LIVESTOCK PRODUCTION SYSTEMS

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Summary

About 10 000 years ago, sheep were the first food animals to be domesticated, marking the beginning of a new era of exponential change. Today, we may be on the verge of a “livestock revolution” that will require massive increases in animal production. Livestock production, particularly from non-ruminants, has increased steadily during the last decade. Animal-source foods are essential components of human diets because they are the best sources of some of the most critical nutrients for people: iron, zinc, calcium, vitamin A, and vitamin B12.

Livestock systems can be classified as grazing, mixed, and industrial. Grazing systems are characterized by the direct consumption of native or permanent pastures, and they depend directly on ecosystem services. Mixed systems integrate cropland and grasslands, where crop products are inputs for livestock, and livestock waste is used as input for crops. Pasture crop rotations have unique positive effects on soil fertility. One of the main problems in mixed systems is nutrient balance, to maintain good plant and animal nutrition while preventing environmental pollution. As in grazing systems, mixed livestock systems require matching of feed requirements and supply over time, which is achieved by making hay or silage. Industrial livestock systems produce less than 10 % of the feed they use, and are currently responsible for more than 40 % of global meat production. They are the fastest growing form of animal production. Industrial systems are managed based on animal nutrition and health principles. One of the major problems of industrial systems is manure management.

Livestock systems have caused negative environmental impacts such as erosion, deforestation, and water pollution, but these impacts are small relative to other food production systems and other human activities. As humans face a future in which livestock production will increase dramatically, a series of questions become outstanding. How will this large increase in production be achieved? How will we abate the negative environmental impacts? What technologies will be socially acceptable and embraced by consumers? Clearly, the future of livestock systems will offer formidable challenges. Yet, it will simultaneously present unique opportunities for positive change.

1. Introduction

About 10 000 years ago, sheep were the first food animals to be domesticated. Domestication of the precursors of cereals did not take place until 1000 years later. Thus, after about 2 million years of relatively stable subsistence as hunters and gatherers, humans were propelled into a new era of exponential and vertiginous change by the evolution of agriculture. Livestock were perhaps even the catalyst for the burst of cultural evolution.

Since the agricultural revolution, humans and livestock have coevolved and became integral parts of each other’s ecological community. It is intriguing to think that livestock and humans can be considered mutualistic, in the sense that they have enabled each other to multiply explosively and to colonize essentially all habitats on Earth. Although in recent years both animal and crop agriculture have been debatably responsible for a large number of negative impacts on the environment and humans, it is not possible to question the fact that most cultures of the world are fundamentally dependent on livestock. Thus, some of the changes proposed and even needed in the way livestock are produced may only be possible if other aspects of societies and cultures also change dramatically.

We may be on the verge of a “livestock revolution” that will require massive increases in animal production, particularly in less developed countries, and that will have consequences potentially greater than those of the “green revolution.” However, this revolution will differ because it will be demand-driven, and because its consequences will be strictly dependent on how governments and the international community decide to face the increasing demand.

The contribution of livestock to food security and agricultural development is frequently underrated. Food security is often measured in terms of the availability of food grains, although forty percent of the total food energy consumed by half the population of sub-Saharan Africa, for example, is from foods other than cereals. Livestock contribute both directly and indirectly to agriculture, and the non-food outputs of livestock are often overlooked. In addition to providing high quality food, livestock play multiple and varied roles. They constitute a valuable capital asset, and they provide cash income (from livestock products), employment, draught power, and manure for fertilizer and fuel.

In considering the current status and possible future of livestock systems, one must take into account the vast and increasing gap in the way that people live, and in the way in which people think of food and the future, between developed and developing countries, and between the rich and the poor within any region. Perhaps as a direct consequence of human population dynamics, the expected average increase in the standard of living will occur together with an increase in the number, and even proportion, of people who are very poor and have tenuous food security. It is expected that the path taken by livestock systems in the first 20 years of the twenty-first century will determine whether things improve or get worse. Key questions are whether demand for animal products can be met in a sustainable and environmentally friendly manner, and whether the gap between rich and poor will widen or narrow. The main determinants will likely be national and international agricultural policies, not technologies. The main difficulty will be to break free from traditional paradigms of development, and from the lure of trying to follow the currently infeasible paths traced by developed countries.

In this paper, we present an overview of livestock systems of the world, their interaction with the environment, and the most urgent challenges they face. First, we give a basic description of the most fundamental characteristics of livestock that determine the boundaries of potential livestock systems, and emphasize the ecological role of livestock. Livestock productivity, nutritional niche, advantages, and limitations are rooted in their ecological characteristics and their evolutionary past. Our ability to face current and future production challenges depends on conserving a varied genetic pool for all species and breeds. Second, a brief section gives a basic description of the main types of livestock systems. The section serves as the basis for understanding the options available, their productivity, geographical distribution, and environmental impacts, and it should be considered with the caveat that, in reality, there is a continuum between the major systems described. Third, a section on the role of livestock in human nutrition and food security shows that most people in the world are not consuming enough animal-source foods. This is diametrically opposed to the public's concerns in developed countries, where there is a focus on reducing heart disease, which is linked to poor dietary habits. Fourth, a section on the relation between livestock systems and the environment focuses on the main challenges we face because of the demand for animal products. The fact that humans need more animal products does not cancel the reality that livestock production has significant negative impacts on the environment. A fifth section before our concluding remarks expands on critical challenges faced by livestock production and outlines potential solutions and future scenarios.

2. Role of Livestock in Food Systems

2.1 Types of Livestock

Humans use a few dozen livestock species that comprise thousands of breeds. However, only a few species, and within these, a few breeds, account for most of the number and mass of livestock in the world (Figure 1). Cattle, sheep, goats, and pigs account for 92 % of all livestock in the world, with relative abundance of the different species varying significantly among regions (Figure 2).

Most of this variation is due to pig and goat stocks, with goats being most abundant in Africa and Asia, whereas pigs dominate livestock numbers in China. In terms of total production (Figure 3), two aspects are noteworthy in the last ten years. First, the production of meat by pigs and poultry has increased steeply. Second, the proportion of total production represented by poultry is much greater than the proportion of stocks represented by poultry.

This is in part explained by the much faster turnover and relative growth rates of birds than the larger ruminant livestock. Overall, in the past decade, there has been a steady increase in global production, but the production from non-ruminants has been much steeper than for ruminant products.

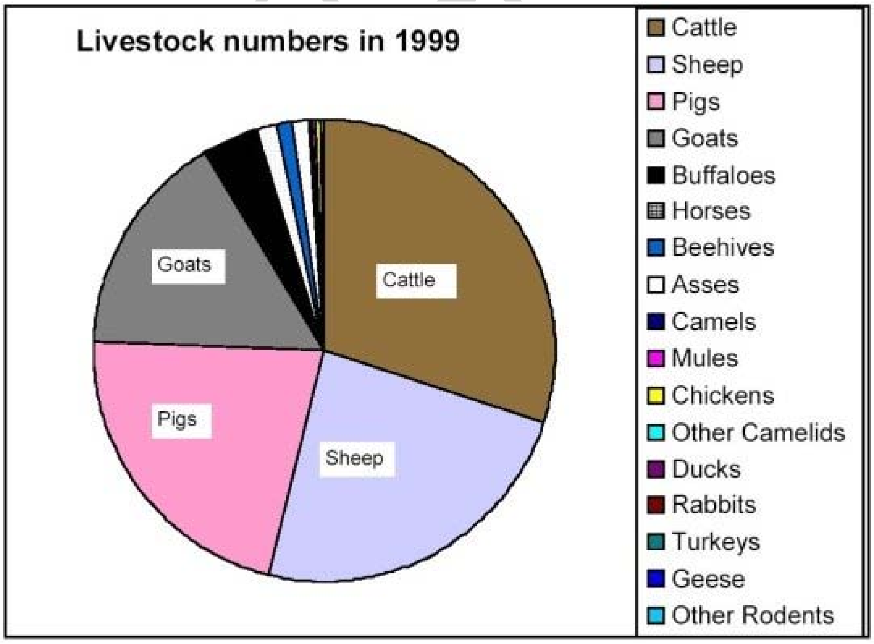

Figure 1. Proportions of different types of livestock in the world. Based on 1999 data from FAO's (United Nations Food and Agriculture Organization) electronic database. Animals are listed in order of decreasing abundance.

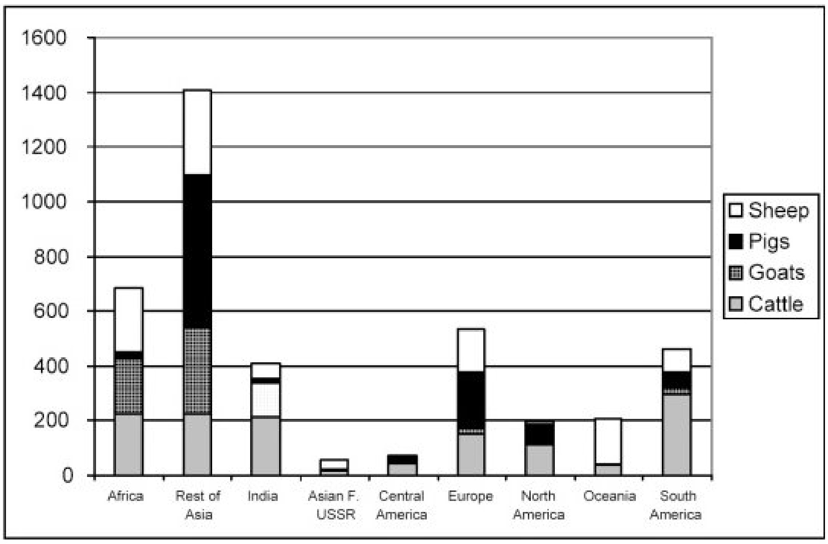

Figure 2. Abundance (millions of heads) of cattle, sheep, pigs, and goats in the different regions of the world. Based on 1999 data from FAO's (United Nations Food and Agriculture Organization) electronic database.

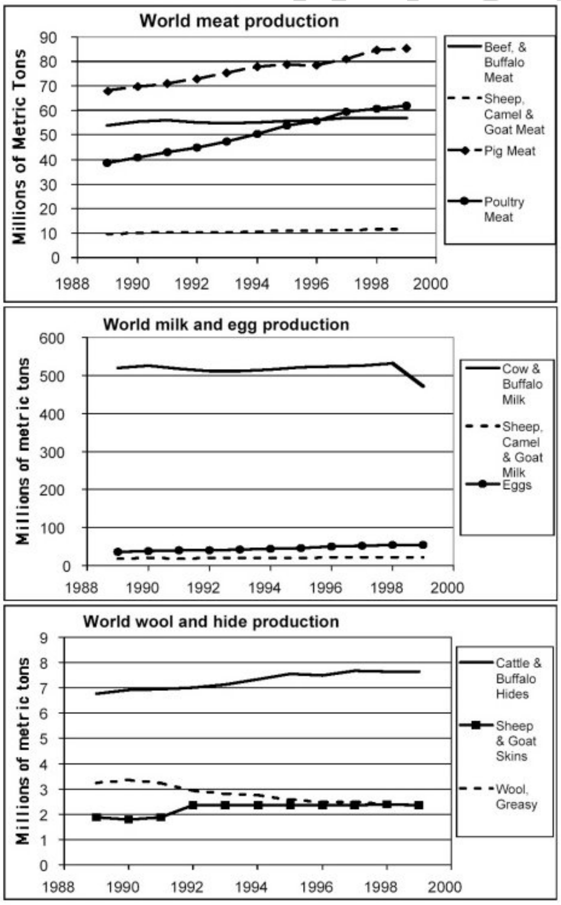

Figure 3. Total world production of different types of livestock products. Based on 1999 data from FAO's United Nations Food and Agriculture Organization) electronic database.

These figures also illustrate the lack of diversity in species used for animal production. In part due to globalization, increased communications, exposure to external markets, and environmental degradation, genetic diversity of livestock is constantly under risk. About 30 % of all livestock breeds are at high risk of loss. Many breeds have already become extinct, with the consequent loss of genetic diversity. Maintenance of a diverse genetic pool is difficult because industry and consumers demand high quality and uniformity of products, and both of these characteristics directly oppose genetic diversity. Producers, particularly for developed and industrial markets, must keep uniform herds and cannot afford to be the reservoir of diversity, at least in the traditional paradigm of livestock production. Local scientists and ill-advised development programs frequently emphasize the introduction of high-yielding strains that obliterate locally adapted breeds. Introduction of breeds and genetic improvement should take a carefully planned systems approach, whereby markets, local environment, and local social values and preferences are taken into account simultaneously.

Because of the constraints of market conditions, maintenance of genetic diversity has high external costs that cannot be borne by producers, and are not easily passed on to consumers. In other words, producers cannot afford to keep "odd" animals just in case they need them for genetic improvement. Therefore, genetic conservation of livestock will require active intervention of governments and other institutions. Nevertheless, simple "grass-roots" activities, such as sharing and rotating rams and bulls, can significantly reduce the loss of genetic diversity at local levels.

One of the most important differences among livestock species is in the digestive systems of ruminants versus non-ruminants. Cattle, sheep, goats, buffaloes, bison, yaks, reindeer, red deer, and camelids (camels, dromedaries, llamas, and alpacas), have ruminant-like digestive systems. Horses, asses, mules, pigs, rodents, and avian livestock are non-ruminants, and horses, asses, and mules are cecal fermenters and have the capacity to subsist on very low quality, fibrous foods. Pigs and avian livestock are adapted to consume feeds of higher quality and have a limited capacity to produce exclusively on fibrous forages such as hay and pasture.

2.2 Ruminants Versus Non-ruminants

Ruminants account for 75 % of all livestock in the world, and most of them are raised under extensive grazing conditions in the rangelands of the world. Although equines are not ruminants, the have the ability to ferment fibrous foods in the large intestine (caecum), and are grazing or browsing animals that occupy the same habitats as ruminants, and have a relatively similar niche. Thus, ruminants and cecal fermenters constitute the vast majority of livestock and occupy a special ecological niche that has made them a key link between primary productivity and foods that are suitable for humans and carnivores. Even before the agricultural revolution, ruminants played a crucial role for humans by providing meat and materials, as most of the hoofed animals that were hunted were ruminants.

In order to understand the ecological and nutritional niche of ruminants, it is necessary to understand the functional capacities of different digestive systems. Herbivores are usually classified into ruminants and non-ruminants, and this classification cuts across taxonomic lines. The sequential order in the gut of fermentation, acid pepsin digestion, and nutrient absorption differs between the groups and is an important element in determining the ecological and nutritional capacities of each group.

Fermentation occurs in either or both the foregut and the hindgut of most mammals, herbivore and omnivore alike. Foregut fermentation is found in all ruminants and in some non-ruminants. The foregut is an environment with a diverse array of microbial populations. Microbial action in the foregut can perform a number of functions. First, unlike mammals, microbes have evolved to produce cellulase, an enzyme that breaks down fiber into compounds that can be used by the host for energy. Second, in the process of digesting the fiber and scavenging other nutrients in this foregut environment, microbes grow and synthesize for their own bodies many of the nutrients (amino acids, proteins, and vitamins) essential to the host. The movement of ingesta out of the foregut results in a considerable flow of microbes from the foregut into the site of acid digestion, where these nutrients become available and then are absorbed in the small intestine. Hence, foregut fermentation is a synthesizer of many high quality, nutritional entities required by the animal. Third, the microbes can also detoxify some of the compounds that plants manufacture for their defense against herbivores. Having the site of detoxification up front before the sites of absorption has obvious advantages.

Microbial fermentation has a cost. While microbes ferment fiber, they will also rapidly ferment any soluble carbohydrates and sugars that enter the foregut. In the process of fermentation, the microbes generate heat. This and other processes use energy that cannot be captured by the host. Hence, fermenting nutrients that are readily digestible by the host is a cost of foregut fermentation. Diets richer in soluble carbohydrates and sugars and lower in fiber are therefore much more efficiently converted to energy by hindgut fermenters. Diets that are composed of mostly fiber, are high in toxic compounds, or are low in nutrients are more effectively used by foregut fermenters.

Ruminants are a special case of the foregut fermenters. They have evolved the capacity to regurgitate their food and re-chew it, a process called rumination. The main advantage of this characteristic is that it increases the efficiency of digestion of fiber by preventing the escape of undigested particles. Fibrous foods are more digestible to ruminants than to non-ruminants. However, this system has an important constraint. Because the rumen works like a sieve and particles must be broken down in size to be passed from the organ, the ruminant must do considerable work to reduce the particles. The rate of reduction is related to the fiber content of the particle. Therefore, some very fibrous foods cannot be broken down rapidly enough to allow high enough intake rates to meet ruminant requirements. Thus, the rumen allows access to the nutrients in fibrous foods, but it may constrain total food intake.

These digestive characteristics set up a diversity of feeding strategies for ruminants and non-ruminants. Ruminants can specialize on fibrous foods of lower quality, but very low quality foods are difficult for them to process. Non-ruminants can use high quality foods because of their greater conversion efficiency with soluble nutrients. Since they do not ruminate, they also can ingest very low quality foods at high rates. The different constraints produce an interesting pattern of body size in wild species of the two groups. Small animals like rodents, which need quality foods to meet their high metabolic rates relative to body size, are generally non-ruminants. Ruminants are primarily medium sized animals, like wildebeest and antelope species, and eat grasses that contain high levels of digestible fiber. Larger herbivores need large quantities of food to supply their absolute needs of nutrients and, therefore, cannot be selective and must eat lots of low quality foods. Since ruminants cannot ruminate this material rapidly, the non-ruminant digestive strategy is most common in the largest mammals, like elephant and rhinoceros.

This continuum of feeding and the historical evolution and development of animal agriculture have led to some interesting ironies. Development of the dairy industry has been dependent on breeding cows, which are ruminants. Historically, these animals were chosen because of the requirement to convert available pasture and fields into a human edible product: milk. As dairy systems evolved under pressure to increase production and returns on capital investment, getting more energy into the cow and converting it most efficiently to milk became the most limiting constraint. A similar trend was followed by the use of cattle to produce beef. As a result, diets of cattle changed from being mostly fibrous forages to being mostly grains with a high concentration of rapidly fermentable carbohydrates.

These diets resemble non-ruminant diets and pushed ruminants to the limits of their digestive niche. One of the main challenges has been how to feed this non-ruminant-like diet to ruminants. Because of the foregut fermentation, ruminants cannot be as efficient as non-ruminants in transforming high quality food into products. The maximum efficiency of conversion is about 0.56 kilograms of product per kilogram of food (obtained with poultry), whereas the maximum for ruminants is about 0.12 kilograms of product per kilogram of food. Moreover, high concentration of rapidly fermentable carbohydrates taxes the digestive system of ruminants, which is adapted to fibrous forages, with negative health consequences for the animals. In retrospect, and given the present trends in diet formulation, one could argue that it would have been better to breed a non-ruminant, such as the pig, for dairy production, because of their much greater efficiency of conversion of high quality diets!

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Biographical Sketches

Dr Emilo Laca is an agricultural ecologist who conducts research on foraging behavior, range management, spatial heterogenicity, and geostatistical applications.

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