2 The Agroecosystem Concept

An *agroecosystem* is a site or integrated region of agricultural production — a farm, for example — understood as an ecosystem. The agroecosystem concept provides a framework with which to analyze food production systems as wholes, including their complex sets of inputs and outputs and the interconnections of their component parts.

Because the concept of the agroecosystem is based on ecological principles and our understanding of natural ecosystems, the first topic of discussion in this chapter is the ecosystem. We examine the structural aspects of ecosystems — their parts and the relationships among the parts — and then turn to their functional aspects — how ecosystems work. Agroecosystems are then described in terms of how they compare, structurally and functionally, with natural ecosystems.

The principles and terms presented in this chapter will be applicable to our discussion of agroecosystems throughout this book.

STRUCTURE OF NATURAL ECOSYSTEMS

An *ecosystem* can be defined as a functional system of complementary relations between living organisms and their environment, delimited by arbitrarily chosen boundaries, which in space and time appear to maintain a steady yet dynamic equilibrium. An ecosystem thus has physical parts with particular relationships — the *structure* of the system — that together take part in dynamic processes — the *function* of the system.

The most basic structural components of ecosystems are *biotic factors*, living organisms that interact in the environment, and *abiotic factors*, nonliving physical and chemical components of the environment such as soil, light, moisture, and temperature.

Levels of Organization

Ecosystems can be examined in terms of a hierarchy of organization of their component parts, just as the human body can be examined at the level of molecules, cells, tissues, organs, or organ systems. At the simplest level is the individual organism. Study of this level of organization is called autecology or physiological ecology. It is concerned with how a single individual of a species performs in response to the factors of the environment and how the organism's particular degree of tolerance to stresses in the environment determine where it will live. The adaptations of the banana plant, for example, restrict it to humid, tropical environments with a particular set of conditions, whereas a strawberry plant is adapted to a much more temperate environment.

At the next level of organization is groups of individuals of the same species. Such a group is known as a *population*. The study of populations is called population ecology. An understanding of population ecology becomes important in determining the factors that control population size and growth, especially in relation to the capacity of the environment to support a particular population over time. Agronomists have applied the principles of population ecology in the experimentation that has led to the highest-yielding density and arrangement of individual crop species.

Populations of different species always occur together in mixtures, creating the next level of organization, the *community*. A community is an assemblage of various species living together in a particular place and interacting with each other. An important aspect of this level is how the interactions of organisms affect the distribution and abundance of the different species that make up a particular community. Competition between plants in a cropping system or the predation of aphids by lady beetles are examples of interactions at this level in an agroecosystem. The study of the community level of organization is known as community ecology.

The most inclusive level of organization of an ecosystem is the ecosystem itself, which includes all of the abiotic factors of the environment in addition to the communities of organisms that occur in a specific area. An intricate web of interactions goes on within the structure of the ecosystem.

These four levels can be directly applied to agroecosystems, as shown in Figure 2.1. Throughout this text, reference will be made to these levels: individual crop plants (the organism level), populations of crop species or other organisms, farm field communities, and whole agroecosystems.

An important characteristic of ecosystems is that at each level of organization properties emerge that were not present at the level below. These emergent properties are the result of the interaction of the component "parts" of that level of ecosystem organization. A population, for example, is much more than a collection of individuals of the same species, and has characteristics that cannot be

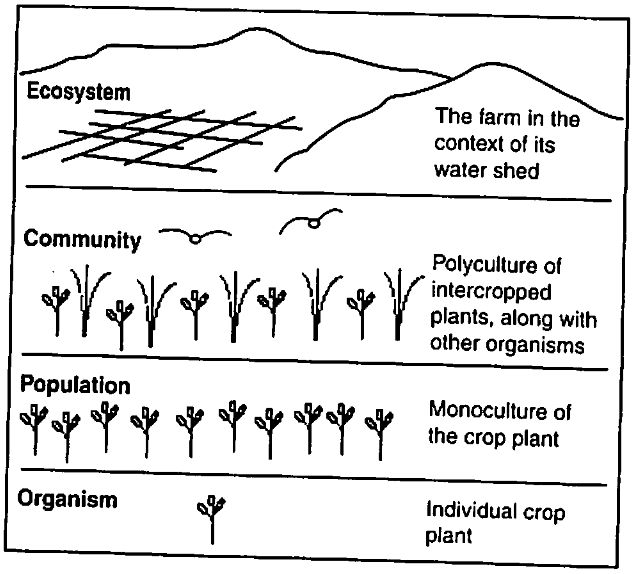

FIGURE 2.1 Levels of ecosystem organization applied to an agroecosystem. The diagram could be extended in the upward direction to include regional, national, and global levels of organization, which would involve such things as markets, farm policy, even global climate change. In the downward direction, the diagram could include the cellular, chemical, and atomic levels of organization.

understood in terms of individual organisms alone. In an agroecosystem context, this principle means in essence that the farm is greater than the sum of its individual crop plants. Sustainability can be considered the ultimate emergent quality of an ecosystem approach to agriculture.

STRUCTURAL PROPERTIES OF COMMUNITIES

A community comes about on the one hand as a result of the adaptations of its component species to the gradients of abiotic factors that occur in the environment, and, on the other hand, as a result of interactions between populations of these species. Since the structure of the community plays such an important role in determining the dynamics and stability of the ecosystem, it is valuable to examine in more detail several properties of communities that arise as a result of interactions at this level.

Species Diversity

Understood in its simplest sense, species *diversity* is the number of species that occur in a community. Some communities, such as that of a freshwater pond, are exceedingly diverse; others are made up of very few species.

Dominance and Relative Abundance

In any community, some species may be relatively abundant and others less abundant. The species with the greatest impact on both the biotic and abiotic components of the community is referred to as the *dominant species.* Dominance can be a result of an organism's relative abundance, its size, its ecological role, or any of these factors in combination. For example, since a few large trees in a garden can dramatically alter the light environment for all the other species in the garden, the tree species is dominant in the garden community even though it may not be the most abundant species. Natural ecosystems are often named for their dominant species. The redwood forest community of coastal California is a good example.

Vegetative Structure

Terrestrial communities are often characterized by the structure of their vegetation. This is determined mostly by the form of the dominant plant species, but also by the form and abundance of other plant species and their spacing. Thus vegetative structure has a vertical component (a profile with different layers) and a horizontal component (groupings or patterns of association), and we learn to recognize how different species occupy different places in this structure. When the species that make up vegetative structure take on similar growth forms, more general names are given to these assemblages (e.g., grassland, forest, shrubland).

Trophic Structure

Every species in a community has nutritive needs. How these needs are met in relation to other species determines a structure of feeding relationships. This structure is called the community's *trophic structure.* Plants are the foundation of every terrestrial community's trophic structure because of their ability to capture solar energy and convert it, through photosynthesis, into stored chemical energy in the form of *biomass*, which can then serve as food for other species. Because of this trophic role, plants are known as *producers*. Physiologically, plants are classified as *autotrophs* because they satisfy their energy needs without preying upon other organisms.

The biomass produced by plants becomes available for use by the *consumers* of the community. Consumers include *herbivores,* which convert plant biomass into animal biomass, *predators*, which consume herbivores and other predators, *parasites*, which consume blood or tissues of a host but usually do not kill it, and *parasitoids*, which are insects whose larvae live within and consume their host, which is usually another insect. All consumers are classified as *heterotrophs* because their nutritive needs are met by consuming other organisms.

Each level of consumption is considered to be a different trophic level. The trophic relationships among a community's species can be described as a food chain or a food web, depending on their complexity. As we will see later, trophic relationships can become quite complex and are of considerable importance in agroecosystem processes such as pest and disease management (Table 2.1).

TABLE 2.1
Trophic Levels and Roles in a Community

Type of Organism	Trophic Role	Trophic Level	Physiological Classification
Plants	Producers	First	Autotrophic
Herbivores	First-level consumers	Second	Heterotrophic
Predators and parasites	Second-level (and higher) consumers	Third and higher	Heterotrophic

Stability

Over time, the species diversity, dominance structure, vegetative structure, and trophic structure of a community usually remain fairly stable, even though individual organisms die and leave the area, and the relative sizes of populations shift. In other words, if you were to visit and observe a natural community and then visit it again 20 years later, it would probably appear relatively unchanged in its basic aspects. Even if some kind of *disturbance* — such as fire or flooding — killed off many members of many species in the community, the community would eventually recover, or return to something close to the original condition and species composition.

Because of this ability of communities to resist change and to be resilient in response to disturbance, communities — and the ecosystems of which they are a part — are sometimes said to possess the property of stability. The relative stability of a community depends greatly on the type of community and the nature of the disturbances to which it is subjected. Ecologists disagree about whether or not stability should be considered an inherent characteristic of communities or ecosystems.

FUNCTIONING OF NATURAL ECOSYSTEMS

Ecosystem function refers to the dynamic processes occurring within ecosystems: the movement of matter and energy and the interactions and relationships of the organisms and materials in the system. It is important to understand these processes in order to address the concepts of ecosystem dynamics, efficiency, productivity, and development, especially in agroecosystems where function can determine the difference between the success and failure of a particular crop or management practice.

The two most fundamental processes in any ecosystem are the flow of energy among its parts and the cycling of nutrients.

Energy Flow

Each individual organism in an ecosystem is constantly using energy to carry out its physiological processes, and its sources of energy must be regularly replenished. Thus energy in an ecosystem is like electricity in a home: it is constantly flowing into the system from outside sources, fueling its basic functioning. The energy flow in an ecosystem is directly related to its trophic structure. By examining energy flow, however, we are focusing on the sources of the energy and its movement within the structure, rather than on the structure itself.

Energy flows into an ecosystem as a result of the capture of solar energy by plants, the producers of the system. This energy is stored in the chemical bonds of the biomass that plants produce. Ecosystems vary in their ability to convert solar energy to biomass. We can measure the total amount of energy that plants have brought into the system at a point in time by determining the *standing crop* or biomass of the plants in the system. We can also measure the rate of the conversion of solar energy to biomass: this is called *gross primary productivity*, which is usually expressed in terms of kilocalories per square meter per year. When the energy plants use to maintain themselves is subtracted from gross primary productivity, a measure of the ecosystem's *net primary productivity* is attained.

Herbivores (primary consumers) consume plant biomass and convert it into animal biomass, and predators and parasites (secondary and higher-level consumers) who prey on herbivores or other consumers continue the biomass conversion process between trophic levels. Only a small percentage of the biomass at one trophic level, however, is converted into biomass at the next trophic level. This is because a large amount of energy is expended in maintaining the organisms at each level (as much as 90% of the consumed energy). In addition, a large amount of biomass at each level is never consumed (and some of what is consumed is not fully digested); this biomass (in the form of dead organisms and fecal matter) is eventually broken down by *detritivores* and *decomposers*. The decomposition process releases (in the form of heat) much of the energy that went into creating the biomass, and the remaining biomass is returned to the soil as organic matter.

In natural ecosystems, the energy that leaves the system is mostly in the form of heat, generated in part by the respiration of the organisms at the various trophic levels and in part by the decomposition of biomass. Other forms of energy output are quite small. The total energy output (or energy loss) of an ecosystem is usually balanced by the energy input that comes from plants capturing solar energy (Figure 2.2).

Nutrient Cycling

In addition to energy, organisms require inputs of matter to maintain their life functions. This matter — in the form of nutrients containing a variety of crucial elements and compounds — is used to build cells and tissues and the complex organic molecules required for cell and body functioning.

The cycling of nutrients in ecosystems is obviously linked to the flow of energy: the biomass transferred

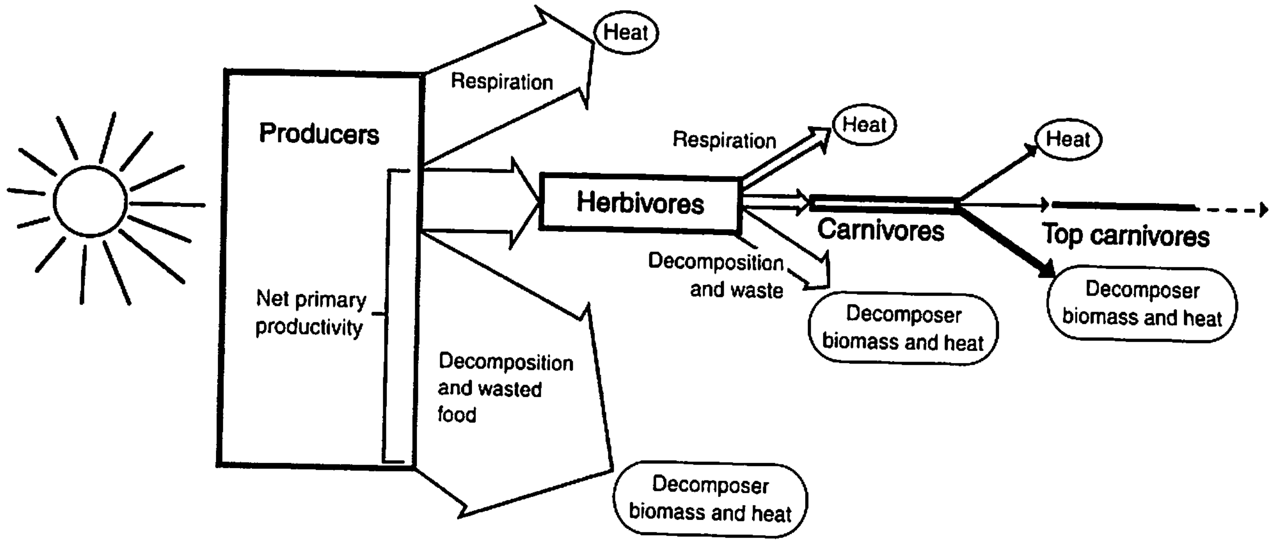

FIGURE 2.2 Ecosystem energy flow. The size of each box represents the relative amount of energy flowing through that trophic level. In the average ecosystem, only about 10% of the energy in a trophic level is transferred to the next trophic level. Nearly all the energy that enters an ecosystem is eventually dissipated as heat.

between trophic levels contains both energy in chemical bonds and matter serving as nutrients. Energy, however, flows in one direction only through ecosystems — from the sun to producers to consumers to the environment. Nutrients, in contrast, move in cycles — through the biotic components of an ecosystem to the abiotic components, and back again to the biotic. Since both abiotic and biotic components of the ecosystem are involved in these cycles, they are referred to as *biogeochemical cycles*. As a whole, biogeochemical cycles are complex and interconnected; in addition, many occur at a global level that transcends individual ecosystems.

Many nutrients are cycled through ecosystems. The most important are carbon (C), nitrogen (N), oxygen (O), phosphorus (P), sulfur (S), and water. With the exception of water, each of these is known as a *macronutrient*. Each nutrient has a specific route through the ecosystem depending on the type of element and the trophic structure of the ecosystem, but two main types of biogeochemical cycles are generally recognized. For carbon, oxygen, and nitrogen, the atmosphere functions as the primary abiotic reservoir, so we can visualize cycles that take on a global character. As an example, a molecule of carbon dioxide respired into the air by an organism in one location can be taken up by a plant halfway around the planet. Elements that are less mobile, such as phosphorus, sulfur, potassium, calcium, and most of the trace elements, cycle more locally, and the soil is their main abiotic reservoir. These nutrients are taken up by plant roots, stored for a period of time in biomass, and eventually returned to the soil within the same ecosystem by decomposers.

Some nutrients can exist in forms that are readily available to organisms. Carbon is a good example of such a material, easily moving between its abiotic form in the atmospheric reservoir to a biotic form in plant or animal matter as it cycles between the atmosphere as carbon dioxide and biomass as complex carbohydrates. Carbon spends varying lengths of time in living or dead organic matter, or even humus in the soil, but it returns to the atmospheric reservoir as carbon dioxide before it is recycled again. Figure 2.3 is a simplified depiction of the carbon cycle, focusing on terrestrial systems and leaving out the reservoir of carbon found in carbonate rocks.

Nutrients in the atmospheric reservoir can exist in forms much less readily available and must be converted to some other form before they can be used. A good example is atmospheric nitrogen (N_2). The conversion of molecular nitrogen (N_2) to ammonia (NH_3) through biological fixation by microorganisms begins the process that makes nitrogen available to plants. Once incorporated into plant biomass, this "fixed" nitrogen can then become part of the soil reservoir and eventually be taken up again by plant roots as nitrate (NO_3). As long as this soil-cycled nitrogen is not reconverted back to gaseous N_2 or lost as volatile ammonia or gaseous oxides of nitrogen, it can be actively cycled within the ecosystem (Figure 2.4). The agroecological significance of the biotic interactions involved in this cycle are discussed in more detail in Chapter 16.

Phosphorus, on the other hand, has no significant gaseous form. It is slowly added to the soil by the weathering of rock, and once there, can be taken up by plants as phosphate and then form part of the standing crop, or be returned to the soil by excretion or decomposition. This cycling between organisms and soil tends to be very localized in ecosystems, with two major exceptions: (1) phosphates may leach out of ecosystems in ground water if they

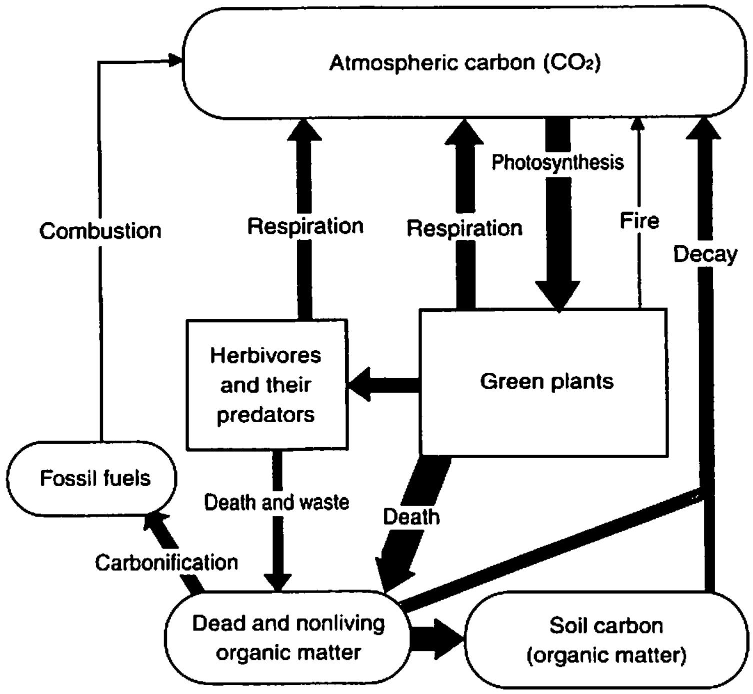

FIGURE 2.3 The carbon cycle.

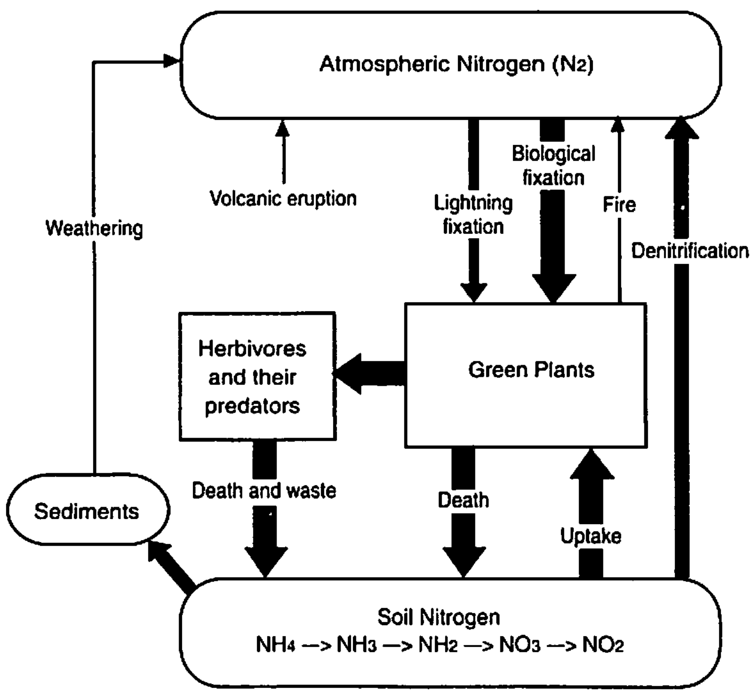

FIGURE 2.4 The nitrogen cycle.

are not absorbed or bound and (2) phosphates adhering to soil particles may be removed by erosion. In both of these cases, the phosphates leave the ecosystem and end up in the oceans. Once phosphorus is deposited into the sea, the time frame required for it to cycle back into terrestrial systems enters the geological realm, hence the importance of the localized cycles that keep phosphorus in the ecosystem (Figure 2.5).

In addition to the macronutrients, a number of other chemical elements must be present and available in the ecosystem for plants to grow. Even though they are needed in very small quantities, they are still of great importance for living organisms. They include iron (Fe), magnesium (Mg), manganese (Mn), cobalt (Co), boron (B), zinc (Zn), and molybdenum (Mo). Each of these elements is known as a *micronutrient*.

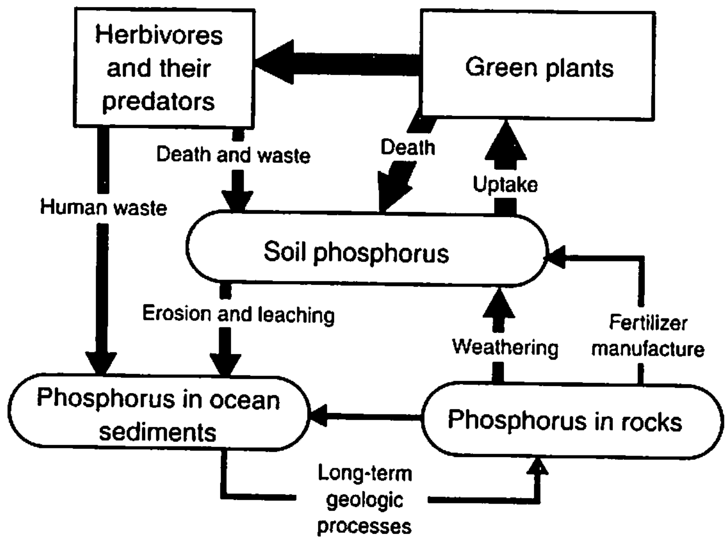

FIGURE 2.5 The phosphorus cycle.

Both types of nutrients are taken up by organisms and are stored in living or dead biomass or organic matter. If too much of a nutrient is lost or removed from a particular system, it can become limiting for further growth and development. Biological components of each system are very important in determining how efficiently nutrients move, ensuring that the minimum amount is lost and the maximum amount recycled. Productivity can become very closely linked to the rates at which nutrients are able to be recycled.

REGULATION OF POPULATIONS

Populations are dynamic: their size and the individual organisms that make them up change over time. The demographics of each population are a function of that species' birth and death rates, rate of population increase or decrease, and the carrying capacity of the environment in which they live. The size of each population in relation to the other populations of the ecosystem is also determined by the interactions of that population with other populations and with the environment. A species with a broad set of tolerances of environmental conditions and a broad ability to interact with other species will be relatively common over a large area. In contrast, a species with a narrow set of tolerances and a very specialized role in the system will be common only locally.

Depending on the actual set of adaptive traits of each species, the outcome of its interaction with other species will vary. When the adaptations of two species are very similar, and resources are insufficient to maintain populations of both, *competition* can occur. One species can begin to dominate another through the removal of essential materials from the environment. In other cases, a species can add materials to the environment, modifying conditions that aid its own ability to be dominant to the detriment of others. Some species have developed ways of interacting with each other that can be of benefit to them both, leading to relationships of *mutualism*, where resources are shared or partitioned (the importance of mutualisms in agroecology is discussed in Chapter 15). In natural ecosystems, selection through time has tended to result in the most complex structure biologically possible within the limits set by the environment, permitting the establishment and maintenance of dynamic populations of organisms.

ECOSYSTEM CHANGE

Ecosystems are in a constant state of dynamic change. Organisms are coming into existence and dying, matter is being cycled through the component parts of the system, populations are growing and shrinking, and the spatial arrangement of organisms is shifting. Despite this internal dynamism, however, ecosystems are remarkably stable in their overall structure and functioning. This stability is due in part to ecosystems' complexity and species diversity.

One aspect of ecosystem stability, as discussed earlier in terms of communities, is the observed ability of ecosystems to either resist change that is introduced by disturbance, or to recover from disturbance after it happens. The recovery of a system following disturbance, a process called *succession*, eventually allows the reestablishment of an ecosystem similar to that which occurred before the disturbance. This "end point" of succession is called the *climax* state of the ecosystem. As long as disturbance is not too intense or frequent, the structure and function that characterized an ecosystem before perturbation is reestablished, even if the community of organisms that eventually regains dominance may be slightly different.

Nevertheless, ecosystems do not develop toward or enter into a steady state. Instead, due to constant natural disturbance, they remain dynamic and flexible, resilient in the face of perturbing forces. Overall stability combined with dynamic change is often captured in the concept of *dynamic equilibrium*. The dynamic equilibrium of ecosystems is of considerable importance in an agricultural setting. It permits the establishment of an ecological "balance," functioning on the basis of sustained resource use, which can be maintained indefinitely despite ongoing and regular change in the form of harvest, soil cultivation, and replanting.

AGROECOSYSTEMS

Human manipulation and alteration of ecosystems for the purpose of establishing agricultural production makes agroecosystems very different from natural ecosystems. At the same time, however, the processes, structures, and characteristics of natural ecosystems can be observed in agroecosystems.

NATURAL ECOSYSTEMS AND AGROECOSYSTEMS COMPARED

A natural ecosystem and an agroecosystem are diagrammed, respectively, in Figure 2.6 and Figure 2.7. In both figures, flows of energy are shown as solid lines and movement of nutrients is shown with dashed lines.

A comparison of Figure 2.6 and Figure 2.7 reveals that agroecosystems differ from natural ecosystems in several key respects.

Energy Flow: Energy flow in agroecosystems is altered greatly by human interference. Inputs are derived from primarily human sources and are often not self-sustaining. Thus agroecosystems become open systems where considerable energy is directed out of the system at the time of each harvest, rather than stored in biomass, which could otherwise accumulate within the system.

Nutrient Cycling: Recycling of nutrients is minimal in most agroecosystems and considerable quantities are lost from the system with the harvest or as a result of leaching or erosion due to a great reduction in permanent biomass levels held within the system. The frequent exposure of bare soil between crop plants and, temporally, between cropping seasons, also creates "leaks" of nutrients from the system. Farmers have recently come to rely heavily upon petroleum-based nutrient inputs to replace these losses.

Population Regulating Mechanisms: Due to the simplification of the environment and a reduction in trophic interactions, populations of crop plants or animals in agroecosystems are rarely self-reproducing or self-regulating. Human inputs in the form of seed or control agents, often dependent on large energy subsidies, determine population sizes. Biological diversity is reduced, trophic structures tend to become simplified, and many niches are left unoccupied. The danger of catastrophic pest or disease outbreak is high, despite the intensive human interference.

Stability: Due to their reduced structural and functional diversity in relation to natural ecosystems, agroecosystems have much less resilience than natural ecosystems. A focus on harvest outputs upsets any equilibrium that is established, and the system can only be sustained if outside interference — in the form of human labor and external human inputs — is maintained.

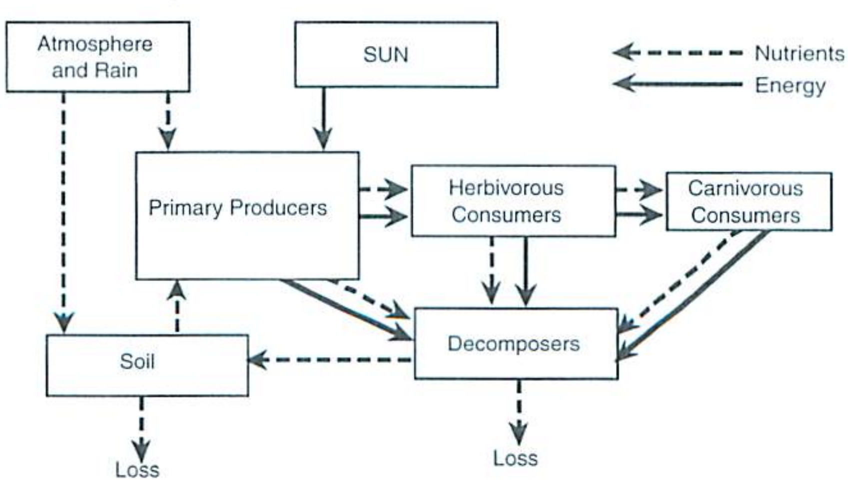

FIGURE 2.6 Functional components of a natural ecosystem. The components labeled "Atmosphere and Rain" and "Sun" are outside any specific system and provide essential natural inputs.

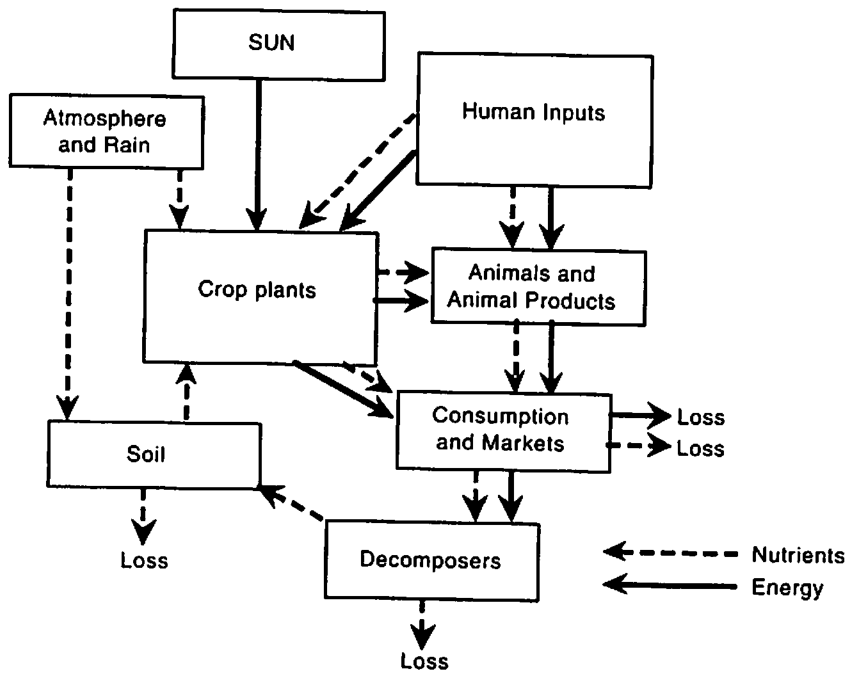

FIGURE 2.7 Functional components of an agroecosystem. In addition to the natural inputs provided by the atmosphere and the sun, an agroecosystem has a whole set of human inputs that come from outside the system. An agroecosystem also has a set of outputs, labeled here as "Consumption and Markets."

TABLE 2.2
Important Structural and Functional Differences Between Natural Ecosystems and Agroecosystems

	Natural Ecosystems	Agroecosystems
Net productivity	Medium	High
Trophic interactions	Complex	Simple, linear
Species diversity	High	Low
Genetic diversity	High	Low
Nutrient cycles	Closed	Open
Stability (resilience)	High	Low
Human control	Independent	Dependent
Temporal permanence	Long	Short
Habitat heterogeneity	Complex	Simple

Source: Odum, E. P. 1969. *Science* 164: 262–270.

The key ecological differences between natural ecosystems and agroecosystems are summarized in Table 2.2.

Although sharp contrasts have been drawn between natural ecosystems and agroecosystems, actual systems of both types exist on a continuum. On one side of the continuum, few 'natural' ecosystems are truly natural in the sense of being completely independent of human influence; on the other side, agroecosystems can vary greatly in their need for human interference and inputs. Indeed, through application of the concepts presented in this text, agroecosystems can be designed that come close to resembling natural ecosystems in terms of such characteristics as species diversity, nutrient cycling, and habitat heterogeneity.

The Agroecosystem as a Unit of Analysis

We have so far described agroecosystems conceptually; it remains to explain what they are physically. In other words, what is the thing we are talking about when we discuss the management of an agroecosystem? This is first of all an issue of spatial boundaries. The spatial limits of an agroecosystem in the abstract, like those of an ecosystem, are somewhat arbitrary. In practice, however, an "agroecosystem" is generally equivalent to an individual farm, although it could just as easily be a single farm field or a grouping of adjacent farms.

Another issue involves the relationship between an abstract or concrete agroecosystem and its relationship and connection to the surrounding social and natural worlds. By its very nature, an agroecosystem is enmeshed in both. A web of connections spreads out from every agroecosystem into human society and natural ecosystems. Coffee drinkers in Seattle are connected to coffee-producing agroecosystems in Costa Rica; the Siberian taiga may experience impacts from conventional corn production systems in the U.S.

In practical terms, however, we must distinguish between what is external to an agroecosystem and what is internal. This distinction becomes necessary when analyzing agroecosystem inputs, since something cannot be an input unless it comes from outside the system. The convention followed in this text is to use an agroecosystem's spatial boundary (explicit or implicit) as the dividing line between internal and external. In terms of inputs supplied by humans, therefore, any substance or energy source from outside the spatial boundaries of the system is an *external human input*. Even though the word *external* is redundant with *input*, it is retained in this phrase to emphasize off-the-farm origins. Typical external human inputs include pesticides, inorganic fertilizers, hybrid seed, fossil fuels used to run tractors, the tractors themselves, most kinds of irrigation water, and human labor supplied by nonfarm residents. There are also natural inputs, the most important of which are solar radiation, precipitation, wind, sediments deposited by flooding, and plant propagules.

Sustainable Agroecosystems

The challenge in creating sustainable agroecosystems is one of achieving natural ecosystem-like characteristics while maintaining a harvest output. Working toward sustainability, the manager of any particular agroecosystem strives as much as possible to use the ecosystem concept in his or her design and management. Energy flow can be designed to depend less on nonrenewable sources, and a better balance achieved between the energy used to maintain the internal processes of the system and that which is available for export as harvestable goods. The farmer can strive to develop and maintain nutrient cycles that are as "closed" as possible, to lower nutrient losses from the system, and to search for sustainable ways to return exported nutrients to the farm. Population regulation mechanisms can depend more on system-level resistance to pests, through an array of mechanisms that range from increasing habitat diversity to ensuring the presence of natural enemies and antagonists. Finally, an agroecosystem that incorporates the natural ecosystem qualities of resilience, stability, productivity, and balance will better ensure the maintenance of the dynamic equilibrium necessary to establish an ecological basis for sustainability. As the use of external human inputs for control of agroecosystem processes is reduced, we can expect a shift from systems dependent on synthetic inputs to systems designed to make use of natural ecosystem processes and interactions and materials derived from within the system.

Agroecosystems in Context: The Food System

Agroecology finds its most immediate applications at the farm or agroecosystem level, where it can effectively deal with production, short-term enterprise economics, and environmental impacts in the immediate vicinity of the farm. But each farm or agroecosystem is part of a much larger system, a global network of food production, distribution, and consumption called the *food system*.

Sustainability in agriculture can only come from understanding the interaction of all components of the food system. Therefore, this text lays the groundwork for developing a food-system perspective from which to view all questions of agricultural sustainability. This perspective pays attention as much to the people in agroecosystems as it does to the ecological conditions on the farm. It takes into account the large amounts of energy and materials that are integral to the processing, transportation, and marketing that take place in the human "food chain." It pays attention to the equity issues of hunger, *food security*, and access to good nutrition and diet. It weighs the impacts of globalization in the marketplace and in farm communities, and sees producers and consumers as actively connected parts of a single system.

The agroecosystem concept and the science of agroecology provide a foundation for examining and understanding the interactions and relationships among the diverse components of the food system (Francis et al., 2003). A grounding in ecosystem thinking — wherein a complex web of interacting and independent parts contribute to the emergence of a sustainable whole — allows a framework for integrating social, economic, political, and ecological perspectives to take shape. It is the goal of the chapters ahead to establish this grounding in ecological thinking, apply it to agricultural systems, and then to broaden the scope of agroecology to include all components of the food system.

FOOD FOR THOUGHT

1. What kinds of changes need to be made in the design and management of agriculture so that we can come closer to farming in "nature's image"?
2. It seems that for modern agriculture to be sustainable, it has to solve the problem of how to return nutrients to the farms that they come from. What are some ways this might be done in your own community?
3. The concept of ecosystem stability is one that is currently under much discussion in ecology. Some ecologists claim that there is no such thing as stability in ecosystems, since change is constant and disturbance inevitable. Yet in agroecology, we strive for stability of agroecosystem structure and function. How is the concept of stability being applied differently in these different contexts?
4. As a consumer, how do your choices affect the global food system?

INTERNET RESOURCES

Agroecology in Action
www.agroeco.org
A website dedicated to demonstrating the many and varied ways to apply agroecology, with special emphasis on issues in Latin America.

Center for Agroecology and Sustainable Food Systems
zzyx.ucsc.edu/casfs
The Center for Agroecology & Sustainable Food Systems is a research, education, and public service program at the University of California, Santa Cruz, dedicated to increasing ecological sustainability and social justice in the food and agriculture system.

Ecology and Society
www.ecologyandsociety.org
A journal of integrative science for resilience and sustainability

University of California Santa Cruz Agroecology Program.
www.agroecology.org
This website is an information resource for developing sustainable agroecosystems, emphasizing international training, research, and application of agroecological science to solving real world problems.

RECOMMENDED READING

Altieri, M.A. 1995. *Agroecology: The Science of Sustainable Agriculture.* 2nd ed. Westview Press: Boulder, CO. A pioneering book on the foundations of agroecology, with emphasis on case studies and farming systems from around the world.

Carroll, C.R., J.H. Vandermeer, and P.M. Rosset. 1990. *Agroecology.* McGraw-Hill: New York. An edited overview of agroecology that introduces the reader to many of the main currents of thought in the field in an interdisciplinary context.

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