nature of ecosystems, separating spatial and functional phenomena. The Crossley et al. chapter also argues a unique perspective on noncrop organisms. They emphasize a dearth of information on mutualistic or cooperative interactions that occur in managed ecosystems.

Ecosystem-level research and management entails understanding and manipulating complex interactions among physical, chemical, and biological processes where modeling and system-analysis tools are employed to tease apart cause-and-effect relationships. The papers by Spedding and Rykiel address this important aspect of agroecosystem science. Rykiel's approach is to discuss systems science and then apply it to the analysis of agricultural ecosystems. In contrast, Spedding's paper is oriented towards management and development of models for decision making.

Because of their anthropogenic nature, it is difficult to discuss agricultural systems and not comment upon human value systems. In reality, it is probably artificial to make such a separation. The first (Odum) and last (Jackson) chapters and Langdale and Lowrance's contribution on erosion explore issues that have very direct economic and political ramifications. All three authors converge on the concept of long-term stability or sustainability of crop production.

In Lowrance R, BR Stinner & GJ House (Eds.) Agricultural Ecosystems, Unifying Concepts John Wiley & Sons (1984)

# Properties of Agroecosystems

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Agroecosystems are domesticated ecosystems that are in many basic ways intermediate between natural ecosystems, such as grasslands and forests on the one hand, and fabricated ecosystems, such as cities on the other hand. They are solar powered as are natural ecosystems, but differ in that (1) the auxiliary energy sources that enhance productivity are processed fuels (along with animal and human labor) rather than natural energies; (2) diversity is greatly reduced by human management in order to maximize yield of specific food in other products; (3) the dominant plants and animals are under artificial rather than natural selection; and (4) control is external and goal oriented rather than internal via subsystem feedback as in natural ecosystems (Fig. 1) (see also Patten and Odum, 1981, for a discussion of cybernetics of ecosystems).

Agroecosystems resemble urban-industrial systems in their extensive dependence and impact on externals; that is, they both have large input and output environments (Fig. 2). Agroecosystems differ in being autotrophic rather than heterotrophic. The power density level (rate of energy flow per unit area) of pre-industrial agriculture, as practiced in economically undeveloped countries, is not much different from that of natural ecosystems. Power density of industrialized agriculture is 10-fold or more greater than that of most natural ecosystems due to the high energy and chemical subsi-

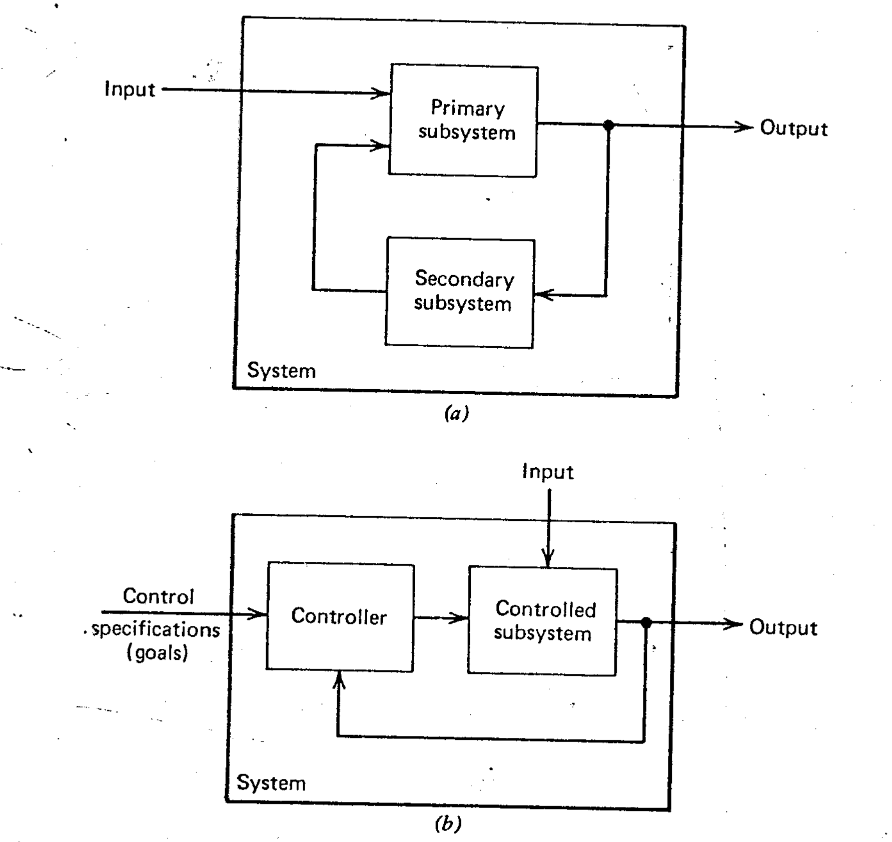


**Figure 1.** Natural ecosystems (*a*) are controlled by diffuse subsystem feedback in contrast to organisms and man-made systems (*b*) which have goals or set-points (after Patten and Odum, 1981).

dies. Accordingly, the impact of agricultural chemical pollutants and soil erosion on waterways, the atmosphere, and other global life-support systems can approach in severity that of urban-industrial areas.

Given the increasing cost of both energy and pollution, many agree that major technological, economic, and political efforts must be made to reduce the input and output costs of both agricultural and urban systems; otherwise, excesses in either or both will very soon jeopardize the capacity of the natural life-support systems to support them. Viewing croplands and pasturelands (and also plantation forestlands) as dependent ecosystems that are functional parts of larger regional and global ecosystems (i.e., a hierarchical approach) is the first step in bringing together the disciplines



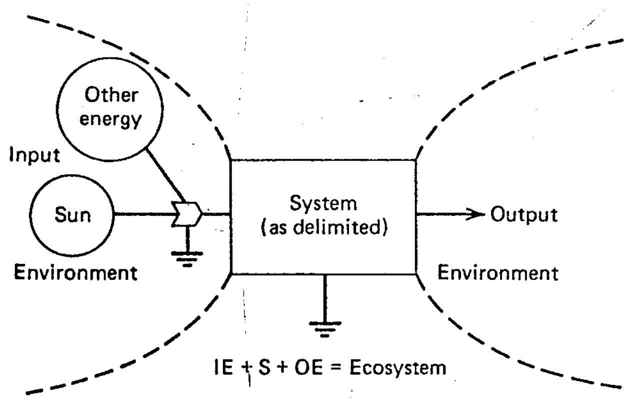


**Figure 2.** Input and output environments are a basic component of ecosystems which function as far-from-equilibrium systems. The properties of agroecosystems have changed dramatically as dependence and impact on externals has increased (after Odum, 1983).

necessary to accomplish long-term goals. The so-called world food problem cannot be mitigated by efforts of any one discipline, such as agronomy, working alone. Nor does ecology as a discipline offer any immediate or direct solutions, but the holistic and system-level approaches that underlie ecological theory can make a contribution to the integration of disciplines.

The properties of agroecosystems and the nature of their impact on other ecosystems have changed dramatically during the past half-century in the United States and other industrialized nations. It is important that we review this history in order to gain perspective on current problems and research needs. Auclair (1976) has described the development of intensive agriculture in the Midwest in three stages as follows:

> 1833–1934. Some 90% of prairie, 75% of wetlands and all forest land on good soils converted to croplands, pastures and wood lots. Natural vegetation restricted to steep land and shallow, infertile soils. However, farms were generally small, crops diversified, human and animal labor extensive, so impacts of farming on water, soil and air quality was not overall deleterious.
>
> 1934–1961. Intensification of farming associated with inexpensive fuel and chemical subsidies, mechanization, and increase in crop specialization and monoculture. Total cropland acreage decreased and forest cover increased 10% as more food was harvested from fewer acres by fewer farmers.
>
> 1961–1980. Increase in energy subsidy, size of farm, and farming intensity on the best soils, with emphasis on continuous culture of grain and soybean cash crops, much of which is grown for export trade. Conservation practices—such as crop rotation, fallowing, terracing, vegetated runoff waterways, etc.—de-

creased as farmers were more and more forced to expand cash crops to pay for increasing costs of energy and machinery. Yields per unit area increased but for some grain crops peaked during this period. Losses of farmland to urbanization and soil erosion accelerated, as also did the decline in water quality due to excessive fertilizer and pesticide runoff.

Brugam's (1978) analysis of the chemical composition of dated sections of cores from the bottom of a lake in Connecticut (Linsley Pond) provides a history of the changing impact of both agriculture and urbanization on adjacent ecosystems. Early farming in the 1800s had very little effect on the lake, but intensification of agriculture after about 1915 caused eutrophication of the lake resulting from an inflow of agricultural chemicals. From 1960 to the present, rapid urbanization and increased farming intensity has resulted in "hypereutrophication" due to agroindustrial wastes and extensive erosion that brought large amounts of soil, heavy metals, and other toxic substances into the lake. Marked changes in the biota directly related to changes in the input environment have been documented in this lake.

In summary, market and other economic and political forces, along with urbanization and the pressures of human population growth, have transformed agroecosystems from "domesticated" ecosystems that were relatively harmonious with our general environment into increasingly "fabricated" ecosystems that more and more resemble urban-industrial ecosystems when it comes to energy and material demands and waste production.

From the ecological perspective agroecosystems, coupled with natural ecosystems, constitute the human life-support module for spaceship earth since they provide the food, the water and air purification, and the other goods and services that sustain us. However, when agricultural products become valued more as market commodities to be sold to the highest bidder rather than as food to nourish us, and when short-term yields are maximized at the expense of long-term sustainable production, then the agroecosystem becomes more of a drain than a contribution to the life-support environment.

As the undesirability of some of these trends becomes evident, there is renewed interest in redeveloping conservation farming practices that first emerged in the 1930s following the soil erosion and dust bowl disasters. Among practices that should benefit from new technology and a better understanding of nutrient and water metabolism of crop systems are those that would (1) increase energy efficiency; (2) reduce irrigation water wastage and soil erosion; (3) increase nutrient retention and recycling so as to reduce fertilizer inputs; (4) promote use of crop residues for mulch, silage, and as energy sources; (5) increase diversity through multiple and rotational cropping; (6) reduce excessive dependence on broad-spectrum pesticides; and



(7) reduce plowing (limited-till and no-till). The latter alone can reduce costs of fuel and loss of soil by as much as 50% with only a moderate reduction of yield over the short term (Crosson, 1981). Theoretically, yields under no-till should exceed that under conventional till in the long-term due to reduction in erosion and improved maintenance of soil quality, but this theory is difficult to test when economics discourages investment in long-term experiments.

All of the conservation farming practices have the general effect of making the agroecosystem more like the natural ecosystem and less like the urban-industrial system, and hence a less disorderly and a more harmonious component of our total landscape.

On the basis of a national, interregional linear programming model, Olson et al. (1982) project that widespread adoption of what they term "organic farming" would increase net farm income and satisfy domestic demands for agricultural projects. Consumer food costs would increase, which benefits the farmer who would then have the means and motivation to maintain the quality of the land rather than "mine" the soil in a desperate effort to pay his debts. However, surpluses for export would decline sharply with widespread conservation farming. The dilemma here is that conservation farming is good for the farmer and the land, but not for the national economy of a nation committed (1) to exporting food to balance oil and mineral inputs and (2) to the manufacture of ever more farm machinery and agricultural chemicals.

Of the several characteristics of agroecosystems listed at the beginning of this chapter, I believe the one that merits special attention at this time is the manner of control (item 4). As we pointed out, control of agroecosystems is largely external, that of natural ecosystems to a considerable extent at least, internal. Subsystem controllers are more quickly responsive than external controllers to both internal feedback and external inputs. The independent, land-owning farmer, the backbone of American farming for most of our history, is an efficient "controller," as it were, since he is able to respond and adjust to local conditions and needs. His goal is not only to make a living but also to pass on his farm to the next generation in as good or better shape. To some extent, at least, such a farmer is an "internal controller" since he operates within the farming system. Unfortunately, in the past decade or so, control has more and more passed from the farmer to more distant controllers absentee landlords, corporations, the federal government, and, especially, the grain and food markets. These remote controllers cannot respond effectively to the numerous positive and negative feedbacks that originate within the crop system itself. Furthermore, the goal of the remote controllers is primarily directed to obtaining the largest possible yield of a cash crop, not to maintaining long-term productivity.

In many ways, today's grain farmer, although much more affluent and better educated, is in the same frustrating position as the tenant farmer and sharecropper of yesterday's rural South who had to grow the same cash crop year after year even though he knew it was a vicious cycle that would soon impoverish both the land and himself.

Recognizing this basic problem is the first step in devising means to reestablish controls and goals to a more responsive local level in the hierarchy of agroecosystems. Beyond that, it may be feasible to design agroecosystems so that internal controls such as operate in natural ecosystems can contribute to overall efficiency, homeostasis, and stability. The theory here is that any services we can get from natural internal self-organizing and self-maintaining processes will reduce the need to spend money and energy to provide these services by artificial, external means.

Low-energy feedbacks that have high-energy effects are basic features of cybernetic systems. In ecosystems "downstream" components in the food chain such as predators or parasites may have a large-scale effect on primary production as a result of their control of herbivores, even though the predators and/or parasites utilize only a very small part of total community energy flow. Likewise, energy flow in a mycorrhizal network may be quantitatively small, but primary production of the whole ecosystem may be greatly enhanced by the direct soil to plant nutrient transfer work accomplished by the mycorrhizae. These are just two examples of potential subsystem controllers in natural ecosystems that can also operate in agroecosystems.

In our experimental research on agroecosystems at The University of Georgia, we are comparing ecosystem-level processes in conventional till and no-till cultivation of sorghum and soybeans with winter and spring rotations of rye or clover. Fertilizer applications are the same for both cultivations, and no insecticides or irrigation have been used on either. Just enough herbicides are used in no-till to prevent weeds from overtopping crops. For the first four years of our long-term experiment, crop yields have been very similar for the two treatments and comparable to yields obtained by farmers in the general region. In the no-till plots we are beginning to see some improvements in desirable properties such as nutrient and water retention and an increase in insect predators and parasites. We suspect, but have not yet demonstrated, that mycorrhizal networks developing in the upper layer of the undisturbed soil improve nutrient retention and may even link the root systems of volunteer plants and crop plants. If so, nutrients taken up by the former might become available to the latter (or vice versa). Accordingly, weeds between the rows or as an understory could be mutualistic rather than competitive with the crop.

In summary, viewing agroecosystems as intermediate between solar-powered natural ecosystems and fuel-powered urban-industrial systems helps to put current agricultural dilemmas in perspective. Increasing industrialization of agriculture has increased energy and chemical inputs, on the one hand, and chemical pollution and soil erosion outputs on the other hand. Control of the agroecosystem has become more remote (involving export market forces, absentee owners, and federal government), which results in maximizing short-term yield of cash crops at the expense of long-term production and maintenance of soil fertility. New forms of conservation tillage and a return to more local control are needed to reverse these undesirable trends. As a result of our own research and that of many others, we are encouraged to believe that reducing soil disturbance and toxic chemicals will allow natural mutualistic subsystems to develop that will improve the long-term fertility and stability of agroecosystems.



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