Linking ecologists and traditional farmers in the search for sustainable agriculture

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For centuries, traditional farmers have developed diverse and locally adapted agricultural systems, managing them with ingenious practices that often result in both community food security and the conservation of agrobiodiversity. This strategy of minimizing risk stabilizes yields, promotes dietary diversity, and maximizes returns using low levels of technology and limited resources. These microcosms of agricultural heritage still cover no less than 10 million ha worldwide, providing cultural and ecological services not only to rural inhabitants, but to mankind generally. These services include the preservation of traditional farming knowledge, local crop and animal varieties, and native forms of sociocultural organization. By studying these systems, ecologists can enhance their knowledge of the dynamics of complex systems, especially the relationship between biodiversity and ecosystem function and practical principles for the design of more sustainable agroecosystems appropriate to small farmers. Novel agroecosystem designs have already been modeled on successful traditional farming systems.

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The majority of farmers in the developing world tend small plots in marginal environments, using indigenous agricultural methods. These diversified agroecosystems have emerged over centuries of biological evolution, and represent the experiences of farmers interacting with their environment without access to external inputs, capital, or scientific knowledge (Wilson 1999). Using self-reliance and experiential knowledge, these farmers have developed systems that generate sustained yields to meet their subsistence needs (Wilken 1987; Denevan 1995). Part of this performance is linked to the high levels of agrobiodiversity, which in turn positively influence traditional agroecosystem function (Vandermeer 2003).

The continued existence of millions of hectares of raised fields, terraces, polycultures, and agroforestry systems represent a successful indigenous adaptation to difficult environments, and are a tribute to the creativity of rural farmers (Altieri 1999; Figure 1). These microcosms of traditional agriculture offer promising models for other areas as they promote biodiversity, thrive without agrochemicals, and sustain year-round yields (Denevan 1995). Traditional crop management practices represent a rich resource for ecologists interested in understanding the mechanisms at work in complex agroecosystems, such as the interactions between biodiversity and ecosystem function or the use of natural succession as templates to design this type of system. It is only recently that ecologists have recognized the virtues of traditional agroecosystems, where sustainability is based on complex ecological models. An examination of the ways these farmers use biodiversity can speed the emergence of the principles needed to develop more sustainable systems. In fact, such studies have already helped several agroecologists create novel farm designs, well adapted to local circumstances (Altieri 2002). A key challenge involves the translation of these principles into practical strategies for natural resource management. More research is needed urgently, before this ancient ecological legacy is lost to industrial agricultural development.

In a nutshell:

- Traditional agriculture conserves agrobiodiversity and safeguards reservoirs of genetic diversity and local ecological knowledge
- Ecologists can enrich ecological theory by understanding the complex interactions in traditional agroecosystems
- A dialogue between farmers and ecologists could lead to participatory development aimed at improving smallholder agriculture

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Extent and importance of traditional agriculture

Despite the increasing industrialization of agriculture, millions of peasant farmers fill rural landscapes with small-scale, diversified agricultural systems (Beets 1990; Netting 1993). It is estimated that 10–15% of the 960 million ha of land under cultivation in the developing world is managed by traditional farmers (Table 1). In Latin America, the rural farming population includes 75 million people with farm sizes averaging 1.8 ha. Together, these farms contribute greatly to the regional food supply, producing approximately 41% of the agricultural output for domestic consumption (Browder 1989). Another two million indigenous people living in the Amazon and southern Mexico use integrated agroforestry systems, the products of which are aimed at subsistence and local or regional markets (Toledo 2000).

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Figure 1. Traditional terraces in the Andes. Farmers divide the mountain into agroecological belts where various crops are grown according to the changing, slope-induced environmental conditions. Farmers typically have plots in various belts to decrease the frequency of disaster from events such as droughts and frosts. More than 30 varieties of potatoes are mixed in each terrace, which are designed to conserve soil and water

In Africa, the majority of farmers are smallholders with farm sizes of less than 2 ha. Most practice "low-resource" agriculture, producing most of the grain and legumes and almost all root, tuber, and plantain crops with virtually no fertilizers or improved seed. This situation has changed, however, as food production per capita has declined and Africa, once self-sufficient in cereal production, 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 (Asenso-Okyere and Benneh 1997). Of the over 200 million rice farmers living in Asia, few farm more than 2 ha of rice. In China alone, there are probably 75 million rice farmers who still practice farming methods that are over one thousand years old (Hanks 1992). Local cultivars, grown mostly on upland ecosystems, make up the bulk of the rice eaten by the rural poor, while large areas planted with modern, semi-dwarf varieties supply most of the rice for urban centers.

■ The complexity of indigenous knowledge

Traditional agroecosystems and associated plant diversity are the result of a complex coevolutionary process between natural and social systems, resulting in strategies for ecosystem appropriation. Indigenous peoples' knowledge of ecosystems usually result in diverse agricultural landscapes managed for multiple uses, resulting in local food self-sufficiency (Figure 2). The indigenous knowledge behind the agricultural modification of the physical environment is very detailed (Brokenshaw *et al.* 1980). Ethnobotany is the most common source of folk knowledge, and also the way in which farmers discriminate soil types, degree of soil fertility, and land use categories (Williams and Ortiz-Solorio 1981; Alcorn 1984). Information is obtained from the environment by special cognition and perception systems (ways of detecting or understanding soils, plants, etc) that select for the most adaptive information about these environmental factors, and successful adaptations are passed from generation to generation (Wilken 1987).

Most traditional agriculture is place-specific, evolving in time in a particular habitat and culture, and this is both where and why it tends to be successful. The transfer of specific technologies to other places may fail if soils, tools, or social organization differ. This is why agroecologists do not focus on specific technologies, but look at the underlying principles used by traditional farmers to meet the environmental requirements of their localities. Despite the diversity of agricultural systems, most traditional agroecosystems share a number of structural and functional similarities (Gliessman 1998):

- High species numbers
- High structural diversity in time and space
- Exploitation of the full range of local microenvironments
- Maintenance of closed cycles of materials and waste through effective recycling practices
- Complex biological interdependencies, resulting in a high degree of natural pest suppression
- Dependence on local resources and human and animal energy, thereby using low levels of input technology and resulting in positive energy efficiency ratios
- Use of local varieties of crops, wild plants, and animals

Rural knowledge is based not only on observation, but also on experimental learning. This approach is apparent in the selection of local seed varieties, and in the testing of new cultivation methods to overcome particular biological constraints. Most farmers have an intimate knowledge of their surroundings, especially within a small geographical and cultural radius. This local expertise cannot be matched by the generalized knowledge of the ecologist, yet the ecologist's sophisticated training cannot be matched by the experiential knowledge of local farmers (Vandermeer 2003). This is why a "dialogue of wisdoms" is necessary between ecologists and traditional farmers, so that those who possess the local knowledge participate in development strategies that combine local and external innovation in the planning of appropriate farming techniques (Richards 1985).

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What have ecologists learned from traditional farmers?

The prevalence of diversified cropping systems is key to local farmers, as synergistic interactions between factors such as crops, soils, and animals improve soil fertility, pest control, and productivity (Reinjtjes *et al.* 1992; Altieri 1995). This means that ecologists would do well to learn more about the dynamics of traditional systems. For example, understanding how interplanting allows cropping systems to reuse their own stored nutrients can improve the way in which modern farmers manage soil fertility. Similarly, determining which biological mechanisms minimize crop pests in complex agroecosystems can lead to improvements in pest management (Altieri 1994). A series of novel farming designs have been modeled after successful traditional farming systems, including the following examples.

Figure 2. *A diversified traditional agricultural landscape mosaic in Guatemala. Farmers derive environmental benefits from the surrounding forest, such as litter to fertilize crops, a diversity of food items (wild plants, birds, mushrooms, etc), water, and beneficial insect predators and pollinators that colonize the fields.*

Mimicking nature

For centuries, small farmers in tropical regions have incorporated a variety of crops with different growth habits in their home gardens. The result is agroforests, which are similar to tropical forests and include diverse species in a multi-layered configuration (Denevan 1995). Like their natural models, these mimics tend to be productive, biodiverse, pest resistant, and nutrient conserving (Ewel 1999).

Ewel (1986) termed this strategy the "succession analog method". It requires a detailed description of a specific natural ecosystem and the identification of crop plants that are structurally and functionally similar to the plants in the natural ecosystem. The plants' natural spatial and chronological arrangements are then used to design an analogous crop system, by replacing wild species with botanically and structurally similar cultivars (Figure 3).

According to Ewel (1999), imitating natural ecosystems rather than planting monocultures managed with high input is the only sensible strategy in the humid tropical lowlands. This region epitomizes environments with low abiotic stress, but enormous biotic intricacy. The keys to agricultural success in this region are to channel productivity into crops of nutritional and economic importance, maintain adequate vegetative diversity to compensate for losses, encourage biodiversity to increase resistance against

Table 1. Distribution and extent of traditional agriculture in the developing world (Altieri 2002)

Region	Number of farmers	Area	Contribution to food security
Latin America	16 million peasant farms; 50 million indigenous people	38% of total land devoted to agriculture, about 60.5 million ha	41% of food crop consumed domestically; half of humid tropics in Mexico and Amazon
Brazil	4.8 million family farms	30% of total agricultural land	50% of land devoted to food crops
Cuba	1612 cooperatives and individual peasants	1.5 million ha	10% of all food crops
Africa	60-80% labor force involved in agriculture; 70% of population (about 375 million) living in rural areas of sub-Saharan Africa	100–150 million ha	80% of cereals, 95% of meat
Asia	200 million small-scale rice farmers	7.3 million ha of upland rice; 20.5 million ha of rainfed rice	250 million rural people supported by upland shifting cultivation
Global estimate for developing world	50-100 million smallholder family farms	50–100 million ha	30–50% of basic food crops

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Figure 3. A succession analog cropping system evolving towards a complex agroforest in the lowland tropics. Perennials play both productive (fruits, wood, fuel, construction materials) and protective (soil cover, microclimate amelioration, biomass production) roles.

herbivores, and use perennial plants to maintain soil fertility, guard against erosion, and fully utilize resources.

Mechanisms underlying productivity in multi-species agroecosystems

In small-scale multiple cropping systems, productivity per unit area is higher than in monocropping systems with the same level of management. Yield advantages can range from 20–60%. These differences can be explained by the reduction of losses due to weeds, insects, and diseases, and a more efficient use of available water, light, and nutrients (Vandermeer 1989). In Mexico, maize/squash/bean polycultures yield more that monocultures, producing up to 4 tons per ha of dry matter (Figure 4). In drier environments, maize is replaced by sorghum without affecting the productive capacity of cowpeas or beans. This system exhibits greater production stability, since sorghum is more tolerant to drought (Francis 1986).

The higher productivity of polycultures is the result of facilitation, whereby one crop modifies the environment in a way that benefits a second crop by, for example, lowering the population of a critical herbivore, or by releasing nutrients that the second crop needs (Vandermeer 1989). Polycultures exhibit greater yield stability and productivity declines less during drought or other stresses. Natarajan and Willey (1986) examined the effect of drought on these enhanced yields by manipulating water stress on intercrops of sorghum, millet, and peanut. All the intercrops consistently yielded more than monocultures at five levels of moisture availability. The yields actually increased with water stress, so that the relative differences in productivity between the planting techniques became greater as the stress increased.

Vegetative diversity and pest outbreaks

Field populations of insect herbivores are less abundant on the wild relatives and ancestors of crops than on domesticated plants (Rosenthal and Dirzo 1997). It is only when traditional systems are modernized, reducing the plant and genetic diversity, that herbivore abundance increases to pest levels. Although traditional farmers may be aware that insects can cause crop damage, they rarely consider them pests, according to Morales *et al.* (2001), who studied traditional methods of pest control among the highland Maya of Guatemala. Influenced by local attitudes, the authors reformulated their research questions; rather than studying how the farmers control pest problems, they focused on why they do not have them in the first place. This line of inquiry proved more productive, as it allowed the authors to understand how the farmers managed pest-resilient cropping systems, and to recognize how the intercropping of diverse plant species helps prevent insect pest buildup. One crop may be planted as a diversionary host, protecting other, more susceptible crops from serious damage, or crops grown simultaneously may increase the abundance of predators and parasites that biologically suppress pests (Altieri 1994).

Greater plant diversity leads to reduced herbivorous insect numbers (Andow 1991; Altieri 1994). Differences in pest abundance between simple and diverse annual cropping systems can be explained by both differences in the movement, colonization, and reproductive behavior of herbivores, and by the activities of natural enemies (Andow 1991; Altieri and Nicholls 1999; Landis *et al.* 2000; Figure 5).

Insect communities can be stabilized by constructing vegetatively diverse agroecosystems that support natural enemies and/or directly inhibit pest attack (Smith and McSorely 2000). An example is the push–pull system developed at the International Center of Insect Physiology and Ecology to control lepidopteran stemborers in Africa. This system uses Napier grass (*Penisetum purpureum*) and Sudan grass (*Sorghum vulgare*) along the borders of maize fields to attract stemborers away (the "pull"), as well molasses grass (*Melinis minutiflora*) and silverleaf (*Desmodium uncinatum*) intercropped with the maize to repel them (the "push") (Khan *et al.* 1998). Border grasses also increase the parasitization of stemborers by the wasp *Cotesia semamiae*, and are important fodder plants. The

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leguminous silverleaf (*Desmodium uncinatum*) suppresses parasitic witchweed (*Striga* sp) by a factor of 40 when compared to a maize monocrop. *Desmodium*'s nitrogen-fixing ability increases soil fertility, and it is also an excellent forage. As an added bonus, sale of *Desmodium* seed is proving to be a new income generator for local women.

The push–pull system has been tested on over 450 farms in Kenya, and is now being promoted by the national extension systems in East Africa. Participating farmers are reporting a 15–20% increase in maize yield. In semi-arid areas plagued by both stemborers and *Striga*, a substantial increase in milk yield has occurred in the last 4 years, due to the fact that farmers can support more dairy cows on the fodder produced. When they plant maize together with the push–pull plants, they make a return of $2.30 for every dollar invested, compared to the $1.40 they obtain by planting a maize monocrop (Khan *et al.* 1998).

More research along these lines is crucial to a huge number of small farmers who rely on the complex of predators and parasites associated with their mixed cropping systems for insect pest control. Major changes in the levels of plant diversity in such systems could disrupt natural pest control mechanisms, making farmers more dependent on pesticides.

Genetic diversity and disease incidence

In general, traditional agroecosystems are less vulnerable to catastrophic loss because they involve a wide variety of cultivars, including landraces (native parental varieties), which are genetically more heterogeneous than modern cultivars and offer a variety of defenses against vulnerability (Thurston 1991). In areas of crop diversity, traditional agroecosystems also contain populations of wild and weedy relatives of crops that enrich genetic diversity. Clawson (1985) described systems in which tropical farmers plant multiple varieties of each crop, providing interspecific diversity and improving harvest security. Genetic diversity heightens disease resistance and lets farmers exploit different microclimates and derive multiple uses, nutritional and otherwise, from the genetic variation within species.

Studies by plant pathologists provide evidence to suggest that genetic heterogeneity reduces the vulnerability of crop monocultures to disease. Mixing crop species and/or varieties can delay the onset of diseases by reducing the spread of disease-carrying spores, and by making environmental conditions less favorable to the spread of certain pathogens. Four different mixtures of rice varieties grown by Chinese farmers on farms over 3000 ha suffered 44% less blast incidence and produced 89% greater yield than homogeneous fields, without the use of fungicides (Zhu *et al.* 2000). More studies along these lines are needed to validate the strategy of genetic diversification, allowing more precise planning of cropping designs for optimal pest and disease regulation.

Diversity provides security against diseases, pests, droughts, etc, allowing farmers to exploit the full range of

Figure 4. *A typical milpa (maize–bean polyculture) in the Latin American tropics. These crops complement each other nutritionally, and their interactions result in a series of ecological synergies that benefit farmers.*

agroecosystems that exist in each region. Ecological research can be of great value in assessing the potential impact of introductions of transgenic crops into areas of crop diversity. Scientists are already posing intriguing questions. Does unintended gene flow from GM maize compromise maize biodiversity, or is it likely to confer an evolutionary advantage to local varieties (Quist and Chapela 2001)? If transgenes do persist, will they prove disadvantageous to farmers and crop diversity (McHughen 2000)? Can genetically engineered plants increase crop production, while at the same time repelling pests, resisting herbicides, and conferring adaptation to the stress factors commonly faced by small farmers?

There is a danger that traits important to indigenous farmers (resistance to drought, competitive ability, performance on intercrops, storage quality, etc) could be traded for transgenic qualities that may not be important to them (Jordan 2001). Farmers could lose the ability to adapt to changing biophysical environments and to produce relatively stable yields with a minimum of external inputs.

A challenge for agroecologists is to help farmers design local conservation strategies for plant species that represent an important resource for subsistence farming communities (Brush 2000). At the same time, conservation of traditional varieties is important for industrial agriculture, as

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Figure 5. By intercropping, Costa Rican farmers successfully hide tomatoes from virus-transmitting whiteflies amid cilantro. Tomatoes are less vulnerable to colonization by whiteflies, whose host-finding cues are altered by the presence of the cilantro.

they are the source of traits needed to adapt to evolving pests and changing climates and soils.

■ Optimizing traditional agriculture through research

The traditional crop management practices used by many resource-poor farmers are an important resource for researchers seeking to create novel agroecosystems that are adapted to local circumstances (Dewalt 1994). Rural farmers use a wide range of techniques that are knowledge- rather than input-intensive. Not all are effective or applicable, however, and modifications may be necessary. The challenge is to keep the foundations of such modifications grounded in traditional local knowledge.

The slash-and-burn (milpa) technique is perhaps one of the best examples of an indigenous ecological strategy for managing agriculture in the tropics. By maintaining a mosaic of plots in use with some fallow areas, farmers capture the essence of natural processes of soil regeneration typical of ecological succession. The use of "green manures", a recent discovery, has made it possible to intensify this old technique in areas where long fallow periods are not possible anymore (Buckles *et al.* 1998). Experiences in Central America show that maize systems based on mucuna (*Mucuna pruriens*) are fairly stable and allow respectable annual yields (usually 2–4 mg/ha) (Buckles *et al.* 1998). The system diminishes drought stress, because the mulch layer left by mucuna helps conserve water in the soil profile, making nutrients readily available in synchrony with periods of major crop uptake. In addition, mucuna suppresses most weeds, either by physically preventing them from germinating and emerging, or by inducing shallower rooting in the litter layer–soil interface, making them easier to control. Data show that this system, involving the continuous annual rotation of velvetbean and maize, can be sustained for up to at least 15 years with reasonable yields, and without signs of soil degradation (Buckles *et al.* 1998).

Surveys conducted on hillsides after Hurricane Mitch struck Central America in 1998 showed that farmers using sustainable practices such as mucuna cover crops, intercropping, and agroforestry suffered less damage than their neighbors. The survey, spearheaded by the Campesino a Campesino movement, mobilized 1743 farmers from 360 communities to carry out paired observations of specific agroecological indicators on 1804 neighboring farms (both sustainable and conventional). Sustainable plots had 20–40% more topsoil, greater soil moisture, and less erosion, and experienced lower economic losses than their conventional neighbors (Holt-Gimenez 2001). These data are of great importance to resource-poor farmers living in marginal environments, and should provide the basis for a natural resource management strategy emphasizing crop diversification, since this leads to greater resilience in the face of climatic variability.

As illustrated with the mucuna, an increased understanding of traditional farming systems is necessary to continue developing contemporary systems. Local adaptation and innovation are typically facilitated by an experiential, "learning-by-doing" approach, rather than by gaining knowledge solely through structured scientific research. This is why ecologists need to understand the range of traditional strategies, cultural processes, and associated belief systems that foster adaptive natural resource management at each site. Traditional resource management practices and the knowledge of ecosystem processes upon which they are based are embedded in often elaborate social institutions.

A major task, therefore, is to assess the traditional knowledge framework and resource management practices used by rural communities. This may require integration of agricultural, ethnological, and ecological methodologies. This combination helps determine the many factors that affect how farmers perceive their environment and subsequently modify it, and later assists in the translation of such information into practical management schemes that promote the dynamic conservation of indigenous agroecosystems (Figure 6).

■ Conclusions

Diverse agricultural systems that confer high levels of tolerance to changing circumstances are extremely valuable to

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poor farmers; thus, agrobiodiversity acts as a buffer against natural or human-induced variations in conditions (Thrupp 1998; Altieri 2002). Anthropological and ecological research conducted on traditional agriculture has shown that most indigenous modes of production exhibit a strong ecological basis, and lead to the regeneration and preservation of natural resources (Denevan 2001). Traditional methods are particularly instructive because they provide a long-term perspective on successful agricultural management. A few key principles seem to underlie the sustainability of such systems: species diversity, organic matter accumulation, the enhanced recycling of biomass and nutrients, the minimization of resource losses through soil cover and water harvesting, and the maintenance of high levels of functional biodiversity.

Ecologists can help resource-poor farmers translate these principles into practical strategies to enhance production and resilience. This requires redirecting research to be more problem solving and participatory, so that it is relevant to rural people. It is necessary to both understand the ecological mechanisms underlying the sustainability of traditional farming systems, and to translate them into principles that make locally available and appropriate technologies applicable to a large number of farmers. Ecologists will also have to be more proactive in cautioning against agricultural modernization efforts that ignore the virtues of traditional agriculture. It is not a matter of romanticizing subsistence agriculture or considering development per se as detrimental. Rather, if the goal is to "improve" traditional agriculture, researchers must first understand and build on the system that is to be changed, instead of simply replacing it. Traditional agriculture is a critical source of genetic material and regenerative farming techniques, and constitutes the foundation of a sustainable rural development strategy directed at resource-poor farmers (Toledo 2000).

Due in part to a lack of ecological guidance, agricultural modernization promotes monocultures, new varieties, and agrochemical packages, all of which are perceived as critical to increasing yields, labor efficiency, and farm incomes. Strong pressures promote the conversion of subsistence agriculture to a cash agricultural economy; as this happens, the loss of biodiversity in many rural societies progresses at an alarming rate. In areas characterized by the adoption of modern agriculture, traditional patterns are often disrupted, and landraces along with indigenous technical knowledge are progressively abandoned (Brush 1986). This situation could be aggravated by the promotion of emerg-

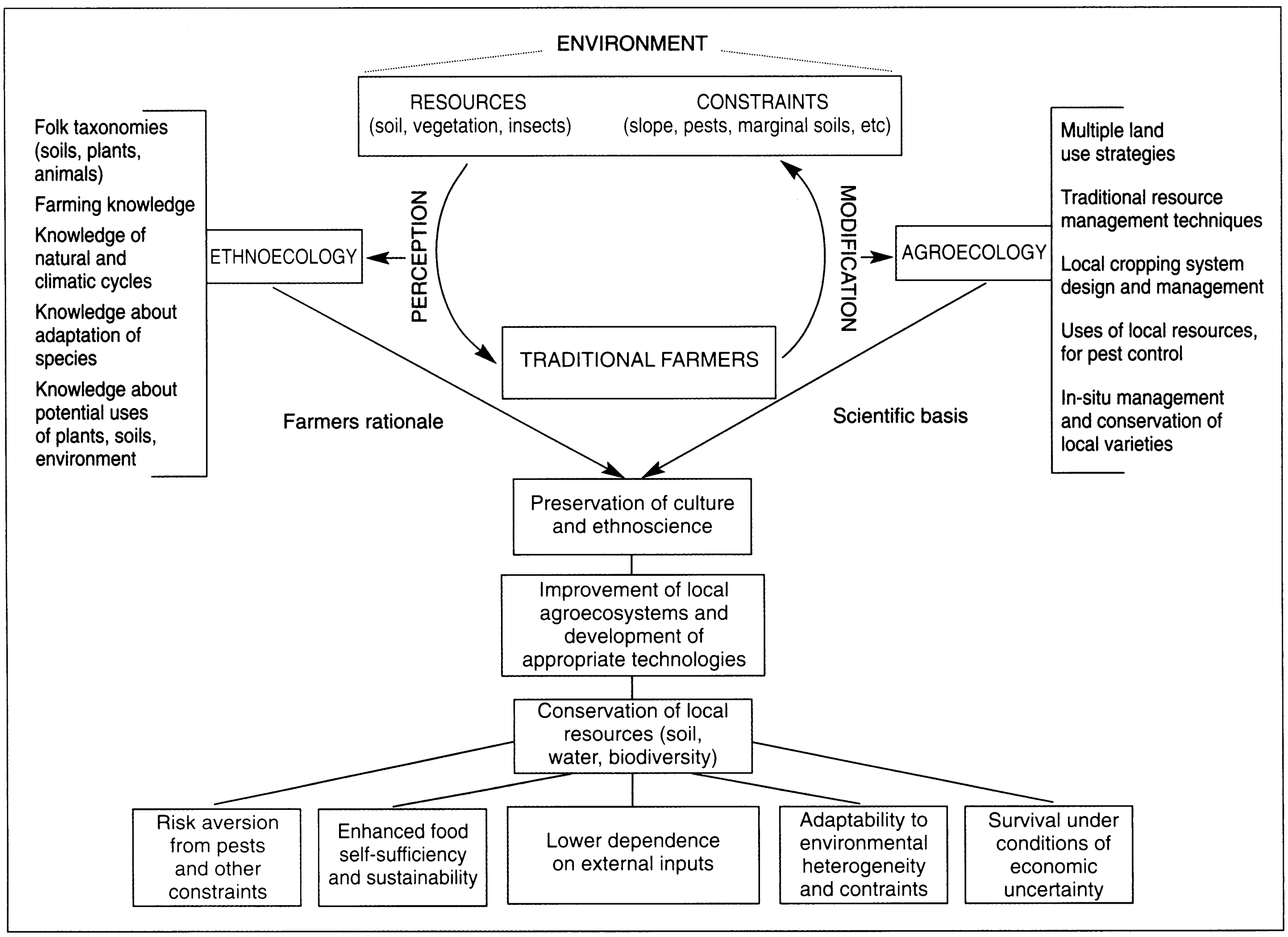

Figure 6. *Agroecology and ethnoecology are key disciplines to understanding and systematizing the ecological rationale inherent in traditional agriculture.*

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ing biotechnologies that emphasize increased agricultural uniformity (Jordan 2001).

The social and environmental impacts of local crop shortfalls resulting from such uniformity can be considerable at the margins of the developing world (Altieri 2000). Crop losses often mean ongoing ecological degradation, poverty, hunger, and even famine. It is here that the traditional skills and resources associated with biological and cultural diversity should be available to rural populations. Ecologists linked to development projects can be of great help in this regard. Of course, we must make major changes in policies that are biased against small farmers. Ecologists can inform policy scenarios that promote alternative technologies through social learning and participatory approaches, improve access to resources and fair markets, and increase public investments to improve infrastructure and services for the poor.

References

Altieri MA. 1994. Biodiversity and pest management in agroecosystems. New York: Haworth Press.
Altieri MA. 1995. Agroecology: the science of sustainable agriculture. Boulder, CO: Westview Press.
Altieri MA. 1999. Applying agroecology to enhance productivity of peasant farming systems in Latin America. *Environ Dev Sust* **1**: 197–17.
Altieri MA. 2000. The ecological impacts of transgenic crops on agroecosystem health. *Ecosyst Health* **6**: 13–23.
Altieri MA. 2002a. Agroecology: the science of natural resource management for poor farmers in marginal environments. *Agr Ecosyst Environ* **93**: 1–24.
Altieri MA. 2002b. Non-certified organic agriculture in developing countries. In: Scialabba N and Hattam C (Eds). Organic agriculture, environment, and food security. Rome: UN Food and Agriculture Organization.
Altieri MA and Nicholls CI. 1999. Biodiversity, ecosystem function and insect pest management in agroecosystems. In: Collins WW and Qualset CO (Eds). Biodiversity in agroecosystems. Boca Raton, FL: CRC Press. p 69–84.
Andow DA. 1991. Vegetational diversity and arthropod population response. *Annu Rev Entomol* **36**: 561–86.
Asenso-Okyere WK and Benneh G. 1997. Sustainable food security in West Africa. Dordrecht, Netherlands: Kluwer Academic Publishers.
Beets WC. 1990. Raising and sustaining productivity of smallholders farming systems in the Tropics. Alkmaar, Netherlands: AgBe Publishing.
Browder JO. 1989. Fragile lands in Latin America: strategies for sustainable development. Boulder, CO: Westview Press.
Buckles D, Triomphe B, and Sain G. 1998. Cover crops in hillside agriculture: farmer innovation with mucuna. Ottawa, Canada: International Development Research Center.
Brokenshaw DW, Warren DM, and Werner O. 1980. Indigenous knowledge systems and development. Lanham, MD: University Press of America.
Brush SB (Ed). 2000. Genes in the field: on farm conservation of crop diversity. Boca Raton, FL: Lewis Publishers.
Chang JH. 1977. Tropical agriculture: crop diversity and crop yields. *Econ Geogr* **53**: 241–54.
Clawson DL. 1985. Harvest security and intraspecific diversity in traditional tropical agriculture. *Econ Bot* **39**: 56–67.
Denevan WM. 1995. Prehistoric agricultural methods as models for sustainability. *Adv Plant Pathol* **11**: 21–43.
Denevan WM. 2001. Cultivated landscapes of Native Amazonia and the Andes. New York: Oxford University Press.
Dewalt BR. 1994. Using indigenous knowledge to improve agriculture and natural resource management. *Hum Organ* **5**: 23–131.
Ewel JJ. 1986. Designing agricultural ecosystems for the tropics. *Annu Rev Ecol Syst* **17**: 245–71.
Ewel JJ. 1999. Natural systems as a model for the design of sustainable systems of land use. *Agroforest Syst* **45**: 1–21.
Francis CA. 1986. Multiple cropping systems. New York: MacMillan.
Gliessman SR. 1998. Agroecology: ecological process in sustainable agriculture. Ann Arbor, MI: Ann Arbor Press.
Hanks L. 1992. Rice and man: agricultural ecology in Southeast Asia. Honolulu, HI: University of Hawaii Press.
Holt-Gimenez E. 2001. Measuring farms agroecological resistance to Hurricane Mitch. *LEISA* **17**: 18–20.
Jordan CF. 2001. Genetic engineering, the farm crisis, and world hunger. *BioScience* **52**: 523–29.
Kahn ZR, Ampong-Nyarko K, Hassanali A, and Kimani S. 1998. Intercropping increases parasitism of pests. *Nature* **388**: 631–32.
Landis DA, Wratten SD, and Gurr GA. 2000. Habitat management to conserve natural enemies of arthropod pests in agriculture. *Annu Rev Entomol* **45**: 175–201.
McHughen A. 2000. Pandora's picnic basket: the potential and hazards of genetically modified foods. Oxford, UK: Oxford University Press.
Morales H, Perfecto I, and Ferguson B. 2991, Traditional soil fertilization and its impacts on insect pest populations in corn. *Agr Ecosyst Environ* **84**: 145–55.
Natarajan M and Willey RW. 1996. The effects of water stress on yield advantages of intercropping systems. *Field Crop Res* **13**: 117–31.
Netting RM. 1993. Smallholders householders. Stanford CA: Stanford University Press.
Quist D and Chapela IH. 2001. Transgenic DNA introgressed into traditional maize landraces in Oaxaca Mexico. *Nature* **414**: 541–43.
Reinjtes C, Haverkort B, and Waters-Bayer A. 1992. Farming for the future. London: MacMillan.
Richards P. 1985. Indigenous agricultural revolution. Boulder, CO: Westview Press.
Rosenthal JP and Dirzo R. 1997. Effects of life history, domestication and agronomic selection on plant defense against insects: evidence from maizes and wild relatives. *Evol Ecol* **11**: 337–55.
Smith HA and McSorely R. 2000. Intercropping and pest management: a review of major concepts. *Am Entomol* **46**: 154–61.
Thurston D. 1991. Sustainable practices for plant disease management in traditional farming systems. Boulder, CO: Westview Press.
Toledo VM. 2000. La Paz en Chiapas: luchas indigenas y modernidad altrenativa. Mexico City: Ediciones Quinto Sol.
Thrupp LA. 1998. Cultivating diversity: agrobiodiversity for food security. Washington DC: World Resources Institute.
Vandermeer J. 1989. The ecology of intercropping. Cambridge, UK: Cambridge University Press.
Vandermeer J. 2003. Tropical agroecosystems. Boca Raton, FL: CRC Press.
Wilken GC. 1987. Good farmers: traditional agricultural resource management in Mexico and Guatemala. Berkeley, CA: University of California Press.
Wilson DJ. 1999. Indigenous South Americans of the past and present: an ecological perspective. Boulder, CO: Westview Press.
Williams BJ and Ortiz-Solorio C. 1981. Middle American folk soil taxonomy. *Ann Assoc Am Geogr* **71**: 335–58.
Zhu Y, Fen H, Wang Y, *et al.* 2000. Genetic diversity and disease control in rice. *Nature* **406**: 718–72.

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