

# A Natural Ecosystem Analog Approach to the Design of a Successional Crop System for Tropical Forest Environments //

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## ABSTRACT

A crop system analogous to a natural successional plant system in a tropical forest environment is described. Field-experiment results and comparisons between the successional crop system and crop systems described by other investigators suggest that the successional crop system has agronomic potential. This potential is related to characteristics of the crop system which reduce weed competition and the energy required to manage the crop system. There is evidence to support a hypothesis that agricultural viability of a particular crop system is directly related to the degree of similarity of that crop system to a natural plant system in the same environment.

TROPICAL AGRICULTURAL RESEARCH has been characterized by a search for high-yielding varieties of crops. The new varieties often require irrigation, fertilizer, and additional labor (Paddock 1970). Farmers have been reluctant to accept some of the new varieties because they require the use of these expensive subsidies. Another reason for the slower-than-expected acceptance of these varieties may be that the farmers' management unit is the farm rather than the crop species. The use of a new variety often requires changes in farm management the farmer may not be willing or able to make. This situation suggests that agronomic research should be applied to a management unit larger than the crop species. The crop system is a management unit currently receiving considerable attention in "multiple cropping" programs.

## CROP-SYSTEM DESIGN

If a system is defined as "an arrangement of physical components, or a set or collection of things, connected or related in such a manner as to form and/or act as an entire unit, an entity or whole" (Becht 1974), then a crop system can be defined as a system in which the components are crop plant populations. A crop system has both structural and functional characteristics. Structurally, a crop system is a physical arrangement of crops over space and time. Functionally, a crop system is a unit which processes inputs (such as solar radiation, water, and nutrients) and produces outputs (such as food and fiber).

In temperate zones, where the growing season is often only slightly longer than the time required to grow one crop, crop systems are usually simple, and a single crop species may be a viable unit of agronomic research. In tropical zones, however, crop sys-

tems are often complex spatial and chronological arrangements of many crop species. Agronomic information pertinent to a single crop grown without interaction with other crops may be of little value to a farmer managing a complex crop system.

Crop-system design requires the generation and testing of potentially viable crop systems. There are three possible information sources for this design process: (1) crop systems currently in use by the farmer, (2) agronomic information about environmental requirements for growth and management of crop species and varieties that may be potential components of a crop system, and (3) natural ecosystems. The first two sources form almost all of the information base for current crop-system research programs. The third source, the natural ecosystem, has not been systematically considered.

The natural ecosystem can be exploited as an information source by selectively applying ecological principles derived from studies of natural plant associations to the crop-system design process, or by considering the natural ecosystem as a model for a crop system. Examples of the former approach are the studies conducted by Harper (1961, 1964) and deWit (1961), in which principles derived from the study of competition between plant populations in natural ecosystems are used to describe crop population dynamics in multi-species crop associations.

The use of the natural ecosystem as a model for crop-system design is based on the assumption of an analogous relationship between natural ecosystems and crop systems. The steps in this methodological procedure are (1) definition of the analogous units, (2) construction of a model of the subsystem of the natural ecosystem which is analogous to the crop system, and (3) design of a crop system based on the model. This natural ecosystem analog approach has

not been reported by other investigators, although it has been suggested in general terms. For example, Trenbath (1975) compared crop communities to natural plant communities and suggested that there may be advantages to mixed cropping. Holdridge (1959) has discussed the possibility of using crops not only to copy a tropical forest community, but also to copy the natural process of succession.

**DEFINITION OF ANALOGOUS SYSTEMS.**—Ecosystems in which crops, domesticated animals, and man are dominant populations of the biotic community can be defined as agroecosystems. Ecosystems which do not include these components will be referred to as natural ecosystems, although the use of the term "natural" is based on convention and does not imply that agroecosystems are less natural than other ecosystems. The analogous systems which should be used in a crop-system design process can be defined by a hierarchical subdivision of both ecosystems into subsystems.

Both natural ecosystems and agroecosystems have plant, animal, and microorganism subsystems. The plant subsystem of an agroecosystem can be further divided into crop and weed subsystems. This hierarchical relationship among agroecosystems, plant systems, and crop systems is shown diagrammatically in figure 1. The plant subsystems of natural ecosystems and agroecosystems are structurally and functionally analogous. However, ideal plant systems of agroecosystems contain no weeds. Therefore, the agronomic unit analogous to the plant system of a natural ecosystem (a natural plant system) would have no niche for weeds. Since the plant system of the agroecosystem is divided into crop and weed subsystems, and in an ideal plant system of the agroecosystem there are no weeds, the crop system will be assumed to be analogous to the natural plant system.

**SUCCESSIONAL CROP SYSTEMS.**—While natural plant systems and crop systems in the same environment can be assumed to be analogous, the systems can be assumed to be structurally and functionally similar only when they are subsystems of ecosystems at the same developmental stage. Ecosystem succession is a predictable and orderly process of community development that includes species, structural, and functional changes with time, culminating in a self-perpetuating climax stage in equilibrium with the physical environment (E. P. Odum 1971). Through successional processes, a disturbed ecosystem (such as a forest which has been cut) returns to a state similar to the original ecosystem. A crop system designed by the natural ecosystem analogy approach

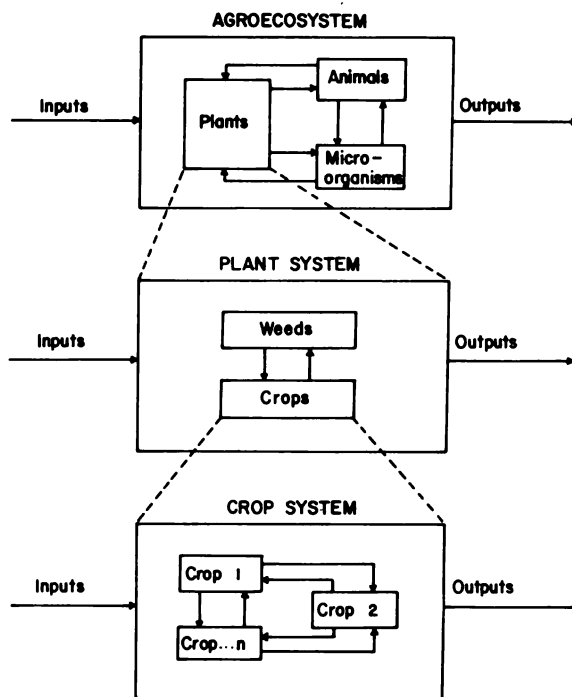


FIGURE 1. Hierarchical relationships among agroecosystems, plant systems, and crop systems.

must include successional stages analogous to natural succession.

There are practical reasons for including successional stages in a crop-system design, even if the crop system desired is composed of mixed perennial crops and is analogous to a climax natural plant system. A climax crop system must begin on bare soil. Instead of planting only the perennial crops and continuously removing weeds until the crops reach maturity, annual crops can be substituted for the weeds, increasing the production from the crop system and possibly reducing weeding costs.

Another reason for including successional stages in the crop-system design is that in some environments a successional stage may be agronomically or economically better than the climax stage. This situation gives a particular crop system greater environmental applicability. For example, in an environment with high availability of labor and chemical inputs and close proximity to a market (such as a vegetable producing area), it may be better to stop the successional process at the first stage. In an environment without these inputs or market proximity, it may be better to allow succession to proceed to a later stage. If the crop system is allowed to reach a mid-successional stage with perennial crops, the options are to maintain the crop system at that stage,

return to the first stage and begin the process again, or allow successional development to continue to an even later successional stage.

A successional crop system is not just a chronological sequence of crops. As in natural succession, each successional stage produces the physical environment required by the next stage in the successional process. It should require less energy to produce a specific spatial arrangement of crops by beginning with the successional stage immediately preceding the desired arrangement than by beginning with bare soil.

In the following discussion, the natural ecosystem analog approach is used to design a tropical crop system which is structurally and functionally similar to a tropical successional forest ecosystem. Qualitative descriptions of the natural successional forest ecosystem are used as a model to design a generalized successional crop system, which is used in turn to outline a more specific successional crop system for Central American forest environments. This crop system is evaluated by comparing it to crop systems described by other investigators, and by a field experiment comparing a succession-analog crop system to non-analogous crop systems. The general agro-

nomic potential of the natural ecosystem analog approach is then discussed.

**TROPICAL FOREST SUCCESSION.**— The design of successional crop systems for tropical forest environments can be based on general descriptions of ecological succession and specific descriptions of tropical forest succession.

The design of crop systems requires three classes of information: (1) the species that are going to be components of the system, (2) the arrangement of the components in space and time, and (3) the quantity and nature of the inputs and outputs. In table 1, information from various authors describing tropical forest succession and general successional trends in other ecosystems is organized into these three categories.

The plants of a forest ecosystem exhibit certain obvious changes during succession. Herbaceous species such as grasses and other annual species, which are more important during early succession, are followed by a transitional community in which perennial woody shrubs are dominant. This community is gradually replaced by trees. Energy is channeled primarily into leaf biomass during early successional stages and into stem and root biomass during later

TABLE 1. *Successional characteristics with implication for crop system design.*

	Successional Stages		Ecosystem	Reference
	Early	Late		
I. COMPONENTS				
A. annuals and perennials	annuals dominant	perennials dominant	temperate	Tramer 1975
B. herbaceous and woody tissue	herbaceous dominant	woody dominant	tropical	Budowski 1965
C. grasses	abundant	scarce	tropical	Budowski 1965
D. shrubs	many, but few species	few	tropical	Budowski 1965
E. biomass in leaves, stems, and roots	percentage in leaves decreasing	percentage in stems and roots increasing	tropical	Ewel 1971
F. fruits	small in size	large in size	tropical	Richards 1973
G. species tolerant to shade	few	many	tropical	Budowski 1965
H. richness	increasing, may decline for short period	increasing, may decline at maturity	temperate	Tramer 1975
II. ORGANIZATION OF COMPONENTS				
A. vertical stratification	low	high	tropical	Budowski 1965
B. horizontal pattern	poorly organized	well organized	general	E. P. Odum 1969
C. component interaction	competition for resources	high mutualism	general	E. P. Odum 1969
D. component replacement time	fast	slow	tropical	Richards 1973
III. INPUT/OUTPUT				
A. mineral cycles	open	closed	general	E. P. Odum 1969
B. role of detritus	unimportant	important	general	E. P. Odum 1969
C. nutrient turnover rate	high	low	temperate	Vitousek and Reiners 1975
D. biomass/unit energy input	low	high	general	E. P. Odum 1969
E. net community production	high	low	general	E. P. Odum 1969

stages. The fruits from earlier stages are usually smaller than the fruits from later stages.

The components of the plant system tend to be poorly organized with strong interspecific competition during early stages of succession. During later stages both horizontal and vertical patterns are more obvious, and there is less competition for resources and more mutualism. Chronological organization is characterized by a faster turnover of species and a greater rate of change in vertical and horizontal arrangement during early succession than during later stages.

The input and output of energy and minerals also change during succession. The changes involve both the absolute quantity of these flows as well as the ratio of the flows to a quantity within the system. Nutrient cycles become tighter as successional processes proceed from early to late succession. In a closed nutrient cycle the role of microorganisms in the detritus cycle becomes more important. With increasing quantities of nutrients in the closed cycle and a constant nutrient mineralization rate, the turnover rate for the system decreases. With increasing biomass and a constant solar energy source, the ratio of biomass per unit of energy input also increases. However, increasing biomass requires increasing energy for maintenance and net community production decreases during succession.

**A GENERALIZED SUCCESSIONAL CROP SYSTEM.**— A successional crop system analogous to the successional plant system of a tropical forest ecosystem would undergo the same general structural and functional changes. The above description of the changes in component, arrangement, and input/output characteristics of the natural plant system during succession and the information summarized in table 1 can be used as a qualitative model to design an analogous successional crop system.

During early succession the components of a successional crop system in a tropical forest environment would be herbaceous annuals, such as grass and legume crops. The grasses and legumes would be replaced by crops with a shrub-like physiognomy. The shrubs would be replaced by mixed perennial crops. Shade-tolerant understory crops would be combined with taller tree crops.

The spatial and chronological organization of the crop components would also change during successional stages. The horizontal arrangement of the crops would be important during early stages. During later stages both the horizontal and vertical arrangement of the crops would be important. During early stages crop species would be planted in

close proximity with high interspecific competition for light and nutrients. During later stages the crop system would have three, or possibly four, vertical strata, with the lower-strata crops not only shade tolerant, but shade demanding. Since the earlier crops would be annuals or fast-growing shrubs, component replacement time for the crop system would be faster during earlier stages and slower at later stages. The spatial and chronological arrangement of the crops would always result in more than one crop occupying the site at one time.

The nutrient cycle of the mixed perennial crops in the later successional stages would be similar to a forest community with larger, possibly leguminous, trees recycling soil nutrients which would be made available to lower-story vegetation through leaf fall. The necessity of fertilizers or other nutrient subsidies during earlier stages would depend on the soil fertility and recent history of the site. If a mature forest is cut and burned, as might occur during slash and burn agriculture, the nutrients released by burning would be enough to start the crop system. If the site has been used for annual crops or pasture for a long period it may be necessary to use fertilizer to start the crop system. If the later stages of the successional system are, in fact, similar in structure to a tropical forest, it should be possible to harvest periodically the valuable wood and cut and burn the perennial crops and have enough nutrients to start the cycle again.

This generalized successional crop system can be applied to any tropical forest environment. The selection of crop species, the arrangement of these crops in space and time, and the inputs which will be used and the outputs expected depend on the specific environment.

The selection of crop species will depend on which plant species occur in the natural plant system in the same ecological environment, and on the constraints of the local socioeconomic environment. The scarcity of information on natural successional plant systems for most geographic areas makes this selection process highly subjective. However, for illustrative purposes, a successional crop system with possible applicability for Central America is outlined below.

## CENTRAL AMERICAN SUCCESSIONAL CROP SYSTEM

Budowski (1963, 1965) has described the characteristics of arboreal components of different successional stages in tropical American humid forests and includes species composition descriptions of sites in

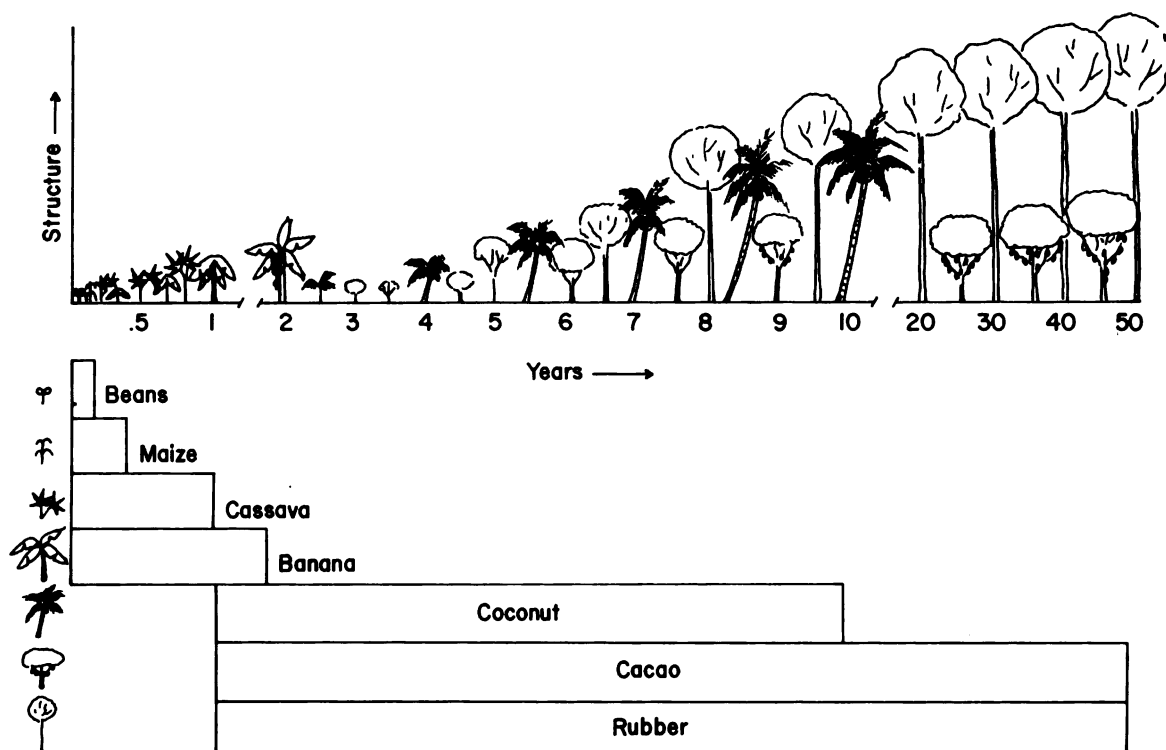


FIGURE 2. The chronological arrangement of crop components in a successional crop system.

Costa Rica and Panama. Snedaker and Gamble (1969) and Ewel (1971) have described the species composition of secondary forest in Panama and Guatemala. The selection of crop species for the successional crop system outlined below is based on these descriptions and on the author's agricultural research experience in Central America.

Early successional dominance of grasses and legumes can be assumed to be analogous to maize (*Zea mays*) and common bean (*Phaseolus vulgaris*) mixtures. Euphorbiaceae, an important family in pioneer stages of early succession, can be represented by cassava (*Manihot esculenta*), a root crop in the same family. In a similar replacement, banana (*Musa sapientum*) can be substituted for *Heliconia* spp. The Palmae family can be represented by coconut (*Cocos nucifera*). Cacao (*Theobroma cacao*) is a shade-demanding crop that can be combined with rubber (*Hevea brasiliensis*) and valuable lumber crops such as *Cordia* spp., *Swietenia* spp., or other economically valuable members of the Meliaceae family to form a mixed perennial climax.

A possible chronological arrangement of these plant components is shown diagrammatically in figure 2. The species used as components in this system

could be modified. For example, in wet sites cowpea (*Vigna unguiculata*) could be substituted for common bean, or african oil palm (*Elaeis guineensis*) could be substituted for coconut.

There are two distinct phases in the proposed successional crop system. The first phase includes the initial planting of beans, maize, cassava, and plantain. The second phase begins when coconut, cacao, and rubber are interplanted in the plantain. The two-phase arrangement is consistent with reports that during tropical forest succession, climax seedlings are almost never present in pioneer stages (Janzen 1975), as well as with reports of a possible decline in diversity between herbaceous and woody phases of natural succession (Tramer 1975).

Given the chronological arrangement described above, the next step is to define the spatial arrangement of the components. The spatial arrangement is very important during the first phase of the crop system. Spatial arrangement, which involves distances between crops and crop populations, depends on the crop varieties chosen as components for the crop system and site-specific characteristics such as moisture and nutrient availability. While agronomic information will probably be the most important cri-

teria for spatial arrangement decisions, ecological descriptions of the differences between wet and dry successional tropical ecosystems might also be valuable information.

Ewel (1977) has described horizontal and vertical development of leaf canopy within a stand during natural succession in wet and dry tropical ecosystems. In wet areas the ground is quickly covered with a layer of leaves. As stem development takes place, the leaf layer moves up and other layers are added. In dry areas the leaf canopy develops in clumps. With stem elongation the canopy of the stand slowly closes. The end point of succession on wet and dry sites may often be similar. The differences are much more noticeable during earlier stages.

The differences between wet and dry forest successional trends suggest several modifications in the spatial arrangement of the successional crop system on wet and dry sites. For example, the crop spacing should probably be wider on dry sites than on wet sites. Perhaps a determinate bean variety which quickly covers the ground should be planted on wet sites. On dry sites an indeterminate variety of beans which would climb the other crop species could be planted to produce clumps of vegetation possibly analogous to the patchy development noted during natural succession on dry sites.

Before field trials of the successional crop system are possible, it will be necessary to make decisions about crop varieties, exact distances between crops, and planting dates. These decisions should be made on the basis of site-specific criteria.

#### EVALUATION OF THE SUCCESSIONAL CROP SYSTEM.

—One way of evaluating the proposed Central American successional crop system is to compare the successional crop system to crop systems described by other investigators. Crop systems including associations of two or more of the crop species used in the successional crop system have been reported. Table 2 lists combinations of these crops which have been observed, evaluated, or recommended by various authors. All crops in the proposed crop system have been successfully combined with one or more of the other crops suggested as components for the successional crop system. This circumstance suggests that specific successional stages in the successional crop system are agronomically feasible. However, this is not evidence that it is possible to proceed from one of these stages to the next stage.

The ideal means of evaluating the proposed successional crop system would be to conduct a field trial and compare the successional crop system with other crop systems. This has not been done, but a

successional crop system which included the first three crops in the proposed successional crop system (beans, maize, and cassava) was compared to three monoculture sequence crop systems consisting of four crops of beans, two crops of corn, and one crop of cassava (Hart 1974, 1975a, 1975b). The yield, as well as gross and net economic return, from the successional crop system was higher than from any of the sequence crop systems. The viability of this nine-month successional crop system is certainly not conclusive evidence that the entire successional crop system would also be viable, but these results are evidence that the proposed successional crop system may have agronomic potential.

In this same experiment, the total weed biomass harvested at six-week intervals from a natural vegetation system and from the four-crop sequence of beans, two-crop sequence of maize, one crop of cassava, and three-crop successional crop system was 34.6, 17.6, 6.4, 6.3, and 4.5 kg/ha, respectively. The amount of weed invasion may be a measure of structural and functional similarity of a crop system to the natural plant system which it replaced. This finding suggests a direct relationship between crop system and natural plant system similarity, and agronomic parameters such as yield and economic return. If there is evidence to support this relationship, the implication for crop-system design and the potential of the natural ecosystem analog approach are obvious.

#### EVALUATION OF THE NATURAL ECOSYSTEM ANALOG APPROACH

The potential of the natural ecosystem analog approach has been demonstrated in the design of a successional crop system with agronomic potential. The general applicability of this approach depends upon the evidence to support the following hypothesis:

TABLE 2. *Combinations of the seven crops suggested as components for a succession crop system which have been previously reported.*

beans	maize	cassava	banana	coconut	cacao	rubber	Selected References
X	X						Willey and Osiru 1973
X	X	X					Hart 1975a, 1975b
		X					Parijs 1957
		X	X				Dubois 1957
			X				Silva and Abreu 1969
				X	X		Owen 1967
					X	X	Imle <i>et al.</i> 1952

the agricultural viability of a particular crop system is directly related to the structural and functional similarity between that crop system and a natural plant system in the same environment. This hypothesis will be referred to as the analog hypothesis.

There is little reason to doubt that similarity between the two systems is directly related to ecological viability of the crop system, but ecological viability is not necessarily the same as agricultural viability. To be agriculturally viable, the crop system must not only survive within the context of the ecological environment, but must also survive within the context of the socioeconomic environment.

The best way to evaluate the analog hypothesis would be to make a direct comparison between the structure and function of crop systems and natural plant systems in the same environment. If an index of similarity and an index of agricultural viability could be defined, and if there were a direct relationship between these indices, the hypothesis could be evaluated quite easily. Unfortunately, the data necessary to make this type of analysis are not readily available. The evidence for the analog hypothesis is, at best, circumstantial.

There may be a structural similarity between the dominant crop system of some geographic area and the natural plant system which occupied the area before the introduction of agriculture. If percent of farm land occupied by a crop system is a measure of agronomic viability, this similarity between dominant crop systems and original natural plant systems may be evidence for the analog hypothesis. Examples of this type of evidence can be cited for both temperate and tropical environments.

Oyington *et al.* (1963) compared plant biomass and productivity of prairie, savanna, oakwood, and maize plant systems in central Minnesota. The total plant biomass for the prairie, savanna, and oakwood plant systems was 8,071, 57,479, and 237,245 kg/ha, respectively. The total biomass for the maize plant system was 6,186 kg/ha, approximately the same as for the prairie ecosystem. If the geographical distribution of what was tall-grass prairie in the United States before the introduction of agriculture and the present geographic distribution of what are now maize fields (Wilsie 1962) are compared, the geographic distribution of both plant systems is remarkably similar.

Tropical mixed-perennial crop systems probably do not come close to having a total biomass of 500,000 kg/ha reported for tropical rainforests (Lugo 1969), but there is no doubt that perennial crop systems are more similar to forest plant systems than are annual crop systems. Tropical perennial crops

such as cacao, banana, coffee, and rubber are concentrated in humid tropical climatic zones which were forests before agriculture was introduced (Wilsie 1962).

Of course, in many geographic areas the dominant crop system is not analogous to the natural plant system which occupied the area before agriculture was introduced. Maize is grown in many areas of the United States which were once forest. It should be emphasized that the analog hypothesis involves comparison of crop systems with natural plant systems in the same environment, not necessarily with the natural plant system which was replaced by the crop system. If the crop system is subsidized by an outside energy source, such as fertilizer, the crop should be compared with a natural plant system receiving the same fertilizer subsidy for sufficient time for the natural ecosystem to come into equilibrium with the new input and to evolve structural and functional characteristics consistent with the new environment. The use of chemicals not found in natural ecosystems or machinery for tillage may produce an environment qualitatively so different from a natural environment that an analogous relationship between a natural ecosystem and agroecosystem may not be possible.

Although the evidence for the analog hypothesis is circumstantial, a logical basis for the hypothesis can be developed on the basis of the functional relationship between the crop system and the other components of an agroecosystem.

A generalized qualitative model of energy flow through an agroecosystem is shown in figure 3. In the diagram, solid lines represent energy-flow pathways; circles, storage tanks, bullet-shaped symbols, and hexagons represent outside sources, passive storages, plant populations, and animal populations, respectively (H. T. Odum 1971). In the model, energy flows from outside sources through the plant, animal, and microorganism populations, with energy lost in each process.

In an agroecosystem the flow of energy into and out of the population labeled man is obviously important. It will be assumed in this discussion that net energy available to maintain "man," for storage, or for export (energy consumed minus energy expended) on a continuous long-term basis is a measure of agricultural viability. Agricultural viability is assumed to include not only biological viability, but economic and social viability as well.

The model suggests that man can choose among, or combine any of, the following five strategies to increase net energy: (1) increase outside energy subsidy, (2) expend less management energy, (3)

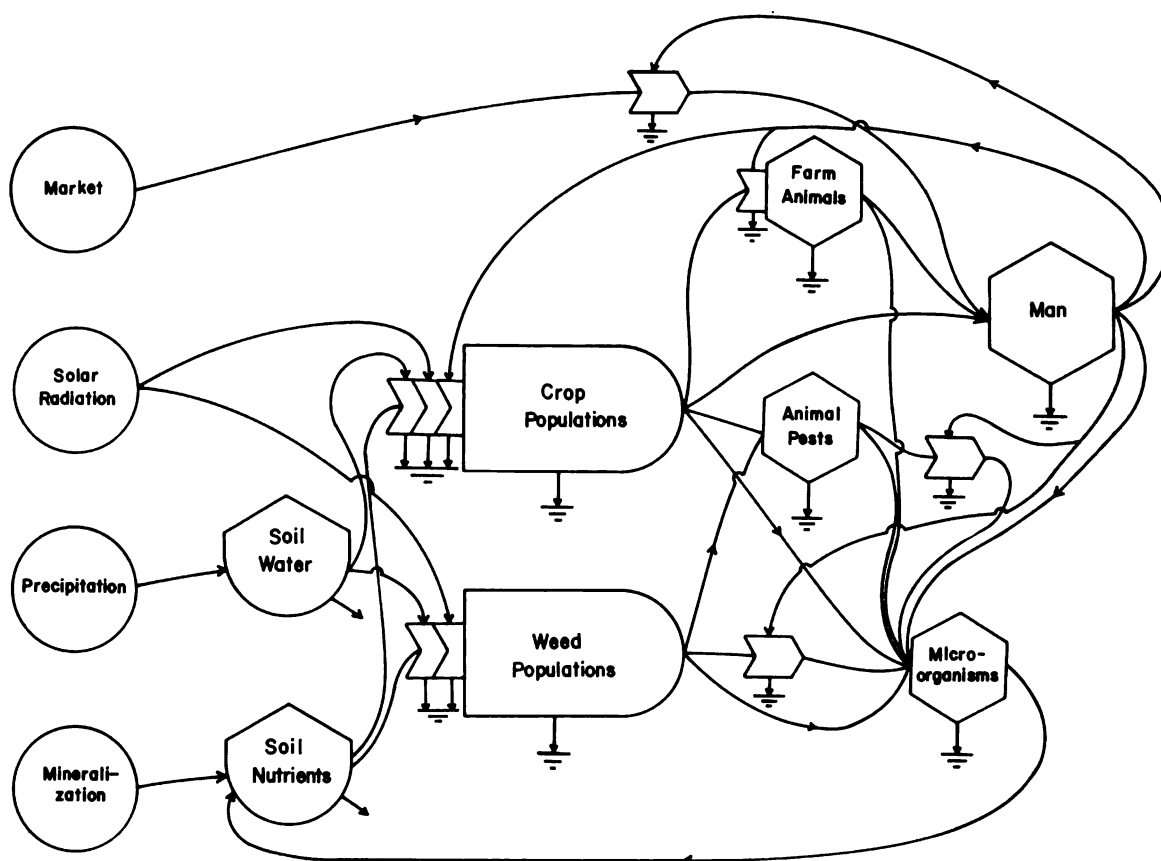


FIGURE 3. Energy flow through an agroecosystem.

reduce the competition from pests and weeds, (4) use different crop species or varieties, or (5) use a different crop system.

An increase in outside energy subsidy is possible if the cost of the subsidy is less than the market value of the increase in net energy. This is the strategy adopted by most temperate-zone farmers because of the relatively low price of fossil fuel. If the cost of the subsidy is more than the value of the increase in net energy, or if there is an unpredictable variability in either the cost of the subsidy or the value of the net energy, the energy subsidy must be reduced until the market value of the increase in net energy is more than the cost of the subsidy.

Reducing management energy (planting, weeding, harvesting, etc.) or reducing the competition from animal pest and weed populations will increase the net energy available to man. Unfortunately, reducing management energy without making other changes usually increases the competition from animal pests and weeds, and reducing competition from

pests and weeds usually requires an increase in management energy.

The use of a new crop species or variety can often increase net energy; however, farmers usually select crop species because of a demand for a particular commodity, and improved varieties usually require expensive energy subsidy in order to demonstrate their full genetic potential. A new disease-resistant variety can increase net energy by decreasing management energy spent on disease control, but often disease resistance lasts only until a new strain of the disease has evolved.

The functional relationship among weeds, pests, and crops of an agroecosystem suggests that one way of increasing net energy production may be to modify the crop system. A crop system that offers strong competition to the weed system or is a less favorable energy source for the animal pest population would require less management energy by man. Net energy will increase if man expends less management energy and receives the same amount of yield from the crop system, or if he diverts the energy previously



spent on reducing biological competition into activities which increase crop yield.

It is highly probable that crop system and natural plant system similarity is inversely related to the amount of biological competition between crops and weeds and between man and pests. The replacement of weeds by analogous crops and an increase in crop diversity will usually reduce the amount of energy used by weeds and pests. A logical argument supporting the analog hypothesis based on the functional relationship among crops, weeds, and pests within an agroecosystem can be stated as follows: if crop system and natural plant system similarity is inversely related to the amount of biological competition from weeds and pests, and if biological competition is inversely related to net energy for man, and if net energy is directly related to agricultural viability, then crop system and natural plant system similarity is directly related to the agricultural viability of a crop system. This argument is summarized in figure 4. High similarity of a crop system and a natural plant system will produce high agronomic viability if each of the premises connecting these two statements is true.

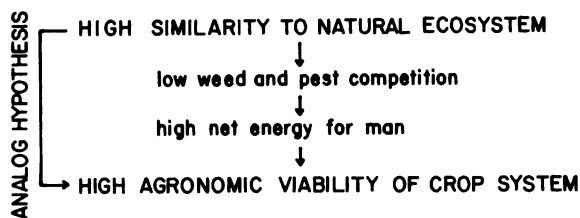


FIGURE 4. The relationships among similarity and competition, competition and net energy, and net energy and viability, supporting the analog hypothesis.


An alternative argument to the similarity-competition-net energy-viability (SCNV) argument outlined above is the suggestion by Trenbath (1975) that crop systems with high diversity (more similar to natural plant systems) are more stable and therefore more viable than less diverse crop systems. E. P. Odum (1971) has also assumed a direct relationship among diversity, stability, and agricultural viability. However, Murdoch (1975) has discussed these relationships relative to pest control and points out that instability is sometimes a pest-control tool, and that there is no good evidence to support the hypothesis that diversity is directly related to stability either in crop systems or natural communities. These relationships have been discussed, often with different definitions of stability, persistence, and resilience, and different conclusions by Margalef (1969), May (1972), Holling (1973), and many

others. While it can probably be assumed that crop systems which are analogous to natural plant systems will be more diverse than non-analogous crop systems, the SCNV argument is not based on a relationship among diversity, stability, and viability.

Socioeconomic environments may exist in which one premise of the SCNV argument may not be true. This possibility invalidates the argument, and although it does not mean the analog hypothesis is also invalid, it would suggest that the natural ecosystem analog approach may be less applicable. For example, the inverse relationship between similarity and biological competition may not be true in an environment in which an inexpensive insecticide is available to reduce insect pests associated with a low-diversity crop system, but no insecticide is available to combat the pests associated with a high-diversity crop system. The direct relationship between net energy and agronomic viability may not be valid in socioeconomic environments in which agricultural viability is associated with the production of a specialized product for a specific market. For example, a crop system producing beets (*Beta vulgaris*) for red dye may produce less net energy than a crop system producing potato (*Solanum tuberosum*) for human consumption, but the economic environment may be such that the beet crop system is more viable than the potato crop system. While the applicability of the analog hypothesis and the natural ecosystem analog approach to crop-system design can be evaluated by analyzing an environment to see if all of the premises of the SCNV argument are true in that particular environment, the approach should not be rejected categorically if one of the premises is not valid. The successional stages of a crop system designed by this approach give wide environmental applicability to any particular crop system. The crop system can be arrested at any successional stage or allowed to proceed to climax, depending on the socioeconomic environment.

In general, the natural ecosystem analog approach will be most applicable in environments in which a diverse array of commodities are required, such as a subsistence farm, and in environments in which biological competition from weeds and pests and the cost of energy subsidies are both high. Many areas in the humid tropics, for which the successional crop system was designed, meet these criteria.

It is likely that the price of energy subsidies which presently pertains in the developed countries in temperate zones will continue to increase as fossil-fuel availability decreases. The present dependence on the strategy of increasing agricultural production by increasing energy subsidy and selecting crop va-



rieties which respond to this subsidy may then have to be reconsidered. Crop-system design, and particularly, the natural ecosystem analog approach, may become more applicable in temperate zones in the future.

## **CONCLUSION**

The successional crop system designed for humid tropical forest environments should be further evaluated in large experimental plots. If such an evaluation is carried out, the structure and function of a natural successional plant system in the same environ-

ment should be continuously compared to the crop system. The field experiments could be used to suggest modifications in the successional crop system. If non-analogous crop systems are included in the comparison, the experiments could also be used to evaluate objectively the analog hypothesis.

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