FORUM

Agroecology in the Tropics: Achieving a Balance Between Land Use and Preservation

STEPHEN R. GLIESSMAN
Agroecology Program
Environmental Studies
University of California
Santa Cruz, California 95064

ABSTRACT / Agroecology is the application of ecological concepts and principles to the design and management of sustainable agricultural systems. An agroecological approach to agriculture has special importance in the humid tropics where agricultural development and the preservation of tropical forests are most often in direct conflict. It is proposed that a more sustainable approach to development is needed, where agroecosystems depend on low external inputs, function more on the use of locally available and renewable resources, have benign impacts on the environment, and are based on the knowledge and culture of the local inhabitants. Examples of traditional agroecosystem management in Mesoamerica that can provide this basis are presented. The preservation of both biological and cultural diversity are integral to the long-term sustainable management of natural resources in the tropics.

In the lowland tropical regions of the world, except for the land within the immediate boundaries of parks and reserves, very little undisturbed rainforest seems to be left. Deforestation rates continue to accelerate despite the growing concern of conservationists throughout the last decade (Myers 1991). Most of the tropical countryside is now covered by a mosaic of different agroecosystems, dominated by pastures for cattle production or cash crops for export such as bananas, sugarcane, coffee, and cacao. Also common, but much less noticeable, is the array of crops that are grown more for local markets or direct consumption by the farmers and their families. A large diversity of fruits, vegetables, grains, and small animals are produced in small plots or home garden systems, providing for a major part of the local subsistence needs, but providing relatively little economic input to the local population.

With the rapid expansion of all-weather highways into most tropical regions, there has been a growing incentive to develop cash crops. In recent years, cattle production has taken the lead as the major form of development in such areas as the lowlands of Tabasco, Mexico, the northeastern lowlands of Costa Rica, and much of central and northern Brazil (Myers 1979; Hecht and Cockburn 1990). Large expanses of forested land, or land that had been in some other form of production, have been converted to pasture through clearing and planting of grasses. For example, in the Para state of the eastern Amazonia of Brazil, from 1975 when the Belem–Brasilia highway was completed until 1988, the area cleared increased from 8700 (0.7%) to 120,000 sq km (9.6%) of the state's territory (Maher 1988). Mexico is listed as one of the ten countries that have lost the most forest during the last decade (Myers 1991). Specialized cash crops are also being attempted, such as citrus, ornamentals, and certain spice plants. Each of these cash crops, however, has particular problems common to an agriculture where available land is concentrated under the ownership of a shrinking proportion of the population, coupled with the ecological problems inherent to larger-scale monocultures in the humid tropics. They must all respond to the complex set of limiting factors that impact any agroecosystem and affect how and which crops are managed (Altieri 1987, chap. 3).

The difficulties faced by agriculture in the humid tropics are well known (Janzen 1973, Ruthenberg 1980, Goodland and others 1984). Many are related directly to the problems that stem from farming under conditions of year-round high rainfall, heavy leaching of the soil, soils that are often of poor agricultural quality, rapid growth of pest problems, and increasing dependence on costly and imported inputs of fossil fuel-based materials. Therefore, the land that has already been cleared for export crops is very difficult to keep in production, putting pressure on the

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increasingly limited forested land for new areas for planting.

In the areas surrounding parks, reserves, and as yet undisturbed rainforest, the integration of studies of land use with those of rain-forest preservation must be accelerated. As the areas undergo deforestation and colonization, later immigrants are finding themselves confined either to progressively smaller parcels of land or to land of lower agricultural productivity. The pressure for new land has increased greatly, and in areas where no new land is available without moving onto still-forested land, it is essential that we look for agricultural management strategies that restore productivity to already deforested land. At the same time, in order to ensure that these new strategies are adopted and used, we need to involve the local people in the development and application of these management strategies (Chambers and others 1989). Indigenous traditional farming and land-use knowledge that has a history of local adaptation and selection is an important starting point for such development (Gliessman and others 1981, Gliessman 1988a, 1991, Altieri and Anderson 1986, Altieri and Hecht 1990).

Throughout much of the tropics today, it is this local land-use knowledge that continues to form the basis for much of the primary food production. This knowledge reflects experience gained from past generations, yet continues to develop in the present as the ecological and cultural environment of the people involved goes through the continual process of adaptation and change. Studies of these traditional agroecosystems can contribute greatly to the development of ecologically sound management practices (Klee 1980, Gliessman and others 1981, Altieri 1987, Wilken 1988). Diverse home garden systems, for example, are able to provide products for local use as well as contribute to regional economies, while at the same time maintaining a diverse vegetative cover over the soil (Gliessman 1988a). Complex crop mixtures, rotations, and practices developed by local farmers can provide environmental protection under tropical conditions as well as an array of harvestable products (Wilken 1988).

Many traditional farming systems make use of locally available resources rather than relying on purchased imported inputs. They can allow for the satisfaction of local needs while contributing to demands on the regional or national level. Most importantly, production takes place in ways that focus more on the long-term sustainability of the system, rather than an overemphasis on maximizing yield and profit. The ability of these systems to maintain productivity on a sustained basis reduces the need for the clearing of new lands. An agroecological approach to understanding how such systems function can provide information that can significantly reduce the pressure on rapidly diminishing forest reserves. Since small-scale farmers who have been displaced by the overall failure of national and international developmental strategies are being blamed for more than 60% of the current deforestation in the tropics (Myers 1991), they are obviously the people in the greatest need. It seems apparent that such an approach must go hand in hand with any efforts to preserve tropical rainforests.

Agroecology and Agroecosystem Management

Great strides have been made by ecologists and biologists towards understanding the ecological processes involved in the natural development and maintenance of tropical rainforest ecosystems. Answers are being found to questions related to such ecosystem properties as population dynamics, growth and regulation, productivity and diversity, nutrient cycling mechanisms, plant–herbivore interactions, and pollination biology. Only recently, however, have ecologists begun to focus such knowledge on the study of agricultural systems as ecosystems (Lowrance and others 1984, Altieri 1987). Out of this focus has emerged the field of agroecology, defined as the application of ecological concepts and principles to the design and management of sustainable agroecosystems (Gliessman 1986).

The ecosystem focus in agriculture serves as an important means of both defining the unit of study as well as establishing a framework for examining the interdisciplinary aspects that management of the system might require (Conway 1985, Gliessman 1985b). The boundaries of the system depend on the scope of the particular study, varying from something as small in scale as an individual crop plant to something as large as an entire farming region. By viewing an agroecosystem as a functional system of complementary relations between living organisms and their environment that are managed by humans with the purpose of establishing agricultural production, we have a basis for integrating the overlapping ecological and environmental traits with sociological, economic, political, and other cultural components of agriculture (Francis 1986). From this integrated analysis we hope to build the basis for sustainable management of tropical forest areas (Altieri and others 1987, Gliessman 1988a).

By considering a particular resource management system as part of a larger ecosystem, the impacts of any particular management practice can be understood. An agroecosystem can then be defined as a particular farm unit, comprised of inputs and outputs that move through an interacting array of biotic and abiotic components and are managed for the purpose of supplying humans with desired food, feed, fiber, and fuel. Human impacts on the agroecosystem, then, can be placed in the context of how nutrients enter, leave, or are recycled in the system. The population dynamics of crop and noncrop organisms respond to how the system is managed. The efficiency with which energy flows through, is stored, or is required for management can be examined and improved. A thorough knowledge of the interplay between physical, biological, and cultural factors of the tropical environment can permit the establishment of an understanding of both the agroecological potentials and limitations of a region. Research on all of these agroecosystem characteristics is needed in order to achieve sustainable land use in the tropics.

Criteria for the Sustainability of Traditional Tropical Agroecosystems

Sustainability refers to the ability of an agroecosystem to improve and maintain production over many generations, in the face of long-term ecological constraints and disturbances, as well as in response to social and economic pressures (Altieri 1987, Conway 1985). The emphasis of most of modern agriculture is undergoing a gradual shift from its primary goal of maximizing production and profits on the short-term, to a perspective that also considers the ability to maintain long-term production (Allen and Van Dusen 1988). This ability is beginning to be evaluated on an expanding set of criteria, including aspects such as soil and water conservation, genetic diversity, and appropriate management, in order to meet the growing demands on the food supply, achieve a reasonable quality of life, and maintain a safe and healthy environment (Allen and Van Dusen 1988, Altieri 1987, Jackson and others 1984, Brown and others 1987). At the same time, there is a growing concern that there may be trade-offs between the goals of maximizing production and maximizing sustainability (Conway 1985).

Research on traditional agroecosystems in the tropics is valuable from the perspective of sustainability (Altieri 1987, Gliessman and others 1981). They have been in use for a long time, and during that time have gone through many changes and adaptations (Wilken 1988). The fact that they still are in use is strong evidence for a social and ecological stability that modern, mechanized systems could well envy. We may have much to learn from them.

This article presents several examples of traditional agroecosystems that can be examined for the criteria of sustainability. These criteria include the following:

- A low dependence on external, purchased inputs.
- Function primarily on the use of locally available and renewable resources.
- Have beneficial or minimal negative impacts on both the on- and off-farm environment.
- Adapted to or tolerant of local conditions, rather than dependent on the massive alteration or control of the environment.
- Focus on long-term productive capacity.
- Conserve biological and cultural diversity.
- Built on the knowledge and culture of local inhabitants.
- Provide adequate domestic and exportable goods.

Sustainable agriculture depends on the integration of all of these components, and this involves understanding the agroecosystem at all levels of organization, from the individual crop plant or animal in the field, to the entire farm, to the region or beyond (Hart 1984).

Ecology and Management of Traditional Agroecosystems

Multiple-Crop Agroecosystems

The use of crop mixtures or multiple cropping can contribute greatly to increasing the sustainability of a cropping system on land that formerly was covered by tropical forest (Amador and Gliessman 1990, Gliessman 1985a). In such systems, more than one crop occupies the same piece of land either simultaneously or in some type of rotational sequence during the season. Yields can be increased, more efficient use of resources takes place, and the land can be occupied productively more continuously. Of course, trade-offs such as higher labor requirements or more complex management needs can occur, but the importance of multiple cropping is being recognized (Francis 1986), and the need for intensive agroecological studies of such mixed cropping has become more evident.

A traditional tropical multiple-cropping system that has been studied in some detail is the maize, bean, and squash polyculture (Figure 1). Intercropping of

Figure 1. Interior of a maize, bean, squash intercrop agroecosystem in Tabasco, Mexico.

maize (*Zea mays*) and beans (*Phaseolus vulgaris*) has been practiced in Central America since pre-Hispanic times and continues to be important in food production in this region today (Pinchinat and others 1976). A series of studies done in Tabasco, Mexico, showed that maize yields could be stimulated as much as 50% beyond monoculture yields when planted with beans and squash (Table 1) (Amador and Gliessman 1990). There was some yield reduction for the two associated crop species, but the total yields for the two crops together were higher than what would have been obtained in a monoculture (overyielding). Studies of the ecological mechanisms of such yield increases are important for establishing a strong basis for recommending widespread use of the cropping system. In a polyculture with maize, beans nodulate more and potentially are more active in biological fixation of nitrogen, which could be made directly available to the maize (Boucher 1979). Net gains of nitrogen have been observed when the crops are associated, despite its removal with the harvest (Gliessman 1982). This contributes to both the future reduction in dependence on externally purchased inputs of fertilizer, as well as a sounder ecological basis for managing resources within the system.

At the same time, study of the management practices employed in this polyculture have demonstrated the ecological basis upon which the practices can function. For example, despite the lower squash yields in the mixed planting, farmers insist that the crop system benefits from the squash presence through the control of weeds (Gliessman 1983). Thick, broad, horizontal leaves cast a dense shade that blocks sunlight, while leachates in rains washing the leaves contain allelopathic compounds that can inhibit weed growth. Herbivorous insects are at a disadvantage in the intercrop system because food sources are less concentrated and more difficult to find in the mixture (Risch 1980), and the presence of beneficial insects is often promoted due to such factors as the availability of more attractive microclimatic conditions or the presence of more diverse pollen and nectar sources (Letourneau 1986). In other systems, leaving weeds in the intercropped system can be advantageous as well (Chacon and Gliessman 1982). *Chenopodium ambrosioides*, for example, has the potential for inhibiting plant pathogenic nematodes through the release of toxic root exudates (Garcia 1980). *Lagascea mollis* can produce chemicals that help control the invasion of weeds detrimental to the crops if it is allowed to form a dense cover after the critical establishment stage in crop development (the first three to four weeks), thus avoiding inhibition of the crop (Gliessman 1983).

Diverse Home Gardens

Another agroecosystem that has been studied in some detail in tropical regions is the tropical home garden system (Figure 2). Home garden agroecosystems are ecologically well adapted to the tropics (Gliessman 1988b) and have even been proposed to be a managed mimic of tropical forest ecosystems (Ewel and others 1982). Many of the values of such systems for tropical farmers have been documented (Allison 1983, Gonzalez Jacome 1985). They are structurally very diverse, with an overstory of trees and an understory of herbs, shrubs, small trees, and vines. Animals are often an integral part of the gardens as well. Such diversity permits year-round harvesting of food products, as well as a wide range of other products used by local people such as firewood, medicinal plants, spices, and ornamentals.

In a home garden on the outskirts of Cañas, Guanacaste Province, Costa Rica, in an area of 1240 sq m, a total of 71 plant species were found, providing food, firewood, medicine, spices, color, and even enjoyment

Table 1. Yields of polyculture of maize, beans, and squash compared to monocultures planted at four different densities, Cardenas, Tabasco, Mexico[a]

	Monoculture densities				Polycultures
Densities of maize[b]	33,000	40,000	66,000	100,000	50,000
Yield (kg/ha)[c]	990	1,150	1,230	1,170	1,720
Densities of beans	56,800	64,000	100,000	133,200	40,000
Yield (kg/ha)	425	740	610	695	110
Densities of squash	1,200	1,875	7,500	30,000	3,330
Yield (kg/ha)	15	250	430	225	80

[a]Adapted from Amador and Gliessman (1990).

[b]Densities expressed as number of plants/ha.

[c]Yields for maize and beans expressed as dried grain, squash as fresh fruits.

Figure 2. View of a diversified tropical home garden agroecosystem in the lowlands of the state of Tabasco, Mexico.

for the household (Table 2). Some of the plant species served more than one function. The Shannon diversity index, taking into account both the number of different species as well as how they are distributed in the garden (Begon and others 1986), was 3.55, a relatively high value for an agricultural system. To a certain extent, plants were also distributed in the garden depending on the uses. Trees were concentrated towards the back of the plot, providing shade for the work area at the back of the house, as well as providing a stabilizing border along a riverbank that parallels the back of the property. Annual food crops were concentrated toward the front of the garden in full sunlight. The large number of ornamental species were clustered in beds or containers around the walls of the house or along the pathway leading from the front of the property to the house. Animal pens behind the house in the shade of the trees contained two pigs, a goat, and a guinea pig. An undetermined number of chickens freely roamed throughout the plot, as did several small dogs and two cats. Free-ranging animals could positively impact the garden by feeding on potential pest insects or recycling garbage, but could be negative by feeding on or digging up desirable plantings. Mango was the principal tree species, with maize, squash, beans, papaya, bananas, and cassava playing the most important roles in food production. The man of the household had full-time employment in the nearby town, so the garden played more of a supplemental role in the family economics.

More research is needed in order to further understand the structure and diversity of home gardens. They are extremely variable in size and design. They respond to local variations in soil type, drainage patterns, cultural preferences, economic standing of the family, family size and age patterns, reflecting a mul-

Table 2. Number of plant species and individuals of each species in home garden agroecosystem on the outskirts of Cañas, Guanacaste Province, Costa Rica, listed according to common use[a]

Plant uses	Number		Percent	
	Species	Individuals	Species	Individuals
Ornamental	36	517	48	21.6
Food	26	164	36	68.2
Medicinal	6	1	8	1.6
Firewood	5	17	7	1.7
Animal feed	1	51	1	6.7
Total	71	758		

[a]Total species and individual numbers are less than the sum of the columns due to the multiple function of some species. (From Gliessman 1988b.)

tiplicity of both ecological and cultural components. At the same time they are flexible, dynamic, and changing, depending on the needs of the family (Gonzalez Jacome 1985). In a typical home garden located in the Atlantic lowlands of Costa Rica, near the town of Puerto Viejo, Sarapiqui, mapping revealed considerable diversity and complexity within an area of approximately 3250 sq m. There were 26 species of trees, 16 perennial ornamentals, 8 annual/biennial crops, and 6 herbaceous species in the garden at the time of the study. The plants were distributed into what could be characterized as five functional areas as follows:

1. A low-diversity, regularly patterned planting of crops of potential cash value, including tuber crops, pineapple, and young coconuts.
2. A high-diversity, irregularly patterned planting of trees, shrubs, herbs, and vines of many uses designed to satisfy domestic needs.
3. A low-diversity, widely spaced planting of trees, most often with low grass or bare soil below, often used for social or recreational purposes.
4. A very high diversity, intercropped planting of ornamental herbs and shrubs planted very close to the house and cared for by the women in the household.
5. A moderate-diversity, alternately planted fencerow surrounding the property primarily composed of fruit and firewood tree species.

The garden reflects an interaction between the need for domestic food or use items, the desire or need for cash income, personal preference and enjoyment, and the constraints of time and space. A move into cash cropping, relatively new to this particular garden, is changing its structure dramatically. This trend will continue as trees mature, markets change, and the socioeconomic status of the family changes.

A Traditional Wetland Agroecosystem

Physical or biological factors of the environment that are limiting to agricultural production require special adaptations for agriculture to be sustainable. Agricultural development projects in much of the tropics have normally attempted to eliminate or alter such limitations. This usually involves the use of high levels of external inputs of energy or materials. There are many and well-known examples of massive irrigation, drainage, or desalination projects that attempted to alter existing ecological conditions but that achieved only limited success in terms of crop productivity and economic viability, while having little applicability for small-scale farmers (Barkin 1978). In many areas of Mesoamerica, where heavy rainfall and low-lying topography combine to generate conditions of water-logging, local farmers have found ways to accommodate the factor of excess soil moisture into the design and management of quite sustainable traditional agroecosystems.

An important indication of how to manage low areas of the tropics comes from evidence for the prehispanic use of the wetlands of Mesoamerica. Recent studies have demonstrated that the prehistoric Maya of the Yucatan peninsula region developed several types of technologies that enabled them to cultivate wetlands. This included a range of types of raised or drained fields (Turner and Harrison 1981, Siemens 1982, Darch 1983, Gliessman and others 1985), including a type of tropical chinampas more typical today in the central valley of upland Mexico (Gomez-Pompa and Jimenez-Osornio 1987). Observations of archeological ground patterns suggest that large areas of wetlands were devoted to cultivation, relying on systems of canals or drains, raised platforms, and other structures that permitted water manipulation.

In a study of a large depression or bajo in southern Quintana Roo, Mexico, a wetland system that encompassed up to 20,000 ha was examined (Gliessman and others 1985). Topographic surveys and soil analysis demonstrated the presence of an intricate system of depressions and raised surfaces that formed a complex and interconnected network of canals and platforms. They were constructed as early as the Late Preclassic Maya period (800 BC–150 AD) and were utilized until the Late Classic period (600–850 AD) when they were abandoned for unknown reasons. Evidence suggests that this system was used continuously for over 1000 years.

Dark grey soil layers found only in the soil profile of the platforms is the remnant of the ancient planting bed that was excavated from the lower depressions (canals) and mounded up to form a planting surface, available for planting even at the peak of the wet season. Fertility of the soil and the structure of the platforms was probably maintained by a combination of periodic canal clearing and agricultural practices that promoted organic matter inputs (e.g., intercropping, rotations, mulching). Very limited evidence exists on the actual types of cultivation practices associated with these relict farming systems. Work in nearby Belize indicates that maize and cotton may have been important species (Turner and Harrison 1981). It is also unknown with what frequency the canals may have been cleaned for mounding up the platforms. The intensity of cropping of the platforms, as well as yields, would have been influenced greatly by this practice, much as we observe in present-day raised-field systems (Wilken 1988). Otherwise, only by studying present-day traditional use of wetlands in southeastern Mexico, which may in part be derived from Mayan practices, can evidence on past uses be derived (Gliessman and others 1981, Gomez-Pompa 1987).

A very interesting and productive present-day use of wetland areas has been observed in Tabasco for the production of maize and other crops (Orozco-Segovia and Gliessman 1991). Since this practice is most often observed in communities of indigenous background, the practice may have been handed down from generation to generation. In this system, maize is planted on higher ground around flood-prone areas during the wet season months of June–December. As water levels drop during the dry season months of February and March, farmers follow the receding water line with another maize planting, known locally as the March planting (marceño). Similar systems have been observed as far north in Mexico as Veracruz (Siemens 1990).

During much of the year, the low areas are inundated to depths ranging from a few centimeters to as much as a meter. Marsh vegetation densely covers the area during the wet season and is felled quickly with machetes as the water level recedes (Figure 3). A very dense mat of organic matter is produced by this process (10–20 cm), into which seed is planted with a pointed stick. About a week following planting, fire is used to burn part of this organic mat, as well as to kill back any weed seedlings or sprouts of the marsh plants. The timing of burning is very important in order to ensure that the fire burns only the dry leaves on top of the mat and does not reach the soil. The maize seed, planted 10–15 cm below the surface of the soil, is not harmed by the fire. Local short-cycle varieties of maize (two to three months from planting to harvest) are most frequently used. The practice of

Figure 3. Swamp vegetation being cleared for the planting of maize in a low-lying area subject to flooding for the greater part of the year; planted during the short dry season between March and May, near Cardenas, Tabasco, Mexico.

using seed from the previous harvest for the subsequent planting favors the use of local varieties. The use of a 2 1/2-month variety known as "mejen," a Maya word meaning precocious or early maturing, again shows the link between the past and present day systems.

The maize grows very quickly in this system, and when fire is not used excessively and flooding is allowed to occur every year, weeding is usually not necessary. At approximately 2 1/2 months the mature maize stalks are doubled over just below the corn ear, facilitating final drying of the grain for another two to four weeks before harvest. Yields between 4–5 tons/ha of dry grain are common, and in one year in five, yields can reach 10 tons/ha. This is many times the average yield for mechanized production on lands that have been cleared and drained in the same region, but at a fraction of the input labor and cost (Amador and Gliessman 1990).

Following the harvest, all crop and noncrop residues are left on the soil surface. Soil profiles demonstrate the presence of a thick organic soil to a depth of 30–40 cm below the surface. During inundation, organic matter produced by the marsh plants or left by the previous cropping cycle are incorporated and conserved below water. Nutrient minerals that enter the system with surface drainage are captured by the highly productive aquatic sector of the ecosystem, leading to the formation of a soil that analysis has shown to have organic matter levels over 30%, total nitrogen as high as 3%, and high levels of other important plant nutrients (Gliessman unpublished data). The key element, then, in the management of this system is to take advantage of the benefits gained from a period of inundation. When the system is drained artificially in an attempt to extend the cropping season, the organic layer in the soil can be reduced to 5 cm in less than two years, and yields drop dramatically.

Future Directions

An agroecological focus for agricultural development in the humid tropics goes much beyond crop yields, delving deeply into the complex set of factors that contribute to agroecosystem sustainability. Local traditional agroecosystems that have developed a degree of permanence in face of the diverse and often limiting conditions facing farmers in the tropics are adapted to this set of factors. They have evolved through time with little dependence on purchased inputs, a greater reliance on renewable resources, and ecologically based management strategies. Future research in agriculture for the humid tropics must take advantage of this knowledge and experience. It represents the blending of knowledge gained by ecologists studying the dynamics and stability of tropical rain-forest ecosystems with the knowledge of farmers and agronomists on how to manage the complexities of food-producing agroecosystems. From this can come the sustainability in the production base so critical for giving small farmers the stability and viability they need to provide for their own needs, to contribute to meeting the needs of the greater society, and ultimately to reduce the pressure on tropical forests.

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