

Another advantage of animal products over plant products as food for humans, especially children, is the greater concentration of food energy per unit of weight compared with plant material. For example, to obtain 375 kcal of food energy from sweet corn one has to consume 455 g, whereas one can derive the same amount of food energy (375 kcal) from only 140 g of beef. Thus, beef has more than three times as much food energy per unit of weight as sweet corn.

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