5 Sustainable Land-Use Systems for Sloping Uplands in Southeast Asia

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In Southeast Asia there are many serious problems of agricultural sustainability, associated with all of the major agroecosystems. But the sloping uplands are geographically the most extensive ecosystems, and the most threatened. The nonsustainability of land-use systems in the uplands is associated with increasing populations of subsistence farm families cultivating infertile sloping soils, accelerating land degradation and soil erosion, the impending loss of most tropical hardwood forest, and the failure of reforestation. Inequitable and insecure access to land resources exacerbates the tendency toward inappropriate land use. More productive and sustainable land-use systems must be developed under conditions of severe social and economic constraints. The crisis appears largely intractable unless systematically and innovatively addressed.

The problems of upland resource base deterioration extend across all national frontiers in the region, but they are only now beginning to be grappled with by the respective governments. Within each country the domain of the uplands is usually a complex division of responsibilities among the forestry department and the agriculture department. This greatly complicates technology generation, land tenure, and the delivery of infrastructure and services in these ecosystems.

The objectives of this chapter are: First, to characterize the humid sloping uplands of Southeast Asia as a distinct ecosystem, and to convey a sense of the problems of generating sustainable agricultural systems for them; second, to discuss the critical agricultural sustainability issues, and the technologies being evolved to meet those needs; third, to discuss the unique ways in which research must be organized, managed, and located, in order to address the problems comprehensively. Finally, I will propose a more comprehensive international effort to address sustainable land-use systems in the acid sloping upland ecosystems in Southeast Asia.

THE SETTLEMENT OF SOUTHEAST ASIAN ECOSYSTEMS

To begin, it is useful to put the contemporary problems of Southeast Asian farming systems in a brief historical and ecological perspective. The major populations of the Southeast Asian nations have based their livelihood predominantly on wet rice (*Oryza sativa* L.) culture. The great civilizations that evolved in the region tended to develop on the wide floodplains of the region's major river systems (Fig. 5-1). Wetland rice culture was a basis for comparatively sustainable farming systems. The unique properties of the flooded rice field, particularly the enhanced N fixation and greater P solubility in flooded soils, and minimal soil loss from bunded landscapes, has made continuous rice cultivation reasonably productive for centuries. These systems are amenable to a great degree of intensification.

Although they are of dominant economic importance, the lowlands represent only a small fraction of the total land area in the region. The up-

Fig. 5-1. The distribution of lowland rice and upland ecosystems in Southeast Asia.

land areas constitute from 60 to more than 90% of the total land area of the respective countries. Permanent upland settlement that occurred prior to recent decades was mainly restricted to the more fertile volcanic soils, as encountered in Java, and parts of the Philippines. Exceptionally favorable soil resources in these limited areas made highly productive, diverse upland farming systems possible. But the Southeast Asian uplands are predominantly sloping lands of strongly acid Ultisols and Oxisols. Of the 180 million hectares of acid uplands, about 118 million hectares are estimated to have pH values below 5.0 (IRRI, 1987).

The world's mountains have been given considerable attention in recent years (Rhoades, 1990). But sloping uplands or hilly lands are geographically dominant, and are arguably more ecologically fragile than the mountainous highland areas. The sloping upland ecosystems include the undulating and steep lands that range in elevation from near sea level to about 1000-m elevation. This zone, between the high mountains and the coastal plains remains poorly conceptualized and characterized, and lacks focus in research and development. The highlands of Southeast Asia, with their unique climatic characteristics and farming systems are relatively minor in area, and are not discussed here.

This chapter will argue that the sloping uplands demand a distinct ecosystem focus. As Rhoades (1990) stated, "without the slopeland perspective both our science and technological fixes will miss the mark... research that is removed from the ecosystem context often leads to shortsighted policies and programs."

Where crop cultivation was practiced on the acid, infertile sloping uplands, it was formerly limited to shifting cultivation systems as the only practical method of exploitation. However, during the last couple of decades, the lowlands and fertile uplands became densely settled in most countries, and the land frontier on favorable soils virtually closed. Millions of families that could not otherwise be absorbed in the national economies, began an accelerating migration to the sloping, acid uplands. As in past generations, they sought modest permanent landholdings to provide a livelihood, but encountered serious difficulties as increasing population pressure shortened or eliminated the fallows that were essential to accumulate nutrients for crop production.

In the Philippines, permanent cultivation or fallow rotation within the farm boundaries, is now observed throughout the hills of the entire archipelago. The number of people living in areas of 18% slope or greater, was recently estimated at 17.8 m, or almost 30% of the country's total population (Cruz & Zosa-Feranil, 1988). And the population growth rate in the uplands is significantly higher than that of the lowland population. In northern Thailand, the forest cover has predominantly disappeared within the past generation. The uplands have largely been transformed into farmland, and brush or grass fallows, by cultivation of upland rice and other subsistence food crops. In China, which is ecologically contiguous with northern Thailand, there is evidence of severe pressure on the sloping Ultisols and Oxisols, known locally as the red soils, throughout the southern one-third of the country. In Indonesia, settlement of the infertile uplands of the outer islands is proceeding rapidly, due both to spontaneous migration and a massive government-sponsored transmigration program.

Many of the prevalent cereal-based farming systems practiced by small-scale farmers are highly unsustainable. This is widely evident in negative trends in the condition of the land resource base, and in declining production flows. Due to the relative inaccessibility, fragility, and marginality of the sloping uplands, the sustainability of utilization and production flows are inseparable from the sustainability of the resource base itself (Jodha, 1990). Damage to the resource base is characteristically rapid. It is reversible only over a long period of time.

DEGRADATION OF THE LAND BASE

The extent of the massive rate at which the Southeast Asian land base is degrading may be deduced from data on the rate of soil loss in the region, compared to other areas of the world. The magnitude of the discharge of sediment from Southeast Asia's major river systems dwarfs that of other river basins around the world (Fig. 5-2). The river systems of mainland Southeast Asia discharge over 3.2 billion tons of sediment annually. The island nations of the region are nearly as prodigious as the mainland countries in production of river sediments, with 3.0 billion tons per year. Each of these areas produce more than an order of magnitude more river sediment than than the Mississippi River drainage system in North America, and twice the sediment of the Amazon River basin.

The factors responsible for the extraordinarily high soil losses in Southeast Asia are both man-induced, climatic, and geologic. The region's geographically steep young landscapes, occupied by extraordinarily dense human populations, experience abundant and intense annual rainfall (1500–3000 mm). Intensive rainfall interacts with relatively steep slopes and intense human land-use pressures. The net result is a regionwide pattern of soil loss of alarming extent. Most of the upland soils in Southeast Asia are physically fairly deep, and do not overlie shallow constricting layers. But they are chemically shallow due to high Al saturation in the subsoil. Roots are inhibited from downward penetration by Al toxicity. The rapid loss of topsoil further constricts crop rooting depth, confining the roots to a shallow zone of activity, and reducing the available nutrient and water reserves.

SUSTAINABLE FOOD CROP SYSTEMS ON SLOPES

The upland ecosystem is composed of a great diversity of land-use systems. These include large-scale ranching (open grasslands), cash cropping [eg, sugarcane (*Saccharam officinarum* L.)], perennial crop plantations [particularly coconuts (*Cocos nucifera* L.)], rubber [Hevea brasiliensis (Willd. ex Adr. Juss.) Mudl. Agr.], and oil palm (*Elaeis guineensis* Jacq.) and for-

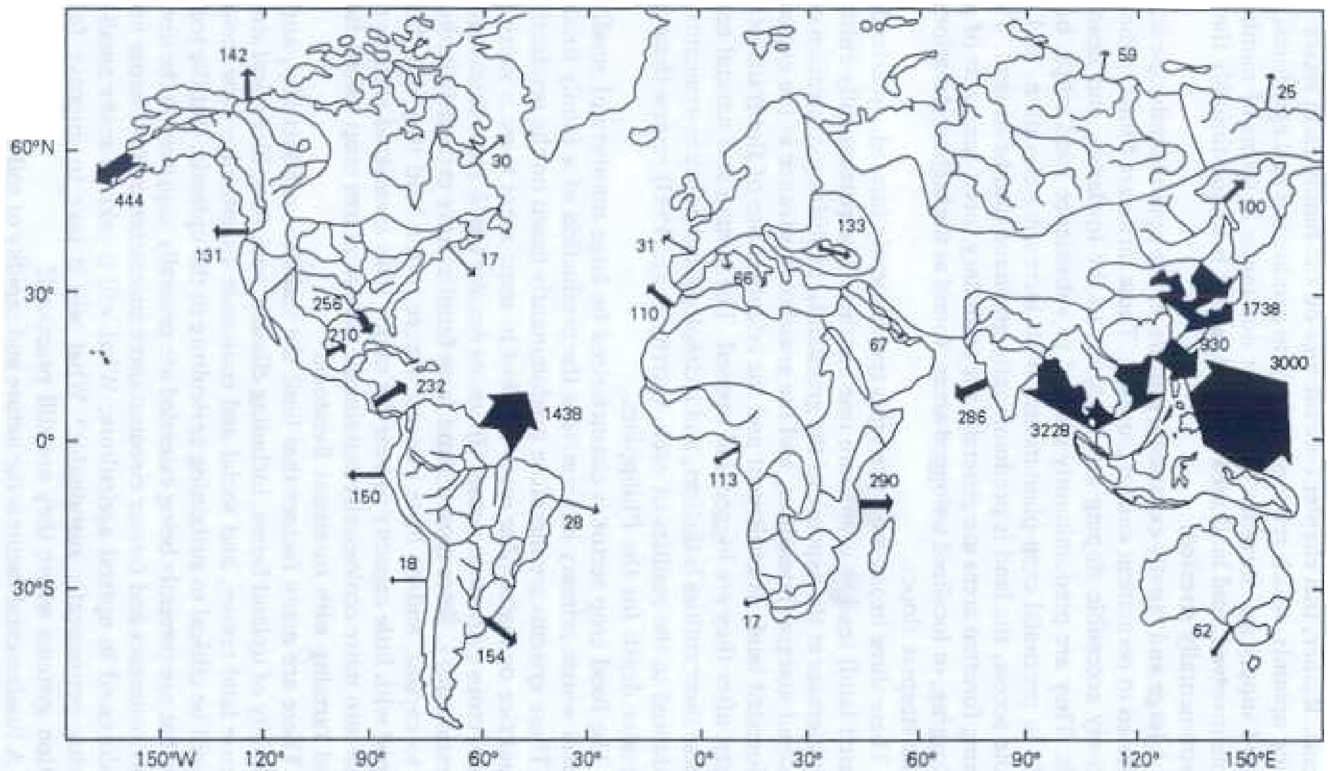

Fig. 5-2. Annual discharge of suspended sediment from various drainage basins of the world. Width of arrows corresponds to relative discharge, numbers millions of tons (Milliman & Meade, 1983).

estry (natural and plantation), in addition to small-scale subsistence farming. No attempt will be made to review the sustainability issues of all these systems. Rather, this chapter concentrates on the family farm sector in the sloping uplands, which relies on field crop production and agroforestry for its food supply and income. This sector dominates in terms of numbers of people involved, and land area affected, and it is unquestionably the most environmentally stressed.

A large and rapidly expanding portion of the upland landscape is being converted to permanent annual cropping. These farms are found in the more relatively accessible sloping areas, closest to the lowlands, and nearest to roads. They are predominantly planted to subsistence food crops, but are partly in perennial crop plantations. With increasing elevation, and more remote access, the land is predominantly grassland and brushland. The remaining forested areas are generally the secondary forest remnants of previous logging, or localized unlogged areas, found at the highest elevations and on the steepest slopes.

These three broad land-use types (permanently farmed, grassland, and forested land) tend to grade into one another. The permanently cultivated lands increase at the expense of the grasslands, as shifting cultivation on the grassland margins intensifies, and the grasslands advance at the expense of the forested land, as settlement and the relentless use of fire transform the forests, after they are logged and opened. The human and natural ecology of these three entities is distinct, and technology and policy instruments must be adapted to the realities of each. Garrity et al. (1993) review these issues in greater depth for the Philippines.

The food crop sector is characterized by large numbers of small-scale farmers whose primary imperative is the production of a family food supply. These systems are therefore predominantly based on the production of upland rice or maize (*Zea mays* L.), but in some areas there is more focus on root crops {viz. sweet potato [*Ipomoea batatas* Lamk.] and cassava (*Manihot esculenta)*}. Since most upland farm families have extremely limited access to capital, and/or have insecure tenure to the land they till, they are trapped with little capacity to bear the major risks associated with diversification into more ecologically sustainable perennial tree crop enterprises, or mixed farming with ruminant livestock.

There are many factors that limit the stability, productivity, and sustainability of upland farms, including climatic variation, biological stresses, insecure land tenure, and social and economic uncertainty. New technologies will be critical to sustaining agriculture in the uplands. But the technologies that are currently being extended are generally unproven in the diversity of environments and farmer circumstances encountered. Two issues need to be addressed in upland agriculture: What will it take to make small-scale farming permanently sustainable? What will it take to improve fallow-rotation systems where they are still practiced?

A fundamental factor is the nature and rapidity of soil degradation. Permanent small-scale upland farming systems are evolving in the sloping upland areas to replace shifting cultivation. Accelerating the trend toward permanent systems will fundamentally require: (i) simple, effective soil erosion control on open fields, through vegetative barriers and residue management; (ii) mineral nutrient importation to balance crop nutrient offtake, and stimulate greater biological N fixation; and (iii) enterprise diversification toward mixed farming systems that includes ruminant animals and perennials, in addition to subsistence food crops.

Some technologies to meet these needs are known (Garrity et al., 1993). Some even fulfill multiple requirements (e.g., trees in contour hedgerows may provide erosion control, fodder, and crop nutrients). However, research to evaluate and adapt them to the wide array of diverse ecological niches encountered by upland farmers is woefully inadequate.

CONTOUR HEDGEROW FARMING SYSTEMS

Since the mid-1970s there has been considerable interest in the concept of planting hedgerows of leguminous tree species along the contour on sloping fields, to provide a vegetative barrier to soil erosion while contributing green leaf manure to the cereal crops (rice or maize) grown in the alleys. This idea was not new in the region. Farmers in Nalaad, Cebu, have indigenously used a contour hedgerow system of *Leucaena leucocephala* in cultivating steep slopes since before 1923 (MacDicken, 1990). On Flores Island in eastern Indonesia, contour terracing with *Leucaena* was promoted by church and extension organizations in the 1970s, and was adopted on an area of over 20 000 ha (Parera, 1989, unpublished data).

Leucaena leucocephala is a commonly observed tree in the rural areas of Southeast Asia. It is widely grown in fencerows as a fodder source for cattle. Reports in the mid-1970s (Natl. Res. Council, 1977) indicated that the tree showed outstanding possibilities as a hedgerow intercrop that would supply large quantities of N and organic matter to a companion food crop. These observations stimulated applied research on hedgerow intercropping at several locations, with promising results. Guevara (1976) reported yield advantages of hedgerow intercroping of 23%. Vergara (1982, unpublished data) cited experiments in which yields were increased about 100%, with no advantage of inorganic N application beyond the N supplied by the green leaf manure. Alferez (1980, unpublished data) observed a 56% yield advantage when upland rice was grown in alleys between hedges of *Leuceana*.

On sloping land, hedgerows of *Leucaena* were observed by a number of researchers to provide an effective barrier to soil movement. Data from runoff plots on a steeply sloping site in Mindanao indicated that both runoff and soil loss were dramatically reduced (O'Sullivan, 1985). This study also observed a consistent yield advantage over a 4-yr period with corn fertilized by the *Leucaena* prunings obtained from adjacent hedgerows.

By the early 1980s, hedgerow intercropping was widely advocated as a technology to better sustain permanent cereal cropping with minimal or no fertilizer input, and as a soil erosion control measure for sloping lands. In the Philippines, a 10-step program was developed for farmer implementation of *Leucaena* hedgerows (Watson & Laquihan, 1987), known as Sloping Agricultural Land Technology (SALT). It was adopted by the Philippines Department of Agriculture (DA) as the basis for its extension effort in the sloping uplands. The SALT guidelines recommended that every third alleyway between the hedgerows of *Leucaena* be planted to perennial woody crops, such as coffee (*Coffea arabica* L.), with the majority of the alleys maintained in the continuous cropping of food crops. This concept offered the possibility of more diversified sources of farm income, and improved soil erosion control.

Some adoption of *Leucaena* hedgerows occured in high-intensity extension projects, but there was no strong evidence of spontaneous farmer interest. The lack of secure land tenure was implicated as one major constraint to the implementation of contour hedgerow systems or of other long-term land improvement among tenant farmers, or occupants of public lands. Among farmers with secure tenure, the large initial investment of labor, difficulty in obtaining planting materials, and the degree of technical training and backup required to install and manage the system, were observed to be serious constraints to adoption. In addition, the labor required to manage the hedges (pruning 3–10 times/year depending on the management system) was observed to absorb a large proportion of the household's available labor, and to compete with other income-generating tasks. This would normally limit the land area that can be farmed in this manner to less than about 0.5 ha.

After 1985 the extension effort on *Leucaena* hedgerows suffered a major setback when a psyllid leaf hopper (*Heteropsylla cubana*) naturally invaded the region and devastated hedgerows, killing or stunting the trees. *Gliricidia sepium* was the most common replacement species, but it must be propagated from cuttings in most areas, increasing the labor investment to establish the hedges.

Nongovernmental organizations made noteworthy contributions toward developing farmer participatory approaches to devising and implementing local solutions to the dominant constraints in crop cultivation on sloping land. A system of contour bunding was developed through efforts by World Neighbors (Granert & Sabueto, 1987). The bunds provided a base for the establishment of double contour hedgerows of leguminous trees or forage grasses, and were a barrier to surface runoff, which is carried off the field in contour ditches.

The experience with alley cropping discussed above was predominantly obtained on high-base status soils of recent volcanic or marine limestone origin. The contour hedgerow concept was more recently applied to strongly acid soils in the uplands of Mindanao by the International Rice Research Institute (IRRI) and the Philippine DA (Fujisaka & Garrity, 1988). After 3 yr of hedgerow intercropping, there was a distinct development of forward-sloping terraces. Regardless of species, the vegetative barriers' effects in reducing soil loss were striking, compared to soil loss in conventional open field cultivation (Table 5-1). All species induced rapid terrace formation. The rapid soil movement was largely attributed to the high frequency of animal-powered

Table 5-1. Soil loss as affected by contour hedgerow vegetation, Claveria, Misamis Oriental (Mindanao), Philippines, August 1988 to April 1990 (D.P. Garrity and A. Mercado, 1990, unpublished data).

Hedgerow species	Soil loss
Gliricidia + *Paspalum*	
Napier grass	
Gliricidia + *Napier*	
Gliricidia alone	
Open field (conventional practices)	

tillage in the alleys (5–6 times annually). Tillage-induced downhill soil slumpage apparently contributed more to soil redistribution than water-induced erosion.

Modest yield benefits were observed in upland rice associated with hedgerows of *Cassia spectabilis* (Basri et al., 1990). Yield benefits were observed consistently for upland rice and corn associated with hedgerows of *Gliricidia sepium* trees or Napier grass (*Pennesitum purpureum*) (D.P. Garrity and A. Mercado, 1991, unpublished data). Crop yields were most seriously affected in the rows adjoining the hedges, with or without the application of external N and P fertilizers (Fig. 5-3). The roots of the two tree species were observed to spread laterally at a shallow depth (20–30 cm) in the alleyways, just beneath the plow zone. This indicated that a major potential existed for nutrient and water competition between the respective root systems of the trees and the crop.

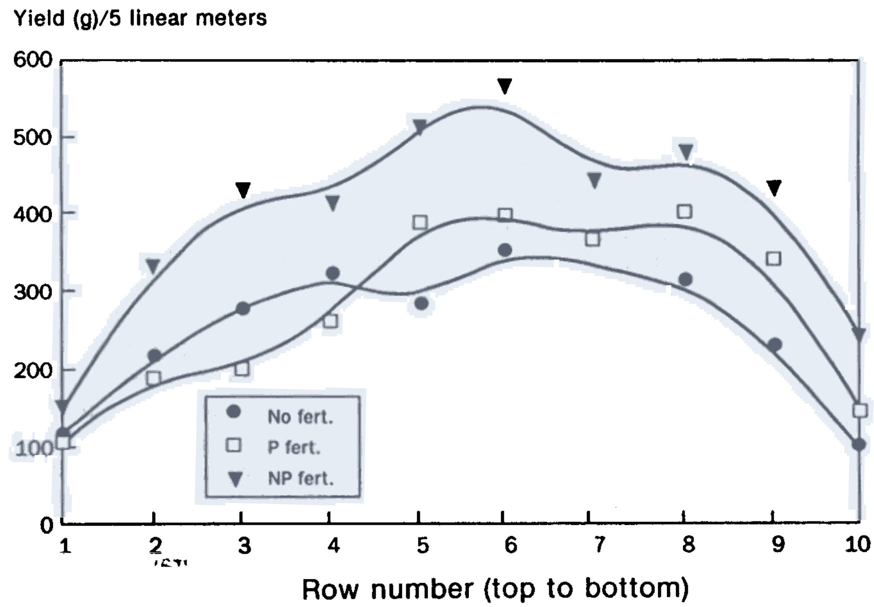

Fig. 5-3. Grain yield of upland rice on a row-by-row basis grown between hedges of *Cassia spectabilis* which supplied green manure for the crop (Basri et al., 1990).

The sustainability of crop yields in tree hedgerow intercropping is a major concern on all soil types, but recent work raises particular questions about its viability on strong acidic soils. The high exchangeable Al in the subsoil inhibits the deep tree rooting patterns typically observed on higher base status soils. Phosphorus and other mineral elements are often more limiting than N in these soils. The strong subsoil acidity appears to promote intense root competition between the annual crop and the perennial hedge for mineral nutrients in the surface soil of the alleys, and prevents deep rooting by the perennial that would promote nutrient pumping from the deeper soil layers. The organic matter inputs of hedgerow prunings of *Gliricidia* and *Cassia* do not supply adequate quantities of P to meet the minimal requirements of the cereal crops (Mercado et al., 1989; Basri et al., 1990). Further, the prunings are composed of P that the tree may have captured predominantly from the crop root zone. Other recent alley cropping results on acid Ultisols in Peru (Fernandes, 1990) and Indonesia (Evenson, 1989) support the results obtained by IRRI in Mindanao. Under such circumstances, the intimate association of trees and crops in pruned hedgerow systems may not be advantageous.

Grass strips also have received major attention as contour vegetative barriers for erosion control in Southeast Asia, and in other parts of the world (Lal, 1990). Considerable work has been done on the evaluation of grass strip technology in northern Thailand (Thai-Australian Highland Development Projects, 1989, unpublished data), in the central highlands of Java, Indonesia, and in the Philippines (Fujisaka & Garrity, 1988; Granert & Sabueto 1987). Predominant attention has been given to the use of vigorous forage grasses, since these provide high biomass production for ruminant fodder. Therefore, they are presumed to serve as a beneficial way to use the field area occupied by the hedgerows, which is lost to food crop production. They have the potential to markedly reduce erosion and rapidly develop natural terraces on slopes (Table 5-1). Therefore, the establishment of planted forage grasses has been extended as a practical alternative to tree legumes on contour bunds. Data from northern Thailand (M. Hoey, 1990, personal communication) indicated that erosion control may be a prevalent factor in systems sustainability, since grass strips were equally effective as *Leucaena* strips in increasing upland rice yields.

Two major problems have emerged with the use of grass strips. Farmers tend to have difficulty keeping the tall, rapidly growing forage species trimmed frequently enough to prevent them from shading adjoining field crops. The biomass productivity of grass hedgerows exceeds the fodder requirements of most small-scale farm enterprises. The unnecessary foliage becomes a burden to cut frequently. High biomass production also tends to exacerbate resource competition with the adjoining food crops and reduces crop yields.

The constraints observed with both trees and forage grasses have stimulated the concept of employing hedgerows that contain noncompetitive or relatively "inert" species (Garrity, 1989). This concept places primary emphasis on the rapid and effective development of terraces in order to improve the field hydrology and maximize soil and nutrient retention. An inert species is one with short stature and a low growth rate to minimize hedgerow-crop competition for resources, but provides an effective ground cover for filtering out soil particles. *Vetiver zizanoides* may exemplify this type of hedgerow species (Smyle et al., 1990). *Vetiver* is found throughout the Philippines under various names (*anias, ilib* or *anis de moras* in Luzon, *amoras* or *muda* in the Visayas). It tends to form a dense barrier and does not self propagate to become a weed in cultivated fields. However, it must be planted by vegetative slips, a somewhat laborious process.

An alternative approach that has received very little attention, is the installation of natural vegetative filter strips. These are narrow strips of field area laid out along the contours and left unplowed. They may be put in at the time that a piece of fallow land is brought into cultivation, or in the interval between crops in a continuous cropping system. The dominant species in natural vegetative filter strips are native weedy grasses—*Imperata cylindrica, Paspalum conjugatum, Chrysopogon aciculatus*, or others depending on the location, and the management regime the strips are subjected to. These natural grasses may be suppressed by grazing between crops, by periodic slashing, or by mulching them with crop residue. Natural vegetative filter strips have shown an outstanding capability to reduce soil loss, a characteristic in which they are potentially superior to the commonly recommended introduced species. They generally are less competitive as hedgerow components, and are ruggedly adapted to the locale.

There have been some isolated observations of the indigenous development of natural vegetative barriers by upland farmers in the Philippines (Ly, 1990; Fujisaka, personal communication, 1991). However, research has not been targeted to this option. There has, however, been extensive research on filter strips for sediment and chemical pollution control in the USA (Williams & Lavey, 1986).

Initial adoption of natural vegetative filter strips is comparatively simple—contour lines are laid out at the desired spacing with a simple A-frame or water level, and the field is plowed on the contour, avoiding the designated strips to be left in fallow vegetation. The advantages of this approach are the simplicity of installation, the absence of input costs or off-farm materials, and the low labor requirements for installation and maintenance. As terraces form, the farmer may diversify the terrace risers into other enterprises, including trees or perennial crops, as they fit management objectives. These characteristics suggest that the natural filter strip concept could be a comparatively practical basis for rapid, widescale dissemination of hedgerow technology. Simplicity is critical, given the constraints of very limited upland extension capability, and the necessity of reaching very large numbers of farmers. The one significant limitation of natural vegetative strips, which also is observed with other types of hedgerow vegetation, is that the development of natural terraces from the rapid redistribution of soil across the alleyways between strips tends to result in scouring of the topsoil in the upper alley. Serious degradation of the soil fertility on the upper half of the alley is often observed. Methods to alleviate soil degradation as the terraces develop are needed. A substantial effort in both strategic and farmer-participatory research on natural filter strips is warranted.

Institutional support will be crucial in fostering the expanded use of hedgerows as a soil conservation tool. There are promising signs that support mechanisms can be evolved. For example, the Philippine Crop Insurance Corporation, and local cooperatives, are implementing policies that enable the availability of crop insurance and credit for crop input purchase on sloping lands if the farmer has hedgerows installed.

Hedgerows also may be particularly suitable for the production of cash perennials. Examples of perennial crops that have been used in these systems include coffee, papaya (*Carica papaya* L.), citrus (*Citrus* spp.), mulberry (*Morus nigra* L.), and others. The suitability of the perennial species is limited by the degree of shading projected onto the associated food crops. Cash income from the hedgerow is a major advantage of this approach. The Robusta cultivars of coffee, for example, are architecturally well suited to hedgerow intercropping. Their stature is erect, providing minimal competition with the food crop. Erosion control is not adequately provided by the perennials, but is induced by a grass strip occupying the area between the widely spaced plants. Filipino farmers tend to view natural vegetative strips as the first stage in a process that leads to hedgerows of perennial crops.

Backyard production of cattle with cut-and-carry methods has become an important enterprise in many densely settled upland areas. Tree legumes, particularly *Leucaena* and *Gliricidia*, are widely used as high-protein forages, especially in the dry season. Backyard ruminant production will stimulate a more intensive husbandry of manure. One model of tree legume hedgerow development is to use the prunings as a source of animal feed, either for on-farm use or for off-farm sales (Kang et al., 1990). This will potentially increase the value of the hedgerow prunings, but it will even more rapidly deplete soil nutrient reserves. The manure can be returned, but borrowed nutrients will not be fully replaced. Nutrient augmentation through fertilizers may be made more necessary, but possibly more affordable, because of the added income generated by the animals.

The experience of the past 15 yr with alley cropping and contour hedgerows suggests that appropriate solutions are diverse, and must be uniquely tailored to variable soil and environmental conditions, farm sizes, labor availability, markets, and farmer objectives. Several basic types of hedgerow systems are recognized (Garrity, 1989), each adapted to a unique combination of ecological and market conditions. Table 5-2 illustrates some of the tradeoffs that enter in the choice of hedgerow enterprise among farmers. Such factors as relative effectiveness in soil conservation, potential hedgerow-crop competitiveness, and the value added by the hedgerow enterprise, are shown for a range of hedgerow choices.

Extension systems are strongly conditioned to employ a package approach in popularizing a new technology. This is not suitable for hedgerow technology, which needs an extension approach that recognizes the wide range of possible hedgerow species, and management systems, suitable for different farm circumstances (Fujisaka & Garrity, 1988). Unfortunately, there has

Table 5-2. Comparison of several major alternatives for contour hedgerow enterprises.

Hedgerow component	Soil loss control	Potential crop competition	Value added
Natural vegetative filter strips	High	Minimal-low	
Planted grasses or legumes	Moderate-High	Low-high	
Multipurpose trees	Moderate	Moderate-high	
Perennial crops	Moderate	Moderate-high	

been very little attempt to clarify the technology-environment fit for different hedgerow systems, and inappropriate recommendations are very common. Elucidating the recommendation domains for the various hedgerow systems, in relation to the range of specific local physical and institutional settings, is a task needing urgent attention. Carson (1989) has recommended that a simplified land classification system be developed that is practical for research and extension workers to use.

PHOSPHORUS AS A CRITICAL CONSTRAINT

The acid upland soils of Southeast Asia are predominantly fine textured, with organic C contents often observed as high as 2 or 3% (Garrity et al., 1989). Phosphorus, rather than N, is commonly the most limiting nutrient. Typically, P deficiency must be overcome before there is any response to N (Garrote et al., 1986; Basri et al., 1990). Over 50% of the P taken up by the major food crops is removed in the grain, and a lower proportion of P is retained in the residue than for any of the other major crop nutrients (Sanchez & Benitez, 1987). This exacerbates the difficulty of maintaining adequate available P in a highly P-deficient agroecosystem through nutrient cycling. Phosphorus pumping from deeper soil layers also is limited by Al toxic subsoils and low subsoil P reserves. Since constant nutrient offtake is occurring, sustained crop yields and significant biological N fixation, will become dependent on the importation of P and lime.

Application of small or moderate amounts of P is a realistic strategy with a high marginal return for low-cash flow food crop farming on strongly acid upland soils (Garrity et al., 1989). Fertilizer P recommendations for upland rice range from 15 to 20 kg P/ha on P-deficient Ultisols in a number of Asian countries (Santoso et al., 1988). Local supplies of phosphate rock are an efficient source of both P and Ca (Briones & Vicente, 1985). The exploitation of phosphate rocks for upland farmers' use has been neglected, and should be expedited. This would require greater government and commercial recognition of the fundamental importance of these minerals to permanent agriculture in the uplands.

Nearly all Southeast Asian upland farmers participate in the national cash economy. Wherever they are capable of exporting agricultural commodities off-farm for sale, they are also physically capable of shipping them in. Fertilizers will not be used as long as nutrients can be obtained without charge in fallow rotations. But as shortened fallows fail to provide adequate nutrients, or as limited farm size makes it necessary to farm all available land permanently, there will be a progressive adoption of external fertilizer sources. On acid soils, the efficient use of on-farm biological nutrient sources will lower external fertilizer requirements, but seldom can eliminate them.

The serious limitations encountered in generating and conserving adequate quantities of nutrients within the cropping system, leads to debate on the appropriate balance between research attention on technology that will raise the marginal returns to fertilizer application and other inputs, vs. technology that attempts to better conserve and cycle nutrients on-farm. Odum (1989) examined this issue in his study of the state of Georgia, USA, as an ecosystem. Formerly a "wasted land" of shifting cultivation in a "soil-destroying agriculture" on acid Ultisols, the net primary productivity of the state more than doubled during the past 50 yr, increasing from 2.5 to 6.4 t/ha of dry matter, while the yield of food quadrupled. This was associated with a sevenfold increase in commercial fertilizer use. There was initial emphasis on increasing external nutrient inputs to the agroecosystem, followed by a more recent shift to input management efficiency that shall foster a reduced input agriculture.

Experience with hybrid maize and other cash crops by small-scale farmers in the Philippines lends support to this approach: Sloping upland farmers readily adopt fertilizers and lime with these crops because the perceived marginal returns to input use are promising, relative to their own cash investment opportunities. On subsistence food crops, the perceived marginal returns are not adequate to justify such levels of investment. Therefore, emphasis is needed on the development of nutrient responsive cultivars for food crops on unfavorable soils.

REDUCED TILLAGE

The practice of retaining surface residues through conservation tillage systems is wholly unexploited in Southeast Asian upland farming systems, yet its ecological value is nowhere as profound in reducing erosion than on the tropical sloping uplands. Clean cultivation is the universal practice of upland farmers, whether they use animal power or hand tillage on the slopes. Crop residues are either plowed under, burned, or removed as fodder. Many studies have shown significant benefits in maintaining a surface mulch. For example, Paningbatan (unpublished data, 1989) found that soil loss was reduced by over two-thirds by the presence of a vegetative barrier, but the maintenance of crop residues on the soil surface reduced soil loss by more than 95%.

Reduced tillage systems could be of enormous benefit in sustainable land management in the uplands, but as yet there is no practical approach to satisfactorily cope with weeds. The intense weed pressure on upland farms, and the tendency for weed populations to rapidly shift to resistent species, has severely constrained the development of herbicide-based solutions.