The effect of interlevel hierarchical system communication on agricultural system input-output relationships

Hart R.D.

Workshop agroecology

Paris : CIHEAM
Options Méditerranéennes : Série Etudes; n. 1984-I

1984
pages 111-124

THE EFFECT OF INTERLEVEL HIERARCHICAL SYSTEM COMMUNICATION ON AGRICULTURAL SYSTEM INPUT-OUTPUT RELATIONSHIPS

Robert D. Hart
Winrock International
Morrilton, Arkansas, USA

Key Words: Hierarchy, Social-economic, System Model, Honduras.

ABSTRACT

It is proposed that agricultural systems are made up of a hierarchy of systems, extending from the crop plant system to the state, regional, or international systems. Agricultural systems always contain social and biological subsystems. In the study of crop systems or farming systems which are undeveloped the biological subsystems may be a special interest. At higher levels of the hierarchy or in modern agro-industrial systems the social subsystem may be most significant. Interlevel communication is important in the analysis of agricultural systems. Communication may be in the form of energy, materials, and / or information. In operational terms study of interlevel communication means that other systems above and below the systems of interest must be analysed to quantify interlevel flows.

These ideas are developed in examples of analyses of farm systems in Honduras.

RESUMEN

Se propone que los sistemas agrícolas están conformados por una jerarquía de sistemas, que se extiende del sistema de plantas de cultivo a los sistemas estatal, regional o internacional. Los sistemas agrícolas contienen siempre subsistemas sociales y biológicos. Los subsistemas biológicos pueden ser de especial interés en el estudio de sistemas de cultivos o agrícolas que están sin desarrollar. A niveles más altos de la jerarquía o en sistemas agroindustriales modernos, el subsistema social puede resultar más significativo.

La comunicación entre niveles es importante para el análisis de sistemas agrícolas. La comunicación puede presentarse bajo forma de energía, materiales, y / o información. En términos operativos, el estudio de la comunicación entre niveles significa que otros sistemas por encima y por debajo de los sistemas de interés, deben ser analizados para cuantificar los flujos entre niveles.

Estas ideas se desarrollan por medio de ejemplos de análisis de sistemas agrícolas en Honduras.

INTRODUCTION

Agricultural input-output relationships are usually conceptualized from one of two perspectives. Economists view agricultural production as the inevitable result of combining land, labor, and capital; biologists view agricultural production as net primary or secondary ecosystem production that is a result of plant and animal populations interacting with the physical environment. The economic perspective sees complexity in the processes that bring the inputs together and disposes of the outputs, but assumes the biological process that turns inputs into outputs is a relatively simple mechanical process. The biological perspective sees complexity in the biological process, but assumes that the processes that bring together inputs and disposes of outputs is a relatively simple mechanical process.

A basic premise of this paper is that agricultural systems always include both a social and a biological subsystem. The interaction between these subsystems makes agricultural systems much more than either natural ecosystems with inputs and outputs managed by man, or a social system that uses biological systems to convert a set of inputs into an output with higher economic value. The primary objective of this paper is to present a conceptual framework combining both the biological and social perspectives that can be used to identify and analyze agricultural system input-output relationships. First, a theoretical framework based on hierarchial systems concepts is described. The results obtained when this framework is superimposed on the reality of the agricultural systems of a geographic region in Honduras, Central America is then described. Finally, the input-output relationships at one level of organization in the hierarchial system framework, the farm system, is described in detail by analyzing the inputs and outputs from one farm system in the community of Yojoa, Honduras.

HIERARCHIAL SYSTEMS

General systems theorists (such as Von Bertalanffy, 1968, and Laszlo, 1972) have made the concept of system hierarchy a central paradigm. In simple terms, the universe is conceptualized as a hierarchy composed of different levels of organization. A system at any one level functions simultaneously as a subsystem of a system at the next highest level and as a suprasystem of systems at the next lowest level.

Ecological theorists (such as Margalef, 1968; and Odum, 1983) have applied the hierarchial system paradigm to natural systems and, generally, have identified the organism-population-community-ecosystem segment of the microscopic-to-galactic hierarchy that makes up the universe, as the phenomena of interest to ecology. Allen and Starr (1982) in their book "Hierarchy: Perspectives for Ecological Complexity", make an important contribution to ecological theory. They have addressed both philosophical questions, such as, is nature in fact hierarchial, or is hierarchy a function of human cognizance; and practical questions, such as, how to use scale as a research tool. Among the concepts they discuss, that are of particular relevance to the analysis of agricultural systems, are system-to-system constraints and communication among system levels.

Allen and Starr suggest that a hierarchy can be viewed as a system of constraints. Any system in the hierarchy exerts constraints over all lower systems with which it communicates. This can be material or energy constraints that occur because the higher system is the environment of the lower system, or a constraint imposed by exchange of information. Allen and Starr refer to both these energy, material, and information flows as "interlevel communication". A "signal" is defined as a string of energy or matter that flows between communicating systems; a "scale" is the period of time or space over which signals are integrated; and a "message" is the information content of the signal. As signals are transmitted between levels of a hierarchy, they are filtered and messages are changed through time lags and preferential weighting of some information.

The concept of hierarchial systems is commonly used in the social sciences as well. Sociologists often conceptualize social systems as a hierarchy composed of individuals-families-tribes-communities-states. Institutional structures are usually analyzed as hierarchies. Geographers commonly use hierarchies such as county-state-country.

HIERARCHIAL AGRICULTURAL SYSTEMS

There is no such thing as a general theory of agriculture. This is probably because agriculture science is generally assumed to be the combination of many applied disciplines, including soils, botany, physiology, genetics, ecology, entomology, zoology, plant and animal pathology, economics, sociology, etc. Most of these disciplines take a reductionist approach. Perhaps the broadest perspective is taken by ecologists and economists and the lead in applying systems analysis techniques to agriculture has, in general, been taken by agronomists and animal scientists with an ecological background, and agricultural economists.

It is noteworthy, that most of the interest in the development of a general agricultural systems conceptual framework is a result of the demand from agricultural development projects. These projects usually bring together agricultural scientists from different disciplines and try to identify ways of improving existing agricultural systems. A framework that allows individual scientists to see how their discipline contributes to project objectives is a necessity. Practical experience in agricultural development-oriented research in Latin America and East Africa has convinced me that the concept of hierarchial systems is a useful framework to integrate biological and social science (Hart, 1980; 1982). Conway (1983), working primarily in Asia, has also used the concept of hierarchial agricultural systems as the theoretical framework for development-oriented research.

It is relatively easy to visualize agricultural phenomena as a level within a hierarchy of systems (see Figure 1). A maize plant is a subsystem of a maize plant population, that is a subsystem of a cropping pattern (an arrangement of crop populations in space and time). A mixed farm can be conceptualized as having different crop and livestock subsystems, while at the same time the farm is a subsystem of a larger agricultural sector. A key question is, is it necessary to go beyond the simple recognition that a specific phenomenon is a system within a hierarchy, and to objectively consider hierarchial relationships in the analysis of agricultural systems?

The answer to this question with regards to agricultural phenomena lower on the hierarchy than the ecosystem definitely depends on the nature of the agricultural ecosystem. In general, agronomists working with high techonology temperate-climate systems, have not found it necessary to analyze ecosystem or community-level phenomena (such as energy flow, nutrient cycling) in order to do organism level (breeding, physiology, etc.) or population-level (planting densities, date of planting) research. Population interactions (predator-prey, host-parasite, crop-weed competition) have been studied in temperate climates primarily by scientists working with low-techonology agricultural systems. Agronomists working with tropical agricultural ecosystem with low technology inputs have found that it almost always is necessary to consider ecosystem-level processes in order to explain population and organism-level behavior. High crop species interaction in complex multispecies cropping systems, and even high crop-livestock interaction in tropical mixed farming systems, must be considered to explain crop or population and organism behavior.

How important it is to consider hierarchial levels higher than the ecosystem in order to explain agricultural ecosystem behavior, depends on the type and level of communication that exists between the ecosystem and higher-level systems. In the case of a subsistence farm (where virtually all human needs are produced within the limits of the farm system), it is not necessary to go higher than the farm system in order to explain the behavior of agricultural ecosystems that are subsystems of the farm. In the case of an agro-industrial farm, it is obviously necessary to consider higher-level systems such as the farm community and possibly national or even international systems. The production of maize on a given plot of land in the U.S. is as much a function of price support, land set-aside, and grain export policies as it is a function of soil fertility and rainfall.

The evolution of agriculture is usually described as a process in which man changes from hunting and gathering to farming by deliberately sowing seed selected from wild plants and by domesticating and selective breeding of wild animals. The increase in crop and livestock production allowed the growth of urban centers, and the exchange of goods and services between urban and rural centers began. If this relationship is exploitive or a fair exchange is the subject of much political debate and outside of the scope of this paper; what is germane to the problem of identifying agricultural system input-output relationships is that, what began as a social system with relatively low family-community-state communication, in industrialized countries, evolved into a social system with high interlevel communication.

As family-community-state interlevel communication changed, the interlevel communication within agricultural ecosystems (community-population-organism) also changed. In general, as social system interlevel communication has increased, biological system interlevel communication has decreased. To understand the production of greenhouse tomatoes in an industrial country requires little ecological analysis, but it does require a sophisticated social system analysis. To understand bean production on a subsistence farm in the tropics requires a sophisticated ecological analysis, but relatively little social system analysis.

Figure 1. A hierarchy of agricultural systems.

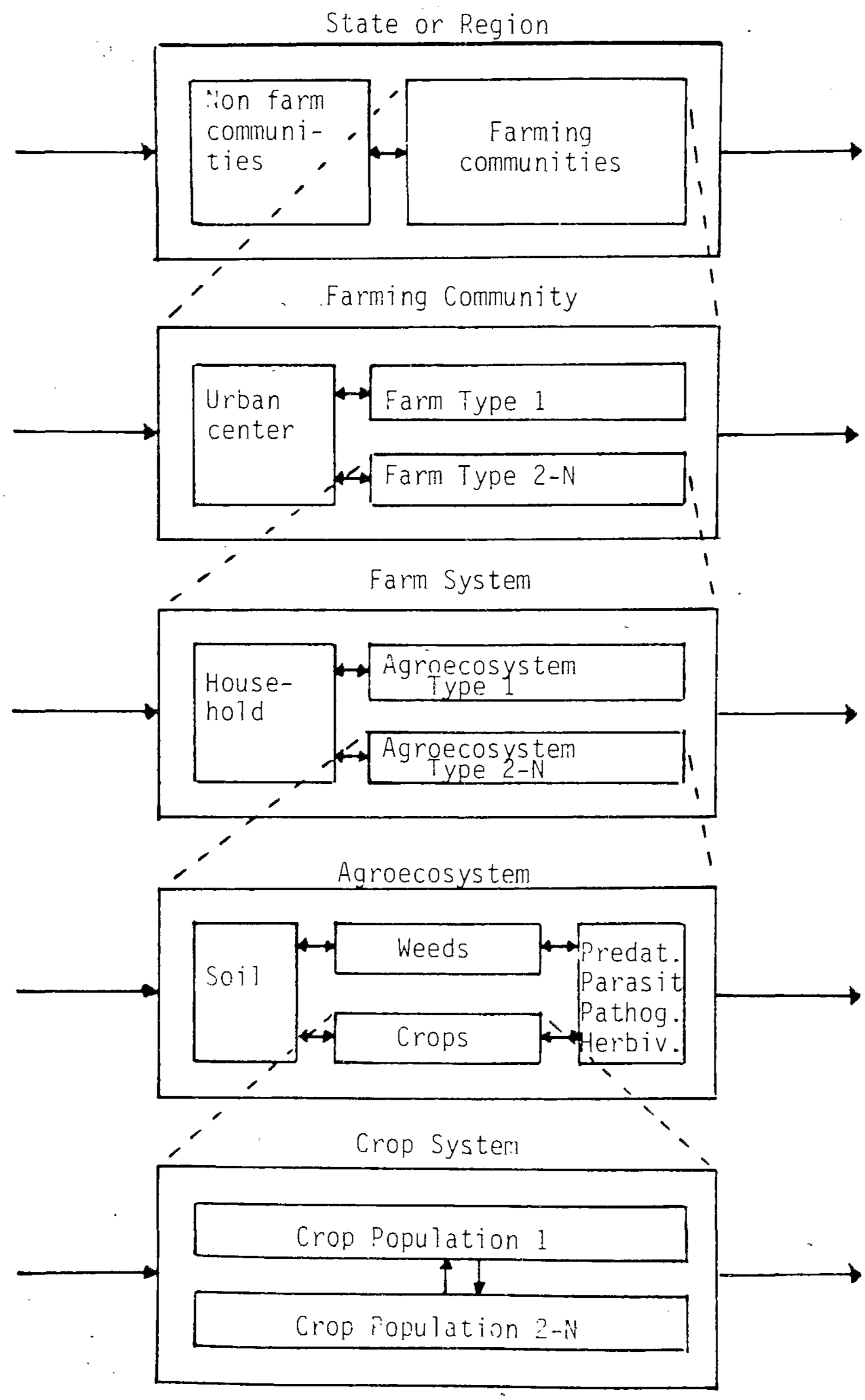


Figure 2. *The inverse relationship between the degree of interlevel system communication in the social and biological subsystems of an agricultural system.*

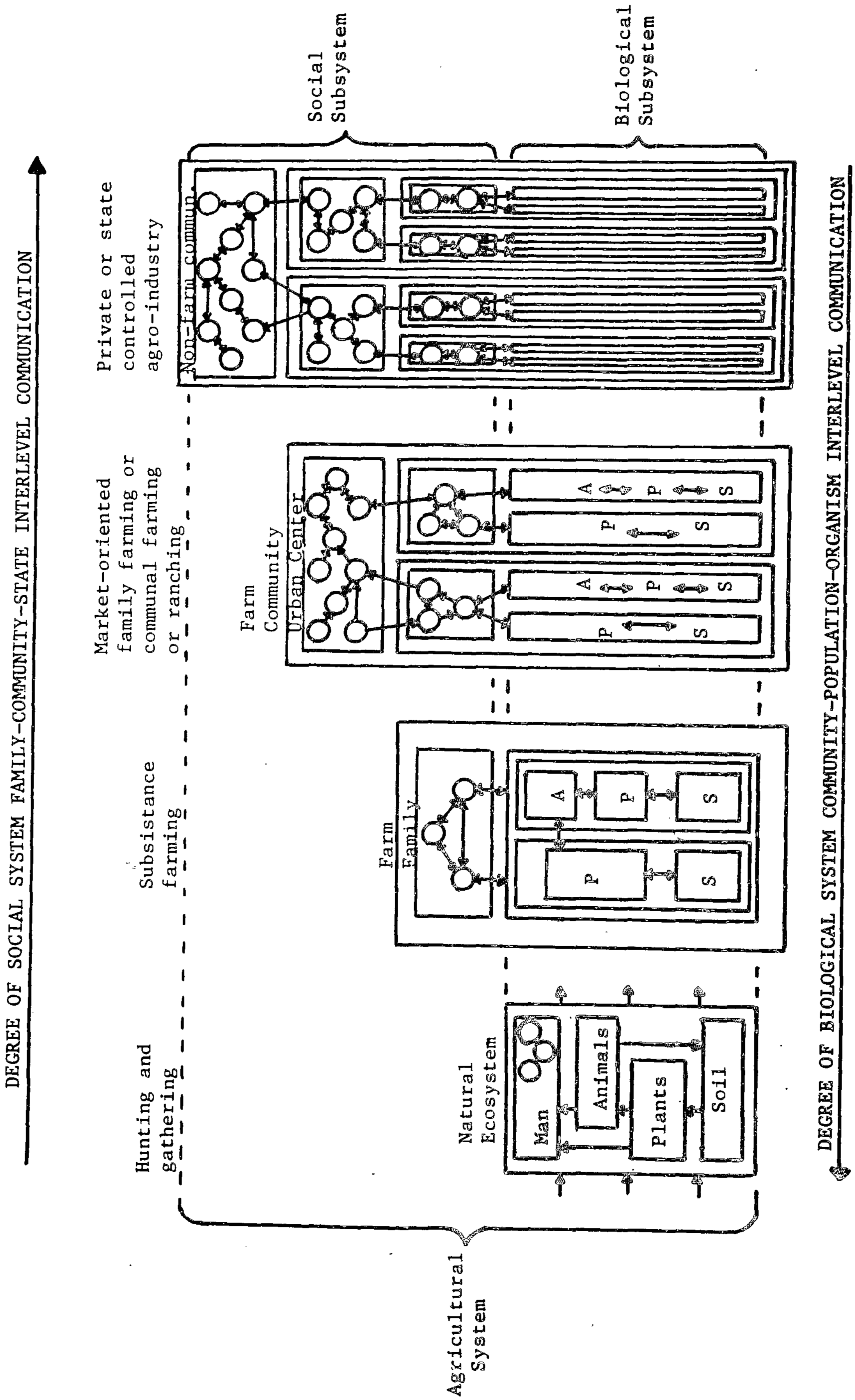
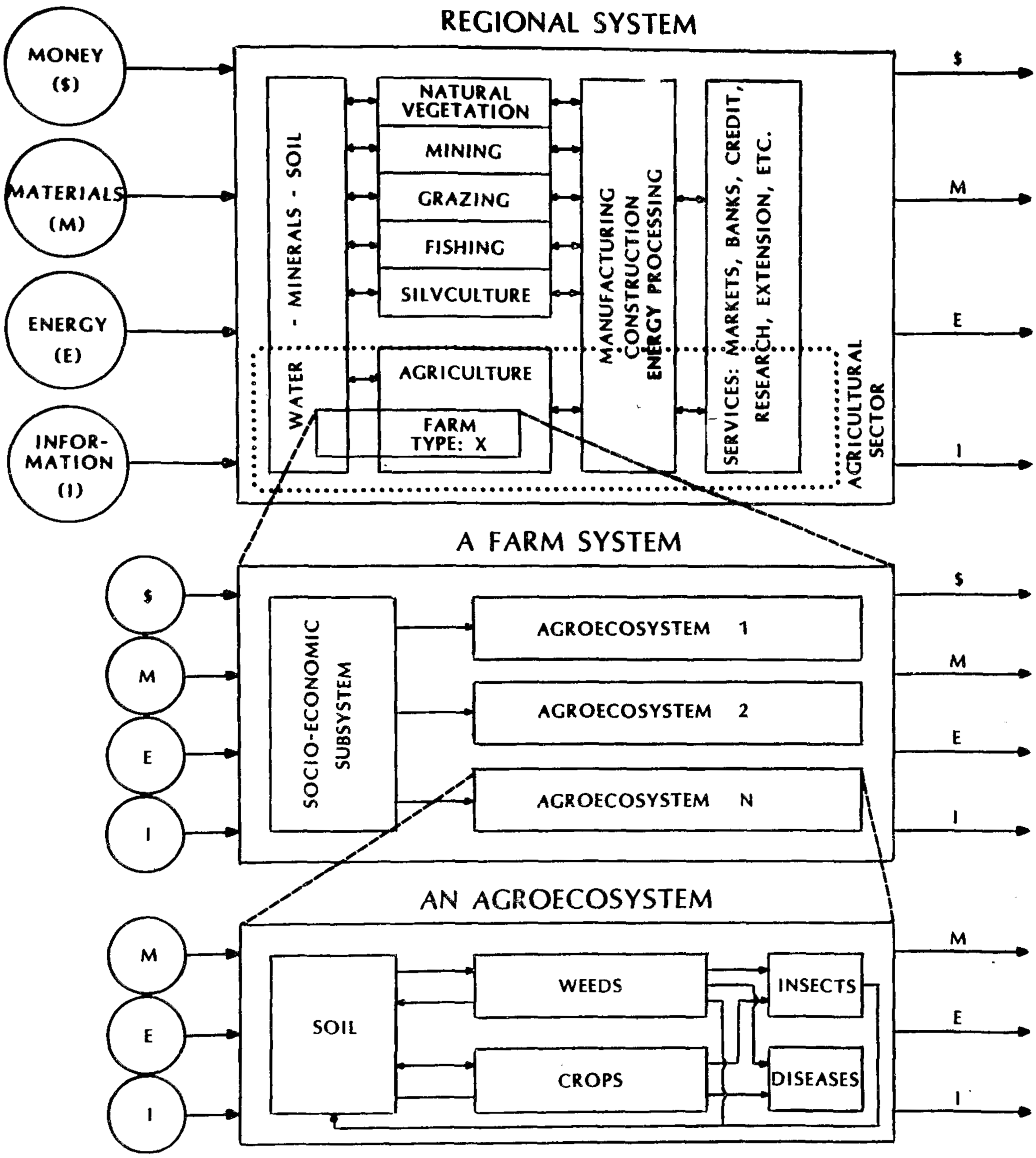


Figure 3. The hierarchial relationships among regions, farms and agroecosystems.



The evolution of increasing social system interlevel communications and decreasing biological system interlevel communications as agricultural changes from hunting and gathering to agroindustry, is depicted in Figure 2. In order to analyze a specific agricultural phenomenon as a system, a first step would seem to be to decide where the system is located on the continuum described in Figure 2. High social system hierarchial interactions will require that social components dominate the model; conversely, high biological hierarchical interactions will require that biological components dominate the model.

The hierarchy of agricultural systems and the farm-level the input-output case studies summarize below decribe agricultural systems in the mid-range of the continuum depicted in Figure 2. Consequently, the agricultural systems exhibit both social system and biological system interlevel communication.

Figure 4. The La Esperanza region of Honduras as a regional system.

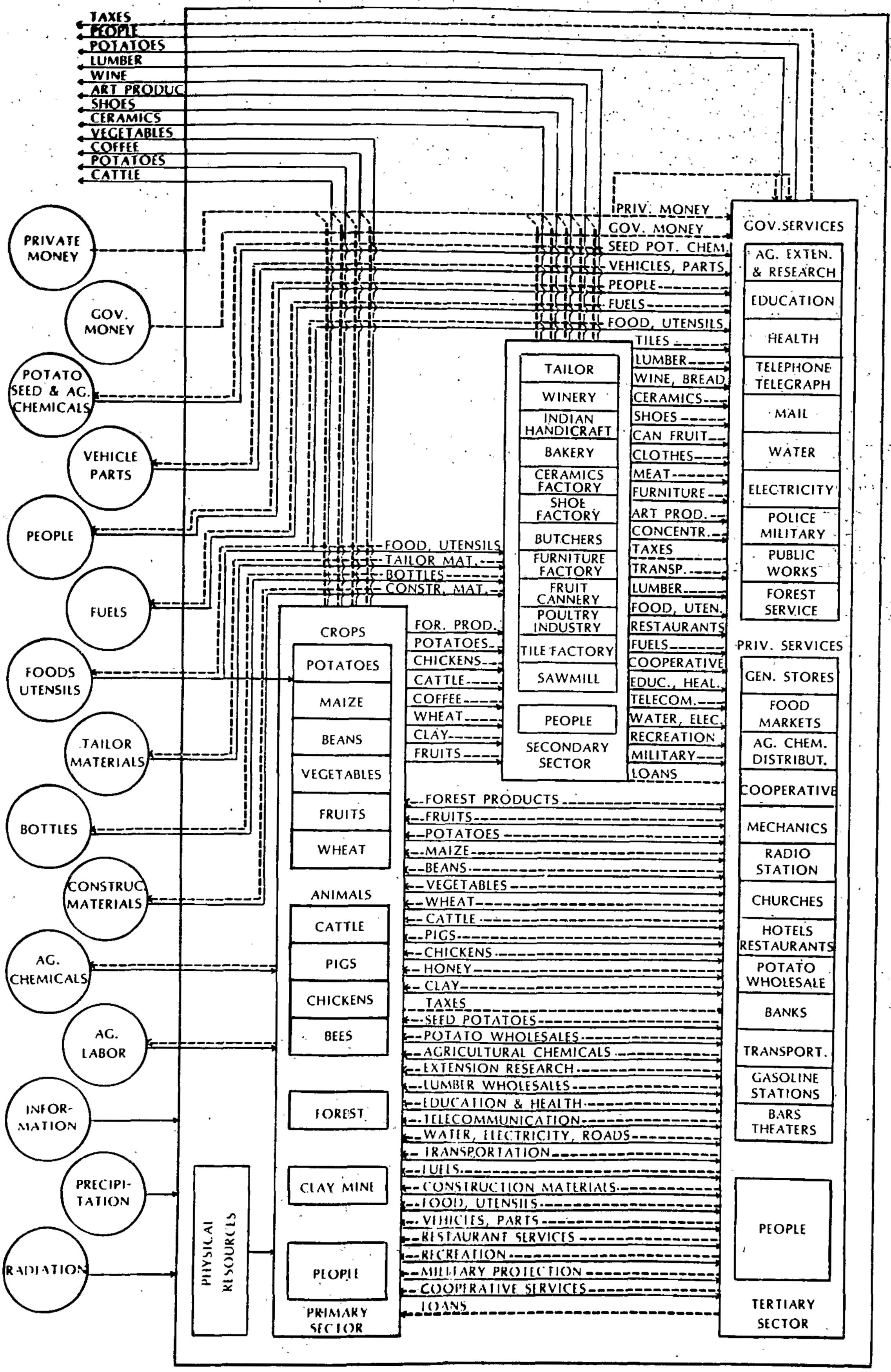
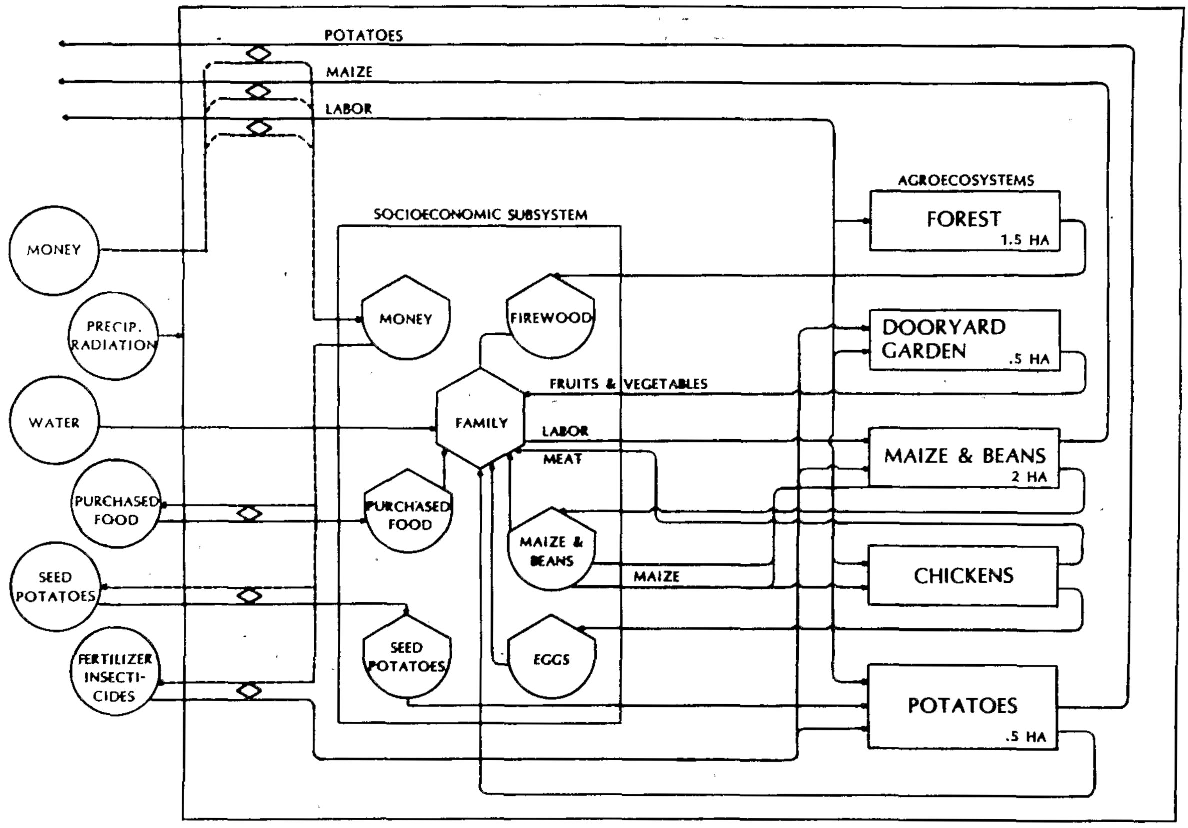


Figure 5. A typical subsistence farm system in La Esperanza, Honduras.



HIERARCHICAL AGRICULTURAL SYSTEMS IN LA ESPERANZA, HONDURAS

The following description of a hiearchy of agricultural systems in the region of La Esperanza, Honduras, was produced by a group of students from the Centro Agronomico Tropical de Investigacion (CATIE) in Turrialba, Costa Rica, in collaboration with technical staff from the Ministry of Natural Resources of the government of Honduras. The objective of the study was to assist a research and development project in the definition of a framework that could be used by a multidisciplinary team to design specific activities (agronomic experiments, marketing studies, etc.). The study was done in these phases. First, all relevant secondary information was collected; secondly, a three-day field study was conducted; and thirdly, information was analyzed and a document was written.

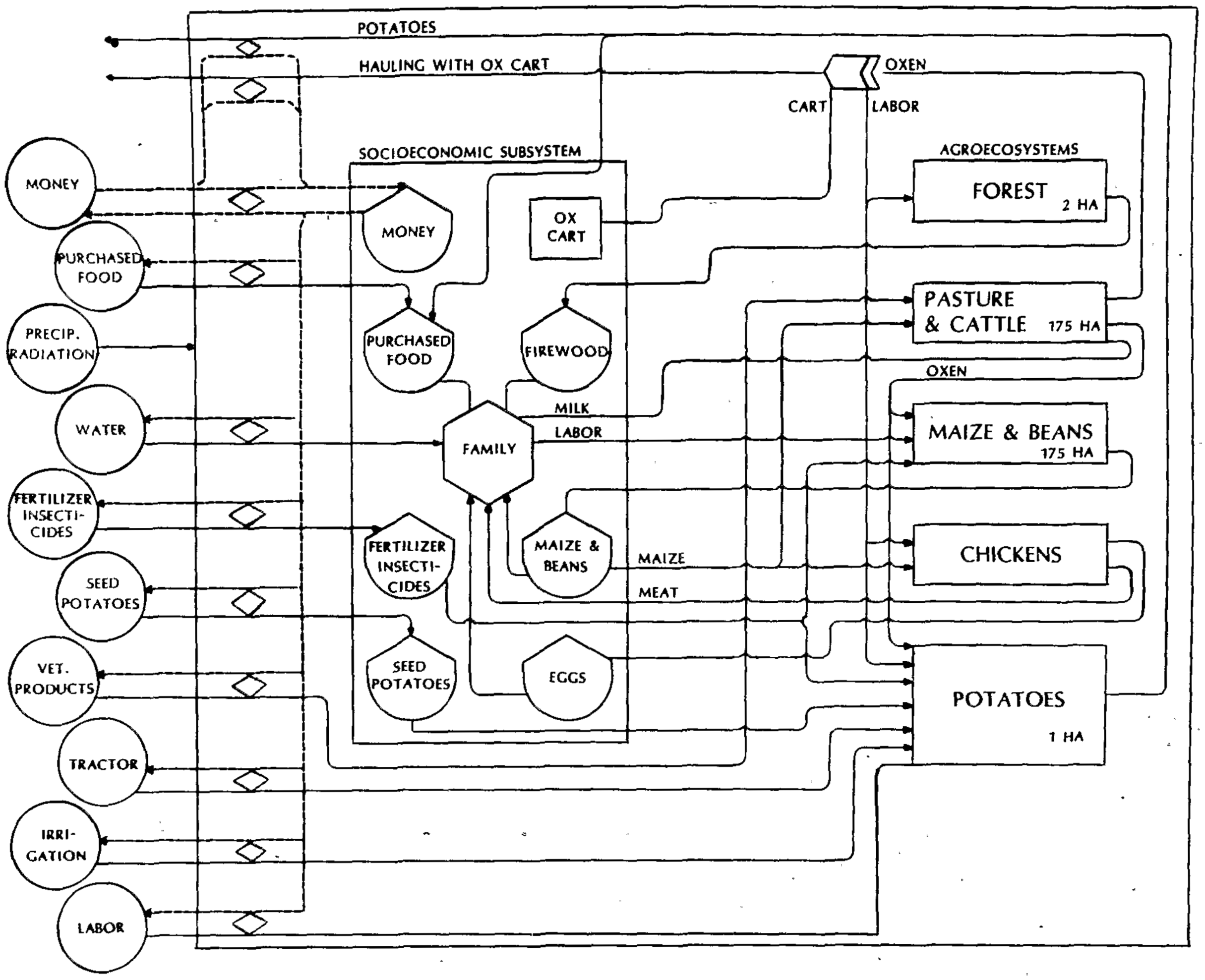
The general conceptual framework for the study was the region-farm-agro-ecosystem hierarchy shown in figure 3. All information that was collected was classified by hierarchial level and the three-day field study was conducted by spending one day analyzing each of the three levels in the hierarchy. Input-output flow diagrams were used extensively. For example, after conducting an interview with a farmer, the students would immediately draw a flow diagram of the farm system.

Figure 4 is a diagram of the regional system of La Esperanza. The regional system was divided into three subsystems, the primary, secondary, and tertiary (services) sectors. The components of each sector were identified, and the inputs and outputs for each sector (flows of material, energy, and information among sectors), and for the region as a whole, were also identified.

As can be seen from the regional system diagram, the region has strong communications with the national economy (the system above the region). The presence of a large secondary and tertiary sector indicates that the farm systems of the region (part of the primary sector) have strong communication ties with the regional system. Consequently, any analysis of farm systems would require consideration of regional-level information to be able to explain farm system behavior.

During the study of the La Esperanza region, five types of farm systems were indentified. The

Figure 6. A typical small commercial farm system in La Esperanza, Honduras.



primary criteria for the farm system classification was the area of land planted with potatoes. This factor is strongly correlated with level of farm-to-region communication, since more land area in potatoes requires purchased inputs, credit, hired labor, etc., and the cash generated can be used to buy machinery, which in turn requires fuel and spare parts. Figures 5 and 6 are diagrams of farm systems with low and medium-to-region communication, respectively. The semi-subsistance farm systems makes few purchased inputs (seed potatoes and a little fertilizer and insecticide) and sells potatoes, maize and family labor. The small commercial farm system, in addition to seed and agricultural chemicals, buys veterinary products, irrigation equipment, labor, and rents a tractor. It sells large quantities of potatoes and also rents oxen. The cash generated from these sales is used to purchase the needed agricultural inputs and invest in other non-agricultural needs such as construction of a better house and sheds for animals and grain storage.

Figure 7 is a diagram of an agro-ecosystem that is often found as a subsystem of many farms in La Esperanza. The predominant crop populations of this system are potatoes, maize, and beans. The most common arrangement of these crops is potatoes followed by intercropped maize and beans (see Figure 8). High amounts of fertilizer are applied to the potato crop and the residual fertility is such that first maize and bean crops usually yield twice as much as the second planting and three times as much as the third planting. Since the maize and beans are planted together (usually in the same hole), and the beans depend on the maize stalks for support, it is impossible to explain the behavior of either maize or beans separately without considering the effect of interspecific interaction. Since the residual fertilizer applied to the potatoes also affects maize and bean yield, the amount of time after the last potato crop must also be considered in the analysis of this agro-ecosystem.

Figure 7. A predominant crop agroecosystem in the region of La Esperanza, Honduras.

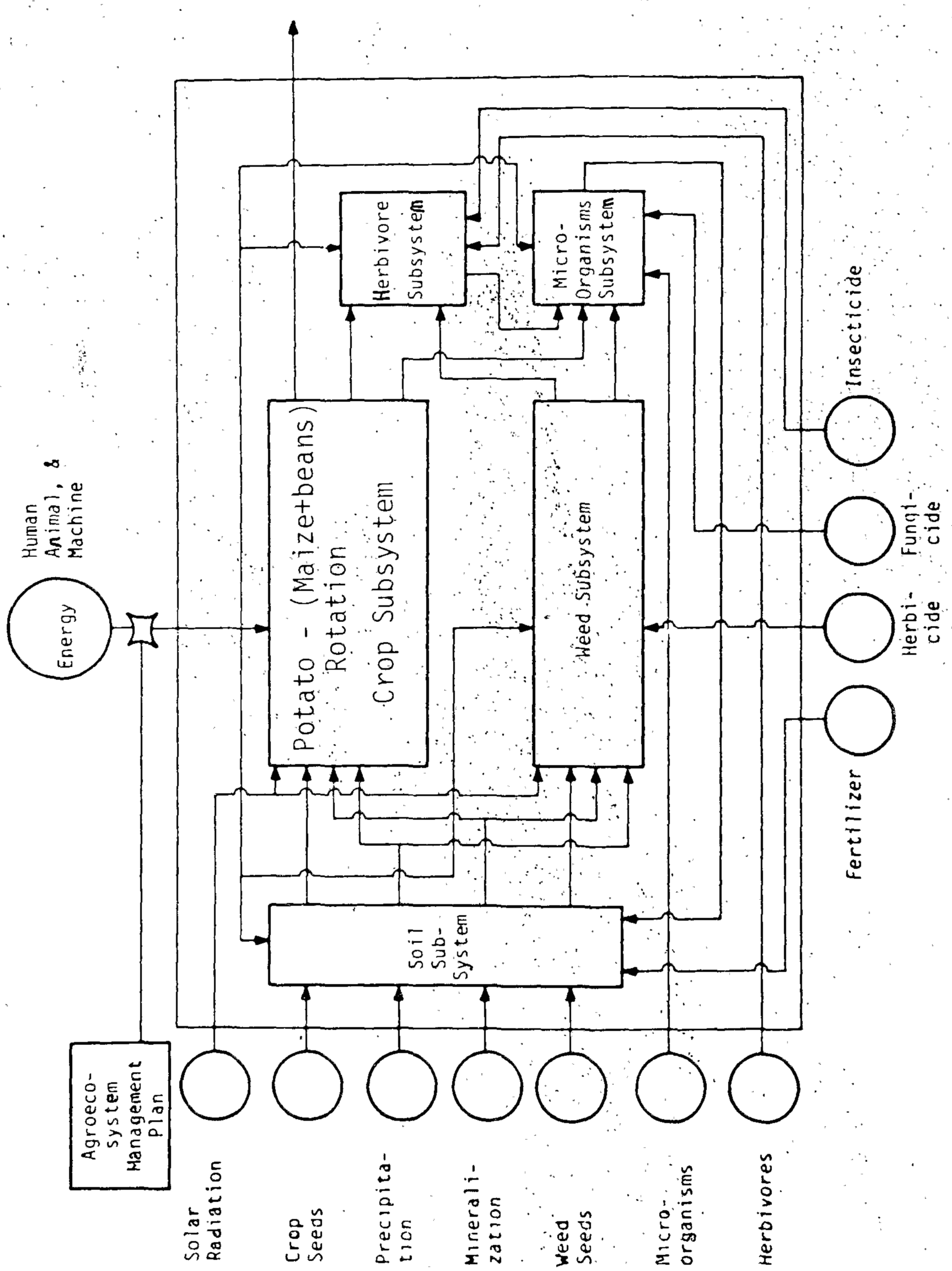
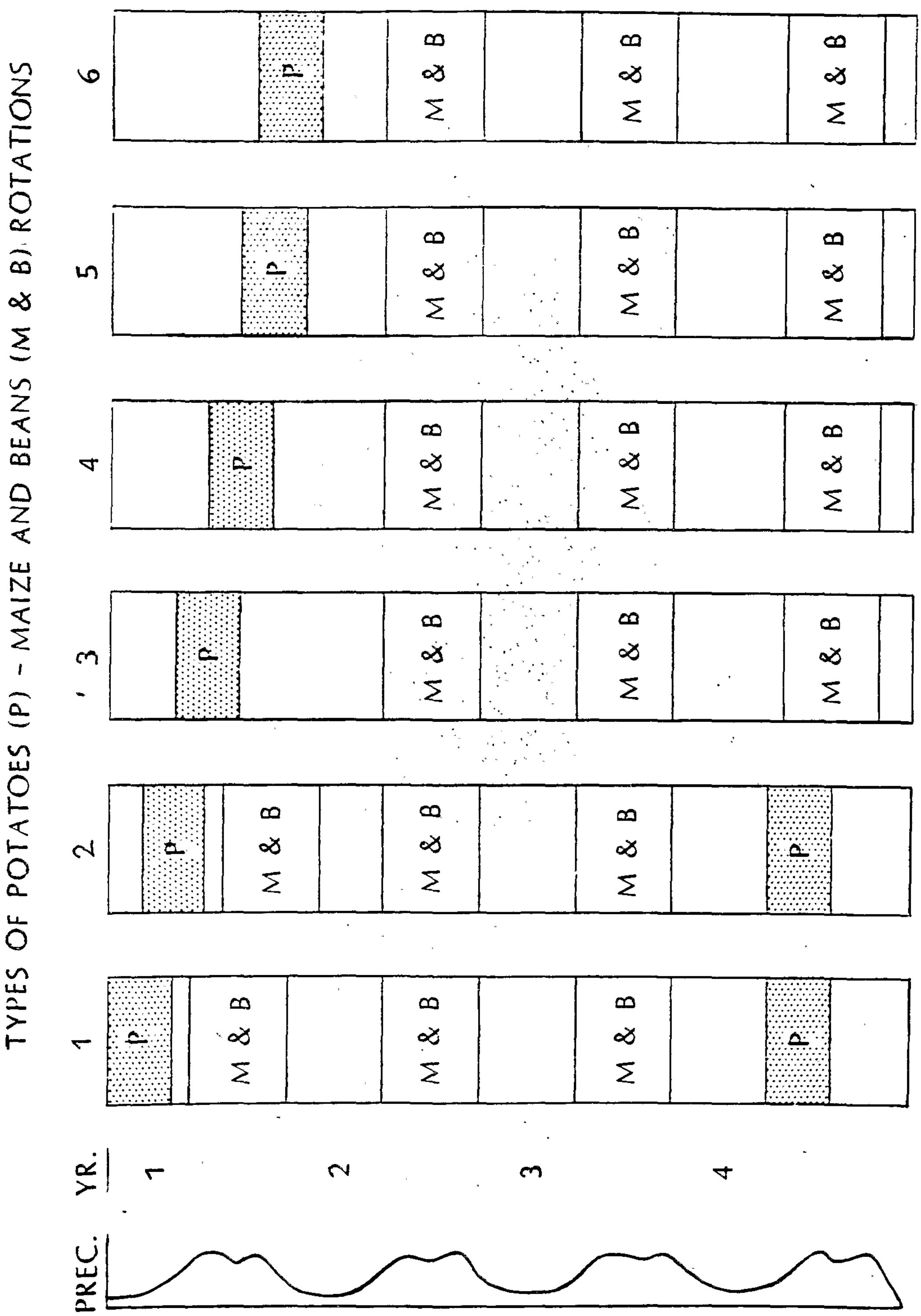


Figure 8. Different types of potato, maize and bean rotations in La Esperanza, Honduras. Potatoes are planted during the dry period, under irrigation, as well as during the wet season. During the three years between potato crops, maize and beans are intercropped.



The level of interlevel system communication within the agricultural systems of La Esperanza is such that an analysis of any of the predominant systems requires the analysis of other systems lower and higher in the hierarchy. Since this interlevel communication is relatively strong in both the biological and social subsystems, the analysis required to understand these systems requires a broadly focused research effort.

A FARM SYSTEM IN YOJOA, HONDURAS

The region-farm-agroecosystem interlevel communication described for La Esperanza can be analyzed further by considering a more quantitative case study of one farm system in the community of Yojoa, about 50 km from the region of La Esperanza. The study was conducted by first drawing a qualitative diagram, such as depicted in Figures 5 and 6; then a quantitative estimate of each of the flows in the diagram was made by designing a questionnaire that was used to interview the farmer every week for one year (see Hart, 1982).

A diagram of the farm system in Yojoa with inputs and output estimates for each flow on a yearly basis, is presented in Figure 9. The farm communicates with the community through the exchange of materials and energy that flow in opposite directions to the flow of money. The farm has inputs of agricultural chemicals, household articles and labor. Rice and beans are bought, even though they are also produced on the farm, because the rice is sold without hulling and then hulled rice is bought, and the bean production from the farm is not sufficient for household needs.

The farm has five agroecosystems: 1) rice planted during the first growing season (May-August) with a small portion of the rice land planted to beans in the second growing season (September-December), 2) double-cropped maize (maize planted in both growing seasons), 3) oxen grazed on unimproved pasture, 4) chickens that scavenge freely during the day, and 5) fruits and shade tree around the house. These agroecosystems have strong communication with the farm system and their behavior can not be explained without an understanding of the farm as a system.

The communication between the farm system and its agroecosystems can be divided into flows of materials, energy, and information. The flow of materials includes fertilizer, insecticide, herbicide, seeds, and harvested rice, beans, maize, eggs, fruits, and wood. The flow of energy includes both human and animal energy. Human labor is distributed among agroecosystem that often "compete" for this resource. Animal energy is an output from one agroecosystem and is used either as an input to two other agroecosystems or as a farm system output to generate cash.

The flow of information in a farm system is a complex process (see Hart, 1984). The decision-making process to direct the flows of materials and energy requires that farmers monitor ongoing behavior of agroecosystems and other factors that determine decisions (for example: rainfall, prices) and make general design decisions (what to plant and in what arrangement) and management decisions once the biological systems are functioning.

The agroecosystems on this farm are relatively simple. While there are two crop rotation systems, the crop species are not intercropped. However, the strong biological interactions among agroecosystems makes it difficult to explain crop population behavior without considering inter-agroecosystem interactions and farm-level phenomenon. For example, the second crop in the maize double-cropping system is affected by the residual soil fertility levels, by the type of land preparation that depends on the input of animal traction energy (that, in turn, is affected by availability of forage) and by the level of inputs such as agricultural chemicals, labor, etc., that the farmer decides to use depending on the ratio of the costs of these inputs to the expected value of the maize that will be produced.

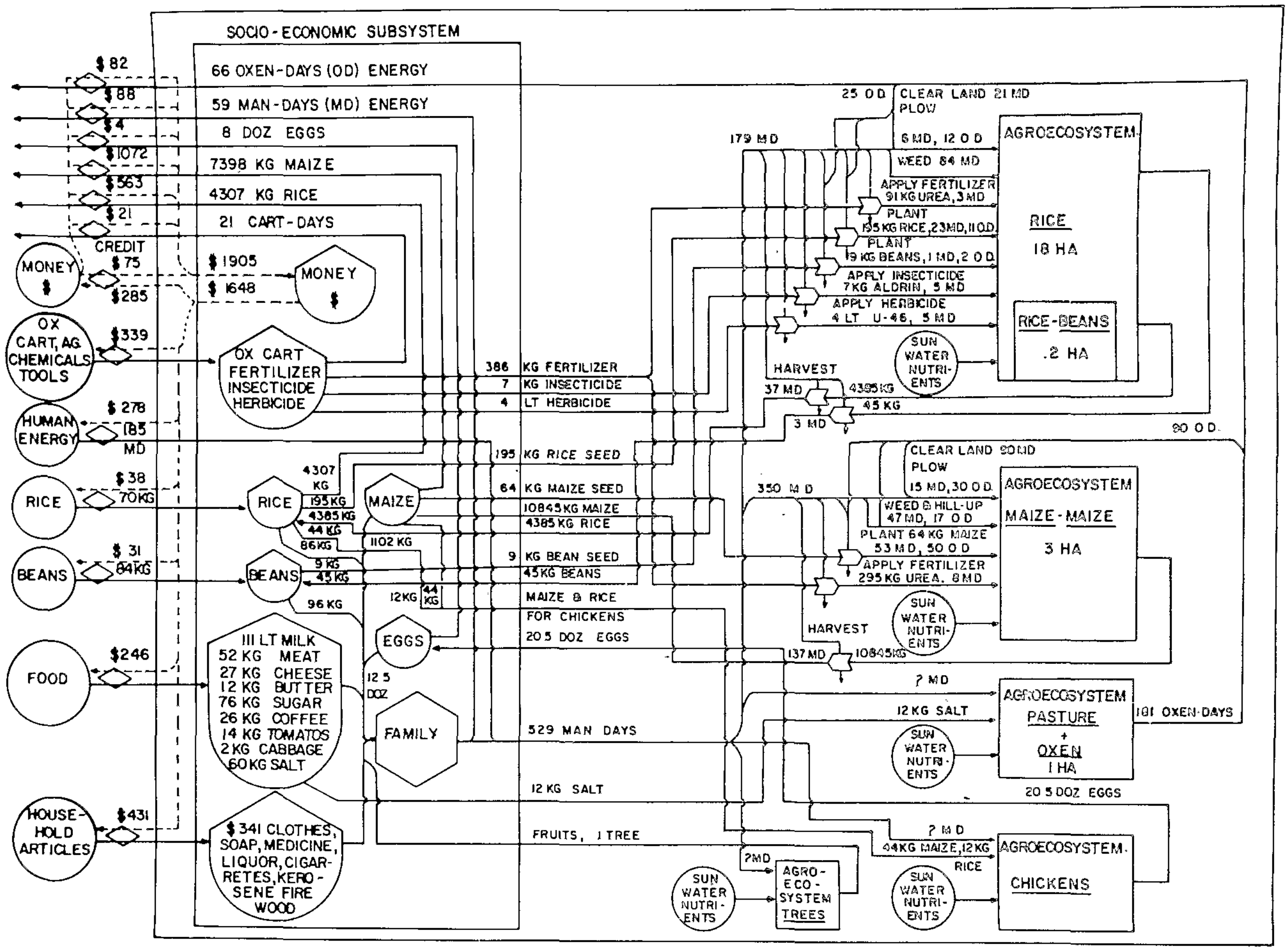
GENERAL AGRICULTURAL SYSTEM INPUT-OUTPUT CONSIDERATIONS

The definition of the inputs and outputs to an agricultural system is certainly not an easy process, but it is the obvious first step in any systems analysis procedure. There are situations, such as a slash-and-burn subsistence agricultural system where a purely ecological approach would seem logical; there are other situations, such as agro-industrial agricultural systems, where a purely economic approach would seem logical. But a large majority of agricultural systems fall between these two extremes, and an approach that considers both the biological and social subsystems of an agricultural system is necessary.

The hierarchical systems framework described above allows for the consideration of interlevel communication in the analysis of any system in the hierarchy. In operational terms what this means is that other systems above and below the system of interest must be analyzed to the level necessary to quantify the interlevel flow.

This will usually require a team composed of individuals with a broad range of biological and social science expertise. The concept of hierarchical system would seem to offer, not only a useful framework to integrate disciplines, but also could serve as a central paradigm for a general theory of agricultural systems.

Figure 9. A quantitative model of a farm system at Yojoa, Honduras, with inputs, outputs, and between-subsystem flows shown as yearly totals. (Symbols after Odum, 1971). Source: Hart, 1982.



BIBLIOGRAPHY

ALLEN, T. F. H. and T. B. STARR. 1982. Hierarchy; Perspectives for Ecological Complexity. The University of Chicago Press. Chicago 310 p.

CONWAY, G. R. 1983. Ecosystem Analysis. Imperial College Center for Environmental Technology. ICCET Series E, No. 1. University of London. 51 p.

VON BERTALANFFY, L. 1968. General System Theory. George Braziller, New York. 295 p.

HART, R. D. 1980. Agroecosistemas: Conceptos Básicos. Centro Agronomico Tropical de Investigación y Enseñanza. Turrialba, Costa Rica. 209 p.

HART, R. D. 1982. One farm system in Honduras: A case study in farm systems research. Pages 59-73. In W. W. Shaner, P. F. Philipp, and W. R. Schmehl, eds. Reading in Farming Systems Research and Development. Westview Pres. Boulder, Colorado.

HART, R. D. 1984. Agroecosystem Determinants. (In Press) Chapter in a book on agricultural ecosystems to be published by John Wiley. New York.

LASZLO, E. 1972. The Systems View of the World. Braziller. New York. 131 p.

MARGALEF, R. 1968. Perspectives in Ecological Theory. University of Chicago Press. Chicago, Illinois. 111 p.

ODUM, H. T. 1971. Environment, Power, and Society. Wiley-Inter-science. New York. 331 p.

ODUM, H. T. 1983. System Ecology. John Wiley and sons. New York. 644 p.