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USING THE CONCEPT OF AGROECOSYSTEM DETERMINANTS TO LINK TECHNOLOGY TRANSFER AND TECHNOLOGY GENERATION TO FORM A FARMING SYSTEMS RESEARCH AND EXTENSION PROCESS

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USING THE CONCEPT OF AGROECOSYSTEM DETERMINANTS TO LINK TECHNOLOGY TRANSFER WITH TECHNOLOGY GENERATION TO FORM A FARMING SYSTEMS RESEARCH AND EXTENSION PROCESS

Farming Systems Research (FSR) without extension is an incomplete process. Information moves from farmers to researchers through studies of representative farmers and farmer participation in the technology generation process, but technology does not move from researchers to farmers unless technology transfer is linked with technology generation. Since the information that moves from the farmer to the researcher usually includes a detailed description of the farmers present system, and the farmer's perceived problems, constraints, goals, and objectives, the technology that is generated is highly likely to be adopted.

Including extension completes the circular process of FSR by moving information from the researcher and the farmers that have participated in technology generation, to other farmers in the population originally subsampled at the beginning of the FSR process. But linking extension and research to form a farming systems research and extension (FSR/E) process is not an additive step. Technology transfer activities cannot be simply added on to the technology generation activities; they must be combined to form an integrated process. The reason that this integration has occurred in very few FSR projects is not just because of a lack of linkages between research and extension institutions. Technology transfer is qualitatively very different from technology generation. While FSR has made a major contribution to linking technology generation to technology transfer by generating technology that is appropriate to specific farm systems, there is still a gap between the information needed for transfer and the information produced by most FSR projects.

FSR is a process that moves from general to particular (area selection, identification of target farmers, specific constraints, etc.), while extension moves from the specific to the general--the goal is to transfer technology to all farmers where the technology is appropriate. In this paper, I analyze the general-to-specific research process followed by FSR to see how the methodology followed to generate technology can be

used to develop the information needed for the specific-to-general technology transfer process. The concept of agroecosystem determinants is proposed as a framework that can be used to design the research activities necessary to produce the information needed to link technology transfer with technology generation. Finally, a general FSR/E strategy is outlined that combines technology generation and technology transfer activities.

Weak Links Between Technology Generation and Transfer

The objective of FSR is generally accepted to be that of generating "improved" technology that can be adopted by farmers. The specific activities implemented to generate the improved technology are often different at the various national, regional, and international institutions with FSR programs, but the general research strategy is unusually quite similar. While different terminology is used, the process usually begins with a description and analysis of the farmers' present farming system and the ecological and socioeconomic environment in which the farm functions. Constraints are identified and alternative technology is designed. Finally, these potential improvements are tested to determine their validity, usually by observing the adoption or lack of adoption by farmers that have participated in the technology generation process.

Most institutions with FSR programs usually add on a "technology transfer" step after on-farm validation. But this last step in the methodology often exist on paper only. The assumption is that since the farmer has participated in the technology generation process and the technology has been demonstrated to be viable on the farms where it was generated, the research scientist has provided all that the extension scientist needs to begin technology transfer. But this is not the case.

For technology transfer to begin, in addition to a description of <u>what</u> technology should be transferred, information must also be available as to <u>where</u> it should be transferred and <u>to whom</u> it should be transferred. Most FSR programs do not systematically answer the questions: What are

the geographic limits of the area where the improved technology is applicable? What are its ecological limits? What are its socioeconomic limits? In what type of farming system is the new technology appropriate? What are the variations within this farming system type that are acceptable?

One advantage of FSR over traditional research is that it follows a general-to-specific process that is a mirror image of the specific-to-general process that is followed by extension. While it is true that many FSR programs do not systematically generate information about the type of farming system and ecological and socioeconomic environment where the new technology should be transferred, with the addition of a few specific research activities, it should be possible to generate the information needed.

A typification of the farming system where the new technology was generated and validated is the first step in answering the question, to what type of farming system should the new technology be transferred? The problem is, there is no generally accepted farming systems classification. It is relatively easy to develop an arbitrary classification of the types of farm in a given area using criteria like farm size, percent of income from the farm vs. off-farm, species of crops and livestock, etc. However, problems arise when an arbitrary classification is used as the basis for technology transfer, because the criteria used in the classification are not necessarily related to acceptability of the new technology. For example, if the technology is scale-neutral than farm size should not be considered in deciding to what type of farming system the technology should be transferred. If the arbitrary classification does not include the degree of interaction among crops and livestock (for example, crop residue is used as livestock feed), but this factor affects acceptability, a technology could be recommended to farmers where it is not appropriate.

A typification of the ecological environment (soils, climate, pests, etc.) where the new technology was generated and validated would seem to be the first step in answering the question, to what type of ecological

environment should the new technology be transferred. While there are many accepted environmental classification systems, most impose arbitrary limits on the environmental types. For example, a unit may be defined as between 1000 and 2000 mm annual rainfall with mean annual temperatures more than 24°C. The problem is specific agricultural technology may be applicable in areas with a rainfall between 1200 mm and 2200 mm within a temperature range of 22-26°. Some technology may be appropriate on only one soil series, others may cross two or more soil orders.

A typification of the socioeconomic environment where a new technology was generated and validated is even more difficult than for the ecological environment. As in the case of both farm system and ecological environment classification, an arbitrary definition of criteria with arbitrary limits is of little usefulness when it comes to technology transfer. It is obvious that the factors that actually affect potential adoption must be the basis of any classification system that is developed.

If the weak link between technology generation and technology transfer is the identification of the ecological and socioeconomic environment and type of farming system where a given technology is appropriate, it would seem that a systematic attempt to generate this information as part of the technology generation process is the place to start. Much of the information needed to develop farm system and ecological and socioeconomic classifications could be generated by identifying the factors that farmers consider when deciding on the type of crops and/or livestock they will produce, and deciding on how these components will be combined to form different agricultural ecosystems.

Agricultural Ecosystem Determinants and Decisions

Like natural ecosystems, agroecosystems are composed of a set of interacting biological and physical components. The presence of specific components and the arrangement of these components in space and time (structure) is determined by the environment. This arrangement of com-

ponents is capable of processing environmental inputs and producing outputs (function). Environmental factors that affect function, either directly through inputs or indirectly through effects on the structure, are defined as "determinants." The farmer monitors the environment and the energy and material processes within the agricultural ecosystem and makes decisions that affect the system's structure and function.

Agroecosystem management cannot be analyzed without considering the fact that agroecosystems are subsystems of farm or pastoral systems. Farm or pastoral systems are composed of a socioeconomic subsystem (the household) and one or more agroecosystems (Hart, 1982a). Figure 1 is a diagram of a farm system showing the flows of materials and energy (solid lines) and information (dotted lines) between the ecological and socioeconomic environment and the farm subsystems. Flows of money between the farm and the socioeconomic subsystem have not been included in the diagram, but it is recognized that, with exception of some subsistance farms, money is used as medium of exchange for flows of materials and energy between the farm and the socioeconomic environment.

In the diagram, the information processing activities required for the management of an agroecosystem are included within the socioeconomic subsystem. Also included in this subsystem are the pool of agricultural resources that can be used as inputs to the different agroecosystems found on the farm, and the social and economic components associated with the household.

Decision-making within the socioeconomic subsystem of a farm system is an extremely complex process, and it analysis is beyond the scope of this paper. Agricultural decision-making has been studied with mixed success by sociologists, anthropologists, and economists. In general, social scientists have had little success in attempts to use formal decision models to predict economic behavior in nonindustrial countries (Johnson, 1980). However, Gladwin (1976) and others have used simple decision-making flowcharts to explain how farmers consider "aspects" such as profit, risk, capital, and knowledge to decide which crops or cropping systems to plant. In general, social scientists studying agri-

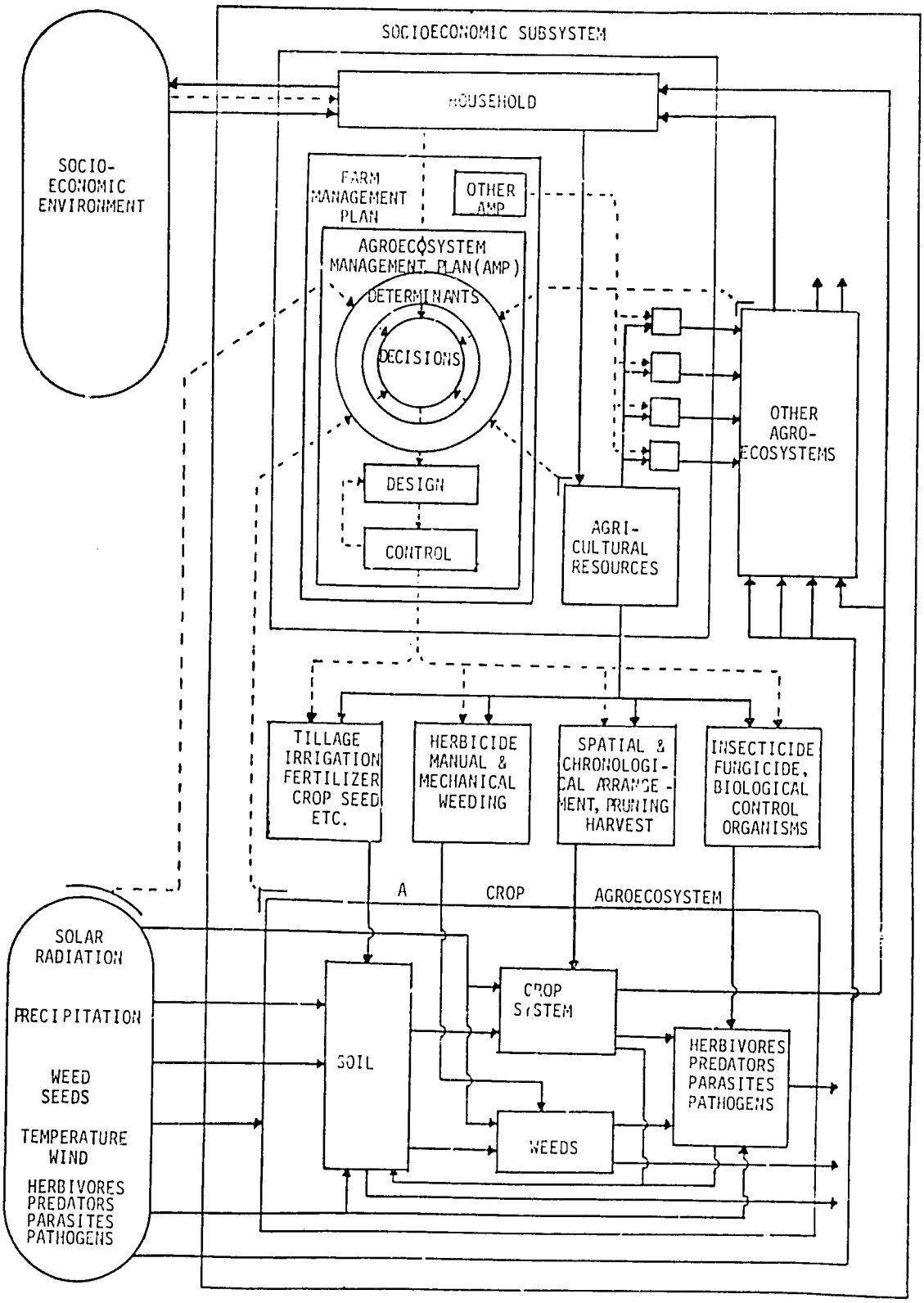

Figure 1. The flow of energy and materials (solid lines) and information (dotted lines) in a farm system. The management of an agroecosystem is conceptualized as a series of decisions based on different types of determinants.

cultural decision-making have focused on farmers' objectives. There has been little research on how these socioeconomic objectives are combined with what is ecologically feasible. How farmers combine crops or livestock to design an agroecosystem, and how they make specific management decisions, has been studied even less.

Decisions

Farm system decision-making can be conceptualized as three subprocesses: (1) definition of socioeconomic objectives, (2) design of a farm management plan that includes agroecosystem plans for each agroecosystem, and (3) control decisions that are made after the design has been implemented and the system is functioning. In the farm system diagram (Figure 1), socioeconomic objectives are assumed to be an output from the household. The second and third processes (design and control) are part of the agroecosystem management plan that is used by farmers to make management decisions about individual agroecosystems.

Agroecosystem design and control are usually cyclical. Design decisions are made during planning, while control decisions are made during implementation. Design decisions are usually seasonal. For example, during the winter in temperate climates or the dry season in the wet-dry tropics, a farmer or pastoralist decides which components to include in the agroecosystem, how they will be arranged in space and time, and the quality, quantity, and timing of inputs and outputs. The product of this decision-making process is a model (usually mental) of the structure of the agroecosystem and a predicted function. Depending on the level of confidence in this prediction, the pastoralist or farmer may include in the design the possibility of implementing optional control activities.

Control decisions are continuous. Once the structure has been designed and the system starts to function (processing inputs and producing outputs), the control phase begins. During this phase, the predicted, real, and projected states of the agroecosystem are continuously evaluated. Some control decisions are programmed and are triggered by the calendar (based on past experience). Other control decisions may re-

quire that a combination of factors meet a combination of criteria. For example, a farmer may design a maize agroecosystem that includes a control decision to plant maize only when the calendar, rainfall, and labor availability meet the criteria of "the first week in May, 25 mm of rainfall during the last week in April, and 5 man-days of labor are available."

Some control decisions are not programmed as part of the original design. When the real behavior of an agroecosystem is very different from the expected, unplanned control decisions must be made. This may require an unplanned return to the design phase (starting over), or in some cases, information processing may be "returned" to the herbivores, predators, parasites, and pathogens (giving up).

Determinants

Agroecosystem design and control decisions are made on the basis of one or more of the following types of determinants:

1. The ecological environment. Some environmental factors are relatively static (soil physical properties, soil fertility, solar radiation); others are very dynamic and less predictable (rainfall patterns, temperature in temperate climates, invasion of pests). These factors affect the agroecosystem (a) directly through the availability of energy and material inputs, and (b) indirectly, when design and control activities are triggered by environmental factors.
2. The socioeconomic environment. These factors include community and regional factors (sometimes national and international as well) such as availability of credit, markets, infrastructure, etc. Political policy that affect these factors are also important socioeconomic determinants.
3. Agricultural resources. These factors include land, labor, capital, management capability, and agricultural inputs, such as agrochemicals and animal and machine energy. Factors that affect resource availability, and therefore indirectly affect the agroeco-

system are (a) the socioeconomic environment, (b) the household, and (c) the state of other agroecosystems. The socioeconomic environment, the household and other agroecosystems can also directly determine design and control decisions and for this reason are listed as "determinants."

4. The household. The principal direct effect (as opposed to indirect effects through other agroecosystems or the resource pool) of the household on the agroecosystem is through design decisions. The definition of socioeconomic objectives (for example, minimize risk) or the demand for specific outputs (for example, goat milk) can greatly affect the design process. Control decisions can also be effected by sudden changes in household demand, for example, animals may be sold earlier than planned because of an unexpected economic crisis.
5. Other agroecosystems. The principal direct effect (as opposed to indirect effect through the resource pool) of other agroecosystems is through the flow of materials or energy among agroecosystems. Examples include the use of crop residue from one agroecosystem to feed livestock in another, and the use of animal energy or manure from one agroecosystem to produce crops in another.
6. The agroecosystem. As suggested earlier, control decisions are triggered by comparing the real and predicted state of the agroecosystem. The cumulative experience with the performance of the agroecosystem is also an important information source for design decisions.

Any of the six types of determinants can be combined with any of three types of decisions to form determinant-decision hypotheses. Specific determinant-design or determinant-control hypotheses can be tested separately, or a complete agroecosystem management plan, with all the design and control decisions and determinants that trigger them, can be tested. It is also possible to identify determinant-control and determinant-design hypotheses by deductive logic or intuition. In a heterogeneous, geographic area where the hypothesized determinants exhibit high enough variation so that decisions, and therefore the structure and function of agroecosystems can be expected to vary among farms, both

determinant and decision data can be collected and analyzed to see if the predicted determinant-decision relationships are statistically significant.

Examples of Decision Determinants

An example of a study of design determinants is an analysis done by Diaz (1982) on 368 farms in Honduras. The relationship between various factors and intercropped maize and beans (M + B), maize and sorghum (M + S), and maize, beans, and sorghum (M + B + S) was studied. Data was collected on cropping systems, farm systems, and soils and climate. Hypotheses relating potential determinants to design decisions were evaluated by analysing the percentage of farmers using a specific cropping system (for example, M + B) at different intervals along environmental gradients, and by using principal component and multiple regression techniques to determine the relationship between potential determinants and different management practices (for example, soil fertility and spatial arrangement of crops).

An ecological determinant that was directly associated with the presence of either M + B, M + S, or M + B + S was altitude above sea level (a proxy for temperature). The M + S cropping system was found between sea level and 750 m above sea level, with the highest concentration between 0 - 250 m. The M + S + B system was found between 0 - 1250 m, but was concentrated between 500 - 1000 m. The M + B system was found over a wide range of altitudes (0 - 2000 m), however, different species of beans were intercropped with maize at different altitudes. *Vigna spp.* was planted below 500 m, *Phaseolus vulgaris* was planted at intermediate altitudes, and *P. coccineous* was planted above 1750 m.

A resource determinant (labor availability) affected chronological arrangement of the crops. The requirements of other agroecosystems were identified as determinants of the quality and quantity of biomass removal. Of the farmers with M + S or M + B + S, 80% fed maize and sorghum stover to cattle, while only 40% of the farmers with M + B had cattle and only 53% used the maize stover for feed.

Examples of the studies of control determinants can be cited from El Salvador and Honduras. A group of extension agents in El Salvador were asked how farmers make decisions in the management of intercropped maize and sorghum (Hart, 1980). Many decisions are triggered by a combination of factors. For example, planting is done either in May after it has rained twice within a two-week period, or in June after one rainfall. Weeding, fertilizer application, hilling-up maize and planting sorghum are "designed" to occur sequentially beginning three weeks after planting maize, but in reality are done within a two- to five-week period depending on rainfall. If rainfall occurs during flowering, maize grain yields will probably be adequate and the intercropped sorghum may be removed before it is mature and fed to livestock.

An example of farmers implementing control decisions that completely alter the structure and function of an agroecosystem can be cited from Honduras (Hart, 1982b). Farmers in the community of Yojoa usually plant double-cropped maize (maize followed by maize) and a rice-bean rotation (rice followed by beans). The rice-bean rotation is "designed" to be planted in May; however, if the rainy season is delayed until June, maize is planted instead. A control decision (what crop to plant) made on the basis of rainfall (an ecological determinant) produces a major short-term change in the agroecosystem. This decision can, in turn, affect the farm system (agricultural resources, other agroecosystems, etc.), and the long-term design decisions that are made during the next dry season.

Determinant-Decisions and Technology Transfer

An identification of the determinants that affect farmers decisions can be used to implement the following process that links technology generation to technology transfer:

1. Classification of the type of farm system where the new technology is appropriate using household, agricultural resources and other agroecosystem determinants as classification criteria, and defining the limits for each farm system type based on the points where the level of a determinant triggers a decision.

2. Classification of the ecological and socioeconomic environment where the new technology is appropriate using ecological and socioeconomic environmental determinants as classification criteria, and defining the limits of each environmental type based on the points where the level of a determinant triggers a decision.
3. Identification of the geographic areas where the appropriate type of ecological and socioeconomic environment is located.
4. Identification of the appropriate farm systems in the geographic areas where the ecological and socioeconomic environments overlap.
5. Demonstration trials on farms in geographic areas contiguous to the area where the technology was generated and validated.
6. Applicability trials on farms in geographic areas not contiguous to areas where the technology was generated and validated.
7. Communication of improved technology to farmers with appropriate types of farming systems in appropriate ecological and socioeconomic environments.

A General FSR/E Process

Figure 2 is a diagram summarizing a general farming systems research and extension (FSR/E) process. The process follows the phases usually associated with farming systems research, i.e., description, analysis, design, evaluation, transfer, and adoption. Each phase is divided into interacting sets of activities with the output of each activity-set serving as an input to one or more other activities. The process is applied to a hierarchy of agricultural systems (Hart and Pinchinat, 1982). The diagram indicates the agricultural system within the hierarchy to which the activity-set is directed; for example, credit and market studies are directed at the community system, household studies at the farm system, commodity experiments at the production system components, etc. In the diagram, the design of alternative technology is assumed to be at the production system level, although it is recognized that there are situations where entirely new farm systems or community-level technology may be designed and tested.

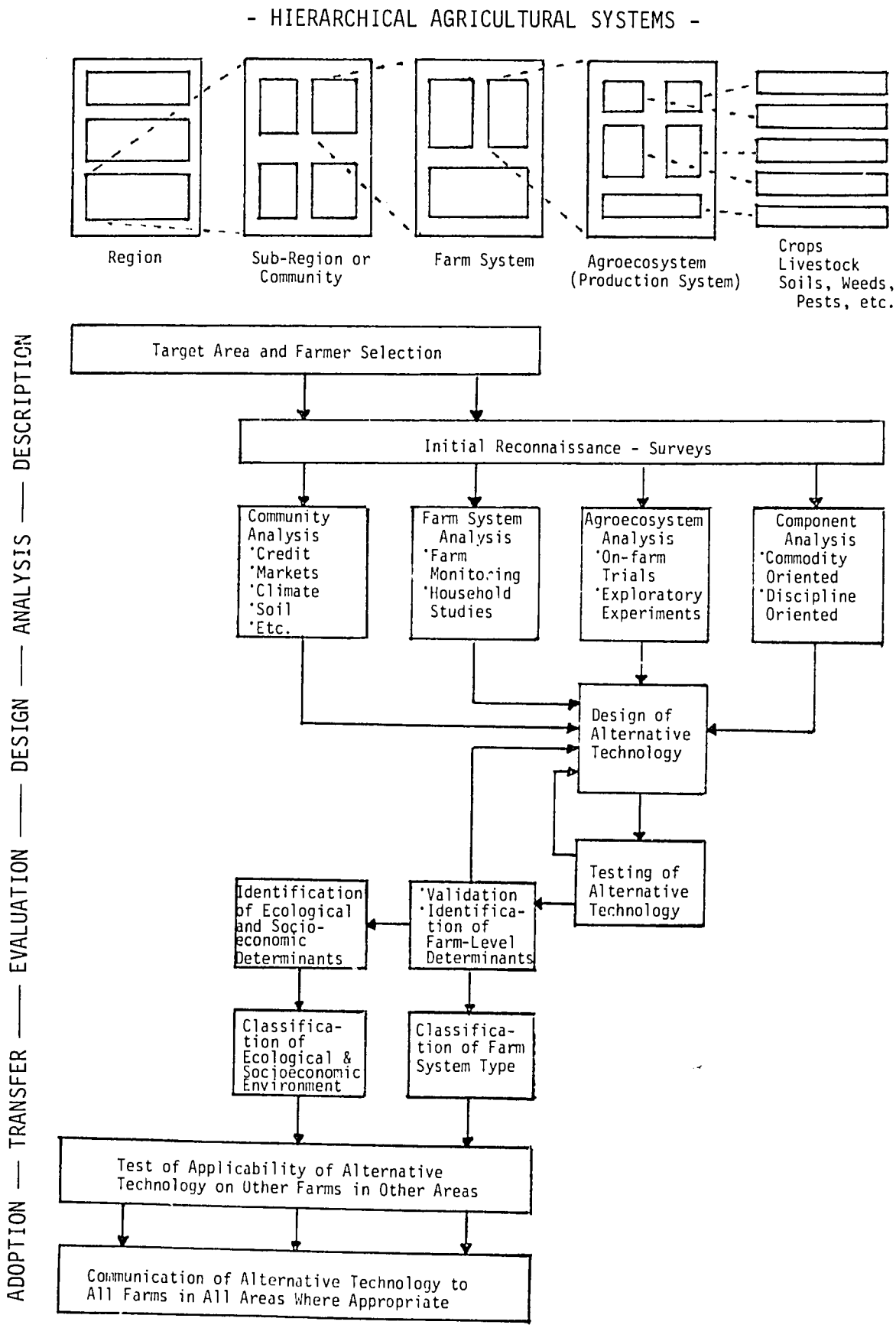

Figure 2. A general farming systems research and extension process composed of interacting sets of activities applied to a hierarchy of agricultural systems.

The process begins with target area and farmer selection. After an initial reconnaissance and surveys directed at the questions generated during the initial reconnaissance, the process moves into an analytical phase with activities directed at a hierarchy of systems from the community, to the farm, to the production systems and the components of the key production systems. With the information from the analysis phase, alternative technology is designed and tested in on-farm trials. During the evaluation phase, alternative technology is tested using farm-level criteria (does the farm system as whole perform better--using farmers' criteria--with or without the new technology?). The linkage between evaluation and transfer is made, using the concept of decision-determinants, by first identifying the type of farm system and ecological and socioeconomic environment where the technology is appropriate, and then testing the applicability on other farms in other areas. Technology that passes this final test is then communicated to all farms in all areas where it is appropriate using a media that is appropriate to the situation.

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