Multifunctional Dimensions of Ecologically-based Agriculture in Latin America

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Summary
Today in Latin America there are still regions with microcosms of traditional farming systems, (i.e., in Mesoamerica, the Andean region, and the Amazon Basin) that have emerged over centuries of cultural and biological evolution and that based on locally available resources and the cultivation of a diversity of crops and varieties in time and space, have allowed traditional farmers to maximize harvest security and the multiple use of the landscape with limited environmental impact. Agro-biodiverse traditional agroecosystems represent a strategy which ensures diverse diets and income sources, stable production, minimum risk, efficient use of land resources, and enhanced ecological integrity. This legacy of traditional agriculture demonstrate that the combination of stable and diverse production, internally generated and maintainable inputs, favorable energy input/output ratios, and articulation with both subsistence and market needs, comprises an effective approach to achieve food security, income generation, and environmental conservation. Traditional approaches represent multiple use strategies that enhance the multifunctional nature of agriculture, an important feature for the health of rural regions in the next century.

Introduction
Agriculture is a process of artificialization of nature. In general, modern agriculture has implied the simplification of the structure of the environment over vast areas, replacing nature’s diversity with a small number of cultivated plants and domesticated animals. In fact, the world’s agricultural landscapes are planted with only some 12 species of grain crops, 23 vegetable crop species, and about 35 fruit and nut type species, that is no more than 70 plant species spread over approximately 1,440 million hectares of presently cultivated land in the world, a sharp contrast with the diversity of plant species found within one hectare of a tropical rainforest which typically contains over 100 species of trees (Thrupp 1998).

But not all forms of agriculture have followed the classic path of artificialization and intensification. In Latin America, systems range from "low intensity" long-fallow swidden to "high intensity" permanent cultivation wherein large areas have been greatly modified from their natural state and are dominated by monocultures. In commercial agricultural areas, natural habitats are lost through expansion of agricultural production, especially of cattle, sugarcane, cotton, soybean, coffee, and (recently) non-traditional export crops. Highly capitalized farms tend either to be on high-quality lands where profitability is contingent on low wages and large landholdings. By contrast, farms of resource-poor peasants tend to be on ecologically marginal lands or on lands recently opened to agriculture. Thus, impoverished farmers lack access to good farmland and capital and are forced by necessity onto remnants of natural areas, which generally occur on steep slopes, along rivers, and in other fragile environments such as forest margins.

In the midst of these extreme types of agriculture, there are, in the region microcosms of traditional
farming systems, (i.e., in Mesoamerica, the Andean region, and the Amazon Basin) that have emerged over centuries of cultural and biological evolution and represent accumulated experiences of peasants interacting with the environment without access to external inputs, capital, or scientific knowledge (Chang, 1977; Wilken, 1987). Using inventive self-reliance, experiential knowledge, and locally available resources, indigenous farmers have often developed farming systems with sustained yields (Harwood, 1979; Reinjtes et al., 1992). These agroecosystems, based on the cultivation of a diversity of crops and varieties in time and space, have allowed traditional farmers to maximize harvest security under low levels of technology and with limited environmental impact (Clawson, 1985). There are also several examples of grass-roots rural development programs in Latin America aimed at the maintenance and/or enhancement of biodiversity in traditional agroecosystems, and which represent a strategy which ensures diverse diets and income sources, stable production, minimum risk, efficient use of land resources, and enhanced ecological integrity (Altieri, 1995; Pretty, 1995).

Increasingly, evidence emerging from analysis of traditional agriculture and NGO-led agroecological projects, shows that the combination of stable and diverse production, internally generated and maintainable inputs, favorable energy input/output ratios, and articulation with both subsistence and market needs, comprises an effective approach to achieve food security, income generation, and environmental conservation (Pretty, 1997; Altieri et al., 1998). As it will be argued in this paper, these approaches represent multiple use strategies that enhance the multifunctional nature of agriculture.

The Multifunctional Nature of Traditional Agriculture

Despite the increasing industrialization of agriculture, the great majority of the farmers in the developing world are peasants, or small producers, who still farm the valleys and slopes of rural landscapes with traditional and subsistence methods. It is estimated that in Latin America there are about 16 million peasant units occupying close to 160 million hectares and involving 75 million people, representing two-thirds of the regions total rural population (Ortega 1986).

Many of these agroecosystems are small-scale, geographically discontinuous, and located on a multitude of slopes, aspects, microclimates, elevational zones, and soil types. They also are surrounded by many different vegetation associations. The combinations of diverse physical factors therefore are numerous and are reflected in the diverse cropping patterns chosen by farmers to exploit site-specific characteristics. Many of the systems are surrounded by physical barriers (e.g., forests, rivers, mountains) and therefore are relatively isolated from other areas where the same crops are grown in large scale. Descriptions of the species and structural diversity and management of these traditional systems are discussed elsewhere (Alcorn, 1984; Altieri et al., 1987; Chang, 1977; Clawson, 1988; Denevan, 1995; Francis, 1986; Toledo et al. 1985).

In many areas, 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 (Altieri, 1995). According to Toledo (1995), indigenous farmers in the hot and humid tropical regions of Latin America tend to combine various
production systems as part of a typical household resource management scheme (Figure 1):

1. The milpa system, which may constitute a system of polyculture including up to 20-25 agricultural and forest species (annual and perennial) and is focused on the cultivation of maize, but in many occasions is combined and even substituted by agricultural market-oriented products (hot pepper, rice, sesame seeds, sugarcane, beans, etc.);

2. The extraction of products from the primary or secondary rainforests of different ages undergoing the succession process;

3. The manipulation of forest-unit sequences at different stages of anthropic disturbance, from which certain marketable products (mainly coffee, vanilla, and cocoa) are obtained;

4. The management of home gardens, which are agroforestry systems located next or close to households.

The main features underlying the sustainability of these multiple use peasant systems are (Marten, 1986; Reinjtes et al. 1992):

- Farms are small in size with continuous production serving subsistence and market demands
- Maximum and effective use of local resources and low dependence on off-farm inputs
- High net energy yield because energy inputs are relatively low
- Labor is skilled and complementary, drawn largely from the household or community relations.
- Dependency on traction and manual labor shows favorable energy input/output ratios
- Heavy emphasis is on recycling of nutrients and materials
- Building on natural ecological processes (e.g., succession) rather than struggling against them
- Diversified farm systems based on several cropping systems, featuring mixtures of crops, and crops with varietal and other genetic variability.

A salient feature of traditional farming systems is their degree of plant diversity, generally in the form of polycultures and/or agroforestry patterns (Clawson, 1985). This peasant strategy of minimizing risk by planting several species and varieties of crops stabilizes yields over the long term, promotes diet diversity, and maximizes returns under low levels of technology and limited resources (Richards, 1985). Traditional multiple cropping systems provide as much as 20 percent of the world food supply (Francis, 1986). Polycultures constitute at least 80 percent of the cultivated area of West Africa, while much of the production of staple crops in the Latin American tropics occurs in polycultures (Table 1). Polycultures produce more combined yield in a given area than could be obtained from monocultures of the component species. Most traditional polycultures exhibit LER values greater than 1.5. Moreover, yield variability of cereal/legume polycultures are much lower than for monocultures of the components (Table 2).

Table 1. Prevalence of polycultures in Latin American countries.1
<table>
<thead>
<tr>
<th>Country</th>
<th>Dominant crop</th>
<th>Percentage of crop grown in polyculture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brazil</td>
<td>Maize</td>
<td>11</td>
</tr>
<tr>
<td>Colombia</td>
<td>Rice</td>
<td>6</td>
</tr>
<tr>
<td>Dominican Republic</td>
<td>Maize</td>
<td>40</td>
</tr>
<tr>
<td>Guatemala</td>
<td>Beans</td>
<td>73</td>
</tr>
<tr>
<td>Mexico</td>
<td>Maize</td>
<td>20</td>
</tr>
<tr>
<td>Paraguay</td>
<td>Beans</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>Maize</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Sweet potatoes</td>
<td>10</td>
</tr>
<tr>
<td>Venezuela</td>
<td>Rice</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>Maize</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>Beans</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Cassava</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Cotton</td>
<td>50</td>
</tr>
</tbody>
</table>

1Modified after Francis (1986).

Table 2. Coefficient of variability of yields registered in different cropping systems during 3 years in Costa Rica.

<table>
<thead>
<tr>
<th>Cropping system</th>
<th>Monoculture (mean of sole crops)</th>
<th>Polyculture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cassava/bean</td>
<td>33.04</td>
<td>27.54</td>
</tr>
<tr>
<td>Cassava/maize</td>
<td>28.76</td>
<td>18.09</td>
</tr>
<tr>
<td>Cassava/sweet potato</td>
<td>23.87</td>
<td>13.42</td>
</tr>
<tr>
<td>Cassava/maize/sweet potato</td>
<td>31.05</td>
<td>21.44</td>
</tr>
<tr>
<td>Cassava/maize/bean</td>
<td>25.04</td>
<td>14.95</td>
</tr>
</tbody>
</table>

Source: Francis 1986

Many traditional agroecosystems are located in centers of crop diversity, thus containing populations of variable and adapted land races as well as wild and weedy relatives of crops. It is estimated that
throughout the Third World more than 3,000 native grains, roots, fruits and other food plants can still be found (Altieri and Merrick, 1987). Thus traditional agroecosystems essentially constitute in-situ repositories of genetic diversity (Altieri et al. 1987). Descriptions abound regarding systems in which tropical farmers plant multiple varieties of each crop, providing both intraspecific and interspecific diversity, thus enhancing harvest security. For example, in the Andes, farmers cultivate as many as 50 potato varieties in their fields (Brush et al. 1981). Similarly, in Thailand and Indonesia, farmers maintain a diversity of rice varieties in their paddies which are adapted to a wide range of environmental conditions, and regularly exchange seeds with neighbors (Grigg, 1974).

Tropical agroecosystems composed of agricultural and fallow fields, complex home gardens, and agroforestry plots, commonly contain well over 100 plant species per field and provide construction materials, firewood, tools, medicines, livestock feed, and human food. Home gardens in Mexico and the Amazon display highly efficient forms of land use, incorporating a variety of crops with different growth habits. The result is a structure similar to a tropical forest, with diverse species and a layered configuration (Brookfield and Padoch, 1994). A list of the most common agroforestry systems prevalent in Latin America is provided in Table 3.

Table 3. Principal agroforestry systems in Latin America.

<table>
<thead>
<tr>
<th>Types of systems</th>
<th>Examples</th>
<th>Typical countries</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Agro-silvicultural systems</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A.1 Taungya</td>
<td><em>Cordia alliodora</em> + maize, beans or rice</td>
<td>Brazilian Amazon</td>
</tr>
<tr>
<td></td>
<td><em>Caesalpina velutina</em> + maize</td>
<td>Guatemala</td>
</tr>
<tr>
<td></td>
<td><em>Gmelina arborea</em> + maize and beans</td>
<td>Mexico</td>
</tr>
<tr>
<td>A.2 Wood-producing trees/annual crop intercropping</td>
<td><em>Pinus elliottii</em> + soybean or maize</td>
<td>Argentina</td>
</tr>
<tr>
<td></td>
<td><em>Populus spp.</em> + maize or potato</td>
<td>Argentina</td>
</tr>
<tr>
<td></td>
<td><em>Inga spp.</em> + rice or banana</td>
<td>Brazil</td>
</tr>
<tr>
<td></td>
<td><em>Eucalyptus spp.</em> + maize</td>
<td>Brazil</td>
</tr>
<tr>
<td></td>
<td><em>Cedrela odorata</em> + maize, rice or sugar cane</td>
<td>Colombia</td>
</tr>
<tr>
<td></td>
<td><em>Spondia mombin</em> or <em>Swietenia macrophylla</em> + maize, beans or rice</td>
<td>Mexico</td>
</tr>
<tr>
<td>A.3 Fruit trees annual crops</td>
<td>Citrus, apples, papaya, mangoes, etc. + annual crops</td>
<td>Mexico</td>
</tr>
<tr>
<td>A.4 Shade trees or soil improvers mixed with crop</td>
<td><em>Erythrina spp.</em>, <em>Inga sp.</em>, <em>Albizia carbonaria</em>, <em>Cordia alliodora</em>, etc. + coffee, banana</td>
<td>Colombia, Costa Rica, Ecuador</td>
</tr>
<tr>
<td>Types of systems</td>
<td>Examples</td>
<td>Typical countries</td>
</tr>
<tr>
<td>------------------------------</td>
<td>---------------------------------------------------------------------------</td>
<td>------------------------------------------------</td>
</tr>
<tr>
<td>A.5 Living fences and/or</td>
<td>Gliricidia sepium, Erythrina abissinica, Leucaena leucocephala, etc.,</td>
<td>Colombia, Mexico, Dominican Republic, Cuba,</td>
</tr>
<tr>
<td>windbreaks</td>
<td>around crops</td>
<td>Guatemala</td>
</tr>
<tr>
<td></td>
<td>Eucalyptus, Populus, Pinus, around crops</td>
<td>Chile, Argentina, Uruguay</td>
</tr>
<tr>
<td>B. Agrosilvopastoral systems</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B.1 Crops and animals within</td>
<td>Pinus caribaea + sheep and/or poultry + sorghum, maize, cassava or</td>
<td>Venezuela,</td>
</tr>
<tr>
<td>forest plantations</td>
<td>peanuts</td>
<td>Dominican Republic</td>
</tr>
<tr>
<td>B.2 Living fences around</td>
<td>Casuarina equisetifolia, Cedrela odorata, Bromissum alicastrum</td>
<td>Cuba, Mexico</td>
</tr>
<tr>
<td>rural communities</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B.3 Home gardens</td>
<td>Several tree, crop, animal mixtures</td>
<td>Dominican Republic, Mexico, Cuba, Haiti</td>
</tr>
<tr>
<td>C. Silvopastoral systems</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C.1 Animal grazing or forage</td>
<td>Populus sp. + Bromus unioloides or Trifolium sp.</td>
<td>Argentina</td>
</tr>
<tr>
<td>production under trees</td>
<td>Pinus caribaea + Anchrus sp.</td>
<td>Brazil</td>
</tr>
<tr>
<td></td>
<td>Pinus sp. or Populus sp. + sheep</td>
<td>Chile</td>
</tr>
<tr>
<td>C.2 Animal grazing or forage</td>
<td>Prosopis flexuosa and Aspidosperma sp. with natural pasture</td>
<td>Argentina</td>
</tr>
<tr>
<td>production within secondary</td>
<td>Secondary forests with browsing of Brosimum alicastrum</td>
<td>Mexico</td>
</tr>
<tr>
<td>forests</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C.3 Commercial wood-</td>
<td>Alnus acuminata + Pennisetum clandestinum</td>
<td>Costa Rica</td>
</tr>
<tr>
<td>producing trees with</td>
<td></td>
<td></td>
</tr>
<tr>
<td>pastures</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C.4 Shade trees or soil</td>
<td>Alnus jorullensis + P. clandestinum</td>
<td>Colombia</td>
</tr>
<tr>
<td>improvers within pastures</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Prosopis sp., Parkinsonia microphylla, Cercidium sp. as shade trees in</td>
<td>Mexico</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Prosopis spp., Atriplex spp.</td>
<td>Chile, Argentina, Peru</td>
</tr>
<tr>
<td></td>
<td>Lividivia coriari and P. juliflora for goats</td>
<td>Colombia</td>
</tr>
<tr>
<td></td>
<td>Brosimum alicastrum for browsing</td>
<td>Mexico</td>
</tr>
</tbody>
</table>

Source: FAO 1984

Small areas around peasant households commonly average 80-125 useful plant species, many for food and medicinal use (Toledo et al. 1985; Alcorn, 1984). Perennials such as fruit trees are a
conspicuous feature of most homegardens (Marten, 1986). In some of the more humid areas, there are so many different kinds of trees and field cops in the homegardens, and they are growing in such abundance that it looks more like a tropical forest than a garden (Clarke and Thaman, 1993). Most diverse homegardens are in reality a collection of domesticated and semi-domesticated plants with a variety of uses including food, fuel, construction materials, herbal medicine, ornamentation, and shade (Table 4). Homegardens are often in continuous production throughout the year and lend themselves to intensive care because they are so conveniently close to the house. They can be fertilized with kitchen wastes, receive supplementary irrigation with well water, and be attended by women and children in their spare time.

Table 4. Ecological and cultural functions and uses of trees in Latin America.

<table>
<thead>
<tr>
<th>Ecological</th>
<th>Cultural/Economic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shade</td>
<td>Soil improvement</td>
</tr>
<tr>
<td>Erosion control</td>
<td>Frost protection</td>
</tr>
<tr>
<td>Wind protection</td>
<td>Wild animal food</td>
</tr>
<tr>
<td></td>
<td>Animal/plant habitats</td>
</tr>
<tr>
<td></td>
<td>Flood/runoff control</td>
</tr>
<tr>
<td></td>
<td>Weed/disease control</td>
</tr>
</tbody>
</table>

| Timber (commercial)                 | Broom                                             |
| Timber (subsistence)               | Parcelling/wrapping                               |
| Fuelwood                           | Abrasive                                          |
| Boat building (canoes)             | Illumination/torches                              |
| Sails                              | Insulation                                        |
| Tools                              | Decoration                                        |
| Weapons/hunting                    | Body ornamentation                                |
| Containers                         | Cordage/lashing                                   |
| Woodcarving                        | Glues/adhesives                                   |
| Handicrafts                        | Caulking                                          |
| Fishing equipment                  | Fibre/fabric                                      |
| Floats                             | Dyes                                              |
| Toys                               | Plaited ware                                      |
| Switch for children/discipline     | Hats, mats                                        |
| Brush/pain brush                   | Baskets                                           |
| Musical instruments                | Commercial/export products                        |
|                                     | Fertility control                                 |
|                                     | Non-alcoholic beverages                           |
|                                     | Stimulants                                        |
|                                     | Narcotics                                         |
|                                     | Masticants                                        |
|                                     | Meat tenderizer                                    |
|                                     | Preservatives, medicines                          |
|                                     | Aphrodisiacs                                      |
|                                     | Fertility control                                 |
The interface of traditional agroecosystems and natural areas

Most of the above studies of traditional agriculture have focused on the productive units where crops are grown. This limited view of the peasant agroecosystem ignores the fact that many peasants utilize, maintain, and preserve, within or adjacent to their properties, areas of natural ecosystems (forests, hillsides, lakes, grasslands, streamways, swamps etc.) that contribute valuable food supplements, construction materials, medicines, organic fertilizes, fuels, religious items, etc. (Toledo et al. 1985). In fact, the crop-production units and adjacent ecosystems constitute a continuum where plant gathering, fishing, and crop production are actively produced.

For many peasant societies, agriculture is considered a part of a bigger system of land use. For example, the P’urhepecha Indians who live in the region of lake Patzcuaro in Michoacan, Mexico, in addition to agriculture, gathering is part of a complex subsistence pattern based on multiple uses of their natural resources (Caballero and Mapes, 1985). These people use more than 224 species of wild native and naturalized vascular plants for dietary, medicinal, household, and fuel needs. Similarly, the Jicaque Indians of central Honduras, who live on the Montana de la Flor reservation, use over 45 plant species from the pine-oak forest, riverine habitat, or dooryard as foods, medicines, fuel, etc. Like their mestizo neighbors, the Jicaque grow corn using slash and burn techniques. The cultivated fields are widely spaced throughout the forest and in travelling from one field to the next, the Jicaque usually collect wild plant food along the way to be added to the cooking pots of the family’s compound (Lentz, 1986).

Agriculture- natural ecosystem interfaces are of key significance as it has been shown that farmers accrue general ecological services from natural vegetation growing near their properties. For example, in many highland regions of Central America, the indigenous flora of the higher forests, not only provide valuable native plants for commercial and subsistence products, but also serve as natural barriers to the lowland agricultural crops against the spread of plant diseases and insect pests. Also, clearing comparatively small agricultural plots in a matrix of secondary forest vegetation permits easy emigration of natural enemies of insect pests from the surrounding jungle (Altieri,
In western Guatemala, small farms depend on nearby forests to manage marginal infertile soils. Leaf litter is carried from nearby forests and spread each year over intensively cropped vegetable plots to improve tilth and water retention. Litter is raked up, placed in bags or nets, and carried to fields by men or horses, or from more distant sources, by trucks. After spreading, the leaf litter is worked into the soil with a broad hoe. In some cases, litter is first placed beneath stable animals, and then, after a week or so the rich mixture of pulverized leaves, manure, and urine is spread over the fields and turned under. Although the quantities applied vary, farmers in Almolonga, Zunil, and Quetzaltenango apply as much as 40 metric tons of litter/ha. each year. Rough calculations made in mixed pine-oak stands indicate that one hectare of cropped land requires the litter production from 10 ha. of regularly harvested forest, or less, if harvesting is sporadic (Wilken, 1987).

A case study of a multifunctional traditional farming system
The study conducted in a Totonaca native community of the Papantla region in the state of Veracruz illustrates of a case multiple use peasant management strategy of hot and humid tropical ecosystems. The community entails 166 households totaling a population of 877 and sharing a 15-17 hectare territory. Most households (72%) have between 7 and 9 hectares, while only 9 % own more than nine hectares and 19% less than seven hectares. Most of these households also handle from 3 to 9 ecogeographic or landscape units as resources for production where they implement the multiple-use strategy. The main units that each family manages during production are: milpa (maize fields), pasture ground, home gardens, rainforest for vanilla production, rainforest to extract wood and other products, and cash crop areas (Figure 2).

Using almost exclusively its own physical energy (with scant, almost inexistent use of chemical fertilizers), making little use of outside inputs, and relying on family or community labor, the productive units of this native community are self-sufficient in terms of food, they are energy efficient, they do not generate waste, and they sustain a high level of agrobiodiversity (with 355 species of plants, animals, and fungi). To this should be added the fact the community succeeds in being economically profitable as a result of selling maize, beef, milk, vegetable, fruits, vanilla, brown sugar, palm leaves and other products (Toledo, 1995).

The Nature and Function of Biodiversity in Agriculture
Today, scientists worldwide are increasingly starting to recognize the role and significance of biodiversity in the functioning of agricultural systems (Swift et al., 1996). Research suggests that whereas in natural ecosystems the internal regulation of function is substantially a product of plant biodiversity through flows of energy and nutrients and through biological synergisms, this form of control is progressively lost under agricultural intensification and simplification, so that monocultures, in order to function, must be predominantly subsidized by chemical inputs (Swift et al. 1996). Commercial seed-bed preparation and mechanized planting replace natural methods of seed dispersal; chemical pesticides replace natural controls on populations of weeds, insects, and pathogens; and genetic manipulation replaces natural processes of plant evolution and selection. Even decomposition is altered since plant growth is harvested and soil fertility maintained, not through nutrient recycling, but with fertilizers.
One of the most important reasons for maintaining and/or encouraging natural biodiversity is that it performs a variety of ecological services (Altieri, 1991). In natural ecosystems, the vegetative cover of a forest or grassland prevents soil erosion, replenishes ground water, and controls flooding by enhancing infiltration and reducing water runoff. In agricultural systems, biodiversity performs ecosystem services beyond production of food, fiber, fuel, and income. Examples include, recycling of nutrients, control of local microclimate, regulation of local hydrological processes, regulation of the abundance of undesirable organisms, and detoxification of noxious chemicals. These renewal processes and ecosystem services are largely biological, therefore their persistence depends upon maintenance of biological diversity. When these natural services are lost due to biological simplification, the economic and environmental costs can be quite significant. Economically in agriculture, the burdens include the need to supply crops with costly external inputs, since agroecosystems deprived of basic regulating functional components lack the capacity to sponsor their own soil fertility and pest regulation. As functional biodiversity decreases, the requirement for higher management intensity increases, thus monocultures must be subsidized with external inputs (Figure 3). Often, the costs involve a reduction in the quality of the food produced and of rural life in general due to decreased soil, water, and food quality when erosion and pesticide and/or nitrate contamination occurs (Altieri, 1995).

Biodiversity refers to all species of plants, animals and microorganisms existing and interacting within an ecosystem. In agroecosystems, pollinators, natural enemies, earthworms, and soil microorganisms are all key biodiversity components that play important ecological roles thus mediating processes such as genetic introgression, natural control, nutrient cycling, decomposition, etc. (Figure 4). The type and abundance of biodiversity in agriculture will differ across agroecosystems which differ in age, diversity, structure, and management. In fact, there is great variability in basic ecological and agronomic patterns among the various dominant agroecosystems. In general, the degree of biodiversity in agroecosystems depends on four main characteristics of the agroecosystems (Southwood and Way, 1970):

1. the diversity of vegetation within and around the agroecosystem
2. the permanence of the various crops within the agroecosystem
3. the intensity of management
4. the extent of the isolation of the agroecosystem from natural vegetation

In general, agroecosystems that are more diverse, more permanent, isolated, and managed with low input technology (i.e. agroforestry systems, traditional polycultures) take fuller advantage of work done by ecological processes associated with higher biodiversity than highly simplified, input-driven and disturbed systems (i.e. modern row crops and vegetable monocultures and fruit orchards) (Altieri, 1995).

All agroecosystems are dynamic and subject to different levels of management so that the crop arrangements in time and space are continually changing in the face of biological, cultural,
socio-economic, and environmental factors. Such landscape variations determine the degree of spatial and temporal heterogeneity characteristic of agricultural regions, which in turn conditions the type of biodiversity present.

According to Vandermeer and Perfecto (1995), two distinct components of biodiversity can be recognized in agroecosystems. The first component, planned biodiversity, is the biodiversity associated with the crops and livestock purposely included in the agroecosystem by the farmer, and which will vary depending on management inputs and crops spatial/temporal arrangements. The second component, associated biodiversity, includes all soil flora and fauna, herbivores, carnivores, decomposers, etc., that colonize the agroecosystem from surrounding environments and that will thrive in the agroecosystem depending on its management and structure. The relationship of both biodiversity components is illustrated in Figure 3. Planned biodiversity has a direct function, as illustrated by the bold arrow connecting the planned biodiversity box with the ecosystem function box. Associated biodiversity also has a function, but it is mediated through planned biodiversity. Thus, planned biodiversity also has an indirect function, illustrated by the dotted arrow in the figure, which is realized through its influence on the associated biodiversity. For example, the trees in an agroforestry system create shade, which makes it possible to grow only sun-tolerant crops. So the direct function of this second species (the trees) is to create shade. Yet along with the trees might come small wasps that seek out the nectar in the tree’s flowers. These wasps may in turn be the natural parasitoids of pests that normally attack the crops. The wasps are part of the associated biodiversity. The trees, then, create shade (direct function) and attract wasps (indirect function) (Vandermeer and Perfecto, 1995).

The key is to identify the type of biodiversity that is desirable to maintain and/or enhance in order to carry out ecological services, and then to determine the best practices that will encourage the desired biodiversity components. As shown in Figure 5, there are many agricultural practices that have the potential to enhance functional biodiversity, and others that negatively affect it. The idea is to apply the best management practices in order to enhance and/or regenerate the kind of biodiversity that can subsidize the sustainability of agroecosystems by providing ecological services such as biological pest control, nutrient cycling, water and soil conservation, etc.

The link between agrobiodiversity and multifunctionality
When agricultural development takes place in a natural environment, it tends to result in a heterogeneous mosaic of varying types of habitat patches spread across the landscape. The bulk of the land may be intensely managed and frequently disturbed for the purposes of agricultural production, but certain parts (wetlands, riparian corridors, hillsides) may be left in a relatively natural condition, and other parts (borders and strips between fields, roadsides, and adjacent natural areas) may occasionally be disturbed but not intensely managed. In addition, natural ecosystems may surround or border areas in which agricultural production dominates (Gliessman, 1998).

The heterogeneity of the agricultural landscape varies greatly by region. In some parts of Latin America, where commercial, export agriculture predominates, the heavy use of agricultural chemicals, mechanical technology, narrow genetic lines, and irrigation over large areas have made the landscape relatively homogenous. In such areas, the agricultural landscape is made up mostly
of large areas of single crop agricultural production. The expansion of such agricultural landscapes disrupts natural areas in three important ways. First, natural ecosystems become fragmented and important ecological linkages may be changed or uncoupled. For example, the conversion of uplands from native grasslands or deciduous forest to cotton will profoundly affect the nutrient and pesticide inputs into any adjacent wetlands. Second, the fragmentation increases boundary phenomena by increasing the proportion of area that is near a boundary. This results in an exacerbation of the impacts from adjacent agriculture. Third, the absolute loss of natural areas generally means that the remaining patches are increasingly more distant from each other. Thus each remnant takes on more and more the properties of oceanic islands in the sense that source areas for recolonization are often very distant. Thus, local extinction events for both species and genes are unlikely to be balanced by recolonization or gene flow. Unlike real islands, remnant patches of natural ecosystems are highly vulnerable to invasion by weedy plants and animals from surrounding agricultural lands and are vulnerable as well to perturbations created by agricultural production practices (Fry, 1995).

In peasant dominated areas, the use of traditional farming practices with minimal industrial inputs has resulted in a varied, highly heterogeneous landscape—possibly even more heterogeneous than would exist naturally. In such heterogeneous environments, natural and semi-natural ecosystem patches included in the landscape can become a resource for agroecosystems. An area of non-crop habitat adjacent to a crop field, for example, can harbor populations of natural enemies which can move into the field and parasitize or prey upon pest populations. (Altieri, 1994) A riparian corridor vegetated by native plant species can filter out dissolved fertilizer nutrients leaching from crop fields, promote a presence of beneficial species, and allow the movement of native animal species into and through the agricultural components of the landscape.

On the other hand, agroecosystems can begin to assume a positive rather than a negative role in preserving the integrity of natural ecosystems. Many small scale-diversified agroecosystems have been designed and managed in ways that make them more friendly to native species. For example, by encouraging hedgerows, vertebrates can be provided with large habitats, better food sources, and corridors for movement. Native plants can have more suitable habitats and find fewer barriers to dispersal. Smaller organisms, such as below ground microbes and insects, can flourish in organically managed soils and thus benefit other species since they are such important elements in ecosystem structure and function (Glissman, 1998).

By managing agricultural landscapes from the point of view of biodiversity conservation as well as sustainable production, the multiple use capacity of agriculture can be enhanced providing several benefits simultaneously (Thrupp, 1998):

- increase agricultural productivity;
- build stability, robustness, and sustainability of farming systems;
- contribute to sound pest and disease management;
- conserve soil and increase natural soil fertility and soil health;
- diversify products and income opportunities from farms;
- add economic value and increase net returns to farms;
• reduce or spread risks to individuals, communities, and nations;
• increase efficiency of resource use and restore ecological health;
• reduce pressure of agriculture on fragile areas, forests, and endangered species;
• reduce dependency on external inputs, and;
• increase nutritional values and provide sources of medicines and vitamins.

The effects of agrobiodiversity in mitigating extreme climatic effects, such as the drought promoted by El Niño’s were recently evident in northern Honduras. An agroforestry project reviving the Quezungal method, an ancient agricultural system, spared about 84 farming communities from destruction. Farmers using the method lost only 10 percent of their crops in 1998’s severe drought, and actually obtained a grain surplus of 5-6 million pounds in the wake of Hurricane Mitch. On the other hand, nearby communities which continued the use of slash and burn, were severely affected by El Niño phenomena, which left a legacy of human misery and destruction of vitally important watersheds.

Such agroforestry programs which reduce deforestation and burning of plant biomass can provide a sink for atmospheric carbon dioxide and also considerably reduce emissions of nitrous oxide. Recent research shows that promoting techniques already familiar to thousands of small farmers in Latin America such as, crop rotation and cutting back on chemical fertilizers through the use of composting can act as important sinks for atmospheric carbon dioxide storing it below the soil surface.

The benefits of agrobiodiversity in enhancing the multifunctional agriculture extend beyond the above described effects as shown by the impacts of shaded coffee farms in Latin America. Farmers typically integrate into their coffee farms many different leguminous trees, fruit trees, and types of fuel wood and fodder. These trees provide shade, a habitat for birds and animals that benefit the farming system. In Mexico, shade coffee plantations support up to 180 species of birds, including migrating species, some of which play key roles in pest control and seed dispersal.

Learning how to manage an agriculture that promotes both environmental as well as productive functions will require inputs from disciplines not previously exploited by scientists, including agroecology, ethnoscience, conservation biology, and landscape ecology. The bottom line, however, is that agriculture must adopt ecologically sound management practices, including diversified cropping systems, biological control and organic soil management as replacements for synthetic pesticides, fertilizers, and other chemicals. Only with such foundation can we attain the goal of a multifunctional agriculture.

**Biodiversity and pest management**

Nowhere are the consequences of biodiversity reduction more evident than in the realm of agricultural pest management. The instability of agroecosystems becomes manifest as the worsening of most insect pest problems is increasingly linked to the expansion of crop monocultures at the expense of the natural vegetation, thereby decreasing local habitat diversity (Altieri and Letourneau, 1982). Plant communities that are modified to meet the special needs of humans become subject to heavy pest damage and generally the more intensely such communities are modified, the more
abundant and serious the pests. The effects of the reduction of plant diversity on outbreaks of herbivore pests and microbial pathogens is well-documented in the agricultural literature (Andow, 1991; Altieri, 1994). Such drastic reduction in plant biodiversity and the resulting epidemic effects can adversely affect ecosystem function with further consequences on agricultural productivity and sustainability.

In modern ecosystems, the experimental evidence suggests that biodiversity can be used for improved pest management (Altieri and Letourneau, 1994; Andow, 1991). Several studies have shown that it is possible to stabilize the insect communities of agroecosystems by designing and constructing vegetational architectures that support populations of natural enemies or that have direct deterrent effects on pest herbivores. For example, at the landscape level, data demonstrates that there is enhancement of natural enemies and more effective biological control where wild vegetation remains at field edges and in association with crops (Altieri, 1994). These habitats may be more important as overwintering sites for predators or they may provide increased resources such as pollen and nectar for parasitoids and predators form flowering plants (Landis, 1994). Many studies have documented the movement of beneficial arthropods from margins into crops and higher biological control is usually observed in crop fields close to wild vegetation edges than in fields isolated from such habitats (Altieri, 1994).

In many cases, weeds and other natural vegetation around crop fields harbor alternate hosts/prey for natural enemies, thus providing seasonal resources to bridge gaps in the life cycles of entomophagous insects and crop pests (Altieri and Letourneau, 1984). A classic case is that of the egg parasitoid wasp *Anagrus epos* whose effectiveness in regulating the grape leafhopper *Erythroneura elegantula* was increased greatly in vineyards near areas invaded by wild blackberry (*Rubus* sp.). This plant supports an alternative leafhopper (*Dikrella cruentata*) which breeds in its leaves in winter. Recent studies show that French prune orchards adjacent to vineyards provide overwintering refuges for *Anagrus* and early benefits of parasitism are promoted in vineyards with prune trees plants upwind from the vineyard.

At the crop field level, most experiments that have mixed other plant species with the primary host of a specialized herbivore show that in comparison with diversified cropping systems, monocultures have greater population densities of specialist herbivores (Andow, 1991). In these monoculture systems, herbivores exhibit greater colonization rates, greater reproduction, higher tenure time, less disruption of host finding and lower mortality by natural enemies (see Table 5 for examples in Latin America).

<table>
<thead>
<tr>
<th>Multiple cropping systems</th>
<th>Pests (regulated)</th>
<th>Factor(s) involved</th>
<th>Country</th>
</tr>
</thead>
</table>

Table 5. Selected examples of multiple cropping systems that effectively prevent insect-pest outbreaks in Latin America.
<table>
<thead>
<tr>
<th>Crop Mix</th>
<th>Pest</th>
<th>Effect</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cassava intercropped with cowpeas</td>
<td>Whiteflies *Aleurotrachelus socialis and *Trialeurodes variabilis</td>
<td>Changes in plant vigor and increased abundance of natural enemies</td>
<td>Colombia</td>
</tr>
<tr>
<td>Corn intercropped with beans</td>
<td>Leafhoppers *Empoasca kraemeri, leaf beetle *Diabrotica balteata and fall armyworm *Spodoptera frugipeda</td>
<td>Increase in beneficial insects and interference with colonization</td>
<td>Colombia</td>
</tr>
<tr>
<td>Corn intercropped with beans</td>
<td>Corn leafhopper *Dalbulus maidis</td>
<td>Interference with leafhopper movement</td>
<td>Nicaragua</td>
</tr>
<tr>
<td>Cucumbers intercropped with maize and broccoli</td>
<td>Flea beetles *Acalymma vitata</td>
<td>Lower crop apparency</td>
<td>Costa Rica</td>
</tr>
<tr>
<td>Corn-bean-squash</td>
<td>Caterpillar *Diaphania hyalinata</td>
<td>Enhanced parasitization</td>
<td>Mexico</td>
</tr>
<tr>
<td>Corn-beans</td>
<td>Stalk borer *Diatraea lineolata</td>
<td>Enhanced predation</td>
<td>Nicaragua</td>
</tr>
</tbody>
</table>

Source: Altieri 1994

There are various factors in crop mixtures that help constrain pest attack. A host plant may be protected from insect pests by the physical presence of other plants that may provide a camouflage or a physical barrier. Mixtures of cabbage and tomato reduce colonization by the diamond-back moth, while mixtures of maize, beans, and squash have the same effect on chrysomelid beetles. The odors of some plants can also disrupt the searching behavior of pests. Grass borders repel leafhoppers from beans and the chemical stimuli from onions prevent carrot fly from finding carrots (Altieri, 1994).

Alternatively, one crop in the mixture may act as a trap or decoy - the ‘fly-paper-effect’. Strips of alfalfa interspersed in cotton fields in California attract and trap Lygus bugs. There is a loss of alfalfa yield, but this represents less than the cost of alternative control methods for the cotton. Similarly, crucifers interplanted with beans, grass, clover, or spinach are damaged less by cabbage maggot and cabbage aphid. Another factor as predicted by the natural enemies hypothesis is that reduced insect pest incidence in polycultures may be the result of increased predator and parasitoid abundance and efficiency (Altieri, 1994).
Conclusions
Most research conducted on traditional and peasant agriculture in Latin America suggests that small holder systems are sustainably productive, biologically regenerative, and energy-efficient, and also tend to be equity enhancing, participatory, and socially just. Besides crop diversity, peasant farmers use a set of practices that cause minimal land degradation. These include the use of terraces and hedgerows in sloping areas, minimal tillage, small field sizes, and long fallow cycles. By concentrating on short rotations and fewer varieties, agricultural modernization in the same areas has caused environmental perturbation and eroded genetic diversity (Altieri 1991, Altieri 1996, Wilken 1997).

By adopting a multiple use strategy, indigenous farmers manage a continuum of agricultural and natural systems, obtaining a variety of products as well as ecological services thus truly enacting a multifunctional agriculture. Diversified cropping systems, such as those used by peasants, based on intercropping and agroforestry have been the target of much research recently. This interest is largely based on the new emerging evidence that these systems are more sustainable and more resource-conserving (Vandermeer, 1995). These attributes are connected to the higher levels of functional biodiversity associated with complex farming systems. In fact, an increasing amount of data reported in the literature, documents the effects that plant biodiversity has on the stabilization of agroecosystem processes.

In a recently conducted, well replicated experiment, where species diversity was directly controlled in grassland systems, it was found that ecosystem productivity was increased and that soil nutrients were utilized more completely when there was a greater diversity of species, leading to lower leaching losses from the ecosystem (Tilman et al. 1996). In traditional agroecosystems this same pattern applies to insects as herbivore regulation increases with increasing plant species richness. Evidence suggests that as plant diversity increases, pest damage seems to reach acceptable levels, thus resulting in more stable crop yields. Apparently, the more diverse the agroecosystem and the longer this diversity remains undisturbed, the more internal links develop to promote greater insect stability. One aspect that is clear is that species composition is more important than species number per se. The challenge is to identify the correct assemblages of species that will provide through their biological synergisms key ecological services such as nutrient cycling, biological pest control, and water and soil conservation (Altieri 1994).

While it may be argued that peasant agriculture generally lacks the potential of producing meaningful marketable surplus, it does ensure food security. Many scientists wrongly believe that traditional systems do not produce more because hand tools and draft animals put a ceiling on productivity. Productivity may be low but the causes appear to be more social, not technical. When the subsistence farmer succeeds in providing food, there is no pressure to innovate or to enhance yields. Nevertheless, NGO-led agroecological field projects show that traditional crop and animal combinations can often be adapted to increase productivity when the biological structuring of the farm is improved and labor and local resources are efficiently used (Altieri 1995). In fact, most agroecological technologies promoted by NGOs can improve traditional agricultural yields increasing output per area of marginal land, enhancing also the general agrobiodiversity and its associated positive effects on food security and environmental integrity (Pretty 1997).
It is not a matter of romanticizing subsistence agriculture or considering development per se as detrimental. The idea is to stress the value of traditional agriculture in the preservation of native crop diversity and the adjacent vegetation communities as this mode of appropriation of nature enhances the multifunctionality of agriculture (Toledo, 1995). Basing a rural development strategy on traditional farming and ethnobotanical knowledge, combined with elements of modern agroecology, not only assures continual use and maintenance of valuable agrobiodiversity, but also allows for the diversification of agricultural areas ensuring a variety of ecological services vital for food security, natural resource conservation, economic viability, climate amelioration, cultural preservation, and community empowerment. The challenge is now to promote the right policies and institutional partnerships that can scale-up ecologically based agriculture so that its multifunctional impacts are rapidly spread across the rural landscapes of Latin America.

References


