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Richard Lowrance, Paul F. Hendrix and Eugene P. Odum

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A hierarchical approach to sustainable agriculture

Richard Lowrance, Paul F. Hendrix, and Eugene P. Odum

Abstract. *"Sustainable agriculture" means many things to different people in agriculture. At least three different definitions of sustainability are available: sustainability as food sufficiency; sustainability as stewardship; and sustainability as community. Since increased human populations will cause demands for food to continue to grow in the foreseeable future, agricultural sustainability needs to be assessed in ways that will incorporate competing definitions. We suggest that analyzing agriculture as a hierarchical system is the appropriate way to incorporate different concepts of sustainability. Using this concept, we propose a hierarchical definition of sustainability. Agronomic sustainability refers to the ability of a tract of land to maintain productivity over a long period of time. Microeconomic sustainability is dependent on the ability of the farm, as the basic economic unit, to stay in business. Ecological sustainability depends on the maintenance of life-support systems provided by non-agricultural and non-industrial segments of a region. Macroeconomic sustainability is controlled by factors such as fiscal policies and interest rates which determine the viability of national agriculture systems. In our view, there are critical constraints to sustainability at different scales of the agricultural hierarchy. We propose that agronomic constraints are most important at the field scale; microeconomic constraints are dominant at the farm scale; ecological constraints override at the watershed or landscape scale; and macroeconomic constraints are foremost at the regional and national scale. In this paper, we describe the actions of these critical constraints, discuss interactions among various hierarchical levels, and propose ways that agricultural researchers and policy makers can integrate the various views of sustainability.*

Introduction

Growing human populations will increase global demands for food and fiber well into the next century. To meet projected demands due to both population growth and increased consumption in the year 2020, agricultural production must increase by 90 to 140 percent for cereal, meat and oilseed, and by more than 60 percent for cotton (Farrell et al., 1984). Just to maintain current levels of per capita consumption in the year 2020 will require grain yields 56% higher than 1985 levels (Wolf, 1987). These increases may come about through innovations in biotechnology (e.g., improved

cultivars, enhanced animal production); more intense cultivation of existing arable land; cultivation of new prime and marginal lands; and through improved storage, transport, and marketing of food. The agricultural systems that are ultimately adopted will have to provide unprecedented levels of production to feed the 10 to 11 billion people projected to make up the stabilized human population of the next century (Ehrlich, 1985). Historical and recent experience with agriculture suggests that these gains are not likely to be achieved without negative effects on natural systems, environmental quality, and rural communities unless chemical and energy subsidies are efficiently assimilated within agroecosystems.

The idea of sustainable agriculture is popular among people interested in alternative systems of agriculture which

minimize the potential negative effects of feeding growing populations. But agricultural sustainability means different things to different people. Douglass (1984) identified three different views of sustainability. The first view, described as the dominant paradigm in American agriculture, was called "sustainability as food sufficiency." This type of sustainable agriculture seeks to maximize food production within constraints of profitability. The second view of sustainability was described by the phrase "sustainability as stewardship" and defined sustainability in terms of controlling environmental damage (Brown, 1984). The third view of sustainability was "sustainability as community" and defined sustainability in terms of maintaining and reconstructing rural value systems (Berry, 1984). Integration of these different concepts should produce a more comprehensive working approach to agricultural sustainability.

In this paper we explore agricultural sustainability from a hierarchical perspective. We propose that different constraints operate at different levels of organization and that management strategies for sustainability must be applied at the appropriate levels. Finally, we provide examples of how management applied at one level affects other levels in the hierarchy.

Agricultural hierarchies

Hierarchical systems are families of subsystems arranged in a hierarchical manner. There are numerous kinds of hierarchies, but there are at least three features common to all kinds (Haines, 1977): "1) higher level subsystems portray or are concerned with a larger portion or broader aspects of the overall system; 2) higher level subsystems have

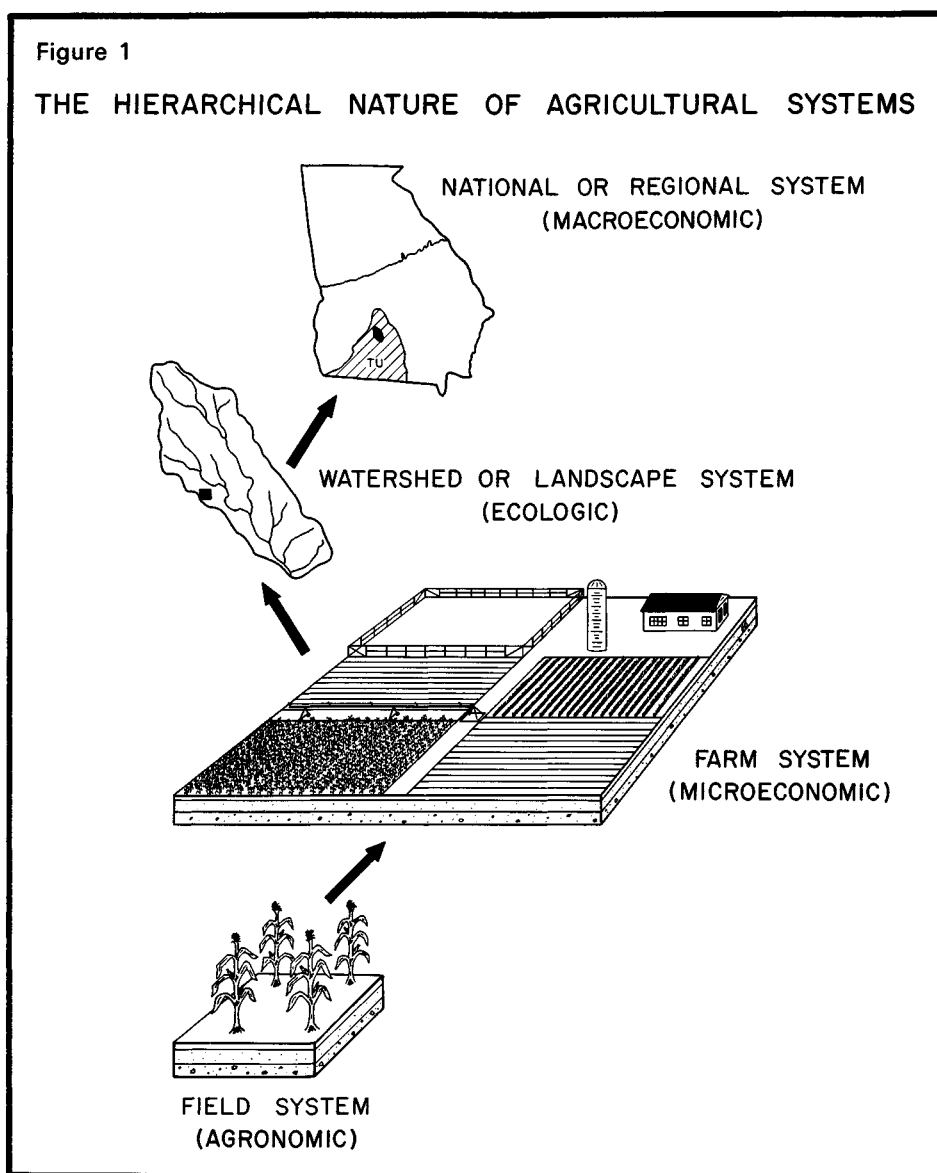
Richard Lowrance is an Ecologist with the Southeast Watershed Research Laboratory, USDA-ARS, Tifton, GA 31794. Paul F. Hendrix is an Assistant Ecologist and Eugene P. Odum is the Emeritus Director at the Institute of Ecology, University of Georgia, Athens, GA 30602.

longer decision horizons - they are concerned with longer range behavior; 3) higher level subsystems have priority of action over lower level subsystems." According to Allen and Starr (1982), a hierarchical structure implies that "a disturbance at one level may be a stabilizing force at another; this state of affairs demands the use of appropriate scales, only one of which will apply for a unified model of a given level of organization." Despite spectacular increases in agricultural productivity per unit of land and labor in recent years (Avery, 1985), modern agriculture still faces serious problems at scales ranging from individual fields to climatic and geopolitical regions. Such problems include increased resistance of pests to pesticides (Dover, 1986), loss of individual farming operations to economic bankruptcy (Guither, 1986), and failure of entire regions to produce sufficient food to avoid massive local famine (Brown and Wolf, 1986). The increasing scale of these problems reflects the hierarchical organization of agricultural systems (Hart, 1984), which is illustrated in Figure 1.

The hierarchical perspective suggests an organizational scheme for policy and management systems that must deal with agricultural sustainability. We suggest that within the hierarchy of agricultural systems, sustainability can best be addressed by recognizing the dominance of agronomic constraints at the field scale, microeconomic constraints at the farm scale, ecological constraints at the watershed or landscape scale, and macroeconomic constraints at the national or transnational level.

Agronomic sustainability

Management begins at the smallest operating unit of agriculture, the fields in which crops or livestock are grown. In theory, any tract of land can be made to produce a high yield almost indefinitely if sufficient inputs are provided. For example, even systems devoid of soil organic matter (e.g., hydroponic and sand culture) can produce high yields given adequate inputs, although such systems are not likely to contribute substantially to world food needs (Camp-



bell, 1978). *Agronomic sustainability* refers to the ability of such a tract of land to maintain "acceptable" levels of production over a long period of time. This time period is not absolutely defined, but is related to such factors as soil formation rates, management practices used, length of land tenure, and geographic location. In a world which has run out of frontiers to bring under the plow, we must attempt to sustain production on the best lands already under cultivation.

The total net value of a crop may not be acquired in one growing season. For instance, the benefit derived from growing a legume cover crop or adding N-fixing legumes into a crop rotation might not be evident until a heavy-feeding crop

such as corn is grown following the legume. Therefore, agronomic sustainability must be evaluated over the course of multiple growing seasons.

Microeconomic sustainability

In practice, continued high levels of input may not be economically feasible and a field with low or declining productivity may be converted to a more suitable agronomic use or to non-agricultural uses (e.g., timber production). This ability to shift productivity among tracts of land defines the basic unit of *microeconomic sustainability*, the farm. Even though there are important economic considerations at the field scale,

the farm is the basic economic unit in the hierarchy of agricultural systems. A field can be an economic loser while a farm remains economically viable. The reverse is not true, however, because the maintenance of agronomic inputs requires the maintenance of the economic unit. Conversely, certain fields on a farm may do well agronomically (i.e., produce high yields) but do poorly economically due to low market prices or high production costs. Thus, agronomic and economic factors interact to determine the sustainability of a farm.

Ecological sustainability

The aggregate of farms and other land uses in an area forms an agricultural landscape. Farms as well as cities and other human-built environments require life support "goods and services" from the environment, such as purification and recycling of air and water (Odum and Franz, 1980; Odum, 1983). At this level such functions are provided by riparian forests which act as nutrient "filters" for agricultural runoff (Lowrance, et al., 1984); by rivers, streams, and wetlands which assimilate and disperse human and animal wastes; and by natural areas and hedgerows which provide habitat for beneficial predators of pest species (Forman and Baudry, 1984). These functions are enhanced by a diversity of managed and unmanaged ecosystems interspersed throughout a landscape.

At the landscape level, additive effects of individual agronomic and economic practices become apparent, sometimes in the form of environmental degradation (e.g., diminished quality of water, air, and soil). Such practices affect *ecological sustainability* which is the maintenance of life support capacity of larger scale landscape units over longer time scales. Ecological sustainability is a necessary condition for the achievement of long-term economic and agronomic sustainability. This can be seen in the case of intensive regional land uses, especially monocropping of large areas. For instance, in the Southern Piedmont region of the U.S. large scale monocropping of cotton caused severe erosion and sedimentation in the 19th and early 20th centuries (Trimble, 1974). This land use

has been replaced by a mix of timber, poultry, dairy, pasture and row crops. These uses have reduced soil loss compared to the 19th century and are probably sustainable for a longer period of time.

In most modern landscapes the pattern of land use is determined largely by economic factors within constraints imposed by the natural environment (geology, soils, climate, water availability, etc.) and legal/social systems (zoning, local attitudes and customs, etc.). Agricultural land uses in particular consist of a mix of high and low input systems with varying potentials to degrade environmental quality. To achieve ecological sustainability, all of the land uses in a region must be able to meet reasonable soil, water, and air quality criteria.

Farm scale economics determine the ability of farmers to buy inputs and thus the intensity of agricultural management practices. Less intensive use of land may not always lead to enhancement of environmental quality. For example, high yields on prime farmland make it possible to keep marginal lands out of production in some cases. In the Amazon basin, sustainable agriculture capable of feeding large populations may not be possible without the ability of farmers to buy inputs which would allow shifting cultivation to be replaced by permanent cultivation (Nicholaides et al., 1985).

The landscape level is where quantitative relationships among potential farm productivity, diet, and population can be integrated to examine agricultural carrying capacity (Ferguson and McAvin, 1980). If a region is not able to sustain present populations, then either different management must be used to produce more food; food must be imported; or people must be exported.

Macroeconomic sustainability

At the national or international scale, macroeconomic constraints, especially monetary and fiscal policy, determine the focus of national economies and eventually determine the ability of national agricultural systems to feed their populations. Some observers feel that macroeconomic policy may have a

greater effect on farms than conventional microeconomic policies aimed at the farm level (Thompson, 1985).

Nonrenewable resources often determine the type of agricultural systems developed within a nation. Countries which are able to exploit nonrenewable resources, such as oil, as the basis of a national economy are less likely to emphasize creation of agricultural systems to provide food and commodities for sale. In most cases, oil-rich Middle Eastern countries have used oil revenues to buy food from countries with agricultural surpluses rather than establish their own agrarian cultures (Christensen et al., 1985).

Conversely, countries which must base their economies more on agriculture (and forestry) are faced with the dilemma of feeding a resident and often hungry population while at the same time producing commodities for export. The way in which government policy and macroeconomic forces address this dilemma will largely determine the structure of field and farm scale agroecosystems and thus the long-term ecological sustainability of those regions.

Interactions among levels: Some examples

In most countries, government policy is an important factor shaping the structure and productivity of agricultural systems. From our discussion it is apparent that policies can be targeted at any level of the agricultural hierarchy. To be effective, not only should policies be aimed at the appropriate levels but their implications at the other levels should be considered. Examples from U.S. agriculture help illustrate these points.

Conservation tillage is becoming widely used in the U.S., largely because it lowers equipment operating costs and reduces soil erosion (Magleby et al., 1985). Government incentives to use reduced tillage on certain classes of land represent a field scale policy with effects at higher levels in the hierarchy. For instance, on the farm scale reduced tillage could lead to different crop rotations and possibly to greater net returns due to savings on energy costs. On the regional scale, reduced tillage could lead

to decreased sedimentation in streams or reservoirs, but could also lead to increased leaching of certain soluble compounds (Gebhardt et al., 1985). On the national or macroeconomic scale, these changes in field scale management might lead to a change in the mix of farm inputs provided by corporations, for instance decreased direct use of fuels for locomotion and increased indirect use of petroleum products as herbicides.

Although one major goal of agricultural policy is to increase farm level income, policies designed to achieve specific structural goals at the farm level are not common in the U.S. since the farm is the basic unit of private enterprise. If policies are made to control the size or direct the operations on individual farms, explicit analysis of effects on other levels of the hierarchy is necessary. For example, some economists claim that moderate-size farms, with about \$100,000 in annual sales, are the optimal size in the U.S. (Tweeten, 1983). Yet the U.S. Office of Technology Assessment (OTA) predicts that emerging technologies in the agricultural sector will result in the demise of over one million small and moderate size farms by the year 2000, leaving 75% of U.S. agricultural production concentrated within 50,000 large farms with annual sales exceeding \$250,000 (OTA, 1986). OTA recommended several changes in U.S. agricultural policy to accommodate new technologies, increase agricultural productivity, and still maintain microeconomic sustainability of small and moderate size farms. The most important policy changes for moderate sized farms would be to help reduce risk and to shift the emphasis of extension to the task of providing technology evaluation and technology transfer programs for moderate size farms that have the potential to survive and grow (OTA, 1986).

If these policies were implemented and were at least partly successful, then the decline in numbers of moderate size farms might be lessened. However, large farms still are likely to become more dominant. Given this scenario at the farm, or microeconomic level, we might expect the following repercussions at other levels in the hierarchy: 1) At the field scale there could be an increase in

the average size of fields and equipment needed to manage them. This might mean greater soil compaction and fuel costs from heavier equipment. Monocropping at a larger scale could also increase the likelihood of problems from insects and plant pathogens, and thereby increase the need for pesticides. 2) At the regional level, larger fields probably would mean fewer hedgerows and wooded areas in the landscape, and therefore, less habitat for beneficial wildlife. New technologies applied at the field level could translate into improved environmental quality and ecological sustainability if, for example, fertilizer use efficiency is increased, or pesticide utilization and soil erosion are decreased. Within a region, disruption of rural communities might occur because the goods and services they offer generally are not used by corporate farms (Tangle, 1986b). This could result in a further decline in rural populations. 3) At the national and transnational levels, stated policy goals are increased productivity and competitiveness of U.S. agriculture, and growth of commodity export markets. An enhanced economic climate for exports could drive the U.S. agricultural system toward increased production of the basic export commodities such as corn, wheat, rice, soybeans, and cotton. The results internationally could be decreased production in other countries, especially developing countries which have been substituting cash crops for subsistence crops.

Recently enacted national policies to achieve regional goals were the so-called swamp-buster and sod-buster provisions incorporated in the 1985 Food Security Act (Block, 1986). Under these provisions, farmers who have wetlands or highly erodible lands in production without an approved conservation management plan will lose benefits from commodity price support programs for their entire farm. This program is designed to achieve regional goals of maintaining water quality and wildlife habitat and reducing wind erosion. In order to attain these goals, land use must be regulated at the field scale and the means to enforce the regulation are economic ones at the farm scale.

Programs such as Payment in Kind,

designed largely to make adjustments in macroeconomic conditions by the exchange of government surplus commodities for new plantings, also produced changes at the lower hierarchical levels. For example, allowing fields to lie fallow with little or no management for a year would tend to increase the populations of weed seeds in a field for the next year. On a farm scale, the farmer may decide to take advantage of a year of fallow and convert a field to some perennial vegetation such as grassland or trees. On a regional scale, the one year fallowing of fields would reduce inputs of fertilizer and chemicals but would have little or no effect on erosion rates and sedimentation.

Conclusions: Putting an idea to work

Some research tools exist to determine the interactions among environmental goals, land use, and farm economics. For instance, linear programming models have been used to examine the effects of pollution control measures on cropping patterns and net farm income in areas such as Chesapeake Bay where nonpoint source pollution has created critical water quality problems (Kramer et al., 1984).

Scientists and engineers who conduct agricultural research have the task of assuring that technical information necessary to create sustainable agricultural systems is available for educational and outreach activities undertaken by extension workers. In 1985, the focus of most field scale research was to maximize productivity, with 74% of public research money going to crop and animal production, protection, and processing (Blosser et al., 1985). Some observers see the emphasis now changing to optimization of resource use to produce yields as efficiently as possible (Tangle, 1986a). One approach in this optimization process is to reduce chemical inputs (fertilizers and pesticides) to that which can be retained and assimilated within the agroecosystem in order to reduce the cost of sustaining crop production. Lands which could not retain and assimilate the quantity of inputs necessary for production would be more

likely to revert to a landuse with lower inputs.

Research and extension activities are much more poorly focused at the higher hierarchical levels. Ecologists and environmental quality experts often examine the potential for environmental degradation created by modern agriculture. This potential may be especially acute in developing regions where population growth and food demands are high but technological skills are inadequate. These environmental problems are seldom analyzed within the context of increasing the economic viability of farms. Environmental quality experts are likely to continue with only a peripheral role in agriculture until on-farm impacts of natural resource management are an explicit part of the analysis.

Efforts by extension offices to focus on the connections between agriculture, land use, and environmental quality have been initiated in the U.S. through studies of agricultural futures. However, the difficulties in dealing with these questions in the U.S., a developed country with secure food supplies, indicate that even greater difficulties will be faced in lesser developed countries with immediate problems of inadequate food supply. Funding agencies such as the World Bank and the Agency for International Development, which deal with agriculture and resource management in developing countries, can address these problems on a global scale by promoting economic and environmental impact analysis within a hierarchical framework.

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National funds sought for alternative agriculture research

Efforts are underway to seek federal FY 1988 funding for the Agricultural Productivity Act, the alternative farming systems legislation passed by Congress as part of the 1985 farm bill. "The importance of the Act was demonstrated when scores of groups testified in support of it in 1985," says Garth Youngberg, Executive Director of the Institute for Alternative Agriculture. "The pressures on American agriculture now make its funding even more vital than in 1985."

The program would include on-farm research comparing conventional and alternative farming methods as well as the organization of existing USDA information on low-cost, environmentally sound farming systems. Senator Patrick Leahy (D-VT), a leading sponsor of the 1985 bill, is now Chairman of the Senate Agriculture Committee and in a position to help move funding on the Act forward, supporters say. A group of national conservation organizations, including the IAA, has formed a steering committee to take leadership in the effort.

Heinz will restrict purchase of crops treated with chemicals

H. J. Heinz Company has announced plans to restrict purchase of crops that have been treated with possibly hazardous agricultural chemicals when these crops are to be used in its baby foods. Heinz will test crops to ensure the lack of residues, the company said in a letter to its contract growers. Consumer activists have pointed to high risk levels for babies exposed to chemical residues in food since babies consume high amounts of food in relation to body weight.