Search Print this chapter Cite this chapter

AGROECOLOGY: ENVIRONMENTALLY SOUND AND SOCIALLY JUST ALTERNATIVES TO THE INDUSTRIAL FARMING MODEL

Miguel A. Altieri
University of California, Berkeley

Keywords: agroecology, agroforestry systems, traditional agriculture, organic farming, sustainable development, biodiversity

Contents

Summary

Two main forms of alternative agriculture which sustain yields without agrochemicals, increasing food security while conserving natural resources, agrobiodiversity, and ecological integrity prevail in the rural landscapes of the world: a more commercial form of organic agriculture and a peasant based more subsistence-oriented traditional agriculture. In this article, the agroecological features of organic agriculture as practiced in North America and Europe, and of traditional agriculture involving millions of small farmers and peasants in the developing world, are described with emphasis on their contribution to food security, conservation/ regeneration of biodiversity, and natural resources and economic viability.

1. Introduction

In July 2003, the International Commission on the Future of Food and Agriculture published the Manifesto on the Future of Food. This report warns that corporately controlled, agrochemically based, monocultural, export-oriented agronomic systems are negatively impacting public health, ecosystem intensity, food quality, traditional rural livelihoods, and indigenous and local cultures, while accelerating indebtedness among millions of farmers and their separation from lands that have historically fed communities and families. The growing push toward industrialization and globalization of the world's agriculture and food supply is increasing hunger, landlessness, homelessness, despair and suicides among farmers. Meanwhile, it is also degrading life support systems and increasing alienation of peoples from nature and the historic, cultural and natural connection of people to their sources of food and sustenance. Finally, it is also destroying the economic and cultural foundations of societies, undermining security and peace, and creating a context for social disintegration and violence.

Despite the above trend, microcosms of intact traditional, community-based agriculture offer promising models for promoting biodiversity, sustaining yield without agrochemicals, and conserving ecological integrity. New approaches and technologies involving application of indigenous knowledge systems and spearheaded by farmers, NGOs and some government institutions are increasing food security while conserving natural resources, agrobiodiversity, and soil and water integrity. Agroecology emphasizes the capability of local communities to innovate, evaluate, and adapt themselves through farmer-to-farmer research and grassroots extension approaches. Technological approaches emphasizing diversity, synergy, recycling and integration, and social processes that value community involvement, point to the fact that human resource development is the cornerstone of any strategy aimed at increasing options for rural people and especially resource-poor farmers. Two main forms of this alternative agriculture dominate; a more commercial form of organic agriculture and a peasant based more subsistence-oriented traditional agriculture. In this report, the agroecological features of organic agriculture as practiced in North America and Europe, and of traditional agriculture involving millions of small farmers and peasants in the developing world, are described with emphasis on their contribution to food security, conservation/ regeneration of biodiversity, and natural resources and economic viability.

2. Agroecology and Sustainable Agriculture for Small Farmers in the Developing World

2.1 Extent of Peasant Agriculture

Although estimates vary considerably, about 1.4 billion rural people in the developing world remain directly untouched by modern agricultural technology. The great majority of these people are peasants, indigenous people and small family farmers, who mostly still farm the valleys and slopes of rural landscapes with traditional and/or subsistence methods. About 370 million of these people are extremely poor and live in the developing worlds highly heterogeneous and risk prone marginal environments of the south. Rural poverty disproportionately afflicts the elderly, women and children. Also the majority of the indigenous people (80 % of some 19-34 million found in Mexico, Colombia, Guatemala and the Andes, but also millions in Africa and Asia) are poor. The great majority of poor farmers have meager holdings, with little or no capital. Most of their diverse framing systems do not rely on synthetic chemical pesticides or fertilizers use low input technologies such as native seeds, manure, plant biomass and other local resources.

It is estimated that there are some 960 million hectares of land under cultivation (arable and permanent crops) in Africa, Asia and Latin America, of which 5-10% of this land could be considered as managed by peasant farmers. This estimate includes 4.42 million small farms (< 5 ha) using sustainable agricultural practices on 3.58 million hectares plus the millions of peasants, family farmers and indigenous people practicing resource-conserving subsistence farming or that are in conversion to agroecological management guided by NGOs or other institutions (Table 1).

Table 1. Partial distribution and extent of traditional-peasant agriculture in the developing world

In Latin America in the late 1980s, the peasant population included 75 million people representing almost two thirds of the Latin America's total rural population. About 16 million peasant production units, averaging 1.8 hectares and totaling close to 60.5 million hectares, or 34.5% of the total cultivated land accounted for approximately 41% of the agricultural output for domestic consumption, including 51% of the maize, 77% of the beans, and 61% of the potatoes consumed at a regional level. In Brazil, about 4.8 million family farmers (about 85% of the total number of farmers) occupy 30% of the total agricultural land and control about 33% of the area sown to maize, 61% of that under beans, and 64% of that planted to cassava, thus producing 84% of the total cassava and 67% of all beans. In addition, many of the 4 million landless families live in the rural areas of Brazil are now turning to agroecology because of new initiatives encouraged by the directives of MST (Landless movement). In Ecuador, the peasant sector occupies more than 50% of the area devoted to food crops such as maize, beans, barley and okra. In Mexico, peasants occupy at least 70% of the area assigned to maize and 60% of the area under beans. In Cuba the peasant and small farm cooperative sector occupies 22% of the island's arable land (about 1.5 million ha.). Since 1990 virtually all this land has been devoted to food crops and is managed organically (most of it non-certified) as imports of fertilizers and pesticides fell drastically in 1984. In addition to the peasant and family farm sector, there are about 50 million individuals belonging to some 700 different ethnic indigenous groups who live and utilize the humid tropical regions of the world. About two million of these live in the Amazon and southern Mexico. In Mexico, half of the humid tropics is utilized by indigenous communities and "ejidos" featuring integrated agriculture-forestry systems with production aimed at subsistence and local-regional markets.

In Africa in the 1980s, the majority of farmers, many of them women, were smallholders with 2/3 of all farms below 2 hectares and 90% of farms below 10 hectares. Most small farmer's practice "low-resource" agriculture based primarily on the use of local resources with little or no use of fertilizers and improved seed but may make modest use of external inputs. Low-resource agriculture produces the majority of grain; almost all root, tuber and plantain crops, and the majority of legumes (Table 2). This situation has changed in the last two decades as food production per capita has declined and Africa, once self-sufficient in cereals, now has to import millions of tons to fill the gap. Despite this increase in imports small farmers still produce most of Africa's food.

In Asia, only a few of the more than 200 million rice farmers farm more than 2 ha of rice. In China alone there are probably 75 million rice farmers who still practice farming methods similar to those used more than one thousand years ago. Local cultivars, grown mostly on upland ecosystems and/or under rain-fed conditions, make up the bulk of the rice produced by Asian small farmers.

Table 2. The contribution of low-external input agriculture to African staple food production (after Office of Technology Assessment 1998.) Enhancing agriculture in Africa: a role for US development assistance. Washington DC.,OTA-F-356, US Government Printing Office

Due to poverty (the bulk of farmers in the developing world are small holders who have small parcels and earn less than 2 dollars per day) and scale biases of modern technology, less than 25% of the total small farmer's population benefited from agricultural modernization. In Mexico less than 12%of the peasants adopted high-yielding varieties, while 11% adopted pesticides and no more than 25% adopted fertilizers. In the Andes less than 10% of the smallholders had access to fertilizers and new potato seeds. There is a large indigenous farming population who have never used elements of modern agronomy, mainly due to tradition and because their production systems do not require external inputs. There are also thousands of farmers who by their own initiative or as part "institutionally sponsored interventions", are now transitioning towards low-external input agriculture. A case in point are the FAO-sponsored farmers field schools in Asia, which have pioneered a totally different approach to IPM innovation scaling it up to a point where in Indonesia alone more than 1 million small-scale rice growers have now been trained. In Africa there are at least 730,000 households covering about 700 thousand hectares that have adopted sustainable agriculture practices. In Asia, this figure rises to about 2.3 million households distributed on 1.75 million hectares.

2.2 Agroecological Features of Traditional Farming Systems

Traditional farmers have developed and/or inherited complex farming systems, adapted to the local conditions helping them to sustainably manage harsh environments and to meet their subsistence needs, without depending on mechanization, chemical fertilizers, pesticides or other technologies of modern agricultural science. Indigenous farmers tend to combine various production systems as part of a typical household resource management scheme.

Traditional agroecosystems are found throughout the developing world, linked to centers of origin and genetic diversity. Some of these systems include:

- Outstanding terraced mountain sides with rice and complex agroecosystems in Asia (e.g. the Cordillera Mountain Range, Philippines; biodiverse systems in the Himalayas and Andes; and Mediterranean fruit gardens.
- Complex agro-silvo-pastoral and aquatic system and diverse tropical/subtropical home gardens, producing multiple foods, medicines, ornamentals and materials,(e.g. East Kalimantan and Butitingui, Indonesia; highlands of Rwanda and Uganda; Titicaca in Peru; Kayapo in Brazil).
- Traditional soil and water management systems for agriculture, including

ancient water distribution systems allowing specialized and diverse cropping systems in Iran; traditional valley bottom and wetland food management (e.g. Lake Chad, Niger river basin and interior delta).

- Specialized dryland systems, including outstanding range/pastoral systems for the management of grasses, forage, water resources and adapted indigenous animal races e.g. Maasai in East Africa; pastoral systems of Ladakh, Tibet, parts of India, Mongolia and Yemen, as well as oases in deserts of North Africa and Sahara and indigenous systems in pays Dogon, Mali and pays Diola, Senegal.

Factors and characteristics underlie the sustainability of multiple use systems include:

- Farms are small with continuous production serving subsistence and market demands;
- Farm systems are based on several cropping systems, featuring mixtures of crops, trees, and/or animals with varietal and other genetic variability;
- There is maximum and effective use of local resources and low dependence on off-farm inputs;
- Energy inputs are relatively low;
- Labor is skilled and complementary, drawn largely from the household or community relations with dependency on animal traction and manual labor;
- There is heavy emphasis on recycling of nutrients and materials;
- Systems build on natural ecological processes (e.g. succession) rather than struggling against them.

Most peasant systems are productive despite their low use of chemical inputs. Generally agricultural labor has a high return per unit of input. In most multiple cropping systems developed by smallholders, productivity in terms of harvestable products per unit area is higher than under sole cropping with the same level of management. Yield advantages can range from 20% to 60%. These differences can be explained by a combination of factors which include the reduction of losses due to weeds, insects, and diseases and a more efficient use of the available resources of water, light and nutrients. In Mexico, 1.73 ha plot of land has to be planted with maize monoculture to produce as much food as one hectare planted with a mixture of maize, squash, and beans. In addition, the maize-squash-bean polyculture produces up to 4 t ha-1 of dry matter for plowing into the soil, compared with 2 t in a maize monoculture. In Brazil, polycultures containing 12,500 maize plants ha-1 and 150,000 bean plants ha-1 exhibited a yield advantage of 28%.

2.3 Examples of Traditional Agriculture around the World

2.3.1 Latin America

Raised field agriculture is an ancient food production system used extensively by the Aztecs in the Valley of Mexico but also found in China, Thailand, and other areas to exploit the swamplands bordering lakes. Called *chinampas* in the Aztec region, these “islands” or raised platforms (from 2.5 to 10 meters wide and up to 100 meters long) were usually constructed with mud scraped from the surrounding swamps or shallow lakes. The Aztecs built their platforms up to a height of 0.5 to 0.7 meters above water levels and reinforced the sides with posts interwoven with branches and with trees planted along the edges (Figure 1). On the *chinampas*, farmers concentrate the production of their basic food crops as well as vegetables. This includes the traditional corn/bean/squash polyculture, cassava/corn/bean/peppers/amaranth, the fruit trees associated with various cover crops, shrubs, or vines. Farmers also encourage the growth of fish in the water courses.

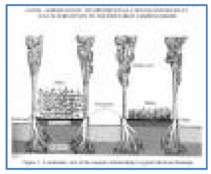

Figure 1. A schematic view of the complex relationships in typical Mexican chinampa.

For example, the *chinampas* in Mexico, which in the mid 1950s exhibited maize yields of 3.5-6.3 t ha-1, were the highest long-term yields achieved anywhere in Mexico. In comparison, average maize yields in the United States in 1955 were 2.6 t ha-1, and did not pass the 4 t ha-1 mark until 1965. Each hectare of *chinampa* can produce enough food for 15-20 persons per year at modern subsistence levels. Recent research has indicated that each *chinampero* can work about three-quarters of a hectare of *chinampa* per year, meaning that each farmer can support 12-15 people.

The high levels of productivity that characterize the *chinampas* result from several factors. First, cropping is nearly continuous; 3 to 4 crops are produced each year. One of the primary mechanisms by which this intensity is maintained is the seedbeds, in which young plants are germinated before the older crops are harvested. The *chinampa* maintain a high level of soil fertility despite the continual harvest of crops because they are supplied with high quantities of organic fertilizers. The lakes themselves serve as giant catch basins for nutrients. The aquatic plants function as nutrient concentrators, absorbing nutrients that occur in low concentration in the water and storing them inside their tissue. The water hyacinth (*Eichornia crassipes*) is a major source of organic matter capable of producing up to 900 kg per hectare of dry matter daily. Supplemented with relatively small amounts of animal manure, the *chinampas* can be made essentially self-sustaining. The animals, such as pigs, chickens, and ducks are kept in small corrals and fed the excess or waste produce from the *chinampas*. Their manure is incorporated back into the platforms. The use of these plants along with canal mud and muddy water (for irrigation) ensures that an adequate supply of nutrients is always available to the growing crops. The narrowness of the *chinampas* ensures that water from the canal infiltrates the *chinampa*, giving rise to a zone of moisture within reach of the crop's roots. Even if during the dry season the lake levels fall below the rooting zone, the narrowness of the *chinampa* allows the *chinampero* to irrigate from a canoe. Fourth, there is a large amount of individual care given to each plant in the *chinampa*. Such careful husbandry facilitates high yields.

Andean Agriculture. Between 3,000 and 4,000 years ago, a nomadic, hunting and gathering way of life in the Central Andes was supplanted by a vertically arranged, village-based agropastoral subsistence economy with crops, animals, and agropastoral technologies designed to yield an adequate diet with local resources while avoiding soil erosion. The evolution of agrarian technology in the Central Andes affected the division of the Andean environment into altitudinally arranged agroclimatic belts, each characterized by specific field and crop rotation practices, terraces and irrigation systems, and the selection of many animals, crops, and crop varieties. About 34 different crops (corn, quinoa, *Amaranthus caudatus*), legumes (beans, lupine, lima beans, etc), tubers (species of potato, manioc, Arrachocha, etc.), fruits, condiments, and vegetables are grown. The main crops are corn chenopods (*Chenopodium quinoa* and *C. pallidicaule*), and potatoes. Individual farmers may cultivate as many as 50 varieties of potatoes in their fields, and up to 100 locally named varieties may be found in a single village. The maintenance of this wide genetic base is adaptive since it reduces the threat of crop loss due to pests and pathogens specific to particular strains of the crop.

Crop patterns in the agroclimatic belts. The local Andean inhabitants recognize three to seven agroclimatic belts, distinguished according to altitude, moisture, temperature, vegetation, land tenure, crop assemblages, and agricultural technology (Figure 2). Three main belts can be distinguished. Sites in the corn belt have soft slopes, located between 3,400 and 3,600 meters and are irrigated and farmed in three alternative four-year rotations:

- corn/fava beans/corn/fallow;
- corn/corn/potato or fallow;
- and potato and barley/fava beans/corn/corn.

The potato/fava/cereals belt is composed of sites with steep slopes, located from 3,600 to 3,800 meters. Potatoes are intercropped with barley, wheat, fava beans and peas. In rainfed areas, there are two main four-year rotations:

- fava beans/wheat/peas/barley and
- Lupinus mutabilis/barley/fava beans/fallow.
- In irrigated areas, common rotations are:
- potato/wheat/fava beans/barley and
- potato or C. quinoa/barley/peas/fallow.

The bitter potato pasture belt is a cold belt located at about 3,800 meters. Rainfed rotations in this belt usually include a four-to-five-year rotation, after a 4-year sequence of potato/*Oyxalis tuberosa*/*Ullucus tuberosus* and *Trapaeolum tuberosum*/barley.

Figure 2. Agroclimatic belts recognized by local Andean inhabitants.

Waru-Warus of Titicaca. Researchers have uncovered remnants of more than 170,000 hectares of 'ridged fields' in Surinam, Venezuela, Colombia, Ecuador, Peru, and Bolivia. Many of these systems apparently consisted of raised fields on seasonally flooded lands in savannas and in highland basins (Figure 3). These Waru-Warus platforms of soil surrounded by ditches filled with water, were able to produce bumper crops despite floods, droughts, and the killing frost common at altitudes of nearly 4000 m in the Peruvian Andes.

The combination of raised beds and canals has proven to have important temperature moderation effects, extending the growing season and leading to higher productivity on the Waru-Warus compared to chemically fertilize normal pampa soils. In the Huatta district, reconstructed raised fields produced impressive harvest, exhibiting a sustained potato yield of 8-14 tonnes/hectare/year. These figures contrast favourably with the average puno potato yields of 1-4 tonnes/hectare/year. In Camjata the potato fields reached 13 tonnes/hectare/year in Waru-Warus. It is estimated that the initial construction, rebuilding every 10 years, and annual planting, weeding, harvest and maintenance of raised fields planted requires 270 persons-days/ha/yr.

Home gardens of Mexico and Belize. According Kitchen gardens (also known as home gardens, dooryard gardens, or huertos familiares) are the second most important agroecological feature among traditional tropical societies after swidden cultivation. They provide subsistence and cash income and offer a repository and domestication experimentation site for many plant varieties.

Figure 3. An integrated agriculture-aquaculture waru-waru system typical of the Andes above 3000 m above sea level.

Mixed tree systems or home gardens, common in the tropical lowlands of Mexico, involve the planting, transplanting, sparing, or protecting of a variety of useful species. The home garden is representative of a household's needs and interests, providing food, fodder, firewood, market products, construction materials, medicines, and ornamental plants for the household and local community. Many of the more common trees are those same species found in the surrounding natural forests, but new species have been incorporated, including papaya (*Carica papaya*), guava (*Psidium* spp.), banana (*Musa* spp.), lemon (*Citrus limon*), and orange (*Citrus aurantium*). In light gaps or under the shade of trees, a series of both indigenous and exotic species of herbs, shrubs, vines, and epiphytes is grown. Seedlings from useful wild species brought into the garden by the wind or animals are often not weeded out and are subsequently integrated into the home garden system. In a survey of the home gardens in the Mayan town of Xuilub in the Yucatan, 404 species were found where only 1,120 species are known for the whole state. Home gardens also provide diverse environments where many wild species of animals and plants can live, although the diversity of species depends on the size of the gardens and the degree of management. Estimated average family plots range from 600 m^2 to 6,000 m^2. Taking into consideration that most households in rural communities of the Yucatan Peninsula have some type of home garden, local traditional practices of orchard management have already contributed to the forest cover in the peninsula and have the potential for contributing more.

The Mopan Maya of southern Belize have kitchen gardens that are multi-storied and contain a mixture of minor crops, fruits, ornamental, and medicinal plants. Mopan Mayan kitchen gardens contain dozens of tree species, shrubs, and herb species Trees are the most important component of Mopan Mayan kitchen gardens, usually containing 35-40 species. Fruit trees are the most common in the kitchen gardens, with timber and ornamental trees making up a smaller percentage. A dominant group of trees in most gardens include the coconut palm (*Cocos nucifera*), papaya (*Carica papaya*), mango (*Mangifera indica*), orange (*Citrus sinsenis*), cacao (*Theobroma cacao*), avocado (*Persea americana*), custard apple (*Annona reticulata*), calabash (*Crescentia cuiete*), mammee apple (*Mammea americana*), breadfruit (*Artocarpus altilis*), coffee (*Coffea arabica*), and several palm species in both the canopy and shrub layer. Palms often provide fruit during times of the year when other trees are barren.

Coffee systems of Mexico and Central America In Mesoamerica, coffee is cultivated on the coastal slopes of the central and southern parts of the region in areas where two or more types of vegetation make contact. Based on management level and vegetational and structural complexity, it is possible to distinguish five main coffee production systems in Mexico: two kinds of traditional shaded agroforests (with native trees), one commercially oriented polyspecific shaded system, and two “modern” systems (shaded and unshaded monocultures) (Figure 4). Traditional shaded coffee is cultivated principally by small-scale, community-based growers, most of whom belong to some indigenous culture group. Traditional shaded coffee plantations are important repositories of biological richness for groups such as trees and epiphytes, mammals, birds, reptiles, amphibians, and arthropods. In Mexico, coffee fields are located in a biogeographically and ecologically strategic elevational belt that is an area of overlap between the tropical and temperate elements and of contact among the four main types of Mexican forests. Betewen 60% and 70% of these coffee areas are under traditional management and many coffee regions have been selected by experts as having high numbers of species and endemics overlap with or are near traditional coffee-growing areas. Regretably, original levels of biodiversity are being lost as coffee systems convert into modern coffee plantations.

As with other major ecosystem transformations in tropical latitudes, the transformation of the coffee agroecosystem involves spectacular landscape changes. In the “modern” monocultural system that is being promoted all over the world, all the shade trees are eliminated, the traditional coffee varieties are replaced by new sun-tolerant and shorter varieties, which are genetically homongeneous and pruned either by row or by plot, and are heavily dependent on agrochemicals, especially herbicides and fertilizers.

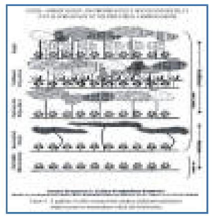

Figure 4. A gradient of coffee systems from complex traditional multistoried shaded systems to monocultures which lack biodiversity.

2.3.2 Asia

Paddy rice culture in Southeast Asia. Beneath the simple structure of the rice paddy monoculture (sawah) lies a complex system of built-in natural controls and genetic crop diversity. Farmers grow a number of photoperiod-sensitive rice varieties adapted to differing environmental conditions. These farmers regularly exchange seed with their neighbors because they observe that any one variety begins to suffer from pest problems if grown continuously on the same land for several years. The temporal, spatial, and genetic diversity resulting from farm-to-farm variations in cropping systems confers at least partial resistance to pest attack. Many farmers allow aquatic weeds, which they harvest for food.

The micro-environment of the *sawah* helps the wet-rice cultivator to produce constant crop yields from the same field year after year. First, the water-covered *sawah* is protected from high temperatures and the direct impact of rain and high winds, thus reducing soil erosion. Second, the high water table reduces the vertical movement of water, thus limiting nutrient leaching. Third, both floods and irrigation water bring silt in suspension and other plant nutrients in solution, renewing soil fertility each year. Fourth, the water in the *sawahs* contain *Axolla* spp. (a symbiotic association of the blue-green alga and fern), which promotes the fixation of nitrogen —adding up to 50 kg per hectare of nitrogen.

The rice ecosystem includes diverse animal species. Depending on the degree of diversity, food web interactions among the insect pests of rice and their numerous natural enemies in paddy fields can become very complex, often resulting in low but stable insect populations (Matteson et al. 1984). Some farmers allow flocks of domestic ducks to forage for insects and weeds in the paddies. Frequently one finds paddies where farmers have introduced a few pairs of prolific fish such as common carp (*Sarotherdon mossambicus).*

The techniques used for rice/fish culture differ considerably. There are two general systems. In the captural system, wild fish populate and reproduce in the flooded rice fields and are harvested at the end of the rice-growing season: when the water is drained off to harvest the rice, the fish move to troughs or tanks dug in the corners of fields and are then harvested. Captural systems occupy a far greater area than the second, cultural system. In the cultural system, the rice field is stocked with fish. This system may be further differentiated into a *concurrent* culture, in which fish are reared concurrently with the rice crop, and a *rotation* culture, in which fish and rice are grown alternately. Fish can also be cultured as an intermediate crop between two rice crops.

Traditional paddy rice growers usually produce only one rice crop each year during the wet season, even when irrigation water is readily available. This practice is partly an attempt to avoid damage by rice stem borers. For the remainder of the year the land may lie fallow and be grazed by domestic animals. This annual fallow, along with the dung dropped by the grazing animals and the weeds and stubble plowed into the soil, will usually sustain acceptable rice yields.

Alternatively, farmers may follow rice with other annual crops in the same year where adequate rainfall or irrigation water is available. Planting alternative rows of cereals and legumes is common, as farmers believe it uses the soil resources more efficiently. Well-rotted composts and manures are applied to the land to provide nutrient for the growing crops. Sowing cowpeas or mung beans into standing rice stubble reduces damage by bean flies, thrips, and leafhoppers, by interfering with their ability to find their host.

Agroforestry in Southeast Asia. Agroforestry in Southeast Asia has been practiced for over a century. The taungya system of Southeast Asia is considered as one of the most successful agroforestry systems. Among the most common agroforestry products of Southeast Asia are the association of commercial timber (particularly teak) or tree crops such as tea, cocoa, bananas, breadfruit, mangoes or kitul with groundnuts, pepper, maize, manioc or pineapples. Cultivation of Sago palms and sago production practiced in supplemented stands similar to the natural forest have been a traditional form of land use in Malaysia for thousands of years. The successful use of tree species and food staples or cash crops has been common in Sri Lanka since the nineteenth century and it is thought that the Sri Lankan Kandy gardens are the best examples of that farming system's potential for the humid tropics. Kandy gardens refer to small farms based on a close association of coconut, kitul and betel palms with cloves, cinnamon, nutmeg, citrus, mango, durian, jackfruit, rambutan and breadfruit, with a lower story of bananas and pepper vines, and a peripheral ground story of maize, cassava, beans, pineapples and other, often supplemented by an outside field of paddy rice. In Indonesia, manioc, pepper and benzoin are grown under the canopy provided by coconut palms and plantains. In most parts of Sumatra, today more than half of the farming area is planted with tree and bush cultures, where rubber, coffee and spices such as cloves, cinnamon and pepper, prevail as cash crops. Tree and bush cultures in combination with fields of paddy rice dominate Sumatra's agrarian landscape today.

In West Java the land can be planted to *huma* (dryland rice) or *sawah* (wet rice paddy) after the forest is cleared. Alternatively, the land can be turned to *talun-kebun*, an indigenous Sundanese agricultural system. It usually consists of three stages —*kebun, kebun-campuran* and *talun* —each of which serves a different function. A mixture of annual crops is usually planted in the *kebun*. In some areas *kebun* is developed after harvesting the *huma* by following the dryland rice with annual field crops. This stage is economically valuable since most of the crops are sold for cash. After two years, tree seedlings have begun to grow in the field and there is less space for annual crops. At this point the *kebun* gradually evolves into a *kebun-campuran*, where annuals are mixed with half-grown perennials. This stage has economic value but also promotes soil and water conservation. After the annuals are harvested, the field is usually abandoned for two to three years to become dominated by perennials. This third stage has both economic and biophysical values. It is not uncommon to find *talun-kebun* composed of up to 112 species of plants. Of these plants about 42 percent provide for building material and fuelwood, 18 percent are fruit trees, 14 percent are vegetables, and the remainder constitute ornamentals, medicinal plants, spices, and cash crops.

A typical home garden has a vertical structure from year to year, though there may be some seasonal variation. The number of species and individuals is highest in the lowest story and decreases with height. The lowest story (less than one meter in height) is dominated by food plants like spices, vegetables, sweet potatoes, taro, *Xanthosoma,* chili pepper, eggplant, and legumes. The next layer (one to two meters in height) is also dominated by food plants, such as ganyong (*Canna edulis*), *Xanthosoma*, cassava and gembili (*Dioscorea esculenta*). The next story (two to five meters) is dominated by bananas, papayas, and other fruit trees. The five to ten meter layer is also dominated by fruit trees, for example soursop, jack fruit, pisitan (*Lansium domesticum*), guaga, mountain apple, or other cash crops such as cloves. The top layer (10 meters) is dominated by coconut trees and trees for wood production, like *Albizzia* and *Parkia*. The overall effect is a vertical structure similar to a natural forest, a structure that optimizes the use of space and sunlight. The most common plants in the pekarangan are cassava (*Manihot esculenta*) and ganyong (*Canna edulis*). Both have a high caloric content and are important as rice substitutes.

Integrated agriculture-aquaculture. In many parts of Asia, the productive use of land and water resources has been integrated by transforming wetlands into ponds separated by cultivable ridges. Overall integrated farming systems that include semi-intensive aquaculture are less risky for the resource-poor farmer than intensive fish farms, because of their efficiency derived from synergisms among enterprises, their diversity of produce, and their environmental soundness. In many traditional systems aquaculture goes beyond fish production and cash income as pond water and pond biota perform many ecological, social, and cultural services on an integrated farm. Thus aquaculture and water management act as an engine driving the sustainability of the entire farming system (Lightfoot 1990). This could also go the other type approaches that interleave water bodies and agriculturally productive land.

An example is the dike-pond system which has existed for centuries in South China. To produce or maintain the ponds, soil is dug out and used to repair the dikes around it. Before being filled with river water and rainwater, the pond is prepared for fish rearing by clearing, sanitizing and fertilizing with local inputs of quicklime, tea-seed cake, and organic manure. The fish stocked in the pond include various types of carp, which are harvested for home consumption and sale. Mulberry is planted on the dikes, fertilized with pond mud and irrigated by hand with nutrient-rich pond water. Mulberry leaves are fed to silkworms; the branches are used as stakes to support climbing vegetables and as fuelwood. In sheds, silkworms are reared for yarn production. Their excrements, mixed with the remains of mulberry leaves are used as fish feed. Sugarcane plants on the dikes provide sugar. Young leaves are used to feed fish and pigs, and old leaves to shade crops, for roofing thatch, and for fuel; the roots are also used as fuel. Grass and vegetables are also grown on the dikes to provide food for the fish and family. Pigs are raised mainly to provide manure but also for meat. They are fed sugarcane tops, by-products from sugar refining, aquatic plants, and other vegetable wastes. Their feces and urine, as well as human excrement and household wastes, form the principle organic inputs into the fish pond.

2.3.3 African Traditional Agriculture

African traditional food production systems. Most food production across Africa is by low-resource agriculture that causes little damage to the natural resource base. Almost all root, tuber, and plantain crops, and the majority of food legumes, plus the majority of grain, except wheat and perhaps maize, are produced on low-resource farms. More than 40% of the cassava, 60% of the maize, and 80% of the beans in that region are grown in mixtures with each other or other crops. A great variety of secondary crops such as fruits and vegetable are also grown under low-resource conditions to supplement these staples. In addition, an estimated 75 percent of all livestock in Sub-Saharan Africa is raised on farms where crop production is the principle source of subsistence. The major food farming systems include shifting cultivation, the bush fallow system or land rotation, the planted fallow system, compound or homestead farming, terrace farming, flood land cultivation, and transhumance pastoralism. Table 5 summarizes major characteristics of each system and indicating their contributions to food security.

Table 5. Elements and contributions of an appropriate agroecological strategy.

By far the most important system of farming is the bush fallow system, which is widely practiced in all ecological regions of Sub-Saharan Africa. Although no distinction is usually made between shifting cultivation and bush fallow, the latter is a more intensive system. It involves rotation of land within fixed farmland, whereas shifting cultivation in its original form was characterized by movement of cultivators from one site to another in search of virgin land without making a conscious attempt to return to former cultivated sites. The bush fallow system, often called slash-and-burn agriculture, is an extensive system of food crop production in which natural forest, secondary forest, or open woodlands are cleared and burnt. Farmers carefully select sites for cultivation using indicator plants as guides, judging the luxuriance of plant growth and the volume of vegetable material that will produce the best chemical-yielding ash when burnt. Temporary clearings are cultivated until crop yields begin to decline, usually after two or three cropping seasons when the soil fertility begins to fall. Then the land is abandoned to return to forest or bush fallow for a period ranging from 4 to 20 years. The system depends on natural capital with no external inputs. The farm implements are simple: hoe, machete, axe, and dibble stick.

Today, as a result of increased population pressure, fallow periods are being reduced. Where fallow period is too short —less than two years —soil fertility deteriorates and crop yields decline. Between 1980 and 1985, nearly half of the 40 Sub-Saharan countries for which data exist recorded declines in yield growth rates for major cereal crops ranging from −0.5 percent to −16.9 percent (World

Bank 1996a). Declines in crop yields force farmers to clear more forests and woodlands, including fragile and marginal lands where soil and climatic conditions are poorly suited to the cultivation of annual crops and yields are therefore low. Thus, much of the increased agricultural production in Sub-Saharan Africa has been achieved through expansion in cultivated area. According to the FAO, Africa's arable land expanded by 14 million hectares between 1973 and 1988. Most countries reflected this general trend. Between 1965 and 1985 untouched primary forests in Cote d'Ivoire were reduced by about 66 percent, whereas the area under cultivation doubled. The cultivated area in northern Nigeria increased from about 11 percent of the total area in the mid-1950s to 34 percent in 1990. There are a number of reasons why agricultural expansion on this scale cannot be sustained.

Traditional Marka systems in the Sahel. The climate in the Sahel region of Africa, made up in part by what is now Mali and Niger, is very dry. Average rainfall is less than 600 mm per year. The Marka, a local ethnic group who are experts in the cultivation of rice in this area and have been cultivating native rice since prehistoric times. Markan knowledge about rice and its cultivation is secret and imparts a specific ethnic identity. Their decisions are influenced by environmental clues —different varieties of rice have different vegetative periods, different adaptations to various flood depths, flood timing, pH tolerance, and fish predation. Different varieties are sown at different time intervals on different soil types. Social systems match production vagaries of this harsh environment. For example, trade buffering forestalls immediate equal compensation for when weather that favors one group may disfavor the other. A hierarchical system of land tenure prioritizes access to land, and the rules regulating access to common property have been encoded into local Islamic law. Prioritized access ensures that those with the specialized knowledge are those that make decisions on varieties of rice to be planted, as well as the timing of the planting.

Agroforestry in tropical Africa. In the populated humid tropical belt of western Africa, particularly on the northern edge of the Gulf of Guinea where the density rises above 80 inhabitants per square kilometer, agroforestry is practiced at the edge of the natural evergreen forests. The cultivators grow food staples such as manioc, yam, maize and plantains, in combination with cacao, bananas, coffee or oil-palm. In terms of both area covered and population involved, southern Nigeria is the heart of agroforestry in the Gulf of Guinea states. Studies estimate that 9269 hectares and 17,744 cultivators were involved in agroforestry in 1979. Southeast Nigeria, spreading over an area of evergreen forests on ferrallitic soils and ferrisols, tends to combine productive trees, such as banana, cacao and oil-palms, with food staples and pastures, whereas western Nigeria (with slightly lower precipitation rates and less population density) specializes in exportable timber species (teak), mixed with cacao, bananas or oil-palm. 'Managed taungya' makes intensive use of certain tree species for protection against wind or excessive insulation, such as Gmelina arborea, one of the most utilized trees in African agroforestry or Terminalia superba and Albizzia spp. Other species, such as the woody legume Leucaena leucocephala and Gliricidia sepium, help restore fertility to the soil. Gmelina arborea appears to be beneficial when planted at particularly convenient interspaces with yams and maize, but not in combination with manioc. Gliricidia increases the content of sodium, potassium, calcium and manganese in the soil. Concurrently, a measurable decrease in soil acidity has been observed when Gliricidia is associated with maize, yams, vegetables and manioc for subsistence purposes.

In the more semi-arid regions of Africa such as Senegal and the Zinder region of Niger highly productive agrosilvopastoral systems based on the use of *Acacia albida* have continued to evolve. This tree species has several characteristics that are valuable in agricultural systems. It drops its leaves at the onset of the rainy season which enriches the topsoil for sorghum and millet production and permits enough light to reach the ground for cereal growth while provides enough shading to reduce the effects of intense heat. During the dry season, the *Acacia's* long taproot draws nutrients from beyond the reach of other plants and stores these in its fruits and leaves that drop to the ground at the beginning of the next rainy season and are consumed by livestock. Livestock manure helps enrich the soil further and the richness of the fodder so more livestock can be supported than without the *Acacia.* Thus, crop yields are greater when an *Acacia* is in a field than when it is not. Using the tree with a proper balance of crop and livestock can also considerably extend the length of cropping without loss of productivity. For example, using the *Acacia* helped maintain continuous cropping of millet in the Sudan for 15-20 years in areas where the norm was 3 to 5 years.

Animal integration. Farming systems that combine animal and crop production vary across agroecological zones. In Asian lowland rice farming areas, buffalo are important animal components and provide (1) traction for cultivating fields and (2) milk and meat that are consumed domestically or sold in markets. Cattle, fowl (mainly chickens and ducks), and swine are also commonly raised on these farms. Feeds include crop residues, weeds, peelings, tops of root crops, bagasse, hulls, and other agricultural by-products. In highland areas, swine, poultry, buffalo, and cattle are raised in combination with rice, maize, cassava, beans, and small grains. Goats and poultry are the dominant animals in the cropping systems of tropical humid Africa. Sheep and swine are less abundant, but still common. Feeds include fallow land forage, crop residues, cull tubers, and vines. The small farms of Latin America typically include crop mixtures of beans, maize, and rice. Cattle are common and maintained for milk, meat, and draft. Swine and poultry are raised for food or for sale. Pastures, crop residues, and cut feeds support animal production.

Several other benefits accrue from agropastoral systems. In effect, incorporation of livestock into farming systems adds another trophic level to the system. Animals can be fed plant residues, weeds, and fallows with little impact on crop productivity. This serves to turn otherwise unusable biomass into animal protein, especially in the case of ruminants. Animals recycle the nutrient content of plants, transforming them into manure and allowing a broader range of fertilization alternatives in managing farm nutrients. The need for animal feed also broadens the crop base to include species useful for conserving soil and water. Legumes are often planted to provide quality forage and serve to improve nitrogen content in soils.

Beyond their agroecological interactions with crops, animals serve other important roles in the farm economy. They produce income from meat, milk, and fiber. Livestock increase in value over time and can be sold for cash in times of need or purchased when cash is available.

2.4 Biodiversity and its Ecological Function in Traditional Agriculture

