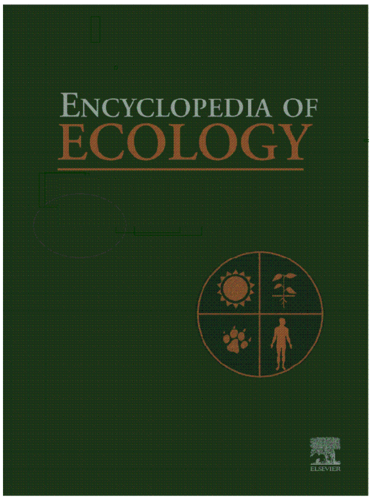

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Agriculture Systems

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Introduction

An agricultural ecosystem is an ecosystem managed with a purpose. This purpose usually is to produce crops or animal products. Agricultural ecosystems are designed by humans, and current agroecosystems are products of a long chain of experimental work. These experiments have been performed by individual farmers as well as research institutions, and when results were positive for the purpose, the methods have been adopted.

The purpose has, however, changed with time. In highly productive regions, for example, Western Europe, the emphasis has changed from maximum productivity to environmental considerations, such as reduction of nutrient losses to groundwater and maintaining an open landscape with high biodiversity, etc. In less-productive regions, where resources such as water or fertilizers are scarce and production is too low to properly feed the farmer, environmental considerations have low priority. This is a major global problem, since this leads to land degradation and even lower production, etc. in a downward spiral.

Agroecosystems are conceptually fairly similar to managed forests and grasslands, and whether extensively cattle-grazed natural grasslands should be included under the category of agroecosystems is a matter of choice in the individual case. Arable land is defined as land that is soil cultivated regularly, but also here the boundaries are not sharp (seminatural grasslands, permanent crops, etc.). At the other end, agroecosystems border horticultural systems, that is, vegetable cropping. Alternatively, horticulture can be viewed as a subset of agriculture. Production of cabbage in a field can be considered as agriculture, but hydroponic (soil-less) production of tomatoes in a greenhouse under artificial light can perhaps not be included. However, in many respects even an artificial ecosystem such as this can be considered as an agricultural ecosystem. It is designed for production of a crop and is just managed to a higher extent than an arable field.

According to FAO statistics for 2002, agricultural ecosystems comprise almost 40% (5 Gha) of the total land area of the Earth. About 11% of the total land area is arable land (cultivated with crops), and approximately 27% of the total land area is under permanent pasture, grazed by cattle, goats, sheep, camels, etc. Clearly, we are actively managing a considerable part of our planet for agricultural purposes, and to this one can add other similar systems, such as intensively managed forest systems (planted and harvested, sometimes fertilized), etc.

Ecological research performed in agricultural systems has many advantages compared with research in most natural ecosystems. For example, there are a number of long-term field experiments running, although originally designed for, for example, crop production response to fertilizer dose, that can give us a 30-year integration of what has happened, for example, to organisms in the soil under different conditions. Further, agricultural fields are 'homogenized', that is, trees, larger stones, etc. are removed and regular soil cultivation evens out differences in topsoil properties over time. However, even after many years of cultivation, a fairly high variability in soil properties remain, which is the incentive for 'precision farming', where soil and crop properties are measured at high resolution (m^2), and management is based on these measurements. For ecological research, this is an opportunity, since any given hectare will yield numerous observation points, each helping us to answer questions such as: Why does this particular location yield more wheat, or why is more water present at that location?

Another advantage is that agricultural crops often have a short lifespan and a small size, compared with, for example, forest trees. Often, an experiment can be started when the soil is bare, and a single crop can be followed from sowing, through harvest, and finally when the stubble is plowed down at the end of the growing season. This life cycle can take a century for a tree in a northern forest, which, to add insult to injury, also may contain several other plant species. Therefore it is not surprising that a considerable part of modern ecological theory (predator–prey interactions, general soil ecology, above- and belowground plant growth dynamics, organic matter decomposition, nutrient mineralization, etc.) is based on work performed in agricultural land, and that the reluctance of ecologists to work in agricultural systems that was obvious 30 years ago seems to have vanished.

The Agroecosystem

Figure 1 is an attempt to summarize the characteristics of an agroecosystem as compared to most natural ecosystems. Note that this comparison is between a typical natural ecosystem and a typical, high-production agroecosystem.

Abiotic Constraints

Just like natural ecosystems, agroecosystems are constrained by climate and soil properties – maize does not grow in Northern Sweden. However, climate can be modified, that is, in dry climates one can irrigate (with surface- or groundwater), and soil properties can be modified through, for example, liming, organic matter amendments, and fertilization. Too high water tables can be lowered through ditching or tile draining.

Nutrients

Highly productive agroecosystems need high inputs of plant nutrients (nitrogen, phosphorus, potassium, and other elements) to replenish the nutrients removed with the exported products. These inputs can be delivered either as commercial fertilizer, recirculated sewage sludge and ash from garbage burning, or manure from cattle, pigs, poultry, etc. All sources have their advantages and disadvantages. Commercial fertilizers are well defined, low in pollutants such as heavy metals (although exceptions exist), hygienically safe, and are concentrated, easy to transport, and rapidly available to the plant when applied in the field. However, production and long-range transport of fertilizers is energy consuming, and the concentrated product increases the risk for too high doses, leading to environmental pollution. An even greater problem is that a large part of the farmers of the world cannot afford to buy enough fertilizer to maintain soil fertility and obtain good yields. In all, world N fertilizer production in 2001 was slightly less than 90 Mt, very unevenly distributed. In sub-Saharan Africa, only 1.1 kg fertilizer nitrogen is used per person and year, whereas in China the corresponding value is 22 kg.

In theory, recirculation of nutrients from waste of the exported products seems to be ecologically sound. In practice, there are a number of problems. First, sewage sludge mainly consists of water, which either must be removed (requires energy) or transported, which is expensive and impractical. Second, sewage sludge contains harmful bacteria, human parasites, etc. and has to undergo hygienic treatment. Third, and most severe, is the problem with contaminants, such as heavy metals and organic toxins. Therefore recirculation of sewage sludge and garbage incineration ash is strictly regulated in most countries. In this perspective, replacement of nutrients using newly produced fertilizer can be a better solution from an environmental viewpoint.

Naturally, animal manure produced on the farm should be and is recycled to soil as much as possible. Compared with fertilizers, manure has the advantage of containing organic matter, which improves soil structure. On the other hand, manure contains mostly water (expensive storage and transportation, heavy machinery needed for spreading), and it will lose nitrogen through ammonia emission, both at storage and spreading.

Crops, Varieties, and Cropping Systems

The vegetation found in an agroecosystem is usually divided into crop and weeds, where weeds are unwanted trespassers, which traditionally have been regarded only as negatives. More recently, this view has been modified,

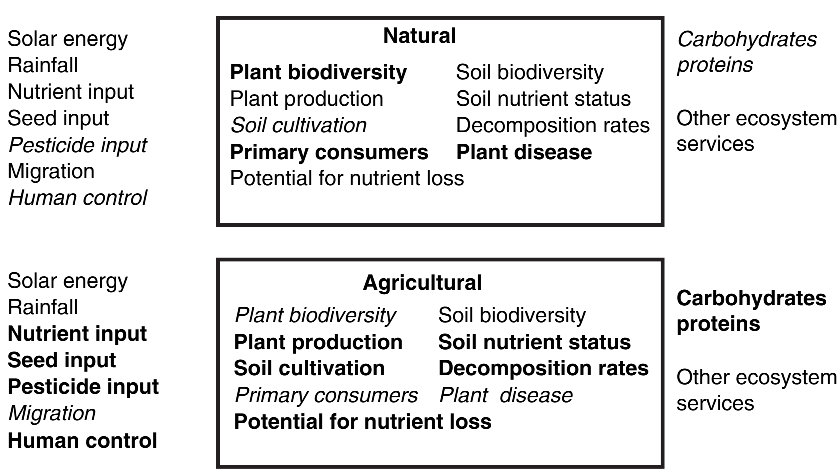

Figure 1 Similarities and differences between typical natural and high-production agricultural ecosystems. Inputs of energy, mass, and control (left), comparison of selected ecosystem properties (center), outputs (right). Note that cattle, etc. are not included as primary consumers here. (**Bold** = markedly higher value than in the other ecosystem type. *Italic* = very low.)

and weeds, particularly weedy border zones can be accepted to some extent, as biodiversity enhancers and refuges, for example, for beetles.

The crops used today are products of many years (in some cases millennia) of plant breeding, and properties selected for are usually productivity, product quality, pest resistance, etc. This directed selection, in recent years augmented by direct manipulation of DNA, is one of the main differences between agro- and natural ecosystems. Crop species and varieties are being redistributed all over the world; maize, a staple food in Africa, comes from Central America, common West European and North American cereals such as wheat come from the Middle East, etc. This breeding and distribution of improved crops, together with improved cultivation/fertilization techniques probably is the main reason for the global success of the human species (three billion in 1960, probably nine billion in 2050). For example, world grain production was 631 Mt in 1950, and in 2000 it had increased to 1840 Mt.

Herbicides, Pesticides, and Fungicides

To reach the goal of high production of crops of good quality, weeds (unwanted plants), pests (unwanted animals), as well as fungal, bacterial, and viral diseases must be kept in check. A monoculture crop is vulnerable to attacks, since one (or a pair) of the pests that enter a field will have a high concentration of food with no transport stretches in between. Potential predators may be absent, since they may need a litter layer on the ground for reproduction, which does not exist in the field, etc. Repeated monocultures may build up specialized pests, such as plant parasitic nematodes. Crop rotations (switching crops from year to year according to a predetermined pattern) can successfully deal with many pests and diseases, and careful soil cultivation can reduce weed problems. Intercropping (growing two or more crops together, such as barley/clover) may also help.

However, most fields will benefit from occasional chemical (or biological) pesticide/herbicide treatment. These types of agrochemicals have a somewhat dubious reputation among laymen and perhaps also ecologists (DDT, Agent Orange, mercury, etc.). Three things should be kept in mind, though. First, the substances and formulations used today are thoroughly tested before approval, and their side effects and the fate of their decomposition products are well known. Second, chemical warfare is common in natural systems – all successful plant species present today have at least some chemical defense against microorganisms and pests. Third, which alternatives do we have? A failed crop in a well-fertilized field will lead to high risks for nutrient losses to the environment. A failed crop in poorer conditions may lead to starvation for the farmer and her family.

Alternative methods, such as increased cultivation, hand weeding, or biological pest reduction by introduction of predators all have their advantages and disadvantages, but there is no 'silver bullet' available. In summary, an integrated approach with a combination of methods is the solution, and modern agriculture has moved and is moving in this direction. Of course, for commercial reasons it can be profitable to cultivate, for example, 'organic' crops (without fertilizer or pesticides) to obtain a higher price, but from an ecological or environmental viewpoint this approach is not necessarily better.

Agriculture can thus be classified according to the use of agrochemicals, for example, biodynamic, organic, integrated, and industrialized farming. Biodynamic farming forbids the use of conventional agrochemicals and replaces them with exotic homemade concoctions, and organic farming *a priori* forbids conventional agrochemicals. None of these farming systems is firmly based on scientific evidence; instead they are based on a green view of nature that leads to the banning of certain chemicals.

Integrated and industrial farming can also be called 'conventional', where economic, legal, and environmental constraints limit the end goal, maximum productivity, and profitability. The main difference between the latter two is that integrated is more environmentally concerned (reduced pesticide use, use of biological pest reduction methods, etc.), and industrialized is more leaning to maximum production with whatever means available, with a minimum of environmental concerns. It should be noted that 'conventional' and particularly 'industrialized' are somewhat derogatory terms, mainly used by those negative to these approaches.

Migration

Natural ecosystems, for example, East African savannas, can be subjected to major migrations of large herbivores that annually move long distances, following the seasonal changes in rainfall and consequential grass growth. Most natural ecosystems are less subjected to migrations, but, for example, in Northern forests at least migratory birds occur seasonally.

In agroecosystems, migration is usually kept to a minimum. Measures are taken to keep large or small grazers out from the cropped field. In some regions, wild grazers are exterminated (or close to extinction – Western European agricultural regions) and in other regions crop fields are guarded or fenced. However, migration is a component in animal husbandry; cattle is often shifted between pastures, which are given time to recover. Nomadic herding of cattle (Sami people, Masai) is similar to the savanna migrations mentioned above; the cattle and herdsmen follow the annual cycles in grazing opportunities.

Biodiversity

In a cereal monoculture, plant biodiversity is extremely low – if weed control is successful there may be only one species present, a highly specialized and genetically homogeneous wheat variety. This is not common in natural ecosystems, although it can occur in extreme environments. As mentioned above, this means that a pest can have a field day if it can reproduce in the field (or migrate into the field at a large scale).

However, agricultural monocultures still are common and continue to produce good yields. There are several reasons for this. First, there is no simple relation between biodiversity, productivity, or ecosystem stability. A plant monoculture that is well adapted, grows under good conditions, and has a reasonable resistance to pests and diseases can survive and produce well. This is exactly what a highly productive agricultural field is – a well-adapted monoculture. The crop variety has been selected for high production under a number of years with different weather (and on different soils) in a region. A variety that would demand intensive treatment with herbicides, pesticides, and fungicides will not be economical and will be rejected.

Second, the low plant diversity reduces animal diversity in the stand, but perhaps less than one would expect. In a cereal monoculture stand, there can be hundreds of species of insects, mites, springtails, snails, slugs, etc. In the soil under a monoculture the biodiversity is almost always extremely high, though usually lower than in natural systems. Thousands, perhaps millions of bacterial species, tens to hundreds of species of earthworms, enchytraeids, soil insects, springtails, mites, spiders, millipedes, flagellates, amoebae, blue-green algae, etc. can be found. There are no consistent indications that soil functions such as organic matter decomposition is hampered by a low biodiversity under monocultures – a given plant residue will decompose at the same rate under a monoculture as under mixed plants, if soil temperature and moisture are the same.

Third, the last line of defense is the crop protection measures that the farmer takes. For example, in several countries there is a sophisticated monitoring and prediction system for aphid outbreaks. Aphids suck the sap from the crop leaves, but they are also vectors for crop diseases. Therefore their hibernating stages are enumerated, weather is monitored, and if the conditions are 'right' the farmers are recommended to spray the fields with an insecticide (or a more specific aphicide) with dose *x* at date *y*. In less technically developed regions, experience and skill is a substitute for the model projections, but the principles are the same. It should also be mentioned that in spite of these defenses, pest insects, pathogens, and weeds still reduce worldwide crop yields considerably, and there is a great potential for improvements.

Other Ecosystem Services

The main ecosystem service from agricultural systems is simply to 'feed the world'. This simple fact is easily forgotten in the richer parts of the world. However, even in Europe, which for centuries has been thoroughly under agriculture, there are other ecosystem services that are appreciated. In the forest-dominated northern Europe, agriculture actually contributes to biodiversity and landscape diversity. Without agriculture, the forest would cover all land area – the only open areas at lower altitudes would be the lakes and rivers (and the newly clear-cut forest areas, rapidly covered by shrubs). The European rural landscape in general, that is so refreshing for the city-dweller, is an agricultural product.

In other areas of the world, where the agricultural land is not sufficient to properly feed the population, other ecosystem services become relatively less important. However, if agricultural productivity can be increased, some agricultural land can be returned to savanna, forest, or other natural or seminatural states – which would be another type of service from the agroecosystem.

Since the agroecosystem is managed, and more or less sophisticated machinery and management skills are in place, it can easily be converted according to new demands from the society. If the quality requirements are met, agricultural fields can be used for recycling organic waste and ashes, and even for drawing nutrients out of sewage water. Conversion to energy crops is not too difficult (grasses, sugar beet, willow, sugarcane, etc.). Another demand from society, to sequester carbon in the soil to reduce CO_2 in the atmosphere, has recently received much attention. Increasing soil carbon content usually has beneficial effects for soil structure, water-holding capacity and general fertility, and C sequestration, perhaps even with direct payments per ton C sequestered to the farmer, is a new potential service.

The Intelligent Choices

As mentioned in the introduction, an agroecosystem has a purpose. It is designed to obtain certain goals, and the state of the system at any given point in time is a consequence of an array of intelligent choices by the farmer, complementing the border conditions set up by weather and soils, etc. The following decision matrix (Figure 2) illustrates how decisions made by a maize farmer in sub-Saharan Africa can be supported by basic science knowledge. Note that the chemical analyses are not necessary for every farmer and decision. Instead, typical values for the different organic resources are estimated, and the individual farmer uses the rule of the thumb based on these estimates.

In the upper part of the Figure 2, the general decision matrix is shown. Let us assume that we have leaves from a

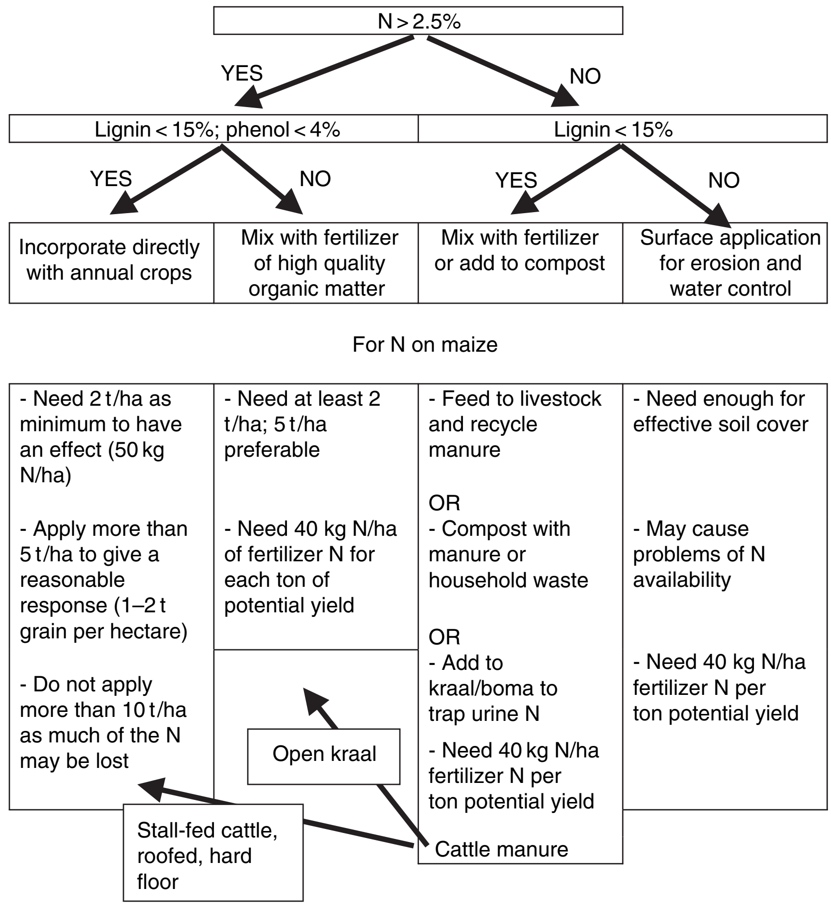

Figure 2 Example of farmer's decisions regarding N management for a maize crop in sub-Saharan Africa, using a decision support system for organic N management depending on resource quality, expressed as N, lignin, and soluble polyphenol content. General decision matrix (top), more detailed for N economy in a maize cropping system (bottom). Modified from Vanlauwe B, Sanginga N, Giller K, and Merckx R (2004) Management of nitrogen fertilizer in maize-based systems in subhumid areas of sub-Saharan Africa. In: Mosier AR, Syers JK, and Freney JR (eds.) *Agriculture and the Nitrogen Cycle*. 124p. SCOPE 65. Washington Island Press.

tree, which we know have a low N content and less than 15% of lignin. Then we should mix the leaves with fertilizer or add to compost. Now, in the lower part of Figure 2 we can see that if we look in more detail at the N economy of a maize system, we have other options – maybe add the low N material to the cattle corral (kraal/boma) to trap urine N or feed to livestock to produce higher quality organic inputs. Organic resources belonging to the third column from the left could be fed to livestock and the manure thus produced could belong to the first or the second organic resource class, depending on the management of that manure.

All over the world, farmers make these kinds of choices, based not only on biophysical knowledge and constraints, but also on economic and sociopolitical opportunities and constraints. An agroecosystem is not only controlled by farmers, but also by the society the farmer operates in. Subsidies can make growing products that have no market an intelligent choice for the farmer; lack of money can make fertilization impossible, even if it would be profitable in the long run, or real or imaginary environmental concerns from the society can force a farmer to, for example, abandon fertilizer use, cereal cropping, or pig farming.

Summing up, the agroecosystem, although limited by climatic constraints, is a product of decisions made by generations of farmers, supported by advice from agronomists and extension workers – all within a societal context of values, traditions, and legislation. In fact, the present and future agroecosystems are at least equally dependent on the societal context as on the climate and soil. However, the organisms involved are, as in any ecosystem, products of millions of years of evolution, and crop and animal breeding has only contributed with small, although important changes to the germplasm.

See also: Agriculture Models; Agriculture Systems; Soil Ecology; Soil Erosion by Water; Xenobiotic (Pesticides, PCB, Dioxins) Cycles.

Further Reading

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http://www.cgiar.org – Consultancy Group on International Agricultural Research.
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Agroforestry

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Introduction

Agroforestry is the relatively new name for the age-old practice of growing trees and shrubs with crops and/or animals in interacting combinations on the same unit of land. Although defined in various ways, the practice encompasses the concept of on-farm and off-farm tree production in support of sustainable land use and natural resource management. (The World Agroforestry Centre defines agroforestry as "a dynamic, ecologically based, natural resources management system that, through the integration of trees on farms and in the agricultural landscape, diversifies and sustains production for increased social, economic and environmental benefits for land users at all levels." The Association for Temperate Agroforestry, AFTA defines it as "an intensive land management system that optimizes the benefits from the biological interactions created when trees and/or shrubs are deliberately combined with crops and/or livestock.")

Agroforestry is perhaps as old as agriculture itself. The practice has been prevalent for many centuries in different parts of the world, especially under subsistence farming conditions. Homegardening, a major agroforestry practice today and one of the oldest forms of agriculture in Southeast Asia, is reported to have been associated with fishing communities living in the moist tropical region about 13 000–9000 BC. Agroforestry in Europe is reported to have started when domestic animals were introduced in forests for feeding around 4000 BC. The dehesa (animal grazing under trees) system of Spain is reportedly 4500 years old. It has been only during the past three decades, however, that these indigenous forms of growing trees and crops/animals together were brought under the realm of modern, scientific land-use scenarios. The motivations for these initiatives were several. The Green Revolution of the 1970s largely did not reach the poor farmers and those in less-productive agroecological environments. In addition, land-management problems such as tropical deforestation, fuelwood shortage, soil