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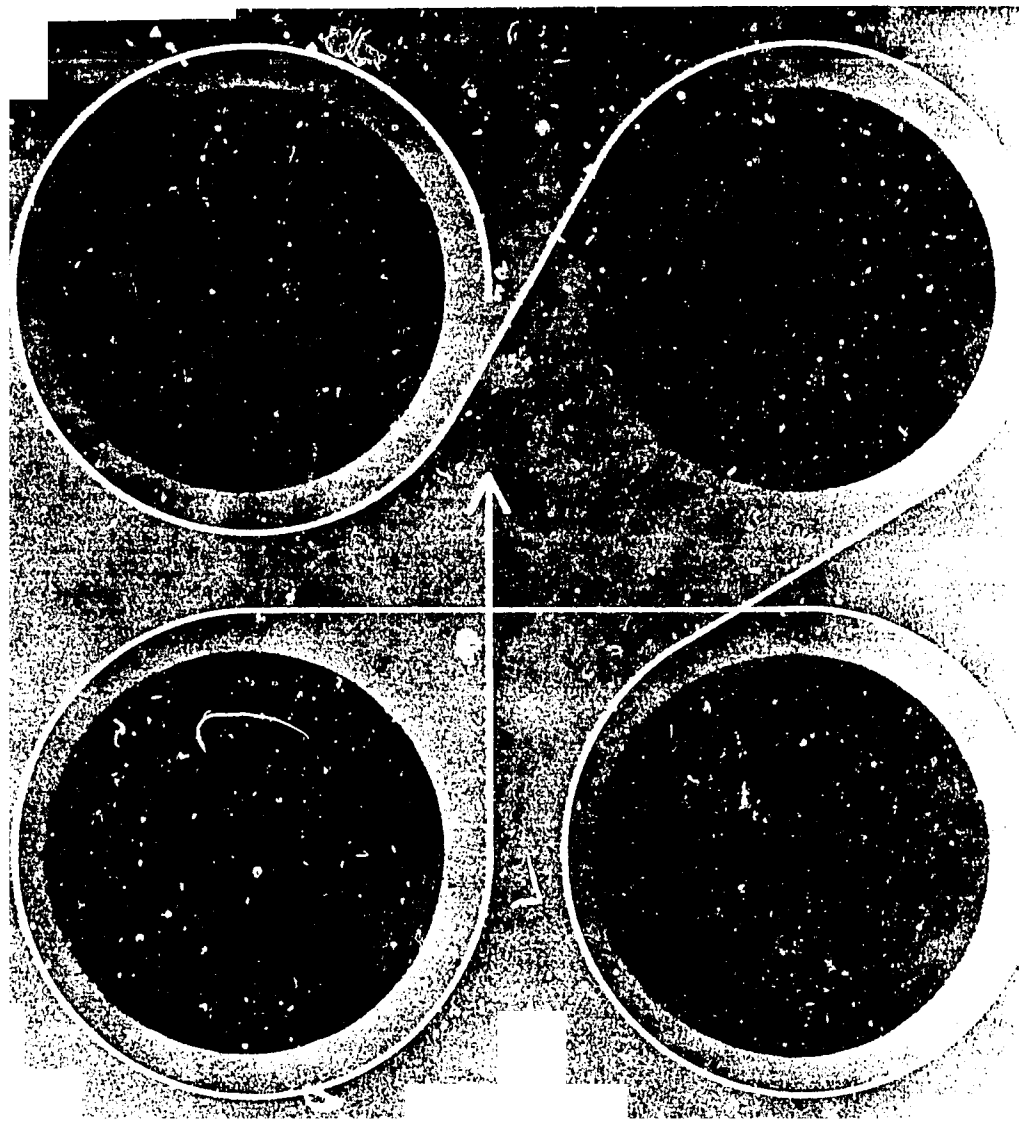

CROP/LIVESTOCK INTERACTIONS AS:

1. CROP PRODUCTION DETERMINANTS

Robert Hart[1]

2. LIVESTOCK PRODUCTION DETERMINANTS

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CROP/LIVESTOCK INTERACTIONS AS CROP PRODUCTION DETERMINANTS

Robert D. Hart

Many research efforts to improve crop production have been less successful than expected because they failed to consider the direct influence of crop/livestock interactions on crop production. This paper examines the effect of livestock on crop production and identifies key types of crop/livestock interactions. Traditionally, agronomists have assumed that crop production is determined by ecological factors (such as rainfall, temperature, and solar radiation) and socio-economic factors (such as availability of land, labor, capital, management expertise, product demand). The direct influence of livestock has seldom been explicitly recognized, except in simplistic disucssions of livestock and crop competition for land, or human and livestock competition for grain. However, crop/livestock interaction involves relationships much more complex than simple resource competition.

Many farmers in the Third World tropics allocate land, labor, and capital to different crop and livestock enterprises, not only on the basis of predicted return to each input, but also taking into consideration that crop residue can be a significant input to livestock production and animal traction and animal manure a significant input to crop production. In addition, these farmers receive a price for grain that is often directly affected by government policy, which is a reflection of crop/livestock interactions such as the use of grains as a livestock feed or in high-technology poultry production. Furthermore, government policy is likely to be influenced by international crop/livestock interactions such as the shipment of grain from the United States to feed livestock in the USSR.

Crop/livestock interactions directly affect crop production in both tropical and temperate-climate environments and in developing as well as developed countries. In this paper, the small mixed farms (crop and livestock enterprises) in the Third World developing tropics will be emphasized, because research efforts to improve crop production on these farms is presently a critical concern of many agricultural scientists. The first section of the paper presents a conceptual framework based on General Systems Theory that can be used to organize the complex environment in which crops are produced into a set of hierarchical systems. Crop/livestock interactions at the ecosystem, farm, and community levels of the systems hierarchy that forms the crop environment are described, and case studies from Kenya, Costa Rica, and Peru are presented to illustrate crop/livestock interactions at different hierarchical levels. The final section of the paper is a brief discussion of how crop/livestock interactions can be considered in the design of appropriate research strategies.

CROP PRODUCTION IN A HIERARCHICAL SYSTEMS FRAMEWORK

Crop production can be analyzed at many different levels, ranging from a crop physiology study of cell wall constituents to an economic study of commodity price elasticity in the international market. The concept of hierarchical systems is a useful way of organizing and tying together the micro and macro aspects of crop production. Hierarchy is the system-to-subsystem relationship that occurs when a component of a system is analyzed as a system with its own components. It is used in biology to describe cell, tissue, organ, organism, and population relationships (cells are components of tissues, tissues are components of organs, etc.); in ecology to describe population, community, and

ecosystem relationships; and in sociology to describe individual, family, clan, and tribe relationships.

Agricultural pehnomena can also be organized into hierarchical systems (Figure 1) in which crops are components of ecosystems that are components of farm systems, and on up a hierarchy that also includes communities, geographic regions, nations, and multinational systems. The function of a system is determined by its structure (how its subsystems interact, the nature of its subsystems, etc.) and its environment. A system's environment includes all the systems above it in the hierarchy. The immediate environment that most affects a given crop is its ecosystem, but the function of an ecosystem is determined by the farm in which it functions, and the function of a farm by the community, and the function of a community by its political environment.

Crop/livestock interactions can occur at all levels of the hierarchy described in Figure 1, but the biological scientist attempting to identify potential crop production improvements usually finds that ecosytem, farm, and community interactions will most directly affect the choice of technology. Different types of crop/livestock interactions in these systems are described below using examples from different Third World countries to illustrate how these interactionsshape the environment in which crops are produced.

CROP/LIVESTOCK ECOSYSTEMS

The traditional unit studied by most temperate-climate production agronomists has been the crop population. Variety selection, fertilizer management, pest control, and other types of agronomic research are usually directed at increasing the output from the total crop population in a specific area. Often there is interaction among these factors and between these factors and the total number of plants planted per area and the spatial arrangement of individual plants (distance between rows and between plants). For example, at low-planting densities the best variety may be different from the best variety at high planting densities.

Agronomists in tropical environments often must direct their research at a unit that is larger than the individual crop population. In addition to an ecological environment that makes it likely that more than one crop will be planted during a cropping season, limiting land resources and low labor costs often combine to form an environment that leads a farmer to design multispecies cropping systems. Crop populations are arranged in space and time (cropping patterns) in such a way that there is often interaction between cropping patterns and individual crop characteristics. For example, the best variety of beans is often different when beans are planted in pure stands (monoculture) as compared to being planted between rows (intercropped) of maize.

Cropping patterns interact with weed, insect, and pathogen populations to form a biological community that, in turn, interacts with the physical environment to form a unit that is similar to a natural ecosystem. These agricultural ecosystems are key management units for farmers. Farmers usually increase natural fertility and moisture input levels and attempt to suppress the negative impacts of plant and animal populations that affect crop production in crop ecosystems and livestock production in livestock ecosystems. Ecosystem by cropping pattern interactions are common. For example, a rice-sorghum rotation is managed very differently in an irrigated ecosystem as compared to a rainfed ecosystem.

There are many situations on small farms in tropical environments in which crop and livestock production are so tightly tied together that crops and livestock must be managed

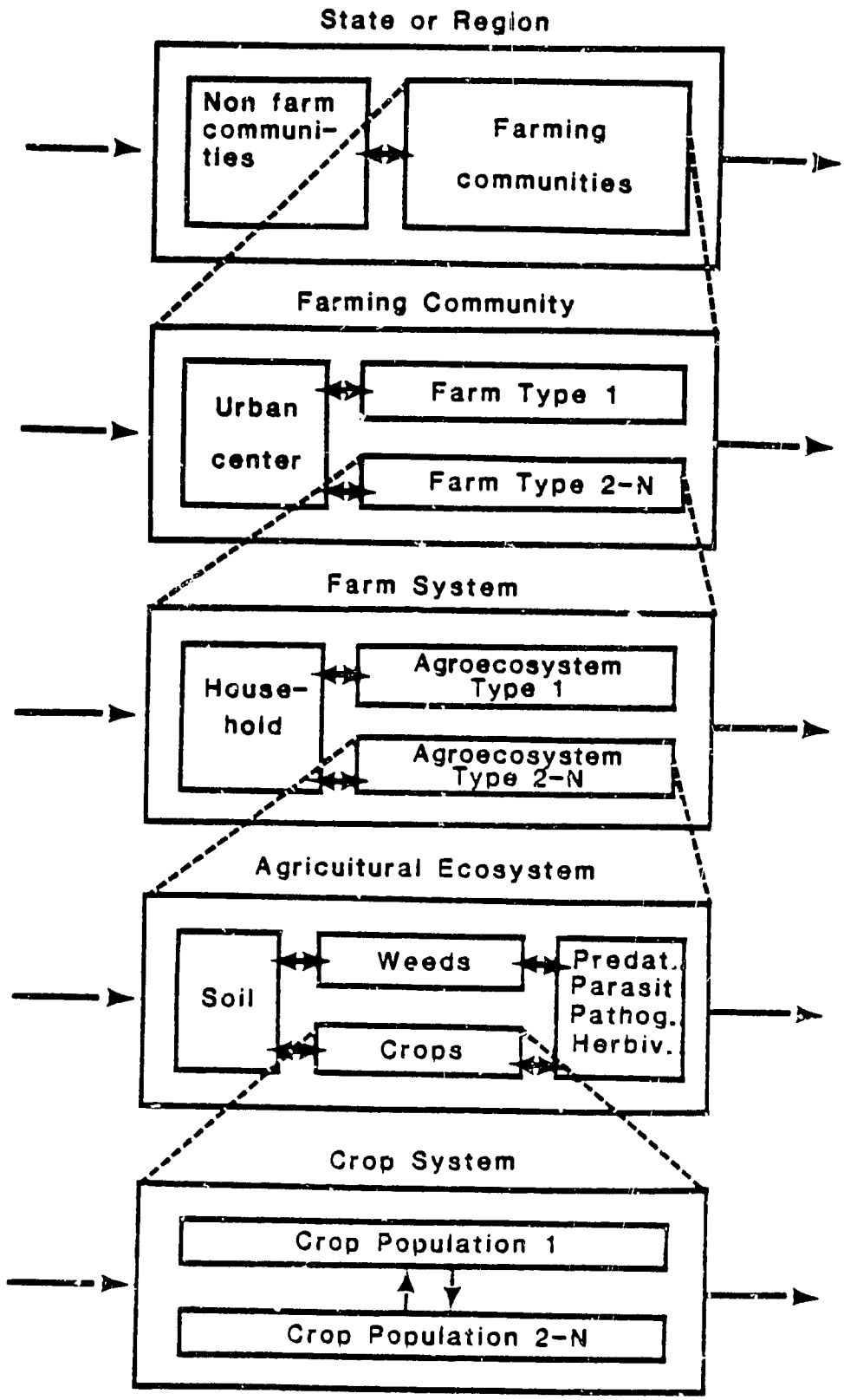

Figure 1. A hierarchy of agricultural systems

as component populations of the same ecosystem. In addition to the population-environment interactions that occur in traditional temperate-climate agricultural ecosystems and the complex multispecies interactions that are often found in most tropical agricultural crop-based or livestock-based ecosystems, these crop/livestock ecosystems also have the added complexity that occurs when crops and livestock are directly linked by the flow of matter of energy. The existence of ecosystems by cropping pattern interactions in crop/livestock ecosystems suggests that any difference in livestock management may imply different crop management and vice versa.

Case Study from Kenya

Figure 2 is a flow diagram of an agricultural ecosystem that is common in the western provinces of Kenya. Farms in this area average approximately 1 ha in size. Almost all farms include both crops and livestock (Sands et al., 1982). Farm size is decreasing as population pressure increases, and cattle populations are beginning to decrease. To provide farmers the milk and meat that are needed, the Ministry of Agriculture and Livestock of Kenya and several U.S. institutions are collaborating in a project to introduce dual-purpose (milk and meat) dairy goats (Fitzhugh, 1983). The crop/livestock ecosystem depicted in Figure 2 is a description of the current system used by many farmers in the project area.

The interaction between crop and livestock on farms in western Kenya is primarily due to the fact that crop residue is an important feed resource for livestock. In general, farmers take resources such as rainfall, soil, available land, and agricultural technology and, given an objective of producing required quantities of maize, beans, cassava, milk, and meat, arrange crop and animal populations in space and time to produce these objectives. Farmers must manage individual cropping patterns (intercropped maize and beans, double-cropped maize, and cassava) as sources of livestock feed as well as sources of human food. As can be noted in Figure 2, each feed resource provides feed at different times. Increasing either crop or livestock production from this system cannot be done without considering the interaction between crops and livestock.

While the level of crop/livestock interaction in the ecosystem described above is obviously high, there are many situations where, in addition to feeding livestock on crop residue, the livestock manure is systematically recycled as an input to crop production and animal traction energy is used as a crop production input. In this case the livestock and crops form a unit that is even more tightly integrated than the crop/livestock ecosystem from western Kenya.

CROP/LIVESTOCK FARM SYSTEMS

Farms systems are a combination of both biological and socioeconomic phenomena. Farmers must analyze total resource availability and design a system that combines both on-farm and off-farm activities that use these resources to meet the social and economic needs of the farm family. The availability of ecological resources, such as rainfall (variable availability over time) or soil fertility (variable availability in space), determines the potential crop, livestock, or crop/livestock ecosystems. The availability of land, labor, capital, and management expertise determines the selection of the socioeconomically appropriate ecosystems from those that are ecologically feasible. But a farmer also has the option of investing many of the socioeconomic resources in on-farm nonagricultural activities (such as handicrafts, etc.) or in off-farm activities. For this reason, and because on many farms crops and livestock are not linked biologically (through energy or material

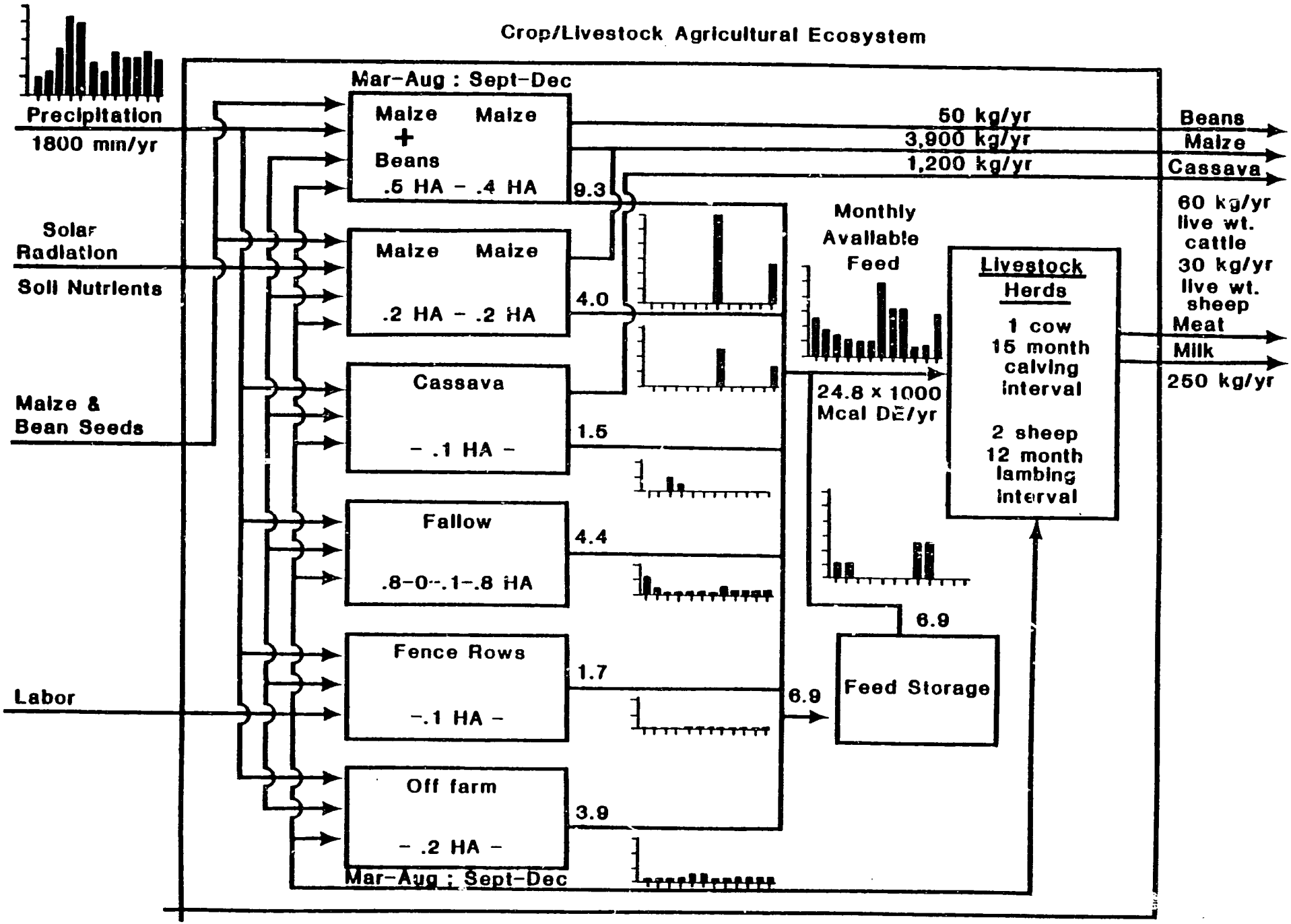

Figure 2. A crop/livestock agricultural ecosystem common in 1 ha-size farms in the western providence of Kenya. Flows between crops and livestock are in 1000 Mcal of digestable energy (DE). Histograms show monthly distributions

flows), the interaction between crops and livestock that occurs because of competitive or complementary use of these resources can be considered farm-level crop/livestock interaction.

Case Study from Costa Rica

Figure 3 is an example of complementary crop and livestock labor use on a farm in Costa Rica (Rockenbach, 1981). The weekly labor-use data shown graphically in Figure 3 was collected as part of an M.S. thesis that compared the weekly flow of energy, material, money, and information in two types of farm systems. A qualitative farm system flow diagram was used to design questionnaires and blank tables that were used by family members and an interview to record direct measurements such as tree growth and crop yield, and indirect estimates, such as labor use on different farm enterprises. The complementary relationship in labor use was a key consideration in the selection of biological technology to be tested on these farms.

The data cited in Figure 3 are from a farm that receives its primary economic return from livestock production. Milk is processed into cheese on the farm (included as a household activity in Figure 3), and the sale of cheese and live animals represents approximately 80% of the farm income. However, the crop ecosystems make the farm almost self-sufficient in food in addition to providing income. The complementary relationship between the use of labor by crops and livestock can be clearly noted in the graph of weekly labor use that is included as an insert in the flow diagram in Figure 3.

If a crop technology were recommended for this farm that required taking labor from the livestock enterprise, the farmer would adopt it only if the return from that labor was more than the return from the livestock system. While this concept of opportunity cost is routinely used by most production agronomists, it is usually applied by simply considering the minimum off -farm wage as the value of labor. Farm-level analysis, including analysis of crop/livestock interactions, must be done in order to measure the true value of land, labor, and capital inputs.

CROP/LIVESTOCK COMMUNITY SYSTEMS

Farm communities are a combination of farm production units and nonfarm urban centers that interact with the farms. The urban centers usually provide services (such as seed and chemical inputs, credit, and marketing) and sometimes include secondary sector units (such as mills and processing plants). Community-level crop/livestock interactions are are to farm-level interactions in that farms compete for land, labor, and capital, and crop residue, animal energy, and animal manure can be transferred among farms. A significant difference between community and farm crop/livestock interactions is that community institutions (banks, labor unions, wholesale buyers, governments, marketing boards, and others) regulate these flows, and many of these resources can be channeled into both nonfarm and farm activities.

Case Study from Peru

Figure 4 is a description of a type of crop/livestock community system that is common in the central and southern Andean regions of Peru. These communities are unusual in that communal institutions are very strong and most of the community resources are communally owned. There is extensive anthropological and sociological literature describing these communities, but the principal source for the information included in

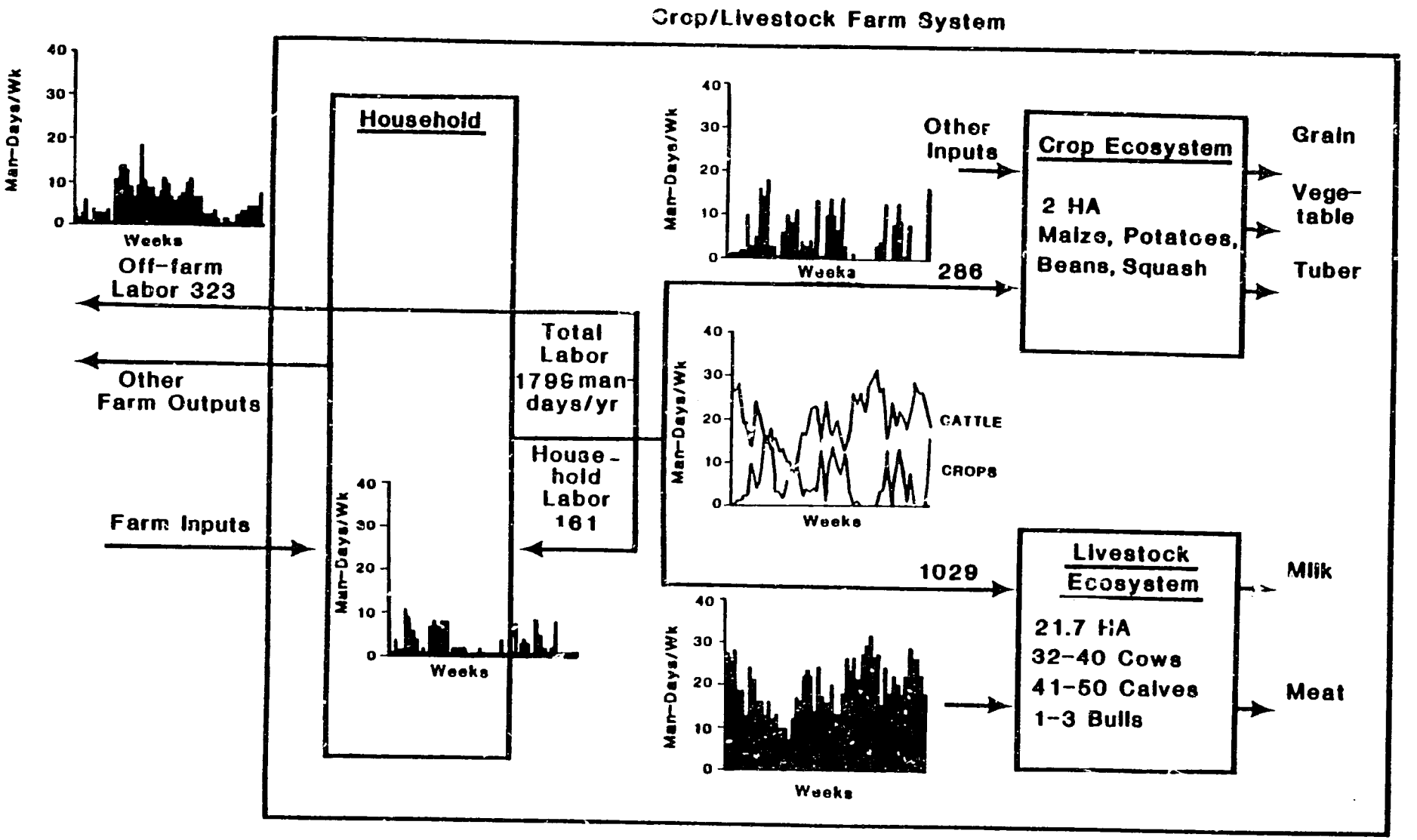

Figure 3. The complementary relationship between labor input requirements to crop and livestock ecosystems on a farm in the Turrialba region of Costa Rica. Modified from Rockenbach (1981).

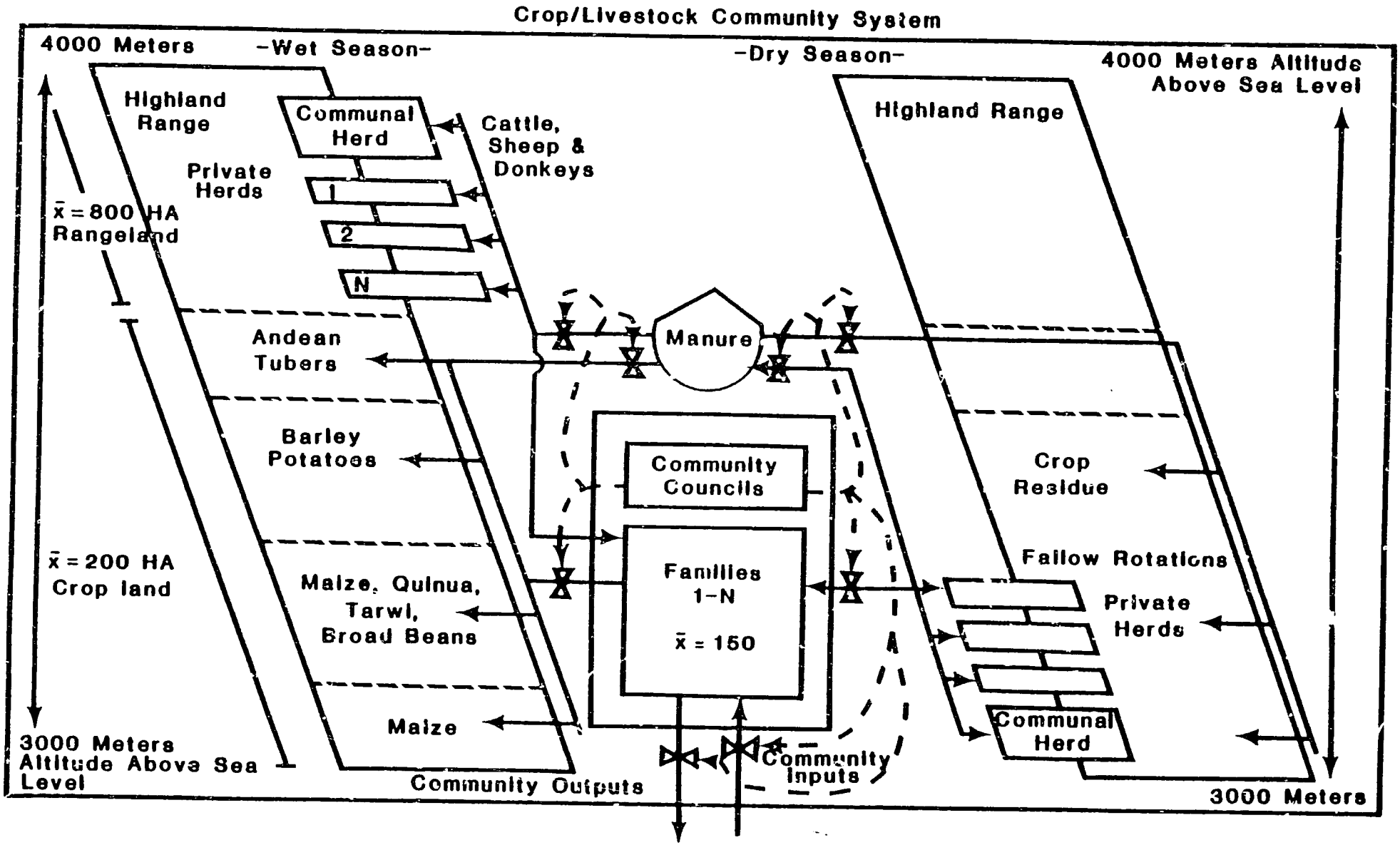

Figure 4. A crop/livestock community system that is common in the central and southern Andean regions of Peru.

Figure 4 was a field trip and project-design workshop organized by the Andean Crops Project (IICA-CIID, 1983) and the Small Ruminant Colaborative Research Project (Hart, 1983). These two projects are collaborating to analyze highland communities as integrated crop/livestock systems.

Community institutions in the Andean regions of Peru have evolved from Inca, Colonial spanish, and modern Peruvian land-reform institutions. Communities usually control areas with an altitudinal range of approximately 1,000 meters. In general, the land between 3,200 m to 3,600 m can be used to produce maize, broad beans (Vicia faba), and quinua (Chenopodium quinoa); between 3,600 m to 3,900 m can be used for potatoes and barley; and between 3,900 m to 4,400 m the land can be used for Andean tubers, such as bitter potatoes, olluco (Ullucus tuberosus), and oca (Oxalis tuberosa), and for natural rangeland.

Sheep production is the primary livestock activity. Although cattle production is second to sheep, oxen are a very important source of animal traction energy. Donkey and horse populations are low but play a significant role in transporting agricultural products from the field to the house and sometimes from the community to the market. They also are used in threshing grain. Sheep, cattle, and donkeys (and often pigs) are usually managed as one herd. Alpaca and llama production occurs in some communities.

Community councils are key community institutions since they regulate family access to land and the movement of livestock herds that feed on crop residue and fallow crop land and produce the manure that is a key crop production input. In many cases individual families control land only as long as it is cropped; fallow land reverts to the community. Many communities have both private and communal herds and private and communal land, and the community councils are the institutions that regulate the movement of livestock from the highland communal grazing land in the wet season to the lowland cropped area in the dry season. There is evidence that the value of livestock as "nutrient concentrators" and "manure producers" is as high as their value as wool, meat, milk, and traction producers.

There is no doubt that crop production in the communities described above is directly influenced by community-level crop/livestock interactions. Any change in crop varieties could change the amount of crop residue available to the community. Any change in cropping patterns that decreased the fallow period would decrease dry-season feed. Any change in livestock management that decreased availability of manure, such as the introduction of a range management plan that made it difficult to collect manure, would have a negative impact on crop production.

RESEARCH IMPLICATIONS OF CROP/LIVESTOCK INTERACTIONS

One difference between most agricultural research and other types of biological research is that it is implicitly, if not explicitly, targeted at a specific type of production system. For example, the results from hybrid maize research is implicitly assumed to be potentially useful to farmers that can purchase seed every planting season and can afford to purchase other inputs that are needed to take advantage of the genetic potential of the new hybrids. Research on sorghum with high seed-to-stover ratio is implicitly assumed to not be for farmers that depend on sorghum stover as a source of livestock feed.

The hierarchical systems conceptual framework described in Figure 1 can be applied anywhere to any type of agricultural situation, but in most cases, it is not worth allocating research funds to the study of all the systems that form the crop production environment. In general the less complex the systems, the less need to formally analyze the systems in

which individual crops function as components. For example, much of the agriculture on temperate-climate farms involves one-crop ecosystems or simply two crop rotations. These farms are often composed of only two or three enterprises with very little biological crop/livestock interaction. Often communities and even large geographic areas are dominated by only one or two commodities. In these situations a research strategy that emphasizes research on one or two commodities and does not explicitly consider crop/livestock interactions is not an illogical approach.

However, in most of the Third World tropics and in some less developed temperate-climate agricultural situations, the crop production environment includes crop/livestock interactions such as described in the case studies from Kenya, Costa Rica, and Peru. This makes the analysis of the ecosystems, farms, and communities a necessity. If a research project specifically identifies the short-term objective of generating technology appropriate for a target type of farmer in a specific environment, and crop/livestock interactions are characteristics of the ecosystems, farms and communities, then a research strategy that allocates research funds to the analysis of these interactions is imperative.

The first step in a research strategy that explicitly recognizes the need to analyze crop/livestock interactions is to quantify the nature of these interactions. This information can then be used to design an appropriate research plan. This has been the approach taken by projects with the objective of improving cropping systems with high crop-species interactions. For example, in a maize and bean intercrop ecosystem there is a potential interaction between the spatial arrangement of the crops and the best crop varieties. However, this interaction is much stronger for beans that it is for maize. Therefore, a research plan might be designed that includes bean variety trials at 4 or 5 maize/bean spacings but with maize variety trials at only 1 or 2 spatial arrangements.

When crop/livestock interactions are analyzed, often it is found that some crop/livestock interactions are very critically affected by changes in specific types of crop or livestock technology while other types of technology will have very little effect on the interaction. For example, on a given farm, manure may be stored and used as a fertilizer for crop production. There may be many different ways that livestock can be managed (such as different feed sources, breeds, and use of veterinary products) that will have very little effect on manure production, but other management practices (grazing schemes, frequency that animals are penned, etc.) might significantly affect availability of manure and therefore significantly affect crop production.

Once the nature of crop/livestock interactions have been quantitied, a research plan can be developed that allocates funds so that multidisciplinary teams can conduct research on phenomenon that must be evaluated as crop/livestock units. Phenomena that are linked only by weak interactions can be analyzed separately and their results can be combined (added together) with the knowledge that interactions do not need to be considered.

The existence of crop/livestock interactions is often considered as a problem rather than an opportunity. Scientists that have traditionally focused on one commodity and have never done research on phenomena that include both crops and livestock often do not recognize that crop/livestock interactions can often be a potential way of multiplying the benefits of certain types of technology. For example, fertilizer use that may seem uneconomical when its effect is measured only in terms of increase in grain production may, in fact, be very economical if the fertilizer also increases the amount of crop residue that can be fed to livestock to increase milk production. An increase in livestock feed

during the dry season may support stronger oxen that can be used to prepare more land area and increase crop production.

A research strategy that addresses crop/livestock interactions must, by definition, be multidisciplinary. It must also systematically apply systems analysis techniques or the multidisciplinary team will either be unable to avoid the pitfalls inherent in not recognizing an important crop/livestock interaction or be unable to capitalize on an interaction that can multiply the benefits of new technology.

ACKNOWLEDGEMENTS

As suggested throughout this paper, the study of crop/livestock interactions requires multidisciplinary teams. Many of the ideas and concepts in this paper are the product of team research by four groups of crop and livestock scientists in Costa Rica, the United States, Kenya, and Peru with whom I have interacted over the last 10 years. The case study from Costa Rica cited was done by Oswaldo Rockenbach while a graduate student at the Centro Agronomico Tropical de Investigacion y Ensenanza (CATIE) in Turrialba, Costa Rica. While I directed the thesis, the exchange of ideas and concepts between members of Mr. Rockenbach's graduate committee -- composed of scientists from crops, animal science, and natural resource departments -- is only one example of many other interdisciplinary discussions with CATIE staff.

The case studies from Kenya and Peru are examples of the types of multidisciplinary studies done by the team of animal and plant scientists at Winrock International with headquarters in Arkansas in the United States. The Kenya research involves African and North American scientists too numerous to mention by name; however, I specifically would like to acknowledge inputs from Mike Sands, Hank Fitzhugh, Sandra Russo, Rick Bernsten, and Moses Onim. The few weeks I spent in Peru were prodcutive because of inputs from Benjamin Quijandria, Mario Tapia, and John De Boer.

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