

Ethnoscience and biodiversity: key elements in the design of sustainable pest management systems for small farmers in developing countries

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Abstract

Biodiversity is a salient feature of traditional farming systems in developing countries and performs a variety of renewal processes and ecological services in agroecosystems. It is of fundamental importance to understand the role biodiversity can play in reducing pest problems, if vegetation management is to be used effectively as a primary IPM tactic in small-scale sustainable agriculture. The maintenance of biodiversity in traditional agroecosystems is not random, but depends on a complex set of indigenous technical knowledge systems (ethnoscience). Thus, the ensemble of traditional crop protection practices used by indigenous farmers represents a rich resource for modern workers seeking to create IPM systems that are well adapted to the agroecological, cultural and socio-economic circumstances facing small farmers throughout the developing world.

Introduction

Traditional farming systems in developing countries exhibit two salient features: a high degree of vegetational diversity (biodiversity) and a complex system of indigenous technical knowledge (ethnoscience). Both elements are obviously highly interrelated since the maintenance of biodiversity is dependent upon local farmers' knowledge about the environment, plants, soils and ecological processes (Toledo et al., 1985). Despite acknowledging the importance of both elements, most agriculturalists have yet to take full advantage of the benefits of biodiversity and ethnoscience in the implementation of rural development projects.

Nowhere is the potential of biodiversity and ethnoscience more applicable than in the realm of pest management. On the one side, the regulating effects of vegetational diversity on pest populations are well known. On the other, there are clear indications that certain ethnic groups of farmers, some more than others, have a thorough knowledge of the history, biology and bionomics of a variety of insect pests (Altieri, 1990). This paper offers a synthesis of current knowledge about the relationships between biodiversity, ethnosci-

ence and pest management, along with an agroecological basis for designing pest control methods tailored to the socio-economic and cultural circumstances of small farmers throughout the developing world.

Biodiversity and pest management

Biodiversity refers to all species of plants, animals and microorganisms existing and interacting within an ecosystem. Polycultural and agroforestry systems typical of most traditional farming systems exhibit a high degree of biodiversity. This biodiversity performs a variety of renewal processes and ecological services in these agroecosystems. The diversity of crops and wild plants provides vegetative cover which prevents soil erosion, regulates the water balance and nutrient cycling and aids in the control of the abundance of undesirable organisms (Altieri and Letourneau, 1982). When these natural services are lost, due to biological simplification through adoption of monocultures or use of high-input technologies, the social, economic and environmental costs can be quite significant.

Ecological theory suggests that diversified cropping systems contain natural elements of pest control. The majority of agroecological studies show that structural (i.e. spatial and temporal crop arrangement) and management (e.g. crop diversity and input levels) attributes of agroecosystems influence herbivore dynamics. Most experiments that mixed other plant species with the primary host of a specialized herbivore showed that, in comparison with diverse crop communities, simple crop communities have greater population densities of specialist herbivores (Altieri and Letourneau, 1984). In these less diverse systems, herbivores exhibit greater colonization rates, greater reproduction, less tenure time, less disruption of host finding and lower mortality by natural enemies (Andow, 1991).

So far, two hypotheses have been proposed to explain the commonly observed lower herbivore abundance in polyculture (Altieri and Letourneau, 1982): the resource concentration hypothesis and the natural enemies hypothesis.

The resource concentration hypothesis

This hypothesis states that crop monocultures represent a concentrated resource for specialized herbivores, which increases the attraction and accumulation of these species, the time they spend in the system and their reproductive success. Visual and chemical stimuli, from host and non-host plants in a polyculture, affect the rate at which herbivores colonize a polyculture and their behavior in these habitats. In a polyculture, non-host species may mask the chemical attractants of the host, reduce the contrast between the host and

its background or simply hide the plants from view (i.e. make them less apparent).

The natural enemies hypothesis

This hypothesis predicts an increased abundance of arthropod predators and parasitoids in polycultures due to the increased availability of alternate prey, nectar sources, and suitable microhabitats. The net effect of natural enemies on pest abundance in polycultures will depend upon whether natural enemies are governed more in their behavior by prey density or by background plant density, although at times both factors operate simultaneously.

There is general agreement that these hypotheses are not mutually exclusive since a particular herbivore population may be affected simultaneously by both the concentration of resources and by natural enemies. In fact, herbivore regulation in polycultures may involve other mechanisms not considered by the hypotheses, such as microclimate, differences in levels of secondary compounds or in plant quality, and so on. The point is that it is important to identify key mechanisms, differences in mechanisms between cropping systems, and which plant assemblages enhance regulatory effects and which do not, and under what management and agroecological circumstances.

Ecological theory and pest management in polycultures

The most vegetationally diverse traditional agroecosystems are those under extensive shifting cultivation and/or those under intensive subsistence farming in the tropics. These systems are usually characterized by complex cropping systems (e.g. intercropping, agroforestry and rotations) with crop sequences and associations managed in a variety of ways in time and space.

Theoretically these systems contain built-in elements of natural pest control. The question is then: how can emergent ecological theories help in designing polycultures that offer even better or more effective herbivore protection features? In other words, is there anything that ecologists can do to help traditional farmers improve the polycultural systems they already have?

From a practical standpoint it is easier to design insect manipulation strategies in polycultures using the elements of the natural enemies hypothesis than those of the resource concentration hypothesis, mainly because we cannot yet identify the ecological situations or life history traits that make some pests sensitive (i.e. their movement is affected by crop patterning) and others insensitive to cropping patterns (Andow, 1991). The recognition that crop monocultures are difficult environments in which to induce the efficient operation of beneficial insects, because these systems lack adequate resources for effective performance of natural enemies and because of the disturbing cultural practices often utilized in such systems, can offer useful insights to

biological control practitioners. Polycultures already contain specific resources provided by plant diversity, and are usually not disturbed with pesticides (especially when managed by resource-poor farmers who cannot afford high-input technology), and are thus more amenable to manipulation. By replacing or adding diversity to existing systems, it may be possible to exert changes in habitat diversity that enhance natural enemy abundance and effectiveness (Altieri and Letourneau, 1982; Powell, 1986) by (1) providing alternative host-prey at times of pest host scarcity; (2) providing food (pollen and nectar) for adult parasitoids and predators; (3) providing refuges for overwintering, nesting, and so on; (4) maintaining acceptable populations of the pest over extended periods to ensure continued survival of beneficial insects.

The specific effect or the strategy to use will depend on the species of herbivores and associated natural enemies, as well as on properties of the vegetation, the physiological condition of the crop, or the nature of the direct effects of a particular plant species. In addition, the success of enhancement measures can be influenced by the scale upon which they are implemented (i.e. field scale, farming unit or region), since field size, within-field and surrounding vegetation composition, and level of isolation (i.e. distance from the source of colonizers) will all affect immigration rates, emigration rates, and the effective tenure time of a particular natural enemy in a crop field.

Perhaps one of the best strategies for increasing the effectiveness of predators and parasitoids is the manipulation of non-target food resources (i.e. alternate hosts, prey and pollen-nectar) (Altieri and Liebman, 1986). Here it is not only important that the density of the non-target resource be high, to influence enemy populations, but that the spatial distribution and temporal dispersion of the resource also be adequate. Proper manipulation of the non-target resource should result in the enemies colonizing the habitat earlier in the season than the pest, and frequently encountering an evenly distributed resource in the field, thus increasing the probability of the enemy remaining in the habitat and reproducing (Andow, 1991). Certain polycultural arrangements increase, and others reduce, the spatial heterogeneity of specific food resources; thus particular species of natural enemies may be more or less abundant in a specific polyculture. These effects and responses can only be determined experimentally across a whole range of traditional agroecosystems. The task is indeed overwhelming since enhancement techniques must necessarily be site specific (Altieri, 1991a).

Although polycultures seem to exhibit pest-suppression potential, most of the data from field tests include polyculture treatments that mimic farmers' practices. Thus, at this point, it is not clear whether these patterns hold across cropping systems managed under farmers' conditions. In their surveys of traditional maize cropping systems in Tlaxcala, Trujillo-Arriaga and Altieri (1990) found that certain crop associations would reduce populations of the

scarab beetle *Macrodactylus* sp., while others would increase them. In a survey of insect communities associated with maize grown in association with other annual crops and with trees or shrubs in Indonesia, it was found that pest damage and abundance of natural enemies varied considerably between fields. It was not clear whether these differences were related to the vegetational structure of the systems, or were merely a consequence of differential management, location, or chance (Altieri and Liebman, 1986). It is clear that pest dynamics will vary significantly between systems depending on insect species, location and size of the field, vegetational composition, and cultural management.

Ethnoscience and pest management

Classification of animals, especially insects and birds, is widespread among traditional farmers and indigenous groups. In their survey of pest control practices used by local farmers in the Philippines, Litsinger et al. (1980) found that farmers had local names in separate dialects in each location for most pests attacking rice, corn and grain legumes. Farmers were not aware of some pests considered as problems by entomologists, and consequently did not attempt control measures.

Insects and related arthropods have major roles as crop pests, causes of disease, food and medicinals, and are important in myth and folklore. In many regions, agricultural pests are tolerated because they also constitute agricultural products; that is, traditional agriculturalists may consume plants and animals that would otherwise be considered pests. In Indonesia, a grasshopper pest in rice is trapped at night and eaten (with salt, sugar, and onions) or sold as bird food in the market. In northeast Thailand, rural inhabitants commonly eat termites and a crab that damages rice stalks. Ants, some of which may be major crop pests, are one of the most popular insect foods gathered in tropical regions (Brown and Marten, 1986).

In his studies of Kabba farmers in Nigeria, Atteh (1984) not only found that farmers could identify the pests affecting their crops, but that they could also rank the pests according to the degree of damage they caused to crops. In addition, further research revealed that, for each pest, farmers had knowledge of (1) the history of the pest, including dates when the pest was noticed, when it became a menace, peak periods of occurrence in the past, and type of damage done; (2) the biology of the pest, including the life cycle of the pest, its breeding behavior, and ecological and climatic conditions facilitating or discouraging increase in numbers; (3) the bionomics of the pest — the feeding preferences and the severity of damage done to plants attacked.

A good example of farmer knowledge of the biology and bionomics of pests is the case of the variegated grasshopper, *Zonocerus variegatus*, in southern Nigeria. Richards (1985) found that local farmer knowledge was equivalent

to that of his scientific team concerning the grasshoppers' food habits, life cycle, mortality factors, degree of damage to cassava, and the egg-laying behavior and egg-laying sites of the females. Farmers were aware that, numerous as these insects are, they congregate under only a few shaded areas on the farm or in an area to lay eggs at a particular period, and that these eggs are kept in pods and inserted an inch or so below the soft ground surface. Farmers had discovered on their own that the egg-laying sites can be marked and the egg pods dug up. Once exposed to the hot sun the eggs die. They had in fact tried this as a control measure. Farmers had also established a close relationship between the presence of a weed (*Eupatorium odoratum*) and the advance and severity of the pests (Richards, 1985). In this particular case, farmers' knowledge added facts to that of the researchers in regard to the dates, severity and geographical extent of some of the outbreaks, plus the fact that the grasshopper was eaten and sold and was of special importance to women, children, and poor people. Thus, the final control recommendation by scientists, of clearing the egg-laying sites from a block of farms, did not require most farmers to learn new concepts, and for some the practice was nothing new.

Indigenous pest control methods

Traditional farmers rely on a variety of management practices to deal with agricultural pest problems. Two main strategies can be distinguished. One is the use of direct, non-chemical pest control methods (i.e. cultural, mechanical, physical and biological practices) (Table 1). The second is reliance on built-in pest control mechanisms, inherent to the biotic and structural diversity of complex farming systems, commonly used by traditional farmers (Brown and Marten, 1986). This ensemble of cultural practices can be grouped into three main strategies, depending on which element of the agroecosystem is manipulated.

(1) Manipulation of crops in time

Farmers often manipulate the timing of planting and harvest carefully and use crop rotations to avoid pests. These techniques obviously require considerable ecological knowledge of pest phenology. Although these techniques often have other agronomic benefits (e.g. improved soil fertility), the farmers sometimes explicitly mention that they are done to avoid pest damage. For example, in Uganda, farmers utilize time of planting to avoid stem borers and aphids in cereals and peas, respectively (Richards, 1985). Many farmers are aware that planting out of synchrony with neighboring fields can result in heavy pest pressure and therefore use a kind of 'pest satiation' to avoid extensive damage. In the central Andes, a potato fallow rotation is carefully

Table 1
Pest management strategies and specific practices used by traditional farmers throughout the developing world

Strategy	Practices
Mechanical and physical control	Scarecrows, sound devices Wrapping of fruits, pods Painting stems, trunks with lime or other materials Destroying ant nests Digging out eggs/larvae Hand picking Removal of infested plants Selective pruning Application of materials (ash, smoke, salt, etc.) Burning vegetation
Cultural practices	Intercropping Overplanting or varying seeding rates Changing planting dates Crop rotation Timing of harvest Mixing crop varieties Selective weeding Use of resistant varieties Fertilizer management Water management Plowing and cultivation techniques
Biological control	Use of geese and ducks Transfer of ant colonies Collecting and/or rearing predators and parasites for field release Manipulation of crop diversity
Insecticidal control	Use of botanical insecticides Use of plants or plant parts as repellents and/or attractants Use of chemical pesticides
Religious/ritual practices	Addressing spirits or gods Placement of crosses or other objects in the field Prohibition of planting dates

observed, apparently to avoid build-up of certain insects and nematodes (Brush, 1983).

Perhaps the most common way in which farmers manipulate the temporal permanence of agroecosystems is through the traditional pattern of slash and burn or shifting cultivation. A parcel of forest is cut and the area burned to release nutrients and eliminate non-crop plants. A mixture of short-term crops, sometimes followed by perennials, is grown until soil fertility becomes inadequate and competition from successional plant species is severe. When that

happens, the farmer prepares a new field and the old one returns to long-term fallow. In Nigeria, kabba farmers affirm that an unacceptable weed and insect pest level is the surest sign that a plot of land must be abandoned (Atteh, 1984).

It has been speculated that bush fallows in the swidden system have potential value in controlling insects. Initial pest colonization is slow since the crops are typically planted among vegetation types (forest) that do not share the same pest complex. The great diversity of crops grown simultaneously in swidden cultivation helps to prevent pest build-up on the comparatively isolated plants of each species. Shade from forest fragments still standing in new fields, coupled with a partial canopy of fruit, nut, fire wood, fiber, medicinal and/or lumber tree species, reduces shade-intolerant weed populations and provides alternate hosts for beneficial (or sometimes detrimental) insects. Clearing comparatively small plots in a matrix of secondary forest vegetation permits easy migration of natural control agents from the surrounding jungle (Matteson et al., 1984).

(2) Manipulation of crops in space

Traditional farmers often manipulate plot size, plot site location, density of crops and crop diversity to achieve several production purposes, although most are aware of the links between such practices and pest control.

Overplanting. One of the most common methods of dealing with pests is planting at a higher density than one expects to harvest. This strategy is most effective in dealing with pests that attack the plant during the early stages of growth. When infested plants are detected, they are carefully removed long before actual death so as to avoid contaminating healthy plants.

Farm plot location. In Nigeria many farmers, linked by kinship ties, age grouping or friendship, locate their farm plots lying contiguous to each other but leaving room for the expansion of each farm in a particular direction. In accounting for this practice, farmers reported that all pests in the area will discover and concentrate on an isolated farm. Plots are therefore grouped together to spread pest risk among many farmers (Atteh, 1984). Conversely, in tropical America Brush (1983) reports that farmers deliberately use small isolated plots to avoid pests.

Selective weeding. Studies conducted in traditional agroecosystems show that peasants deliberately leave weeds in association with crops, by not completely clearing all weeds from their cropping systems. This 'relaxed' weeding is usually seen by agriculturalists as the consequence of a lack of labor and low return for the extra work; however, a closer look at farmer attitudes toward weeds reveals that certain weeds are managed and even encouraged if they

serve a useful purpose. In the lowland tropics of Tabasco, Mexico, there is a unique classification of non-crop plants according to use potential on the one hand and effects on soil and crops on the other. According to his system, farmers recognized 21 plants in their cornfields classified as 'mal monte' (bad weeds), and 20 as 'buen monte' (good weeds) that serve, for example, as food, medicines, ceremonial materials, teas and soil improvers (Chacon and Gliessman, 1982).

Similarly, the Tarahumara Indians in the Mexican Sierras depend on edible weed seedlings (*Amaranthus*, *Chenopodium* and *Brassica*) from April through July, a critical period before maize, bean, cucurbits, and chiles mature in the planted fields in August through October. Weeds also serve as alternate food supplies in seasons when the maize crops are destroyed by frequent hailstorms. In a sense the Tarahumara practice a double crop system of maize and weeds that allows for two harvests: one of weed seedlings or 'quelities' early in the growing season (Bye, 1981). Some of these practices have important insect pest control implications since many weed species play important roles in the biology of herbivorous insects and their natural enemies in agroecosystems. Certain weeds, for example, provide alternate food and/or shelter for natural enemies of insect pests during the crop season but, more importantly, during the off-season when prey/hosts are unavailable (Altieri and Liebman, 1986).

In addition to the type of weed diversity allowed in the field, the timing of field weeding may also impact insect pest dynamics within the agroecosystem. For example, in Nigeria, while the timing of weeding corresponds with growth periods of crops, it is also timed in such a way as to interfere with the egg-laying and breeding times of most of the major pests, thus preventing maturation and consequently reducing their population (Atteh, 1984). Timely removal of weeds that are alternative hosts of specific crop pests is of key importance.

Manipulation of crop diversity. Although most farmers use intercropping mainly because of labor and land shortages or other agronomic purposes, the practice has obvious pest control effects (Altieri and Letourneau, 1982). Many farmers know this and use polycultures as a play-safe strategy to prevent build-up of specific pests to unacceptable levels, or to survive in cases of massive pest damage. For example, in Nigeria, farmers are aware of the severe damage done to an isolated cassava crop by the variegated grasshopper after all other crops have been harvested. To reduce this damage, farmers deliberately re-plant maize and random clusters of sorghum on the cassava plot until harvest time (Atteh, 1984).

(3) Manipulation of other agroecosystem components

In addition to manipulating crop spatial and temporal diversity, farmers also manipulate other cropping system components such as soil, microclimate, crop genetics and chemical environment to control pests.

Use of resistant varieties. Through both conscious and unconscious selection, farmers have developed crop varieties that are resistant to pests. This is probably the most widely used and effective of all the traditional methods of pest control. Litsinger et al. (1980) found that 73% of the peasant farmers in the Philippines were aware of varietal resistance even if they had not consciously tried to manipulate it. There is evidence in traditional varieties for all the modes of resistance that modern plant breeders select for, including pubescence, toughness, early ripening, plant defense chemistry and vigor.

In Ecuador, Evans (1988) found that infestations of Lepidoptera larvae in ripening corn ears were significantly higher in new varieties than in traditional ones, a factor that influenced the adoption of new varieties by small farmers.

Water management. Manipulation of water level in rice fields is a widely used practice for pest control (King, 1927). Water management is also practiced in many other annual crops for the same purpose. For example, in Malaysia, control of cutworms and army worms is effected by cutting off the tip of infested leaves in a number of annual crops, and raising the water level, which carries the larvae into the field ridges, where birds congregate to eat them.

Plowing and cultivation techniques. Farmers frequently report that they deliberately manage the soil (sometimes using more and sometimes less cultivation) to destroy or avoid pest problems. In Peru, for example, peasants use 'high tilling' of potatoes to protect the tubers from insect pests and diseases (Brush, 1983).

In shifting cultivation, after clearing a piece of land farmers set it on fire after a week or two. Farmers reported that this is done, among other reasons, to reduce weed and pest populations during the first year of cropping (Atteh, 1984).

Use of repellents and/or attractants. Farmers have been experimenting with various natural materials found in their immediate environment (especially in plants) for many centuries, and a remarkable number have some pesticidal properties. Use of plants or plant parts either placed in the field or applied as herbal concoctions for pest inhibition is widespread. Litsinger et al. (1980) interviewed small farmers in the Philippines about materials used in the fields to attract or repel insects. In Aloburo, Ecuador, small farmers place castor

leaves in recently planted corn fields to reduce populations of a nocturnal tenebrionid beetle. These beetles prefer castor leaves over corn, but when associated with castor leaves for 12 h or more, beetles exhibit paralysis. In the field, the paralysis prevents beetles from hiding in the soil, which increases their mortality by direct exposure to the sun (Evans, 1988). In southern Chile, peasants placed branches of *Cestrum parqui* in potato fields to repel *Epicauta pilme* beetles (Altieri, 1990). Many times a plant is carefully grown near the household and its sole function is apparently to provide the raw material for preparing a pesticidal concoction. In Tanzania, farmers cultivate *Tephrosia* spp. on the borders of their maize fields. The leaves are crushed and the liquid is applied to control maize pests. In Tlaxcala, Mexico, farmers 'sponsor' volunteer *Lupinus* plants within their corn fields, because those plants act as trap crops for *Macroductylus* sp. (Trujillo-Arriaga and Altieri, 1990).

Diversity improved pest management systems for traditional farmers

The development and extension of conventional agricultural technology for small farmers throughout the developing world, including better crop protection methods, has met with mixed success. Most technologies have not been made available to small farmers on favorable terms and often have not been suited to the agroecological and socio-economic conditions of small farmers (Altieri, 1984). Understanding traditional farming systems, including the role of biodiversity and the use of effective traditional pest management methods, is the starting point in the design and improvement of traditional pest management systems (Altieri, 1985).

A basic step in the generation of technological modifications appropriate to small farmers is to conduct agro-socio-economic studies which determine the conditions influencing traditional farming systems. The analysis of small farm systems must incorporate farmer knowledge, needs, and production criteria, especially with regard to risk. Risk avoidance is expressed traditionally through, for example, farm diversification and flexibility in planting times. In Mexico, for example, farmers often plant maize at high density and use the thinnings for their animals. This practice can also dilute the attack of specific insect pests. In eastern Guatemala, some farmers let weeds grow in their vegetable fields to increase the food supply for cattle, even though this practice may reduce crop yields. On the other hand the presence of weeds can condition the build-up of natural enemies which in turn reduces insect pests. An understanding of the effects of these interactions of current cropping practices is vital for the development and/or pre-screening of new technologies appropriate to farmers' circumstances (Altieri, 1984).

The goal is to maintain agricultural productivity and ensure crop protection with minimal environmental impact, adequate economic returns, and while providing for the needs of the small farmers. Although there are no

recipes on how to achieve sustainability, the idea is to devise an agricultural strategy based on the use of biodiversity and ethnoscience which can bring moderate to high levels of productivity using local resources and skills, while conserving the natural resource base. Given favorable political and ecological circumstances, such systems are sustainable at a much lower cost and for a longer period of time (Altieri, 1991b).

A number of researchers and organizations in developing countries are promoting agroecological techniques in a way which is sensitive to the complexities of local farming methods. This agroecological approach emphasizes properties of food security, biological stability, resource conservation and equity, along with the goal of increased production. Promoted agroecological techniques are culturally compatible since they do not question farmers' rationale, but actually build on traditional farming knowledge, combining it with elements of modern agricultural science.

Linking soil conservation and pest management in Central America

Perhaps one of the major agricultural challenges in Central America is the design of cropping systems adapted to hillside areas in order to maintain yields while reducing erosion (Altieri, 1991b). In Honduras, a couple of non-government organizations (NGOs) have taken on this challenge. One group, in Loma Linda, developed a simple no-till system by which, in a fallow area, weeds are cut initially with a machete without soil being removed. Using a hole or a small plough, small furrows are opened following the contour every 50–60 cm. Crop seeds and chicken manure and/or compost are placed in the furrow and covered with soil. As the crops grow, weeds are kept mowed to avoid excessive competition, with the weed biomass left within the crop row as a mulch for cover and as an addition of organic matter. The mulch also provides a habitat for ground predators and the weed cover can enhance natural enemies or disrupt herbivore colonization by changing the ground color background. Excellent yields have been obtained with this system without the use of chemical fertilizers, and more importantly, without experiencing significant soil loss or pest attack.

In a similar project in Guinope, Honduras, the NGO World Neighbors introduced soil conservation practices among small farmers to control erosion and restore fertility. Various practices such as the use of living barriers and intercropping leguminous plants, increased the vegetational diversity of the farms, with beneficial effects on soil conservation and on crop protection. In the first year, yields increased dramatically from 400 kg ha⁻¹ to 1200–1600 kg ha⁻¹. This tripling in per-hectare grain production has assured the 1200 families participating in the program ample grain supplies for the ensuing year.

In both cases, increased productivity at the farm level has meant that most

farmers are now farming less land than previously, allowing more land to grow back to natural forest and to be used for planting pasture, fruit or coffee trees. The net result is enhanced diversity within farms, and that hundreds of hectares formerly used for erosive agriculture are now covered with trees, thus enhancing regional diversity. There is some evidence to suggest that at a more regional level, pest problems may diminish in a heterogeneous landscape where agroecosystem mosaics are interspersed among natural vegetation (Altieri, 1991a).

Conclusions

Although it is generally accepted that diversification of cropping systems often leads to reduced herbivore populations, the degree of such reductions varies dramatically within the whole range of diversities and management intensities that polycultures exhibit under farmers' circumstances. If certain existing crop mixtures contain built-in elements of pest control, such elements should be identified and then retained in the course of modernization. In other cases, suboptimal interactions between plants, herbivores, and natural enemies could be improved (i.e. by adding or eliminating diversity) to enhance natural enemy effectiveness in regulating herbivore densities.

Some management ideas can be derived from the ensemble of traditional crop protection practices used by small farmers. Ethnoscience represents a rich resource for modern workers seeking to create pest management systems that are well adapted to the agroecological and socio-economic circumstances of peasants. Clearly, not all traditional crop protection components are effective or applicable; therefore modifications and adaptations may be necessary, but the foundation of such modifications must be based on peasant rationale and indigenous knowledge. Nevertheless, most farmers use a diversity of techniques, many of which fit local conditions well. The techniques tend to be knowledge intensive rather than commodity intensive, i.e. their effectiveness is dependent on detailed knowledge of the agricultural environment rather than the use of expensive inputs. What is difficult is that each agricultural situation must be assessed separately, since herbivore–enemy interactions will vary significantly depending on insect species, location and size of the field, plant composition, the surrounding vegetation, and cultural management. In most cases one can only hope to elucidate the ecological principles governing herbivore dynamics in complex systems, but the polycultural designs necessary to achieve herbivore regulation will depend on the agroecological conditions and socio-economic restrictions of each area. In this regard, farmers' needs and preferences must be considered fully if adoption of new designs is expected. New designs will be most attractive if, in addition to pest regulation, polycultures offer benefits in terms of overyielding, increased

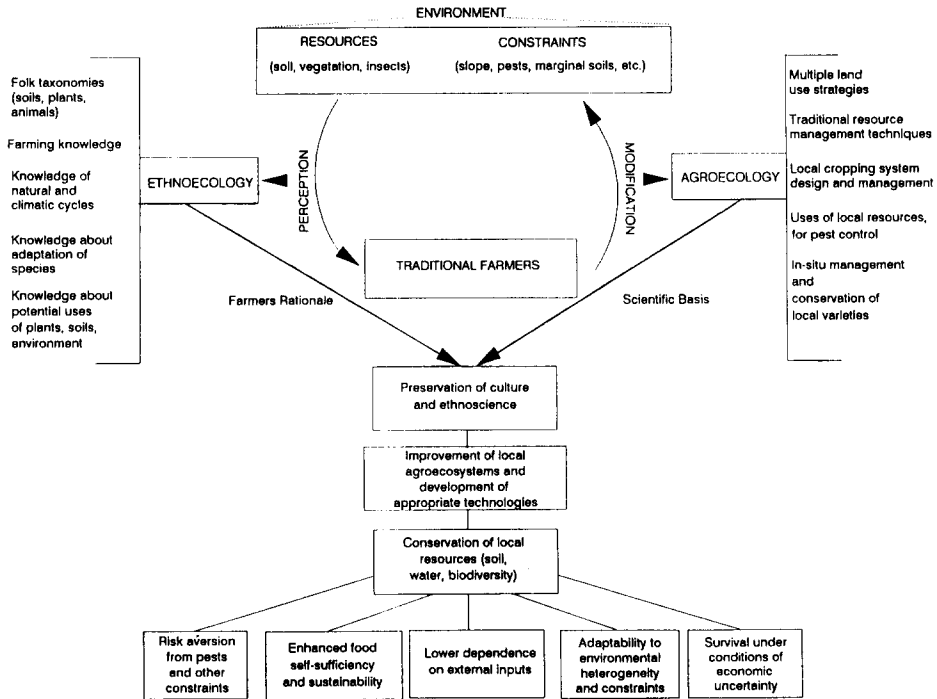


Fig. 1. The role of agroecology and ethnoecology in the retrieval of traditional farming knowledge and the development of sustainable agroecosystems, including appropriate innovations in pest management.

soil fertility, decreased weed competition and diseases and evening-out of labor demands.

Farmers' rationale to maintain certain cropping practices and tolerate a certain amount of yield loss due to pests must be considered if developers desire to convince farmers to adopt improved IPM practices. Otherwise, even if new practices offer reduction in yield loss and cash and labor savings, farmers will not adopt them. For example, in Africa, although burning of the crop residue after harvest is effective to destroy diapausing stem-borers in the dry season, farmers resist the practice because they use maize and sorghum stubble as livestock fodder (Altieri, 1990). A re-evaluation of traditional tropical crop management, which has hitherto assured stable productivity on a long-term basis, will be necessary to develop more sustained and low-input IPM practices and to reverse some of the 'ecological crisis' triggered by modern changes (e.g. large-scale monocultures, promotion of high-yielding varieties and use of pesticides). An increased understanding of the agroecology and ethnobiology of small farming systems can only emerge from integrative studies that determine the myriad factors and conditions influencing farmers' decisions and traditional cropping patterns (Fig. 1). Maintaining the biodivers-

ity of farming systems is essential for the biological functioning of small-scale agriculture. However, biodiversity can only be maintained if cultural diversity is preserved.

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