Serving Multiple Needs with Rural Landscapes and Agricultural Systems

[Ch. 10 in Agroecosystems Analysis, D. Rickerl and C. Francis, eds., American Society of Agronomy, Madison, WI. pp. 147-166]

Charles Francis, University of Nebraska - Lincoln; Lennart Salomonsson, Swedish Agricultural University, Uppsala; Geir Lieblein, Agricultural University of Norway, Aas; and Juha Helenius, University of Helsinki, Finland

Introduction

One important contribution of agroecology is providing a framework and an opportunity to focus on systems at the landscape level. The importance of recognizing multifunctional processes and products of rural landscapes has grown in recent years (Brandt et al., 2000). This is due in part to greater attention to systems dimensions of agriculture and food production, including emergent properties at scales larger than fields or farms. Researchers and practitioners attempt to weave new technologies into practical and economically viable production systems. Students seek relevance in their education, and meaning often comes from higher levels of scale. Farmers are seeking ways to design production strategies that preserve soil, water, and air quality, as well as biodiversity, and numerous support programs are in place to encourage this direction. Broader interest and concern by consumers about the safety of food and the security of the food system for the long term bring additional focus to where and how food is produced, especially the rural environment (Torjusen et al., 2001). Other concerns such as global warming, limited supplies of critical resources such as fossil fuels, and negative environmental impacts of many conventional agricultural practices heighten people's awareness of the connectedness of the food system to the overall environment. Agroecology is emerging as an integrative discipline that will strengthen and support research and education on these complex issues in the agricultural production and food systems, as well as bring more attention to landscape level analyses.

Agroecology, when defined as the ecology of food systems (Francis et al., 2003), is becoming a useful term that encompasses the complexity of resource use, efficiencies of alternative production systems, and social impacts of agriculture including equity of distribution of benefits. When the scope of agroecology extends beyond the production field and the immediate impacts on water quality in nearby streams, we begin to evaluate food systems including conversion of natural resources, efficiency of production, processing food items, marketing, and consumer issues. This allows an analysis of efficiencies through the entire system, and provides tools to look at the global food chain in comparison to local food systems. Such an analysis includes the impacts of regulations and policies at all levels, as well as the potentials and applications of new technologies, and the overall environmental impact. Those who embrace agroecology with this broad definition must consider analysis of the impacts of consolidation and decisions by a handful of multinational food corporations that deal with commodities and global markets. It is useful to look at food systems at different levels in the hierarchy as well as over time. An example of a spatial hierarchy of agroecosystems, including social decisions at several levels, is shown in Fig. 1 (adapted from concept of Olson, 1999). We recognize that individual farmers and consumers make most decisions at the local (farm and community levels), and that only in the aggregate can these influence the global food system.

To study structure of a system at one level of the spatial hierarchy, ie. field or farm or landscape, it is important to recognize the multiple characteristics that define agriculture at that level, and how the factors interact to produce final food or feed products and economic returns. There are environmental and social impacts of agricultural systems at each level, including access to local resources, and community and ethical issues. More importantly, these factors interact across the spatial hierarchy and influence success or failure of production in complex ways. In addition to looking at different spatial levels it is essential to bring in other dimensions such as time: the history and natural ecosystems that are sustainable in a given place, the current production and food systems characteristics, and the desirable future situation that will provide quality, safety, and equity in access to food into the future. These dimensions relate structure to function in the agroecosystem.

The performance of agriculture at the landscape level, often called *landscape function*, is highly influenced by decisions at the community, regional, and national levels. Political forces in each country and across the globe, including strong corporate interests that often transcend national political control and local benefits, influence markets, support programs, national priorities, and agricultural policy. More amenable to management, the key interactions within the landscape are conditioned by processes, mechanisms, and decisions at field and farm levels, as well as by the performance of individual crops and livestock species found across the landscape and the soil/climate complex that has evolved in each place. These in turn interact with components of the surrounding natural habitat. To understand how landscapes function, it is essential to understand mechanisms that operate at the farm and field levels (Olson and Francis, 1995). To appreciate the importance at the landscape level of broader influences such as regional or global climate, international trade, or national agricultural policy, it is essential to look to higher levels in the spatial hierarchy to understand the context in which the landscape is imbedded and the meaning that is attached to that landscape (Fig. 1).

Many examples of the growing attention in research to areas beyond the farm and immediate community were presented in the conference, *Multifunctional Landscapes: Interdisciplinary Approaches to Landscape Research and Management* (Brandt et al., 2000), organized by University of Roskilde in Denmark in October 2000. The conference attracted scientists and educators from a wide range of fields of study, and the participants struggled with their disciplinary dialects and biases in an attempt to deal with the broader issues that emerge at the landscape and regional levels. Many of the current methods and tools used by most agricultural scientists appear to be inappropriate at higher levels of scale, although we often persist in using the comfortable and well-accepted methodology of a given discipline.

We study these mechanisms and implications of how agroecosystems are structured and their major processes or functions in order to better understand how alternative agricultural and food systems work, and to use this information to better design systems for the future. This chapter explores structure and function at landscape level, then defines the importance of mechanisms from lower levels and context and regulation forces provided by higher levels within a spatial hierarchy. We conclude with suggestions about the importance of designing sustainable landscapes. This is a greenprint for the future of agriculture, one based on the ecology of the food system and the impacts of this system on other spheres of human endeavor. The theme is expanded in the final chapter of this book (Francis and Rickerl, Ch. 12) that explores future themes and priorities for the study of agroecology and applications to food systems.

What is a Landscape?

The definition of a landscape is not precise, and in many ways a landscape is a dynamic phenomenon. The Webster definition is "an expanse of scenery that can be seen from a single viewpoint" (Steinmetz, 1993). Most definitions we encounter provide the perspective through the glasses worn by ecologists, other natural scientists, or perhaps agriculturists. Gliessman (1998) defines landscape ecology functionally as "the study of environmental factors and interactions at a scale that encompasses more than one ecosystem at a time." Forman and Godron (1986) present five characteristics that are normally found and repeated in a landscape, obviously from a natural sciences perspective:

- cluster of ecosystem types
- interactions among the ecosystems in the cluster
- climate and geomorphology
- disturbance regimes in the clusters
- relative abundance of different ecosystems within clusters

A landscape may be defined using these terms as "a heterogeneous land area composed of a cluster of interacting components that is repeated in a similar format throughout" (Olson, 1995). A landscape can be highly homogeneous as in the wheat-growing regions of western Nebraska or the Palouse in Washington, or in the vast maize-soybean regions of the Midwest of the U.S. Landscapes can be highly heterogeneous with crop and pasture mosaics embedded in natural forest areas, often where topography is more varied and promotes different types of enterprises. Often there is a mixture of land types and uses, these determined by individual farm owners and managers who choose the crops, animals and rotations that best fit a given field or site. Olson (1995) points out that this is not random heterogeneity, as landscape components such as cultivated fields, linear elements such as roads and fencelines, trees and shrubs growing along water courses, forested uplands, and farmsteads are repeated in similar spatial patterns. What is important is how the structure of these managed rural landscapes influences their function, both the immediate economic returns to owners and the ecosystem services that are provided for the wider society (Daily, 1997).

This same geographic landscape could be described differently if viewed through a set of socio-cultural glasses. The cultural landscape would have areas of sparse human habitation, depending on size of farm and how many operators live on the land, as well as rural dwellings of non farmers. Communities in the landscape are denser aggregations of people along with associated infrastructures of business, manufacturing, social services, and other urban activities. This social landscape overlies the natural and farmed landscape described above, and the interaction of the two results in agroecosystems and associated human population centers important to the function of nearby farmland.

Without a precise definition of size, it may be difficult to conceptualize landscapes and discuss their characteristics as well as their functions in more concrete terms. Landscapes could be considered areas from 10 to 1000 square kilometers (e.g. Risser, 1987, cited by Olson, 1995). In U.S. terms this is about three to three hundred sections, or three to three hundred square miles, a range in size from one large farm to one moderately small county. Some variables such as water quality in a stream coursing past production fields and then used for livestock water could be studied within a farm or across contiguous farms, while others such as community dynamics and emergent properties from multiple farms must encompass study at the higher end of this scale. Calling a landscape an area "larger than a breadbox" but smaller than a watershed does not add precision, but it does allow us to focus on an area that functions in an integrative way and has some of the characteristics described above (Olson, 1995)

Time is another critical dimension in landscape function, and Olson (1995) points out that fields change from year to year, farms shift focus to crops that are more economically viable, forests are cut or thinned, and linear elements are added to or removed from the landscape. These changes are due to relative crop and lumber prices, availability of new crops or technologies, and/or government support programs, among other factors. Changes at the farm level happen more quickly than those at higher levels in the scale, and crop acreage at a level such as county will shift less drastically in the short term unless there is a major change in policy or markets. When we observe a landscape, citing the above Webster definition, this is literally a snapshot at one point in time. To enhance this vision, we must learn the history of this place through written, visual, or oral records, and observe carefully the effects of prior management decisions on current functions in the landscape. Communities likewise change in size and function, as an economy of each area grows or contracts. Age structure of the population changes, and with that the nature and function of community. For example, the median age of farmers in the midwest U.S. is about 58 years, and many small rural towns likewise have an aging and shrinking population. This strongly influences the nature of services needed, buying habits, and connections to the rural landscape.

In the European discourse about landscape management, an interdisciplinary approach is highlighted, encompassing natural, social, and humanistic sciences. Giorgis (1995) proposes four fundamental principles to be considered for landscape quality:

- Respect for life and preservation of landscape diversity.
- Preservation of biological diversity.
- Development of solidarity.
- Respect for regional identity and the right to enjoy beauty.

These encompass some of the ethical and esthetic goals of human residents in the landscape, and clearly represent a view through a set of socioeconomic glasses.

Multidimensional Characteristics of Resources

Natural resources as well as those generated by society can be described as they occur and as they impact agriculture and food systems at any given level in the spatial hierarchy. To classify resources according to any scheme is obviously an arbitrary human construct that is intended to help us better understand the world and its agricultural systems. We find this is useful for exploring the intricacies of structure, function, and factors that contribute to system interactions, and to inform the design of more efficient and sustainable systems for the future.

Resources can be discussed and evaluated as those that occur in the natural system and those in the social system, as shown in Fig. 2 for any one level of the spatial hierarchy. In the upper and left are natural systems components such as geochemical resources (the geological complex that forms the land structure and chemistry), climate and weather, and the biology of the natural and farming environments that interact with the first two. In the lower and right are social systems including economic resources (power to allocate other human efforts), technologies (both the physical structures and the ideas and aggregated information that make them), and cultural dimensions (human information aggregated and tested over a long time span in a defined context) that are usually unique to community, region, or nation. Shown also are major interactions between these categories (bold lines) and other interactions that contribute to the complexity of the system at any level in a spatial scale.

A. Interactions Within the Landscape: U.S. Examples

Important interactions are first described at the landscape level as an illustration, and there are similar interactions of various magnitudes at all levels of scale (see Fig. 2). Specific examples include characteristics of major cropping systems in the Midwest and elsewhere. Primary interactions are found between climate and weather and the geochemical or soil resources in any landscape. Soils are formed from parent materials over centuries by interactions of geological and climate processes such as mountain formation and degradation, volcanic eruptions, glacial ice during ice ages, as well as the prevalent rainfall amount and pattern and attenuated by the temperature and winds that occur seasonally in each place (see Ch. 3). Loess soils along the Missouri River in Nebraska and Iowa were deposited over millenia by wind-blown soil particles originating farther west. The interactions among these soil and climate factors result in unique local environments, biotic complexes, and natural ecosystems. The tallgrass, midgrass, and shortgrass prairies that appear on a transect across Nebraska are the result of rainfall, temperature, and the soils that dominate in each part of the state.

In the social systems, there is a strong linkage between economic resources in a landscape and the access of technology by people living there. Culture also influences use of technology, as shown by differences in use of new innovations by Amish groups in the midwest compared to large corporate farms, often in the same landscapes. There is also an important link between economic level and culture, when one compares the industrial-model farm that raises commodity crops across several thousand acres with the small family farm growing vegetables for local, direct sale from a few acres. All these systems are present and interact in the rural landscape, even though there are great differences in the areas of land occupied and influenced by different farmers and managers, and the amount of production per farm. Most often, the benefits and the impacts on the economy of a landscape are not uniformly distributed.

One of the primary links is between soil productivity and economic resources, as shown by the relative wealth of farms in areas with deep, fertile soils such as central Illinois compared to those with highly weathered soils on hills in southern Missouri or those made saline by decades of irrigation and high evaporation such as the Imperial Valley of California. Soil quality may be influenced by availability of appropriate technologies for tillage or remediation of nutrient deficiencies by fertilizer or animal manure in mixed farming systems. Many areas of the Sahel are low in productivity due in part to lack of phosphorus, while cultural factors such as high status attached to size of family cattle herds can lead to overgrazing and further deterioration of soil productivity.

Climate in a given location determines economic success. For example, well distributed rainfall during the summer growing season in the eastern Corn Belt of the U.S. leads to relatively consistent crop yields and financial benefits to farmers. Unpredictability of weather can impact decisions on technology, such as purchase of larger tractors and planter units in Nebraska to accomplish timely planting when conditions are near optimum. Low-input organic systems appropriate to a given climate niche are used by some small farmers to reduce risk and increase value of products. Climate shapes human behavior in agriculture by determining length of growing season, available days for field work, and thus the types of complementary activities (on- or off-farm jobs) families can accomplish while doing a good job with farming. These are examples of interactions between pairs of factors shown in Fig. 2. It is obvious that many outcomes in farming are the result of more complex interactions, for example soil characteristics with timing of rainfall with available technology and labor for planting. The figure only indicates some of the most simple connections between factors at the landscape level.

B. Interactions Within the Landscape: Nordic Examples

The most fertile soils in the Nordic countries, the clay soils, were formed by the force of the glacial ice during the last ice age. The moving force from the glacial ice crushed stones down to clay size particles, and the weight pressure of the ice pressed the land area down, setting the stage for the later land lift, when the clay sediments were lifted from the lake bottoms to become marsh lands and later the flat, grassland areas that we are now farming.

Another prime determinant of land use at the landscape level in Nordic countries is the location of major cities on or near prime farmland and also near a harbor. Major cities such as Oslo, Trondheim, Gothenburg, Malmö, Copenhagen, and Helsinki all expanded due to excellent harbor potentials for trade at the expense of flat and fertile land for agriculture along the coasts. This is an interaction among soil resources, economics, and sociocultural factors. Favorable climate and fertile soils in south central Norway and the proximity of this land to modest-sized communities provide markets for a wide range of vegetables and fruit crops, and thus interactions between natural factors and the social system at the landscape level.

Proximity of beautiful natural areas and farmland to the population centers such as Copenhagen, Roskilde, and Aarhus in Denmark make these highly susceptible to residential development, as people migrate from the countryside to larger cities in search of urban jobs and greater cultural opportunities. Development of excellent transportation services, especially dependable train schedules, allows people to work in a population center and live up to an hour's travel away (100 km) in a rural community. Although this maintains a population in the smaller rural communities, the nature of business and social activity changes in that economic landscape since many purchases are made in the larger nearby city and this reduces commerce and economic viability in the bedroom communities. Increased purchase of private automobiles by most families in the Nordic region over the past two decades has further eroded small town economies as people travel quickly to shopping malls in nearby cities. Small, locally owned shops in Ås, Norway often close or change management due to pressures from three such regional malls within 15 km travel by car. Economic factors interact with technology in the changing culture at the landscape level.

Spatial Hierarchy and Linkage of Functions Across Levels

There are obvious connections between agroecosystems and across levels in a spatial hierarchy within a given function or characteristic of the system, as illustrated in Fig. 3. The biogeochemical resources may be represented by two or more soil types within a field, although with relatively uniform topography there may be a single type in some fields. The aggregate of different soil types in several to many fields make up the more complex array of soils on a farm in the Midwest, some with deep and fertile, highly productive potential in lower areas near streams; other fields with shallow topsoil and less water holding capacity on hillsides; and relatively fertile areas on the tops of hills where less recent erosion has occurred. These are examples of interactions between field and farm levels.

When a group of farms is viewed as part of a landscape, we find these same soils repeated in similar ways in similar topographic situations, with soil type determined by slope, depth of topsoil, drainage, and position in the landscape. More soil types with a wider array of potential for crop and pasture growth occur at the regional level, as this encompasses numerous landscapes with more variable rainfall, proximity to oceans, and a wider range in physical relief. At the national level, a wide range of soil types is found, depending on the size and location of the country.

Similar aggregation can be described for climate and especially for the unique weather patterns in each landscape and even each farm that can be quite spatially variable within seasons and from year to year. Environments and biotic elements are somewhat uniform at the field level, especially with production of monoculture commodity crops as in the Midwest. There may be more diversity at the farm level, if multiple enterprises including crops and livestock are found in a mixed farming situation such as northeast Nebraska and southeast South Dakota. Progressively more component diversity is found as we view the landscape, the region, and the national levels. Thus the characteristics within a given category are nested within the higher levels of the hierarchy.

Even more intriguing are the connections of elements of one factor at one level with those of another factor at another level. In Fig. 4 there are several examples. Oil reserves at the national level (a biogeochemical factor) can easily influence price of diesel fuel on farms, and thus the choices of technology at all levels in the hierarchy. Entire loss of fossil fuel supply caused Cuba to move toward animal traction, reliance on small-scale food crop cultivation, and more local food systems over a few short years in the early 1990s (Deere, 1997). Economic success in farming at the regional level can strongly influence the acceptance or rejection of new technologies at the landscape level. When the farm economy is strong, there are ample supplies of new equipment at local dealerships, and this further spurs other business in that community. When the economics of farming are fragile there is a greater supply of used equipment, and greater sales of parts to keep existing tractors and implements in service.

Climate and weather at the landscape level can strongly influence cropping success on each farm in that landscape, and thus the financial conditions on each farm in each season. Social factors such as labor available from the farm family (more labor when children grow to an age for driving equipment, or less labor when they leave for college) many be a strong determinant in what technology will be used or what crop enterprises are appropriate for a given field. There is a multiplicity of interactions across levels in the hierarchy, and these examples illustrate the types of interactions that can influence decisions on the farm and in the landscape or community.

A. Interactions Across Levels: U.S. Examples

In the U.S. midwest, dairy farming was once practiced in small economic units integrated with crops on many farms. One often hears that when all the children left the farm for college or other jobs (a change in labor, a social factor at farm level), it became necessary and logical to change to less labor-intensive beef cattle or to abandon livestock all together (enterprise and technology change at the field level). When an elevator closes in the nearest town (a community or landscape level change), this may require individual farmers to change enterprises (field level) or restructure the entire operation (farm level) to accommodate crops or livestock that can still be marketed efficiently.

Economic or regulatory decisions, such as limits on the allowable nitrate in groundwater or physical distance requirements for locating a new well (regional political decisions) may strongly influence cropping systems and practices across the landscapes within that region. Farmers may shift to growing less nitrogen-demanding crops, such as from corn production to corn-soybean rotation or pasture, or to crops that require less irrigation, from corn to grain sorghum. Conversely, periods of greater or more consistent rainfall at the regional level for several years such as in the past decade in eastern Nebraska have stimulated farmers to replace grain sorghum with corn. National economic decisions on a farm support program to target several key commodity crops can strongly influence the areas in those crops at regional, landscape, and farm levels. The Conservation Reserve Program (CRP) has become popular as farmers age and children leave the farm, an interaction of policy with family dynamics over time. These are current examples of interactions across levels in U.S. agriculture.

B. Interactions Across Levels: Nordic Examples

The regionalizing of milk production in Norway is a prime example of a political decision that impacted structure and functions of farms. In the late fifties and early sixties the Norwegian government launched an agricultural policy that essentially enforced a regional specialization of farm production. Grain production was increased, through economic incentives, in the best agricultural areas, mainly in the southwest part of the country. Milk production, and other animal production, was moved to the valley and mountain farms of the country (Lieblein et al., 2001). The decision was effectively enforced by providing quotas and subsidies for production in those designated areas and none in the rest of the country, resulting in a milk price over twice as high for those dairies with quotas. Milk and other cattle production was greatly reduced in the grain cropping areas, leaving a large and valuable infrastructure in barns and other facilities not used. Although farmers were compensated for their loss, and helped to convert to grain production, the change caused a large restructuring and social upsetting of the entire farm sector. Another impact was the spatial separation of animal manure generation from the large grain crop areas. In addition, regions specialized in milk production import an average of 40% of their feed from the grain crop areas of the country. As a result, the distance between the producer and the consumer has increased, and the recycling of animal manure has been greatly hindered. At this same time following World War II, the large and financially powerful *Norsk Hydro* fertilizer company began to grow, and this commercial venture provided the nitrogen and other nutrients to restore soil fertility in areas where manure was not available.

In Norway, the government has decided that the acreage in organic production should be 10% of the total acreage by the year 2009 (Det Konglige Landbruksdepartement, 1999). This ministry of agriculture has recognized that as a result of the regional specialization, the growth of organic farming is not sufficient in the typical field crop areas, because of the low presence of cattle. Therefore new quotas for milk production have been given to farms, but only to those farms that would start up organic milk production.

Another example of interactions across hierarchical levels comes from the European Union (EU) subsidy structure and its influence on enterprises and practices at the farm and field levels in Finland, Denmark, and Sweden. There are many positive incentives for conservation practices, limits to fertilizer application and manure spreading, and conversion to ecological methods (Lohr and Salomonsson, 1999). These are intentional economic decisions that impact both technology use and soil fertility at the farm and field levels. With close to half of the EU budget going to the Common Agricultural Program (CAP) payments, there is concern about the sustainability of this intervention and the high costs of administration. Swedish farmers today say their most important consultant on the farm is the one who understands and helps them fill out forms for support programs, a situation not unlike that in the U.S. As an example of landscape effects in Sweden, the growth of flax for oil was strongly supported by EU subsidies in 1999 but not in 2000, raising the national production of flax seed from about 6000 tons (1998) to 33,000 tons (1999), and then down to 8000 tons (2000). This was recognized by the public through several comments in newspapers and media about the nice blue "new" crop, that came and then disappeared so suddenly.

In Lithuania, a national policy of open trade is moving their markets and agriculture closer to current regulations and standards in the EU. The goal is to become a full member of that regional organization in the near future. While this national level goal of regional integration is perceived by some as desirable in the long term, the present impact on local agricultural profitability is obvious. About 20% of the nation's farmland is currently idle due to lack of economic incentives, and the negative effects on a newly developing free market economy as well as on food security are hard to assess. Similar situations exist in Latvia and Estonia. Policy decisions at the national level affect farm and field level decisions by farmers and the ecosystem functions on these lands.

Finally, the prevailing opinion about food safety, a cultural factor at community, regional, and national levels, is influencing the organic food demand and prices in northern European countries. Recent problems with BSE and foot & mouth diseases in livestock have spurred the markets for locally produced, organic meats and other products in U.K. and Germany, among other countries. This impacts farm level decisions on whether or not to convert to organic production, or whether to expand to meet these new demands. In Norway, in contrast, there is prevailing opinion that the conventional food supply is adequately safe, few pesticides are used, and a long winter make these problems less important than in countries further south. Although the demand for organic food is growing in Norway, it is not nearly as easy to market products at a premium as it is in other countries in the region. These are public opinion (social) factors at the regional and national levels that influence the economics at farm level. In summary, there are many factors that interact across levels in the spatial hierarchy, and these are often complex and changing over time.

Multifunctionality of the Rural Landscape

These interactions among factors at any level in the hierarchy of scale and across levels are operating within a complex rural landscape that performs many functions for farm families as well as for society. Growing awareness of this breadth of functions is leading to a new appreciation of the importance of ecosystem services that derive from the rural landscape (Björkland et al., 1999; Drake, 1999). These functions have been recognized and rewarded for several decades in northern Europe, while this is a relatively new concept in North America (Daily, 1997).

Production of food, fiber, fuel, and other raw materials has been recognized as the primary function of agricultural landscapes. Roles of the natural landscape in receiving and storing water from rainfall and snowfall, preventing floods, cleaning the air by plant photosynthesis (converting carbon dioxide to oxygen), and providing a haven for biodiversity are becoming better recognized and valued by society. We now recognize that virtually all landscapes worldwide are influenced by people in some ways. Thus we have the obligation to preserve these landscapes and their vital functions (Baskin, 1997).

Since many of the best lands and those nearest human communities are farmed with higher levels of intensity, and many hectares are converted to non-agricultural uses each year, we need to understand what functions in addition to production these lands provide to society. Next it is important to design farming systems that can enhance rather than reduce the effectiveness of these functions, including crop rotations, crop/animal integrated systems, and more diverse enterprise mixes on each farm. To promote this process it is essential to provide financial incentives to private land owners, in combination with regulations, to assure concern and compliance. Functions of rural landscapes where agroecosystems predominate include water filtration and storage, carbon capture and storing by annual crops and perennial plants (carbon sequestration), and mitigation of extremes in climate such as preventing floods and reducing wind speed with vegetative barriers. These kinds of ecosystem services are a collective utility to society that has no current market. The main work to produce these utilities comes from nature and is difficult to value with money. The loss of income and extra work for the farmer who opts for alternative land use to promote these services needs to be valued in monetary terms and paid for in some way by society.

Federal water quality standards for drinking water consumption in the U.S. (e.g. 10 parts NO_3-N per million) are one example of a regulation and a goal that all cities must achieve, and which are highly recommended for people with private wells. Communities can often receive federal and state assistance in upgrading a water system to meet standards, such as digging deeper wells, installing special equipment, or locating a new water source. Less often, we try to trace the source of the nitrate and solve the problem upstream in surface waters or in underground aquifers.

Search for Mechanisms at the Farm and Field Levels

Although most educators and researchers in agroecology have expanded their focus to the systems interactions and implications in agriculture, it is essential that we continue to search for understanding of mechanisms at the field and farm levels, as well as recognize the importance of regulating forces from higher levels. As shown in Fig. 1, the need to understand how systems function is met by study of mechanisms at a smaller or lower level of scale. To understand success or problems on the farm, either in production or economics, we need to look in detail at the individual fields or enterprises that make up that farmer's system. To understand the performance of a crop in the field, it often helps to examine the insect damage or the yield components of individual plants. The growth and development of plants depends on nutrient uptake and soil biota. This work needs support and focus. A cursory visit to poster sessions or presentations of agricultural professionals in national and international meetings will convince the observer that this activity is alive and well. Relative to systems research, component investigation is well supported and remains the predominant activity in our research profession.

Two issues in research on mechanisms are important to this discussion. The first is that greater relevance and potential application can be achieved in research on system components if these are clearly identified with elements that improve productivity or economic return, reduce negative environmental impact, and improve the distribution of benefits of the research. Too often we assume that increasing yields will automatically cause good things to happen: higher income, greater efficiency, more food for a hungry world. Most of us trained and practiced in a research environment where higher yields were intrinsic in our goals. We often failed to look beyond that goal to evaluate the potential impacts of the research. It is highly desirable to conduct component and mechanistic research within a systems framework. The other issue is the opportunity cost of research emphasis on narrow component technologies, especially on the subset of innovations that have potential for rapid commercialization. Focus on herbicide-resistant crops and other genetically engineered traits in new varieties has obvious benefit to the seed industry, but questionable value to the farmer. This research emphasis precludes putting the same resources into systems research for reducing weed pressures to below economic levels and even breeding for other traits including higher yields. Research on global positioning equipment and site specific management has the stated goal of reducing input costs, while in fact these new technologies have a high cost and are not scale neutral in application. They provide another technological fix that pushes for larger farm size and less common sense management by farmers who know their fields well because of frequent visits and decisions based on long-time experience and observations. Component research needs to be relevant to both immediate and long-term challenges at the field, farm, and community levels of agriculture and the food system. Equally important is the continued quest to encourage and support systems research at all levels of the spatial hierarchy.

Implications at the Regional and National Levels

The search for meaning or context in agricultural landscapes, as well as the major regulatory forces, and the potential to recognize and reward multiple functions are found at higher levels in the spatial hierarchy (Fig. 1; also Doherty et al., 2000). One contribution of the perspectives in agroecology to decisions at the regional and national levels is the multi-dimensional analysis of problems and the search for holistic and long-term solutions. This is in direct contrast to the linear cause and effect analysis and singular solutions often used to meet food systems and other challenges. To solve a water quality problem of pesticide residue or nitrate contamination, strict limits may be placed on these inputs across a wide geographic area without considering the variation in soil types, insect populations, or cropping patterns that exist in the area. Regulation may spur interest in seeking solutions through research, but frequently this is focused on an alternative product for insect control or a new formulation for chemical fertilization. Because of our dedication to the technological quick fix, few researchers step back and look at the whole system and how it might be modified to alleviate the problems. A broad view of problems at the higher levels in a spatial hierarchy may reveal a wide range of options in how to modify agricultural systems to make them more efficient and profitable for the longer term.

One useful example is the contrast between a global food chain and a local food system (see Fig. 5). In the current expanding global markets and food import/export volume there is emphasis on purchased technology and inputs, and production is often separated from processing by large distances. Likewise, the marketing business is worldwide and much food travels a long distance to reach the consumer. The average food molecule in the U.S. system travels 1400 mi (2400 km) from point of production to the consumer. This requires an extraordinary investment in transportation infrastructure and fossil fuels to keep the system viable. Also, there is little potential for materials cycling at any step in the process. Waste from processing and marketing is more easily discarded, at some cost, to landfills rather than recycled into the production process. From the consumer, it is virtually impossible for any materials to reach the farm, unless there is a local program to apply sewage sludge to farmland. More often this also goes to the landfill for economic or regulatory reasons.

A serious and comprehensive analysis of the potential materials use and cycling in the food system could lead to greater efficiencies, sustainability, and security in the food system. Closer physical proximity of all activities allows obvious efficiencies such as direct sale from producer to consumer or processor to consumer. When these systems activities are spatially and temporally close, and even related to each other through management or ownership, a design for materials cycling is possible. By-products or compost from processing or unsold products in the market can be returned to the farm under some mutually favorable financial arrangement. Some wastes can be used directly as animal feed. Most organic waste can go back into the nutrient cycles, including that from consumer food preparation and from human waste. These cycles can be promoted by local and regional regulations that allow cycling with proper health safeguards, and that provide incentives for these steps to occur. The argument that we could not have bananas or coffee in Nebraska in such a local system is really a "straw man." The objective is to import substitute whenever possible with locally grown foods and to make this both financially and psychologically attractive, and not to exclude all imported food from any local system.

Such changes require creative thinking and planning at all levels, and not a slight modification of business as usual. According to Albert Einstein, "It is not possible to solve today's problems with the same ideas and people who created them."

Conclusions: Designing Multifunctional Landscapes

There is a high level of recognition of the importance of multifunctional landscapes and the need for regulation and legislation to encourage this type of landscape use in northern Europe. It is intriguing to consider that the same basic human genetic stock in North America has moved in a somewhat different direction, one that initiated and developed a high-technology agriculture based on virtually unlimited land and resources at least in the initial stages. The different directions taken by many of the same people could be explained by the environmental determinism described by Diamond (1997). We must recognize that Europeans have been in the food production business for over six millenia, while U.S. industrial agriculture has developed over less than two centuries. We all need to gain perspective on how to manage scarce resources.

One method of increasing income to farmers as well as solving negative environmental impacts from agriculture is the move toward organic farming (often called ecological agriculture in northern Europe). Norway has set a national priority of 10% organic food within 10 years; Sweden has a national goal of 20% within 5 years. Denmark has enough local production to meet the current demand of about 20% for organic milk and meat products, perhaps near the highest level in Europe today. Denmark has also dedicated over DK50 million (US$ 8.5 million) and Sweden over SEK 30 million (US$3 million) annually to research on organic farming, and there are more than 100 scientists involved in this research. Switzerland and Austria have national policies to encourage organic food production. Such national priority attracts many of the best and brightest to this research area, just as genetic engineering attracts young scientists in the U.S. Clearly, national public priorities and research emphases can influence and broaden the research agenda, while that controlled by corporate interests will promote those products or systems that can be patented and provide profits, and thus narrow the agenda.

Multifunctional landscapes in rural areas are an obvious current reality, but we need to explore creative and effective methods to encourage those who own the land and manage agroecosystems to maintain biodiversity and otherwise preserve ecological functions that serve society. Payments for conservation plantings can encourage perennial species and woody buffers, and some practices can promote better preservation of crop residues on the soil surface that will reduce erosion. Regulations that promote local food systems and materials cycles are useful. Promoting the awareness of community economic advantages to local systems can facilitate the process. Land owners can be encouraged to diversify with enterprises beyond food production, such as rural recreation, hunting and fishing rights, farm weekends, educational activities on the farm, and public awareness campaigns. Society should pay for those services that provide for the common good such as flood protection, carbon capture, and clean air and water. Rural open areas should be preserved for their ecological functions, historical relevance, and esthetic values to society. Most European countries have strict rules as well as government support to preserve for posterity the rural cultural landscape.

The design and implementation of sustainable and multifunctional landscapes requires input from a range of disciplines beyond those associated with production agriculture. Natural resource specialists who deal with water, soil conservation, and wildlife habitat are essential to the team. Rural sociologists and community planners are important to understanding human motivations and the potentials for effective design alternatives for human communities. Legal experts can address the complexity of regulations and individual rights that govern building and resource use in the rural landscape. When these people and groups work together toward common goals, their results will be best coordinated and most effective. Combining natural science and social science methods is essential. This strategy is strongly supported by a white paper developed at a June, 2000 workshop supported by the U.S. National Science Foundation (for a full report, http://lsweb.la.asu.edu/akinzig/report.htm).

Finally, the need to look at the landscape as a complex and interactive living system is obvious. It is more than a series of fields and farms connected by tree lines, roads, and streams. The landscape is dynamic and sensitive to human management. We need a proper mix of better systems education, adequate financial incentives within the current economic system, and an awareness that we all have a vested interest in a healthy, multifunctional landscape. To not address these challenges and seek innovative solutions would be to foreclose some options for future generations. We would do well to follow the traditional Native American wisdom and look at the impacts of our decisions today on the landscape with respect to how this will affect people in each place seven generations in the future. Short-term landscape planning will not achieve our long-term goals.

References

Baskin, Y. 1997. The work of nature -- how the diversity of life sustains us. Island Press, Washington, DC.

Björkland, J., K. Limburg, and T. Rydberg. 1999. Impact of production intensity on the ability of the agricultural landscape to generate ecosystem services: An example from Sweden. Ecological Economics 29:269-291.

Brandt, J., B. Tress, and G. Tress (ed.) 2000. Multifunctional landscapes: Interdisciplinary approaches to landscape research and management. Proc. International Conference, Centre for Landscape Research, Univ. Roskilde, Denmark, 18-21 October.

Daily, G.C. (ed.) 1997. Nature's services: Social dependence on natural ecosystem services. Island Press, Washington, DC.

Deere, C.D. 1997. Reforming Cuban agriculture. Development and Change 28:649-669.

Det Kongelige Landbruksdepartement (The Norwegian Ministry of Agriculture). 1999. Om norsk landbruk og matproduksjon (On Norwegian agriculture and food production). St. meld nr. 19 (Ministry Proposition No. 19), Oslo, Norway.

Diamond, J. 1997. Guns, germs, and steel: The fates of human societies. W.W. Norton, New York.

Doherty, S., T. Rydberg, and L. Salomonsson. 2000. Ecosystem properties and principles of living systems for sustainable agriculture. IFOAM Workshop, World Grows Organic Conference, Frick, Switzerland.

Drake, L. 1999. The Swedish agricultural landscape -- economic characteristics, valuations and policy options. International J. of Social Economics 26(7,8,9):1042-1060.

Forman, R.T.T., and M. Godron. 1986. Landscape ecology. John Wiley & Sons, New York.

Francis, C., G. Lieblein, S. Gliessman, T.A. Breland, N. Creamer, R. Harwood, L. Salomonsson, J. Helenius, D. Rickerl, R. Salvador, M. Wiedenhoeft, S. Simmons, P. Allen, M. Altieri, J. Porter, C. Flora, and R. Poincelot. 2002. Agroecology: the ecology of food systems. J. Sustainable Agriculture (in press)

Giorgis, S. 1995. Rural landscapes in Europe: Principles for creation and management. Council for Europe, Strasbourg.

Gliessman, S.R. 1998. Agroecology: ecological processes in sustainable agriculture. Ann Arbor Press, Chelsea, MI

Lieblein, G., C.A. Francis, and H. Torjusen. 2001. Future interconnections among ecological farmers, processors, marketers, and consumers in Hedmark County, Norway: Creating shared vision. Human Ecology Review 8(1):60-71.

Lohr, L., and L. Salomonsson. 1999. Conversion studies for organic production: Results from Sweden and lessons for the United States. Agricultural Economics 22:133-146.

Olson, R.K. 1995. Diversity in agricultural landscapes. p. 121-160. *In* R.K. Olson, C.A. Francis, and S. Kaffka (ed.) Exploring the role of diversity in sustainable agriculture. ASA, Madison, WI.

Olson, R.K. 1999. Introduction. p. 1-13. *In* Under the Blade: the Conversion of Agricultural Landscapes. Westview Press, Boulder, CO.

Olson, R.K., and C.A. Francis. 1995. A hierarchical framework for evaluating diversity in agroecosystems. p. 5-34. *In* R.K. Olson, C.A. Francis, and S. Kaffka (ed.) Exploring the role of diversity in sustainable agriculture. ASA, Madison, WI.

Risser, P.G. 1987. Landscape ecology: State of the art. p. 3-14. *In* M.G. Turner (ed.) Landscape heterogeneity and disturbance. Springer-Verlag, New York.

Steinmetz, S. 1993. Webster's desk dictionary. Gramercy Books, New York.

Torjusen, H., G. Lieblein, M. Wandel, and C.A. Francis. 2001. Food system orientation and quality perception among consumers and producers of organic food in Hedmark County, Norway. Food Quality and Preference 12:207-216.

Chapter 10 Study Questions

1. List and discuss the ecosystem services that are most important in your landscape, region, or state, and describe how these are important to the human and broader biotic community.

2. How can the multiple functions of agricultural landscapes be recognized and rewarded by society? What systems of monetary or tax benefits could be used to encourage private rural land owners to preserve and enhance ecosystems services?

3. Why is it useful to study agroecosystem activities and services within a given level in the spatial hierarchy? How do these things change over time?

4. Why is it essential to study systems structures and processes across levels in the spatial hierarchy? How does this type of study help us understand system resource use and productivity?

5. Discuss the unique emergent properties that characterize the agroecological landscape, and why these are more difficult to observe or study at lower levels in the hierarchy?

6. Discuss the advantages and disadvantages of global food chains. Discuss the advantages and disadvantages of local food systems.

Figure 1. Spatial hierarchy of scale with identification of social systems decisions at field, farm, landscape, and regional scales (inspired by Olson, 1999).

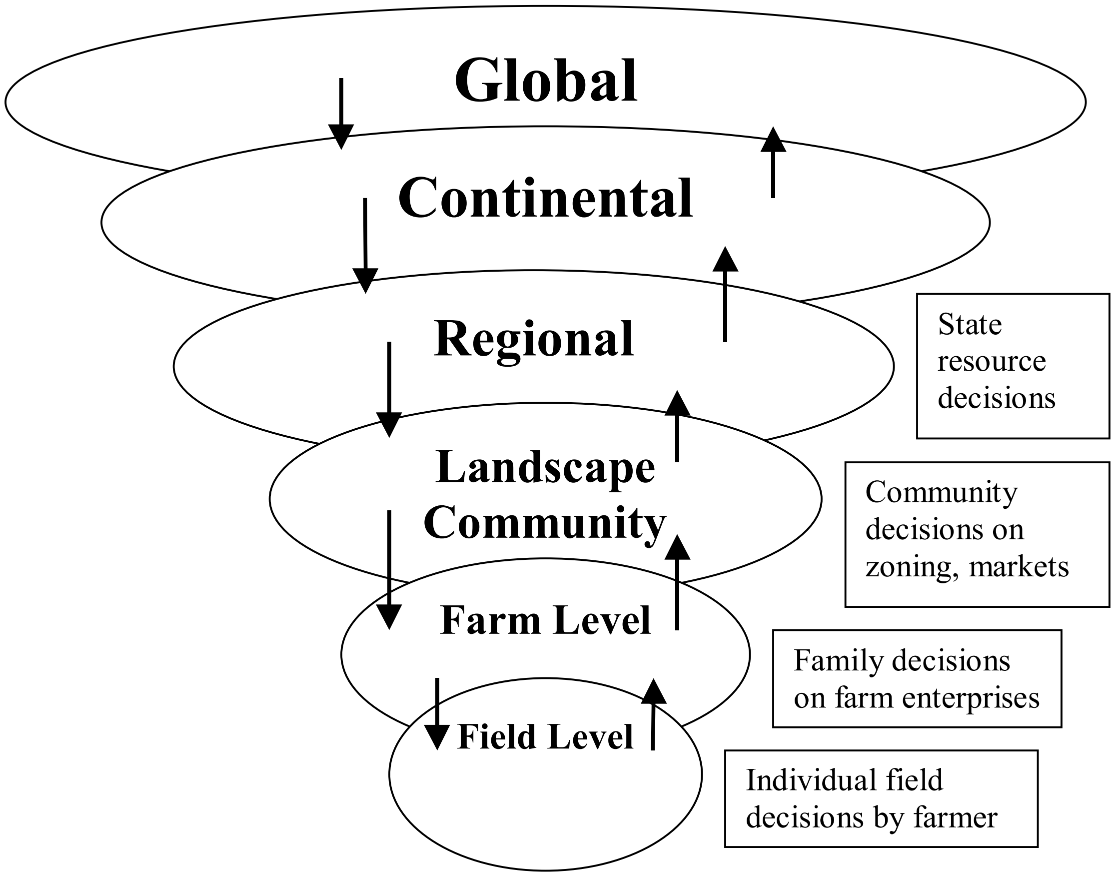

Fig. 2. Multidimensional characteristics of resources in an agroecosystem and their interactions that lead to multifunctionality; shown for a single level in the spatial or geographical hierarchy of scale.

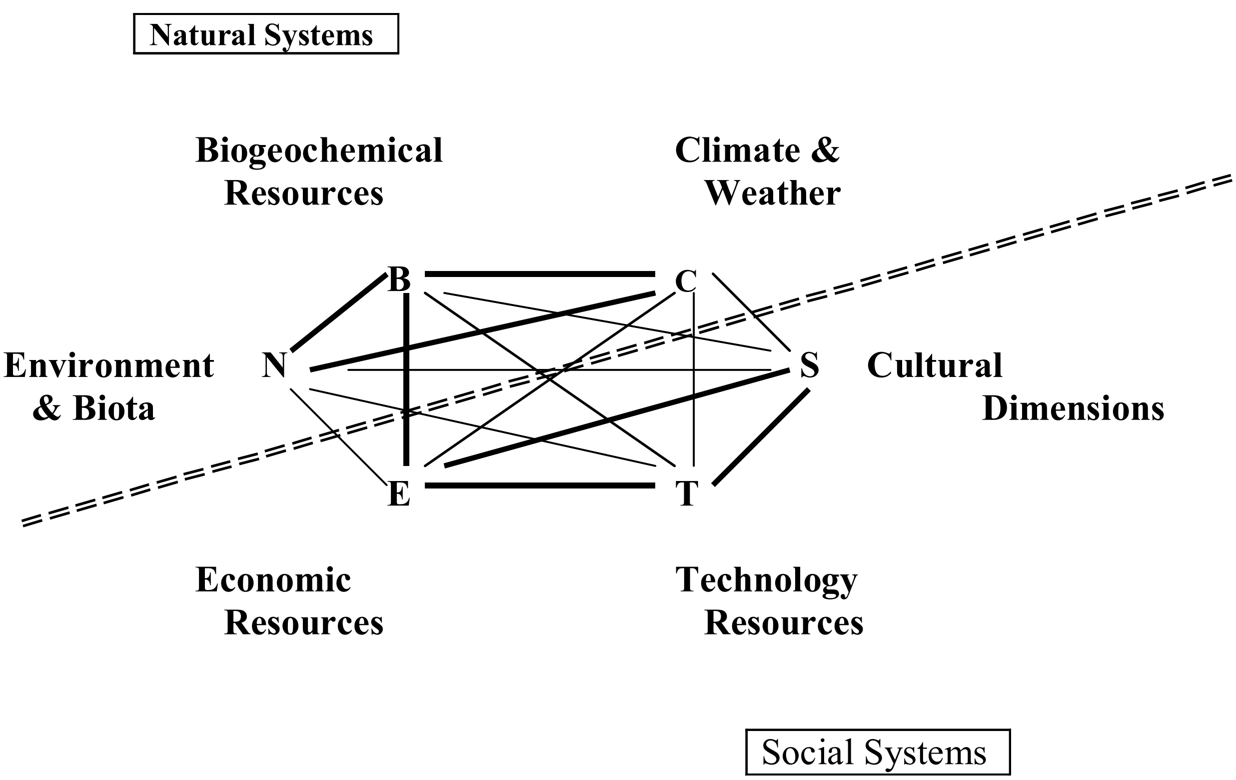

Fig. 3. Spatial hierarchy of characteristics of food systems and agroecosystems, not shown to scale, and aggregations across the spatial scale.

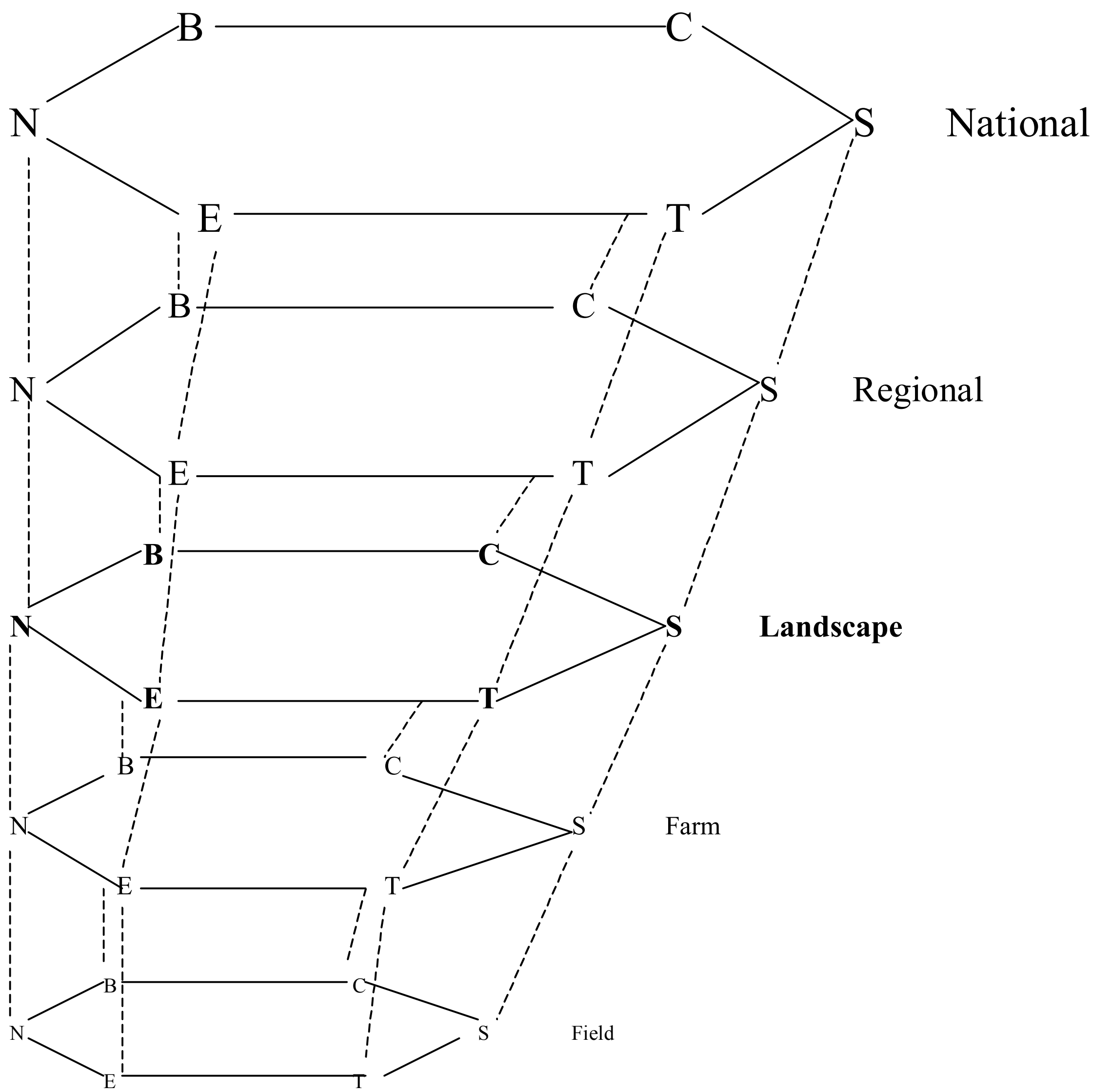

Fig. 4. Examples of interactions across the spatial scales between different factors that are important at the different levels.

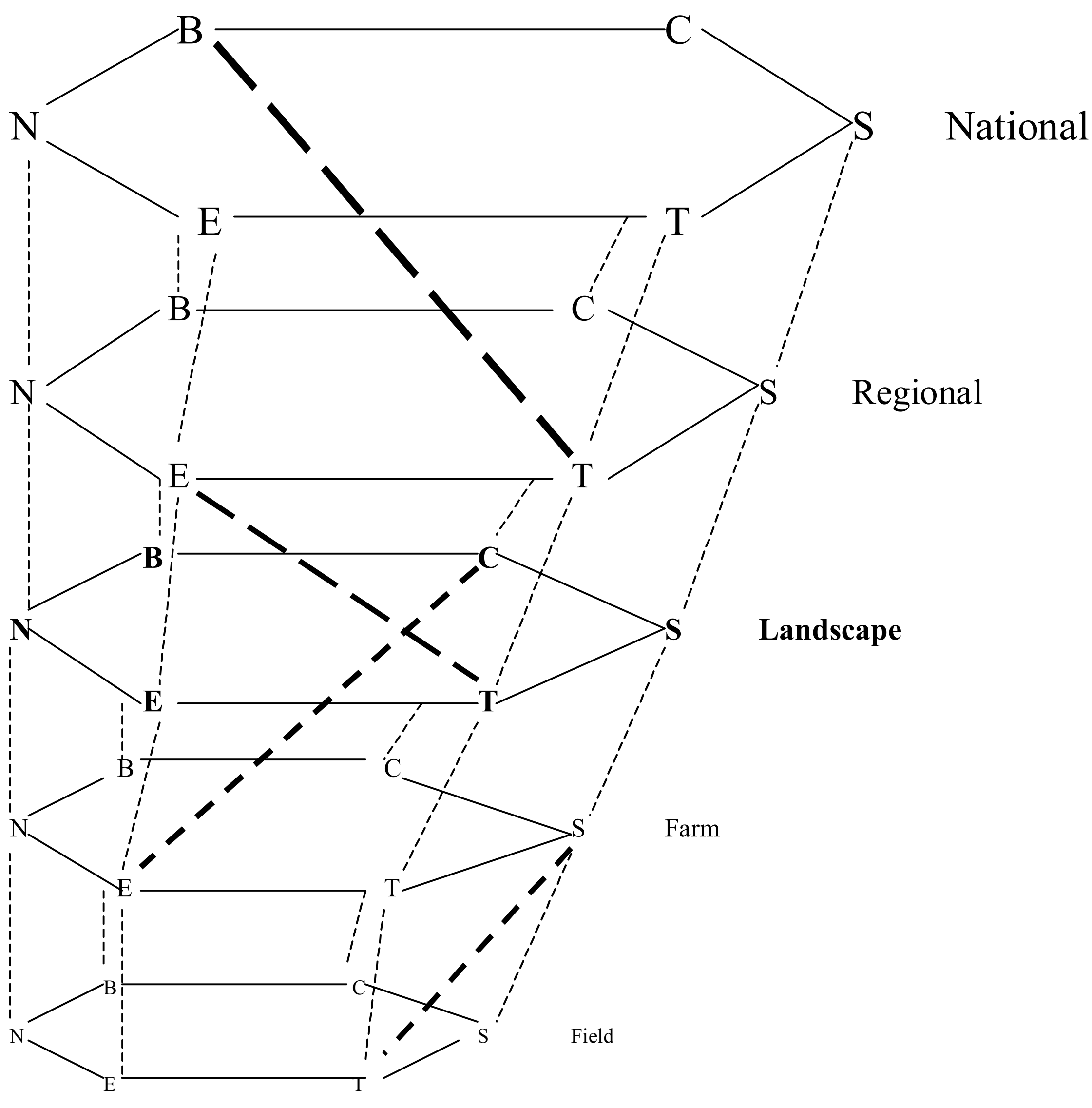

Fig. 5. Contrast between a global food chain and a local food system or cycle.