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The Ecology of Traditional Pest Management in Southeast Asia

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For centuries small-scale subsistence farmers in the tropics have kept the pest damage in their fields within acceptable bounds by employing a wide variety of traditional management practices based on locally available materials. Particularly notable is the fact that they have done so without having to depend on chemical pesticides (Janzen 1973, Trenbath 1975, Gleissman et al. 1981, Altieri et al. 1983). Because the strengths of traditional pest management—its self-sufficiency and environmental compatibility—are in precisely those areas where modern pesticide-based agriculture is weak, it is worthwhile to examine the traditional pest management of subsistence farmers for elements that should be retained in the course of agricultural modernization. Moreover, agriculture in developed countries is undergoing changes, such as reduction in the use of pesticides, that could draw upon traditional pest management technology.

This chapter reviews traditional pest management practices and provides ecological explanations for how they function. Four major sources of information are used:

- Qualitative descriptions of pest problems and pest management practices in traditional agriculture;
- Quantitative studies of pest dynamics in traditional agriculture;
- Ecological studies of natural ecosystems; and
- Agricultural field experiments.

Most available information on traditional pest management is based on qualitative observations rather than detailed quantitative measurements. Published observations that are scattered throughout the agronomic, anthropological, and ecological literature are supplemented with unpublished personal observations, primarily from Indonesia and Thailand. The literature on natural ecosystems and experimental field trials elucidates the ecological mechanisms involved.

PEST PROBLEMS IN TRADITIONAL AGRICULTURE

Perspective

The magnitude of pest problems in traditional agriculture is in part a matter of perspective, because subsistence farmers may have low yield expectations and tolerate relatively high pest losses. Subsistence farmers in Indonesia accept losses of up to 50 percent of total production before implementing pest control measures. They often regard the animals that feed on their crops as fellow creatures with a legitimate claim to some of the produce, as long as the animals do not destroy more than "their fair share."

Agricultural pests also can be tolerated because they are 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. The major bird pest in Indonesian rice fields *(Lonchura)* is caught in spring-loaded traps and eaten. Squirrels and termites, both of which damage crops, also are consumed in Indonesia. Shifting cultivators in Borneo trap and eat wild pigs that are attracted to their crops. In Northeast Thailand, rural inhabitants commonly eat rats, termites, and a crab that damages rice stalks. Food preferences vary geographically and among cultural groups. For example, rats are eaten in Northeast Thailand, but not in Central Thailand. As a consequence, rats are considered a major rice pest in Central Thailand but are not considered the same kind of problem in Northeast Thailand.

Recent ecological research on the relationship between herbivores and their food plants suggests it is not always detrimental for a crop to have an animal feeding upon it (Harris 1973). Indirect, possibly beneficial, effects of herbivores on plants include:

- Increased water-use efficiency (Daubenmire and Colwell 1942, Baker and Hunt 1961);
- Acceleration of nutrient cycling (Mattson and Addy 1975, Bormann and Likens 1979);
- Stimulation of plant productivity (Brown 1982, McNaughton 1979);
- Changes in plant growth patterns, such as increased tillering or branching (Youngner 1972, Simberloff et al. 1978, Owen 1980); and
- Delay of plant senescence (Chew 1974, McNaughton 1976).

As a consequence, insect damage at certain times during the cropping cycle can actually lead to an increase in crop yields (Saunders 1978, Harris 1974).

Weeds can serve a useful function in an agroecosystem by providing habitat for beneficial insects, attracting insect pests away from crops, creating physical barriers that interfere with insect movements, or creating a crop microenvironment unsuitable for pest growth and development (Altieri et al. 1977). Weeds also protect the soil from erosion and may be left intentionally in agricultural fields as a ground cover. *Imperata cylindrica*, an agressive invader of agricultural fields in Southeast Asia, is used as a mulch to control infection by a sugarcane parasite *(Aeginetia indica)* in the Philippines (Datta and Banerjee 1978). Weeds also can be useful to farmers as food, medicine, or fuel biomass. A survey of weeds in dry-season upland agricultural fields in West Java showed 17 of 73 species to be of value to the farmers (Table 12.1). Datta and Banerjee (1978) found that 124 of 158 weed species in West Bengal rice fields had some economic value. Weeds are commonly harvested to feed domestic animals. In fact, West Javanese farmers often decide when to weed based on domestic animal needs rather than on the weeds' competition with crops.

Table 12.1. Useful Weeds Present in Ten Dry-Season Upland Agricultural Systems Near Bandung, West Java, July 1983

Scientific Name	Common Name	Use
Cynodon dactylon (L.) Pers.	Bermuda grass	Ground cover
Phyllanthus urinaria L.	Pick-a-back	Medicine
Ageratum conyzoides L.	Billy goat weed	Medicine
Alternanthera philoxeroides Mart.	—	Forage
Commelina nudiflora L.	Common spiderwort	Forage
Borreria latifolia Schum.	Garden weed	Forage
Amaranthus sp.	—	Forage
Cyperus rotundus L.	Nut grass	Ground cover
Eclipta alba (L.) Hassk.	White heads	Medicine
Vernonia cinerea (L.) Less.	—	Medicine
Euphorbia hirta L.	Hairy spurge	Medicine
Ipomoea fistulosa	—	Medicine, hedge
Urena lobata L.	—	Medicine
Sida retusa L.	Snake's tongue	Medicine
Eryngium foetidum L.	Sea holly	Vegetable
Ageratum houstonianum Mill.	Chickweed	Medicine
Gynura crepidioides Benth.	Fireweed	Vegetable

Note: Based on field work in collaboration with Aseng Ramlan, Sri Endarti Rahayu, and Carolina.

Magnitude

It is likely that traditional agroecosystems always have had their share of pest problems. Glass and Thurston (1978) cite accounts of blights and pestilence dating back to Biblical and ancient Egyptian times. Pest management practices most probably evolved by trial and error along with the development of permanent agriculture, and selection of pest-resistant varieties by traditional farmers may have occurred during this time (Glass and

Thurston 1978). Pest losses in traditional agriculture today generally range from 10 to 40 percent of the crop production (McEwen 1978). This is not a trivial amount, but pest losses in modern agriculture fall in the same range, even though pesticides are employed. The significant difference is that pest losses in modern agriculture can often approach 100 percent if pesticides are not employed.

The nature of pest problems in traditional agriculture can be illustrated by the situation in Indonesia. Many kinds of pests occur in contemporary traditional agriculture, and farmers frequently cite pests and diseases as constraints that limit crop production (Prasadja and Ruhendi 1980). Insect damage is common in Javanese homegardens *(pekarangan)*, upland fields *(kebun)*, and successional cropping systems *(kebun-talun)*, as well as in rice fields. Leaves of banana and rambutan and the fruits of jackfruit and mango are often damaged by insects, and stem-borer damage is common in *Albizia* and bamboo. The amount of damage to crops is generally low in diverse agroecosystems but is sometimes high in monoculture systems (Table 12.2).

Mammals such as rats, mice, and bandicoots are common agricultural pests in Indonesia. There are six species of rats and two species of bandicoots that cause significant losses in rice, corn, cassava, sugarcane, sweet potato, peanut, mung bean, soybean, cocoa, and coconut (Soekarna et al. 1980). Although each of these mammalian pests has particular habitats in which it predominates, all of them can occur to some extent in all agricultural habitats (Lim et al. 1980). *Rattus argentiventer* is a particularly serious pest in lowland rice fields. Squirrels (e.g., *Sciurus notatus)* sometimes do serious damage to coconut and fruit trees, and mango and rambutan are often damaged by fruit-eating bats (e.g., *Pteropus vamphyrus)*. Otters *(Amblonyx cinerea)* raid fish ponds, and frugivorous and seed-eating birds also can be serious pests.

TRADITIONAL PEST MANAGEMENT TECHNOLOGY

Traditional pest management practices can be categorized into two major classes: (1) direct, nonchemical pest control measures; and (2) pest control resulting from the structural complexity of mixed cropping (i.e., spatial or temporal crop diversity).

Direct pest control includes mechanical, cultural, and biological methods (Table 12.3). Direct pest control practices in Java and Thailand are discussed in this section.

Mechanical Control

A variety of mechanical methods are used by traditional Javanese farmers to protect their crops from pests. For example, scarecrows and sound devices (such as strings of empty cans tied together) are used to frighten birds away from rice fields. Fruits are often wrapped in cloth or in baskets to protect them from bats, birds, and caterpillars until harvest *(brongsong* system). Stems of some plants are painted with lime to protect them from

Table 12.2. Pests and Levels of Damage in Traditional Agricultural Systems in West Java

Pest	Plant Part Damaged	Level of Damage: Homegarden	Mixed-Garden (*kebun-talun*)	Garden Monocultures	Rice Fields
Snails (*keong racun*)	Leaves	Low	Low	—	—
Insects (adults and larvae)	Leaves	Low	Low	Low–high	Low–high
	Stems	Low	Low	—	Low–high
	Fruits and grains	Low	Low	Low–high	Low–high
	Roots	Low	Low	—	—
	Wood	Low	Low	—	—
Birds	Grains and seeds	Low	Low	—	Low–high
Rats	Grains	Low	Low	—	Low–high
	Fruits	Low	Low	Low	—
	Roots (tubers)	Low	Low	—	—
	Stems	—	—	—	Low–high
Squirrels	Fruits	Low	Low	—	—
Bats	Fruits	Low	Low	—	—
Mongoose	Fruits	—	—	Low	—

Source: Based on observations by John Iskandar and Linda Christanty.

Note: — indicates pests are not usually a problem.

Table 12.3. Examples of Direct Pest Control Practices in Traditional Agriculture

Control Type and Country	Host Crop	Pest	Control Practice	Source
CULTURAL CONTROLS				
India	Apples, citrus	*Heliothis armigera*	Destruction of pest food source by turning clover into the soil	Batra 1962
China	Legumes, crucifers, and solanaceous crops	Seed-borne bacterial diseases	Ditch and furrow irrigation rather than overhead sprinkling	Williams 1979
China	Chinese cabbage	Bacterial wilt	Plowing under crop residues and drying soil surface for 3–5 days before replanting	Williams 1979
Philippines	Mung bean	Flea beetle	Planting at high crop density (300,000 plants/ha)	Litsinger et al. 1980
Indonesia	Rice	Rats	Cutting or burning vegetation around rice fields	Sanchez 1980
Philippines	Sugar cane	Parasitic plant (*Aeginetia indica*)	Use of *Imperata cylindrica* grass as a mulch	Datta and Banerjee 1978
DIRECT MECHANICAL CONTROL				
China	Vegetables	Aphids	Vertical placement of 0.5 m^2 yellow sheets of greased polyethylene, 15–30/ha	Williams 1979
China	Tomatoes and other crops	*Heliothis armigera*	Placement in fields of bundles of young willow or poplar twigs that have been cut and dried in the sun for two days, 150 bundles/ha. Adult moths attracted to bundles and removed.	Williams 1979
Indonesia	Rice and other crops	Rats	Digging out rat hole and killing rats	Sanchez 1980
China	Vegetables	Cutworms	Baiting with poisoned rice straw bundles	Williams 1979
Indonesia	Rice, corn, legumes	Bacterial wilt, grasshoppers, downy mildew, leaf folder	Removal of infested plants	Prasadja and Ruhendi 1980
Indonesia	Cassava	Scale insects	Manual removal by rubbing or washing with water	Prasadja and Ruhendi 1980
Indonesia	Grain legumes	*Cercospora* leaf spot	Cutting of infected leaves	Prasadja and Ruhendi 1980
REPELLENTS				
Philippines	–	Aphids	Application of ash or soap	Litsinger et al. 1980
Philippines	Rice	*Cercospora* leaf spot	Application of sand	Litsinger et al. 1980
Philippines	–	White grub	Application of salt	Litsinger et al. 1980
Philippines	–	General	Smoke from burning tires	Litsinger et al. 1980

Table 12.3. *(continued)*

Control Type and Country	Host Crop	Pest	Control Practice	Source
REPELLENTS *(continued)*				
Indonesia	Rice and other crops	Rats	Gassing rat holes with rice straw plus sulfur	Sanchez 1980
Philippines	Rice, corn, and other crops	Rice caseworm, whorl maggot	Use of branches and leaves of *Gliricidia sepium*	Litsinger et al. 1980
Philippines	Rice, corn, and other crops	Termites, downy mildew	Use of branches and leaves of *Cordia dichotoma*	Litsinger et al. 1980
Indonesia	Grain legumes	*Phaedonia inclusa,* aphids, ants	Spreading of ash	Prasadja and Ruhendi 1980
Indonesia	Grain legumes	White grub	Application of salt	Prasadja and Ruhendi 1980
BIOLOGICAL CONTROL				
China	Oranges	Insects	Placement of predaceous ants (*Oecophylla smaragdina*) in trees	Doutt 1964
China	Vegetables	Aphids	Raising and introduction of Lace-wing flies (*Chrysopa sinica*) as biological control agent	Williams 1979
China	Vegetables	Aphids	Release into vegetable fields of lady beetles (Coccinellidae) collected in wheat fields by sweeping	Williams 1979
China	Rice, corn, sugar cane	Rice leaf roller (*Cnaphalocrocis medinalis*), sugar cane borer (*Argyroploce schistacaena*), corn borer (*Ostrinia nubilalis*)	Rearing of egg parasites (*Trichogramma* sp.) on silkworm eggs	Williams 1979
China	Crucifers	Cabbage worm (*Pieris rapae*)	Spraying of *Bacillus thuringiensis* in water solution to promote insect parasitism	Williams 1979
China	Rice	Insects	Herding ducks through rice paddies to consume insects	Williams 1979
SEED TREATMENT				
China	Cucumber	*Fusarium, Colletotrichum*	Hot water treatment of seeds, 50–55° C for 15 minutes	Williams 1979
China	Pepper	*Xanthomonas vesicatoria*	Hot water treatment of seeds, 55° C for 15 minutes	Williams 1979

ants (*labur* system), and zinc plates are placed around the stems of coconut palms and fruit trees to prevent rodent damage. Javanese farmers believe that dolls or sharpened bamboo sticks placed at the top of the vegetation canopy will repel bats from homegardens. Squirrels and bats are hunted with blowpipes and slingshots. Smoke from burning rice husks on the dikes around the paddies is believed to repel insects.

Manual removal of pests is a common control measure. During periods of high pest infestation, farmers may hand pick insects from crop plants as often as twice daily (Prasadja and Ruhendi 1980). Caterpillars removed from Javanese gardens by hand or with long poles are used as fishing bait and feed for chickens, caged birds, and pond fish. Farmers in Northeast Thailand use flashlights at night to attract a beetle pest of sesame. The beetles are trapped and consumed by the family or sold in the market.

Ant nests on the ground are burned, and ant nests in the canopy are knocked to the ground with bamboo poles and then burned. Perennial plants are sometimes pruned as a control measure to reduce suitable habitat for ants. Subterranean ants are destroyed by burying coconuts to the depth of the plowed layer in places where ant damage has occurred during the previous cropping season. The outer husk (exocarp) is removed from the coconut, exposing the underlying layer (mesocarp), which attracts the ants from a distance. A small hole is made in the bottom of the coconut for the ants to crawl inside, where they are attracted to the coconut meat. The coconuts are removed after being in the ground for about five days, and any ants they contain are shaken into a fire. The coconuts are then soaked overnight to remove any smoky odor and buried in the ground again to collect more ants.

Rat populations in Javanese rice fields are controlled by a number of traditional practices. Groups of three to ten persons, sometimes accompanied by dogs, hunt rats in the rice fields and destroy rat burrows using hoes and sticks. Fumigation of rat burrows is another common control method; sulfur and rice stalks are burned and the smoke is directed into the burrows through bamboo tubes. Weeding helps to control rats by eliminating suitable habitat, and rats are sometimes caught by traps.

Garlic plants in Northern Thailand can be damaged by a fungal disease known as "purple blotch," which causes tip burn of garlic shoots during the dry season. To prevent fungal growth, farmers go to the field immediately after a light rain and pour large quantities of water over the garlic plants. Although the mechanism responsible for control has not been verified, this practice presumably works by washing fungal spores from the leaves.

Cultural Control

Cultural practices such as tillage, mulching, and burning are used by traditional farmers to control weed pests. Tillage and other types of soil disturbance have been shown to affect weed seed germination by altering soil moisture, temperature, and aeration (Altieri and Whitcomb 1978). In Northeast Thailand weed problems in peanut crops are reduced by repeated harrowing at the end of the dry season. The harrowing breaks the soil water capillarity, leaving the surface soil too dry for weed germination and growth. Weed problems in garlic cultivation are prevented by mulching the garlic beds with rice straw.

Hand weeding is a common traditional pest control measure. The weeding of cassava in Northeast Thailand is timed for maximum effectiveness. Weeds in cassava are hoed early during the dry season, when water is lacking for subsequent weed growth. The weeds are left on the ground as a mulch, making further labor to remove weeds from the field unnecessary. This low expenditure of labor for weeding cassava is important because intensive labor is required for rice preparation during the same period. Later, when rainy season conditions are favorable for rapid weed growth, the cassava canopy is fully developed and weed growth is limited by shading.

Burning the field before cultivation is a weed control practice in some traditional farming systems. For example, weed populations in upland crops in Northeast Thailand are reduced by burning rice stubble on the fields. Slash-and-burn procedures in Costa Rica were observed to reduce the viability of weed seeds in the topsoil by more than 50 percent (Ewel et al. 1981).

Biological Control

Indigenous natural enemies of pests are a major source of pest control in traditional agriculture. The majority of wild bird species in the Citarum watershed of West Java are insectivorous and appear to be a major factor in controlling insect populations in rural areas (Iskandar 1980). For example, caterpillars in Javanese homegardens and upland gardens are controlled by insectivorous birds such as the brown-throated sunbird *(Anthreptes malacensis)*, little spider-hunter sunbird *(Arachnothera longirostra)*, olive-backed sunbird *(Nectarinia jugularis)*, ashy tailor bird *(Orthotomus ruficeps)*, and pied fantail *(Rhipudura javanica)*. Carnivorous birds are also important pest predators. There are relatively few species of frugivorous and seed-feeding birds (the ones usually considered pests) compared with insectivorous and carnivorous species. However, some of the seed eaters, like the Javan munia *(Lonchura leucogastroides)* and scaly-breasted munia *(Lonchura punctulata)*, can cause serious damage in the rice fields. The capture and sale of wild birds, some of which are natural biological control agents, may intensify pest problems.

Manipulation of the natural enemies of pests has probably always been part of traditional agriculture (Glass and Thurston 1978). Ducks have been used for many years in Java to control insect populations in rice fields, though the duck populations have declined recently, apparently due to pesticide use in rice paddies. Chickens, a significant biological control agent in Javanese homegardens, eat leaf-rolling insects and leaf-feeding peanut pests. This method of control is deliberate—the farmers say they plant peanuts around the house so chickens in the yard can remove insects from the crop.

THE ROLE OF MIXED CROPPING

One of the main ways that traditional agriculturalists control pests is by managing agricultural fields as habitats for pests (Anon. 1983, Marten 1985). Because subsistence agriculture usually consists of a diversity of crops to meet a diversity of needs, the particular combinations of crops that are planted together—and the way they are arranged with regard to one another in space and in time—can have a major impact on an agricultural field as a habitat for pests.

In recent years ecologists have shown considerable interest in the relationship between an ecosystem's species diversity and its stability. It has often been postulated that more diverse systems (i.e., ecosystems containing more species) are the more stable in the sense that the populations within them are more constant in abundance. There have been attempts to apply this hypothesis to mixed cropping in agroecosystems (van Emden and Williams 1974, Levins and Wilson 1980), with the implication that a mixture of more crop species should result in fewer pest outbreaks, but theoretical work has cast some doubts on the hypothesis in such a simply stated form (Goodman 1975).

The relation between crop diversity and pest damage is ultimately a question of empirical observation. There have been numerous field-station experiments with simple mixtures of two and sometimes three crops, but there have been few experiments with crop mixtures having the complexity that is so common in traditional agriculture, where ten or twenty crops may be mixed in the same field. Nonetheless, it is clear from the studies of simple crop mixtures that interplanting different crop species does not in itself reduce pest damage. The outcome of mixed cropping depends upon the crop mixture and how the interplanted crops interact with each other, with the pests, and with the rest of the agroecosystem (van Emden and Williams 1974, Kass 1978, Perrin 1980). While some studies have reported lower numbers of herbivores or less damage from herbivores in diverse than in simple systems (Pimental 1961a and 1961b, Tahvanainen and Root 1972, Root 1973), others have reported greater abundance of some insects in the more diverse systems (Cromartie 1975, Thompson and Price 1977). A critical review of 150 studies of crop diversity and insect abundance revealed that 53 percent of 198 herbivore species were less abundant and 18 percent were more abundant in the more diverse systems (Risch 1983). The remaining 29 percent showed no difference or variable response. A variety of studies on herbivory in both agricultural and natural ecosystems have also shown that the rate at which plants are consumed by herbivores is not so much a consequence of the number of plant species per se as the kinds and quantities of edible plant materials present (Ewel et al. 1982, Brown 1982).

In summary, pest damage is not reduced by mixed cropping per se, though appropriately structured diversity can curtail pests. It is therefore not surprising that there are numerous examples of both increased pest abundance and decreased pest abundance associated with intercropping in traditional agriculture (Table 12.4).

Root (1973) suggested two possible mechanisms to explain high resistance to pest attack in mixed cropping: (1) the "enemies" hypothesis and (2) the "resource concentration" hypothesis. The enemies hypothesis supposes that species-rich cropping systems have a higher abundance of predators and parasites than do species-poor systems, and these predators and parasites keep the pests under control. Natural enemies are probably a major part of pest control in virtually all traditional agriculture, but experimental field research has indicated that the impact of natural enemies is generally not augmented by mixed cropping per se. Nonetheless, there are particular crops that provide favorable habitat for natural enemies of crop pests (Table 12.5), and a higher diversity of plants in an agricultural field can lead to a higher diversity of the pests' natural enemies (Nishida et al. 1983).

According to the resource concentration hypothesis, reduced pest problems in mixed cropping are due to the reduced density of host species or interference from nonhost plants. For example, a study of the mango beetle (*Cryptorhynchus gravis*) in Java showed that little damage occurred on mango trees in natural forests, where the mango trees were highly dispersed, but the fruits of mangoes in dense monocultures were severely damaged (Voute 1935). Interplanted crops can interfere with pests in a number of ways:

- They can create a microenvironment that is unsuitable for the pests.
- They can interfere with the movement of pests from one host plant to another.
- They can attract the pests away from host plants.
- They can make the field less attractive to pests.

Shading in mixed cropping systems may provide microenvironmental conditions unsuitable for some crop pests (Table 12.6). Beetles moved away from beans and squash in a corn-bean-squash mixture in Costa Rica due to shading of the beans and squash by the taller corn plants and due to cornstalk interference with beetle flight patterns (Risch 1981). Webworm damage to sesame in Nigeria was lower when the sesame was intercropped with corn or sorghum than when grown in monoculture (Litsinger and Moody 1976). However, a closed canopy that provides an unfavorable microhabitat for certain pests also may provide favorable conditions for other pests and fungal diseases.

It is possible for manipulation of an agricultural habitat to discourage one pest while encouraging another. For example, removal of the stubble from rice fields eliminated a habitat that supports the life cycles of certain stem borers and hoppers in Southeast Asian rice fields, but the stubble is a necessary habitat for natural enemies of other pests (Perrin 1980).

Weed problems are often reduced in mixed cropping systems with continuous crop cover. In Nigeria, cowpeas planted into a sorghum-millet intercrop developed a canopy that reduced weed growth (Summerfield et al. 1974). Cucurbits are grown with corn in the Congo basin for the explicit purpose of controlling weeds (Miracle 1967). Less weed growth was reported

Table 12.4. Increases and Reductions of Pest Problems in Traditional Agriculture by Interplanting

Country	Host Crop	Pest	Interplanted Crop(s)	Source
Reductions in pests				
Indonesia	Mung bean	Beanfly (*Ophiomyia phaseoli*)	Weeds	Litsinger and Moody 1976
Nigeria	Sesame	Pyralid webworm (*Antigastra* sp.)	Corn or sorghum	Litsinger and Moody 1976
Nigeria	Cowpea	Insects	Sorghum-millet	Baker and Norman 1975
India	Jowar	Jowar ear head fly (*Calocoris angustatus*)	Red gram	Raheja 1973
India	Jowar	Jowar ear head fly (*Calocoris angustatus*)	Pigeon pea	Batra 1962
Peru	Cotton	*Heliothis armigera, Dysdercus* sp.	Maize	Southwood and Way 1970
Mexico	General	Nematodes	*Chenopodium ambrosioides*	Chacon and Gliessman 1982
India	Pea	Pod-fly (*Agrotis obtusa*)	Wheat or barley	Batra 1962
India	Mustard	Mustard aphid (*Lipaphis erysimi*)	Wheat	Batra 1962
India	Fruit trees	Flea beetle (*Luperodes* sp.)	Cowpea	Batra 1962
Philippines	Corn	Corn borer (*Ostrinia furnacalis*)	Peanuts	Raros 1973
Increases in pests due to interplanting				
China	Cucumber	*Fusarium solani, F. cucurbitae*	Winter melon and other cucurbits	Williams 1979
India	Wheat, barley	Cutworm (*Agrotis* spp.)	Gram	Batra 1962
China	Chinese cabbage	Turnip mosaic virus, downy mildew (*Peronospora parasitica*), bacterial soft rot (*Erwinia carotovora*)	Leaf mustard, cabbage, cauliflower	Williams 1979
India	Deciduous fruit trees (e.g., peach, plum)	Weevil (*Myllocerus undecemlineata*)	Jowar	Batra 1962
India	Fruit trees	*Aphis craccivora*	Cowpea	Batra 1962
India	Citrus	Nematode (*Meloidogyne* spp.)	Tobacco	Batra 1962
India	Rice	*Leptocorisa varicornis, L. acuta, Hispa armigera, Nymphula depunctalis*	Other rice varieties	Batra 1962
India	Citrus	Root-knot nematode (*Meloidogyne* spp.)	Tomato, brinjal, lady's finger, tobacco	Batra 1962
Nigeria	Cotton	*Heliothis armigera, Cryptophlebia leucotreta*	Maize and tomatoes	Perrin 1977
India	*Colocasia* spp.	*Phytophthora areca*	*Areca* and sandalwood	Raheja 1973
Tanzania	Cotton	*Heliothis armigera*	Maize	Reed 1965
East Africa	Maize	*Ootheca bennigseni*	Cowpea	Kayumbo 1976
India	Castor	Castor semilooper (*Achoea janata*)	Groundnut, kulthi urid, mung bean	Batra 1962
India	Rubber	Root diseases (*Fomes* sp., *Poria hypobrunnea*)	*Crotalaria anagyroides, Tephrosia vogelli*	Raheja 1973

Table 12.5. Interplanted Crops That Favor Natural Enemies

Country	Host Crop	Pest	Interplanted Crop(s)	Natural Enemy	Source
Philippines	Maize	Not specified	Groundnut	Predatory spiders	Gavarra and Raros 1975
India	Not specified	Not specified	Pigeon pea	Dipterans	Bhatnagar and Davies 1981
India	Not specified	Not specified	Sorghum, groundnut, and chickpea	Hymenopterans	Bhatnagar and Davies 1981
Peru	Cotton	*Heliothis virescens*	Corn, beans, sweet potato	*Nabis punctipennis*, *Paratriphleps laeviusculus*	Hambleton 1944

in traditional Latin American polycultures of corn, beans, and cassava than in monocultures of each crop (Hart 1975). Weed reduction in mixed cropping systems is usually attributed to reduced light transmission through the canopy. Shading experiments have shown there is up to a 75 percent reduction in weed biomass at 50 percent transmission of incident light, and up to a 96 percent reduction in weed biomass at 20 percent transmission (Bantilan et al. 1974).

Interplanted crops can reduce pest damage by interfering with the movement of pests between host plants (Table 12.7). Bach (1980) found a lower herbivore abundance in experimental mixtures of cucumber, corn, and broccoli than in cucumber monocultures and concluded it was not due to differences in host plant density or the combined density of all crops per se but could be attributed to different insect movement patterns in the diverse and simple plots. In a study of small-scale farmers' fields in the Philippines, corn borer damage was less when beans or upland rice were interplanted with the corn, apparently because corn borer larvae often landed on the interplanted crop instead of the corn (Hasse 1981). Disease can be checked in a similar fashion. For example, intercropping beans with groundnuts reduces the spread of groundnut rosette virus by a physical interference mechanism—the aphid vector of the virus becoming trapped by the hooked epidermal hairs of the bean plants (Farrell 1976). Host plants also may be physically hidden from their herbivores by nonhost plants in high-diversity systems. For example, the grain of a short, early-maturing rice variety in Indonesia is protected from birds by the camouflage effect of interplanting with a tall, late-maturing variety (Litsinger and Moody 1976).

Pests of one crop may be repelled or attracted by interplanted species (Table 12.8). For example, mixed cropping may lead to chemical interference with pest colonization by providing olfactory deterrents or insect repellents

Table 12.6. Traditional Mixed Cropping Systems in Which Interplanted Crops Create a Microenvironment Favorable or Unfavorable for Pests

Country	Host Crop	Pest	Interplanted Crop(s)	Mechanism	Source
Unfavorable environment					
Congo	Corn	Weeds	Cucurbits	Shade	Miracle 1967
India	Coffee	Stem borer beetle (*Xylotrechus quadripes*)	Shade trees	Shade reduces beetle reproduction	Raheja 1973
India	Cotton	Root rot, red leaf, leaf roll, *Fusarium* wilt near surface	Bean *Phaseolus trilobus*	Reduction in soil temperature	Raheja 1973
Nigeria	Sesame	Webworm	Corn or sorghum	Shade	Litsinger and Moody 1976
Favorable environment					
India	Rope-mustard, radish, turnip (early crops)	Mustard sawfly (*Athalia proxima*), flea beetle (*Phyllotreta cruciferae*)	Shade trees	Shade	Batra 1962
India	Cucurbits	Melon aphid (*Aphis gossypii*)	Shade trees	Shade	Batra 1962
India	Cotton and lady's finger	Leaf roller (*Sylepta derogata*)	Shade trees	Shade	Batra 1962
India	Rubber	Pink disease (*Corticium salmonicolor*)	Unspecified	Shade	Raheja 1973
India	Coffee	Shot-hole borer (*Xyleborus* sp.)	*Erythrina*	Shelter for pests	Raheja 1973
India	Cardamom	Leaf-eating caterpillar (*Eupterote canaraica*)	Shade trees	Shelter for pests	Raheja 1973

Table 12.7. Traditional Mixed Cropping Systems in Which Interplanted Crops Interfere with Pest Movement from One Host Plant to Another

Country	Host Crop	Pest	Interplanted Crop(s)	Source
Pest trapped				
India	Coconut	Coconut beetle	Date palm	Batra 1962
India	Cucurbits	Fruit flies	Corn, sann hemp	Batra 1962
India	Cotton	Cotton boll weevil	*Bhindi*	Raheja 1973
India	Peanut	Thrips, fungus	Corn	P.W. Amin, ICRISAT, pers. comm.
Malawi	Groundnuts	*Aphis craccivora*	*Phaseolus* sp.	Farrell 1976
Host crop hidden				
India	Sugar cane	Sugar cane borers that attack young plants	Berseem	Batra 1962
Indonesia	Short, early maturing rice	Birds	Tall, late-maturing rice	Litsinger and Moody 1976

Table 12.8. Traditional Mixed Cropping Systems in Which Pests are Repelled or Attracted by Interplanted Crops

Country	Host Crop	Pest	Interplanted Crop(s)	Source
Pest repelled				
India	Grain, wheat, jowar	Large predators (e.g., wild pigs)	Safflower (planted on borders)	Batra 1962
India	Coconut	Coconut beetle (*Oryctes rhinoceros*)	*Euphorbia tirucalli*	Batra 1962
Pest attracted				
India	Grain, linseed	Termites (*Microtermes obesi*)	Wheat	Batra 1962
Nigeria	Cotton	Flea beetles (*Podagrica* sp.)	Okra	Usenbo 1976
United States	Citrus	Nematodes	*Crotalaria*	Birchfield and Bistline 1956

(Atsatt and O'Dowd 1976, Tahvanainen and Root 1972). Intercropped companion plants can control nematode problems, either by root exudates that kill the nematodes directly or by interference with the nematode life cycle. Marigold has been shown to kill nematodes directly by root exudates (Visser and Vythilingham 1959). Intercropped *Crotolaria*, itself susceptible to nematode attack, diverts nematodes from other crops and then interferes with the nematode life cycle within its roots (Birchfield and Bistline 1956).

Reduced colonization by insect pests has been observed in mixed cropping systems where a continuous green ground cover was less attractive to insects than a background of widely spaced plants with much bare ground (Perrin 1980). This mechanism may have been operating in an Indonesian case cited by Litsinger and Moody (1976), in which unweeded mung beans (green ground cover) had lower beanfly attack than weeded mung beans (green and brown contrast).

Even when high crop diversity per se does not reduce pest damage, there is abundant anecdotal evidence to suggest that relatively high losses of one crop species in diverse agroecosystems may be offset by compensatory growth of other species so that the total yield is not severely affected. Although there is not much quantitative information to substantiate this hypothesis for traditional agroecosystems, the stabilizing effect of compensatory fluctuations in co-occurring species has been verified in natural ecosystems (McNaughton 1977, Brown 1982). Such compensatory effects in diverse agricultural systems are widely believed to result in reduced risk of complete crop loss to pests. For example, in India gram and linseed are planted with wheat to guarantee a yield when the more palatable wheat is damaged by ants (Batra 1962). Similarly, horse gram or groundnut are planted with castor as insurance against complete loss to the castor semilooper (Raheja 1973).

Landscape Diversity

Patchiness of the landscape (i.e., a diversity of agroecosystems in the same landscape) may be as important as crop diversity within agricultural fields in determining the distribution and abundance of some pest species. The scale of patchiness of the environment and pest mobility patterns determine the importance of surrounding vegetation in influencing pest abundance in a given agroecosystem. There are few studies on the relationship between pest problems and the mosaic character of traditional agricultural landscapes, but the dynamics of insects in naturally patchy environments have been well studied within the framework of island biogeography theory (MacArthur and Wilson 1967, Strong 1979), and attempts have been made to use this theory to explain colonization patterns of insects in agricultural systems (Mayse and Price 1977). According to the theory, the equilibrium number of species on an island is a balance between immigration and extinction and can be predicted from the size of the island and distance from the source of colonizers. However, the present form of the theory is too simplistic for agricultural mosaics because the crop "islands" (i.e., the fields) are not equilibrium systems. They undergo rapid and continuous change, are available for colonization for only short periods, and may be colonized from a variety of sources (Mayse and Price 1977, Price 1976).

The story of the cotton bollworm in the Canete Valley in Peru is a classic example of the importance of landscape diversity. The bollworm became a serious pest on cotton only after the agriculture changed from diversified small farms to almost pure cotton monoculture (Hambleton 1944, Smith and Reynolds 1972). When the farmers in the valley gradually reverted to their traditional agriculture, the bollworm problem decreased, apparently because the diverse landscape provided a habitat for natural enemies of the bollworm. Studies have shown that corn, alfalfa, and sorghum grown in fields adjacent to cotton can reduce bollworm attacks on cotton by harboring predator populations and by acting as a diversionary crop for the bollworm (Litsinger and Moody 1976).

Although the net effect of landscape patchiness is usually to diminish pest problems, there can be effects in the opposite direction. For example, Price (1976) found that colonization of soybean fields was much slower by predators and parasites than by herbivores, leading to rapid herbivore population increases early in the season. In other words, isolation of crop fields to reduce pests may sometimes result in a proportionally greater reduction of beneficial insects than of harmful ones (Rey and McCoy 1979). A diverse landscape also may provide alternative habitats for pest populations. For example, rats in West Java migrate between rice fields and nearby sugar-cane plantations. In some areas, where rice planting is not synchronous or several rice varieties with different growing seasons are used, the rats are continuously provided with a suitable habitat. Leaving strips of uncultivated land between fields is a traditional strategy to reduce rat damage in Indonesia.

Temporal Diversity

Changes in crop species over time are a common characteristic of many traditional cropping systems. Cultural practices such as crop rotation between susceptible and nonsusceptible crops, successional cropping schemes, and fallows result in a "temporal diversity" that interrupts pest life cycles by eliminating suitable habitat for the pests at certain times (Table 12.9). Successful rotations employ a sequence of crops with different growth habits and with few pests in common, so the pests cannot transfer from one crop to the next. For example, farmers in Northeast Thailand rotate sesame with eggplant or cucumber to control a fungus that causes stem and root rot in the sesame.

Crop rotations are particularly effective in controlling soil-borne insect pests and nematodes (Caveness 1971, Nusbaum and Ferris 1973, Brodie and Murphy 1975, Johnson et al. 1975). Planting a nonhost crop reduces the preplanting nematode density for a subsequent susceptible crop, allowing the susceptible crop to be harvested before the nematode population increases to a damaging level. The effectiveness of a particular crop rotation depends on the life cycle of the pest and whether the pest is broad or narrow in

the range of host plants it can attack. Pests with persistent life history stages or a broad range of hosts (e.g., the root-knot nematode *Meloidogyne incognita*) are not easily controlled by crop rotation (Perrin 1980).

It is typical in traditional agriculture to adjust crop cycles to insect life cycles so the insect damage is minimal (Table 12.10). For example, kenaf, an important fiber crop in Northeast Thailand, is usually planted from March to June. When kenaf is planted late yields are low due to severe damage by leafhoppers, so the farmers generally plant the kenaf as early as possible, allowing it to grow to a larger size before leafhopper populations can build up. Early planting is also a traditional control method for a fungal disease that causes root and stem rot of sesame in Thailand. As high rainfall and humidity favor rapid growth of the fungus at the end of the season, early planting of sesame can reduce the severity of the disease.

Some weed pests can be controlled by temporal diversity in the agroecosystem. Crop rotations that include flooding and drying reduce weed problems for species that are adapted to only one condition or the other (William and Chiang 1980, Harwood and Bantilan 1974). Flooding the paddies in Northeast Thailand before transplanting rice delays weed growth. If rainfall is low, some hand weeding is necessary, but weeds removed from the paddies are used as fodder for water buffalo. Field station experiments in the Philippines showed that management practices to control weeds in one crop can reduce the weed populations in subsequent crops (Harwood and Bantilan 1974). For example, weed management in upland crops resulted in fewer weeds in subsequent rice crops due to reduced carry-over of weed seeds in the soil. Similarly, puddling during rice cultivation resulted in lower weed levels in succeeding upland crops.

THE PESTICIDE DILEMMA

Although traditional pest management practices have generally been satisfactory for subsistence agriculture, small-scale farmers are increasingly faced with unacceptable pest losses as they employ introduced crops or improved varieties and change their agricultural practices in other ways to improve their yields. It is natural for farmers to turn to chemical pesticides under such circumstances, but there can be little doubt that in numerous cases the introduction of modern pesticides to traditional agriculture has resulted in new, and often more serious, pest problems than were present before. A common example is the appearance of "secondary pests," animals or plants that previously were not pests but that become abundant when their natural enemies were eliminated by pesticides. The farmer is then dependent on continued pesticide use because natural mechanisms of regulation have been destroyed by the pesticides. This is the pesticide dilemma.

Modern cropping practices, including chemical pest control, may increase pest problems for a variety of reasons (Metcalf 1980). These include:

- The destruction of beneficial insects;

Table 12.9. Traditional Rotation Systems That Reduce Pest Damage

Country	Host Crop	Pest	Control Practice	Source
Peru	Potatoes	Potato cyst nematode (*Globodera pallida, G. rostochiensis*)	Seven-year rotation to reduce pest below economic threshold	Glass and Thurston 1978
Philippines	Mixed crops	Nematodes, bacterial wilt	Rotation of grain legumes and vegetables with dryland rice and corn	Litsinger et al. 1980
Central America	Not specified	Nematode (*Pratylenchus* sp.)	Low dominance in bush fallow; high dominance in continuous cultivation	Nickel 1973

Table 12.10. The Use of Timing to Reduce Pest Damage

Country	Host Crop	Pest	Control Practice	Source
Philippines	Corn	Corn-seedling maggot	No planting in August	Litsinger et al. 1980
Philippines	Mung bean	Flea beetle	Delay planting 1–2 months after rice harvest	Litsinger et al. 1980
Philippines	Rice	Rodents, birds	Synchronous planting	Litsinger et al. 1980
Indonesia	Rice (also corn, sweet potato, cassava, soybean)	Rats	Synchronous planting and harvesting	Sanchez 1980
Indonesia	Rice, corn, legumes, tuber crops	Not specified	Adjusting planting dates, synchronous planting	Prasadja and Ruhendi 1980

- Insect pest resistance to pesticides;
- Decreased crop rotations;
- Reduced crop sanitation;
- Reduced tillage;
- Increased cosmetic standards for crop quality; and
- Increased planting of more susceptible crop varieties in the belief that modern pest control techniques can safeguard them.

Historical Examples

Many cases of pesticide-induced pest problems have been reported in the literature. Conway (1972) described several cases from Malaysia. Cocoa, a crop first planted commercially in Malaysia in 1956, was sprayed in 1959 with dieldrin or DDT to control a ring bark borer and two branch borers. Following spraying, several other pests, including various leaf-eating caterpillars, aphids, and mealybugs, became noticeable. In 1960 spraying was increased to cover the new pests and included dieldrin, endrin, DDT, BHC, and a white oil. By 1961 the branch borers increased, there were outbreaks of two leaf-eating caterpillars and a planthopper, and worst of all, there were outbreaks of several species of bagworms that resulted in large numbers of bare and dying trees. The pesticide-induced mortality of natural enemies was greater than that of the pests, and the pests were able to escape from the control imposed by their natural enemies. Another contributing factor in the ring-bark-borer problem was that an important secondary host tree was common not only in the nearby forest but in the fields among the cocoa trees themselves.

Oil palm is also a relatively new crop in Malaysia, and from its introduction prior to World War II until 1956 there were no significant pest problems. At that time DDT, dieldrin, and endrin, applied on a large scale as a general prophylactic measure or to control minor damage due to cockchafers or bagworms, led to severe outbreaks of the bagworms and consequent crop losses of up to 40 percent in the first year after the attack. The bagworms were again sprayed with DDT, resulting in successive outbreaks in adjacent areas to which the spray had drifted. As with cocoa, the problems in this case were attributed to a greater impact of general contact pesticides on pest predators and parasites than on the pests themselves.

Other cases reported by Conway (1972) concerned rubber pests, rats, and thatch-eating moth larvae that became a problem after malarial control pesticide applications in Borneo. Another example is the brown planthopper, *Nilaparvata lugens*, which was once a minor pest but is now the most serious pest in Indonesian rice fields. Recent planthopper outbreaks are the result of eliminating crop rotations, cultivating only a few improved varieties of rice in a large area, and using pesticides intensively (Soemarwoto 1979). Losses have continued to increase despite massive control programs.

Although these examples of pesticide-induced pest problems in agriculture deal primarily with commercial crops grown on a fairly large scale, small-scale subsistence farmers can be affected similarly. Many subsistence farmers

Table 12.11. Pesticide Use in Traditional Agriculture in West Java

Agricultural System	Level of Pesticide Use
Homegarden	Low to none, only for certain species such as clove, oranges
Tree plantation (*talun*)	None
Mixed garden (*kebun*)	Low, only for certain species such as oranges, some vegetables
Garden monoculture	Medium-high, e.g., for tomato, potato, tobacco, cabbage
Rice field	Medium-high and intensive

who now have chemical pesticides available to them as a new pest control option are faced with decisions on whether to adopt modern control methods. These farmers in developing countries are often untrained in pesticide use, lack capital resources to implement proper pesticide handling and application procedures, and are forced to rely on other uninformed farmers for advice on pesticide selection and use.

The response to pesticide-induced problems is often intensified pesticide usage. This endless cycle leads eventually to environmental side effects such as pesticide residue buildups in nonpest organisms, loss of predators and other natural enemies of the pests, emergence of pest-resistant varieties, honeybee poisoning, and fishery and wildlife losses (Pimentel et al. 1980). Pesticide residues have been detected in water samples from a variety of sites in Java, Bali, Sumatra, and Sulawesi (Soemarwoto 1979). Although the levels of residues are still relatively low, they already may be causing perturbations in both aquatic and terrestrial systems. Pesticide residues are thought to be responsible for the decline in Javanese paddy fish culture from 8,500 ha in 1974 to 1,800 ha in 1978, and also for a decrease in species and numbers of birds in rural areas of West Java (Soemarwoto 1979, Iskandar 1980).

As risks are a major concern of small-scale farmers (Navarro 1977, Binswanger 1980, Roumasset et al. 1979), many of them tend to be cautious about getting involved with pesticides. Mechanical control remains the most common method of pest management in West Java, where decisions on pest control are based on information from neighbors, elderly villagers, extension officers, and experience. Pesticide use in West Java is generally conservative, pesticides being applied only to rice crops and upland crop species with high economic value but not to other annual and perennial crops grown for home consumption (Table 12.11).

Escaping the Pesticide Trap

Where increased pesticide use has escalated pest problems, is there a way out of the cycle? Can natural control agents be reestablished once they

have been destroyed by modern pest control measures? Integrated pest management (Brader 1979, Knipling 1979), as modern agriculture's counterpart to the diversity of pest management techniques in traditional agriculture, recognizes that pesticides represent only one of numerous tools that can be used for maintaining pest populations at acceptable levels and takes full advantage of natural enemies for preventing pest outbreaks. In an integrated pest management approach, it is possible for populations of natural pest control agents such as predators and parasites to reestablish themselves in an area once pesticide use has been stopped or made more selective. Replacing general insecticides (e.g., DDT) with selective insecticides and avoiding wide prophylactic applications in favor of localized treatments for specific pest problems can prevent the destruction of predator and parasite populations and allow them to become reestablished. In the examples from Conway (1972) cited earlier, the cessation of pesticide application, except for the selective insecticide trichlorfon applied locally for bagworms, allowed natural control agents to reestablish themselves in cocoa and oil palm plantations and bring all other pests under control at levels below the economic threshold.

Farmers need not be limited to reestablishing only those biological control agents present before pesticide-induced problems, especially for pests of nonnative crops. The successful introduction of biological control agents is a complex undertaking with potentially great rewards (DeBach and Schlinger 1964, Baker and Cook 1974, Huffaker and Messenger 1976, Coppel and Mertins 1977). Successful biological control programs generally include (Caltagirone 1981):

- Determination of the pest abundance necessary for economic damage to crops;
- Correct identification of pest species;
- Introduction of control agents to cover all habitats and/or environmental conditions that can sustain the pest;
- Facilitation of control agents' dispersal to sites where needed; and
- Avoidance of more control agents than necessary.

There appears to be no easy course for the small-scale farmer who is considering using pesticides. For many subsistence farmers who have adopted chemical pest control methods, increasing pesticide costs make a continued use of pesticides impractical, but farmers who want to get away from pesticides can find it difficult, since returning to strictly traditional pest control methods can leave them in the same predicament that prompted them to use the pesticides in the first place. If the neighbors are all continuing to use pesticides, farmers not using pesticides could be in an untenable position. Integrated pest management may help, but it requires that farmers be knowledgeable not only in pesticide selection and use but also in biological control options, optimum intercropping patterns (and therefore cultigen characteristics) in both space and time, and pest identification and life history patterns.

CONCLUSIONS

Available information suggests that pest problems are low in many, but not all, traditional agroecosystems. It appears that pest reductions are often a consequence of the spatial and temporal complexity of traditional agriculture, but the critical factor is how the complexity is ordered with respect to the particular crops and pests involved. In some cases the ecological mechanisms responsible for reduced pest problems have been identified; in others, only anecdotal evidence and speculation exist. There are relatively few quantitative studies on the pest dynamics of traditional agroecosystems. There is sufficient evidence from ecological theory and field experiments with simple crop mixtures to form hypotheses about the ecological mechanisms of pest control in traditional systems, but there is still a lack of empirical tests of these hypotheses in the traditional systems themselves. Rigorous quantitative research is needed to enumerate the desirable ecological features of complex agriculture and identify the mechanisms that lead to reduced abundance of pests for specific crops. This can help to translate traditional farmer knowledge on pest management into a usable form for agricultural scientists.

Gaining useful information from traditional agriculture requires an appreciation of its complexity. Pest management strategies of traditional farmers are influenced by a multitude of social and cultural factors including economic constraints, time and labor priorities, attitudes toward risk, and farmers' perceptions of pests and pest losses. Any pest management recommendation based only on biological data may not be of much use to farmers who base their decisions on social and economic as well as biological considerations. The focus must be on management of agricultural systems as a whole rather than only on management of pests within the systems.

Progress in the search for ecologically sound pest management strategies depends on the ability to understand pest management within the context of the whole farm system. A multidisciplinary approach is indicated, with farming systems management providing a framework for pest management. Such a holistic approach can increase our understanding of how traditional systems function and provide an ecological basis for designing agroecosystems with pest losses that are within allowable bounds. The need for such research is urgent since traditional agriculture is changing rapidly under the impact of modernization and much of traditional management technology may soon be lost.

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