Conservation tillage: A Southeast Asian Perspective

Dennis P Garrity

Systems Agronomist & Coordinator
Southeast Asian Regional Research Programme
International Centre for Research in Agroforestry (ICRAF)[1]
Bogor, Indonesia

Looking back and Looking forward

Conservation tillage is "any tillage system that reduces loss of soil or water relative to conventional tillage" (Lal, 1989). Most 'good' farmers practice intensive soil tillage. Therefore, conservation tillage is often looked upon as a 'new' thing. This may be true, to the degree that we think of it as moving agricultural systems with intensive tillage to systems with little or no tillage. But in a way, conservation tillage is not propelling us into the future so much as it taking us back to the past: To an agriculture that relies on more natural processes than does a frequent and intensive soil inversion. Let us first take a brief look at the history of conservation tillage.

Slash-and-burn farmers were the initial adherents of conservation tillage. The 'original conservation tillage' was shifting cultivation. This system has had a long and distinguished history in Southeast Asia. (It still is the tillage system of choice for over 200 million people in much of the tropics.) Slash-and-burn is a fairly elegant no-till solution to the challenge of food crop farming. Weeds are suppressed by fallow vegetation so tillage is unnecessary. The ash fertilizer is free. And the brief period that a piece of ground is cropped provides a fair defense against soil erosion. The only problem is that in time the neighborhood tends to get crowded. Farm size declines. Fallow periods grow shorter. And eventually, the shifting cultivator's grandchildren find themselves laboriously turning over the soil a spadeful at a time to fight the weeds and make a living. They do carefully study ways they can avoid having to hoe too often. Ingenious systems evolve, such as the year-round intercropping systems that Indonesian manual cultivators practice, with upland rice, maize, and cassava nurtured so that three crops are harvested with only a single primary tillage operation in a year (Suryatna and McIntosh, 1974).

As population density increases, however, most farmers try to obtain an animal for draft power. This enables a household to intensively till a much larger area than is possible by hand hoe, at a fraction of the time and drudgery. They can plow and harrow frequently enough to control *Imperata cylindrica* (*alang-alang* or *cogon*), the weed that is scourge of hand-hoe farmers. They can hold their own against the annual grasses that invade frequently-tilled fields. Yet, as they gain the capacity to till their land more frequently, they exacerbate erosion, particularly since most dryland cultivators farm sloping fields. They find that retaining surface residue is impractical with animal power. So, their clean tillage accelerates soil loss to typical levels of 50

[1] Jl. Gunung Batu no. 5, P.O. Box 161, Bogor 16001, INDONESIA

to 200 tons per hectare per year (Sajjapongse and Syers, 1995), rapidly wasting their soil assets at a rate 10 to 20 times the maximum soil loss tolerance.

Clean tillage was the path toward higher yields for smallholders: It was the modern way to farm But while it spread across the upland landscape, it gradually revealed its darker nature, with enormously accelerated soil loss at the farm and catchment level. Today, the sedimentation rates from Southeast Asian river systems are an order of magnitude higher than those of any other part of the world (Milliman, JD, and Meade, RH. 1983).

So in our short history of farming we are proceeding back to where we began:

Conservation tillage --->	Intensive tillage ---->	Conservation tillage
[minimum or zero till		[minimum or zero till
with slash-and-burn]		with herbicide or cover crop]

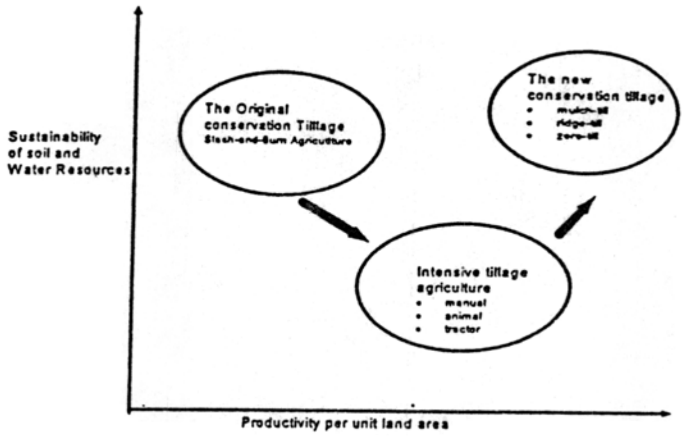
Perhaps a more enlightening way of conceptualizing the above pathway is to look at it in relation to both crop productivity and the sustainability of the soil and water resource base (Figure 1). Productivity generally increased as farming evolved from shifting cultivation to intensive tillage agriculture, in terms of yield per unit agricultural area. But in the process the health of soil and water resources declined dramatically. The new intensive methods produced more, but jeopardized the resource base upon which they depended. Recent approaches to conservation tillage aim to rebuild the sustainability of the land resources while further improving, or at least maintaining productivity and profitability. But we have a long way to go.

Smallholders who have farmed sloping lands with clean-tillage for some years are well aware of the threat of soil erosion, and perceptive to learn about and apply conservation measures (Fujisaka and Garrity, 1989). As long as such methods are practical, within their very limited resources and labor. Unfortunately, most proposed methods are not practical, in the farmer's eyes, and are not adopted. But low-labor, low-investment practices that do the job of saving soil without creating more problems than they solve, are eagerly awaited by small farmers, and will be adopted. The honest admission is that they just haven't been available.

This paper argues that the situation is changing. I will attempt to review some of the most promising directions toward providing conservation tillage practices that may make sense to Southeast Asian upland farmers. These methods ought also to appeal to decisionmakers and the general public, who worry about the health of the land at a broader level: Productive soils, clean and bountiful water, and a (bio)diverse landscape. I will examine some ingenious ways in which some farmers have applied good sense and resourcefulness to the challenges of sustainably managing their land. I will emphasize some of the ways that farmers are combining, or might combine, the best of modern technology with their own dependable practices, to cope better with their limitations in sustainably managing their land. The issue is how we, the research and development community, may build upon their insights to provide new options that meet the ever-changing biophysical and economic environment in this dynamic region.

The discussion will make the distinction that there is a fundamental difference in conservation tillage strategy for those who have no access to draft power, compared to those that do. First, the paper will focus on conservation tillage options for manual cultivation systems. Second, we look at the options for systems with animal-draft power. This paper will not specifically dwell on tractor-powered systems. The number of such farmers in Southeast Asia are few, and they can adapt North American conservation tillage methods (particularly the equipment) in a fairly straightforward manner. The real challenge is to develop conservation tillage systems for backbone of upland agriculture, the smallholder with one to five hectares.

Figure 1. Historical evolution of upland tillage systems as related to productivity and the sustainability of soil and water resources.



Conservation Tillage Systems for Manual Cultivation

I doubt that there are any reasonable estimates, but it is probable that many more households in Southeast Asia manage their land without any draft power than there are those who do. These families may have limited resources, but we shouldn't underestimate their resourcefulness. Relative factor endowments are changing fast in Asia: the most important of which is the real cost of labor. And this is inducing innovation everywhere, even in (perhaps particularly in) shifting cultivation systems.

Shifting cultivation systems and conservation tillage

Natural fallows work eminently well in regenerating soil fertility, if the local fallow species diversity and soil quality have not been degraded. Szott*et al* (1991) have shown that in a humid rainforest environment there was little or no advantage in replacing the natural woody perennial fallow with either a cover crop or fast-growing leguminous trees. But in much of the tropics, natural fallows in shifting cultivation systems have been degraded to the point where grasses, particularly *Imperata cylindrica* in southeast Asia, dominate the abandoned fields. Annual nutrient accumulation in *Imperata* fallows levels off after 1-2 years and is far inferior to that of woody vegetation. The result is a fallow incapable of regenerating adequate nutrient accumulation, yet is very laborious to re-open for cultivation.

The farmers' approach to natural fallows is not passive. The location of prospective plots for cultivation is carefully assessed. Woody vegetation is preferred, and grassland is avoided whenever possible (Cairns, 1994). *Chromalaena odorata* is an important example of a pioneer fallow species that naturally suppresses *Imperata* in the absence of frequent fires, accumulates many times more biomass, regenerates crop productivity much more efficiently and is thus highly desired by shifting cultivators (Dove, 1986; de Foresta and Schwartz, 1991). *The shrub Lantana camara* does this in Timor, Indonesia (Donner, 1987).

Eupatorium inulifolium is an example of an non-native species that proved very beneficial in shifting cultivation systems in West Sumatra (Cairns, 1994). It spread widely after its introduction in the late 19th century. Farmers found that it reduced the necessary fallow period by half. This is a major contribution since shifting cultivation land pressure was serious (Stoutjesdijk, 1935). Cairns (1994) work showed that *E. inulifolium* fallows accumulated over 150 kg N/ha and 20 kg P/ha in 2 years. Nearby *Imperata* fallows accumulated only 25 kg N/ha and 6 kg P/ha.

Shifting cultivators use herbicides to manipulate fallow vegetation.

Shifting cultivation systems are by definition land abundant and labor deficient. The household's challenge is how to make best use of its limited pool of labor. This is where conservation tillage opportunities and shifting cultivators' objectives converge: how to minimize labor in land preparation? The ways that some slash-and-burn communities are harnessing new conservation tillage technology to better cope with their labor constraint illustrate the extent of untapped possibilities. A classic case in point is the village of Belangian in South Kalimantan, Indonesia (ICRAF, 1996a).

South Kalimantan has one of the largest areas of sheet alang-alang in Indonesia (623,000 ha). The grassland lies in a north-south belt on the west side of the Meratus Mountains. Farming in the village of Belangian is based on a manual slash-and burn system. Farmers try to avoid opening *Imperata* due to the enormous amount of work involved. But *Imperata* has spread over most of the village lands, so there is less secondary vegetation available for new fields every year. Plots that are opened are generally dominated by *Chromalaena* with varying amounts of *Imperata*. About three years ago the entire village started using glyphosate (common tradename is Roundup) to control *Imperata* when their fallow land is opened for cultivation. The vegetation is first slashed and burned. When the grass grows back to a height of 20-40 cm after 2-4 weeks, the grassy patches are sprayed. The field is burned a second time. Planting is then done by dibbling the seed during the months of October or November. All farmers are now using Roundup as part of their management practices.

Before glyphosate was adopted farmers confined their cultivation to those areas dominated by *Chromalaena odorata,* a highly desired vegetative cover for slash-and-burn. The farmers claim that glyphosate has enabled them to re-open fields that have a substantial amount of alang-alang. Glyphosate use began subsequent to a demonstration that was set up by a company called Duta Teknik. The demonstration was part of the Regreening Program of the government. A few farmers tried it on their own peanut fields. On fields with a uniform cover of *Chromalaena* no glyphosate is sprayed. Farmers estimate that in 1995 more than 50% of the land opened up was dominated by alang-alang. 90% of those farmers that opened a field this year did so on fields that had some alang-alang.

Farmers claimed that the glyphosate system provided two critical advantages that improved their confidence that their cultivation system could be maintained:

1) They look forward to being able to maintain and increase the amount of land dominated by *Chromalaena*. Now farmers claim that the area of alang-alang land is decreasing. *Chromalaena* is replacing it.

2) They are now able to utilize land that has a considerable infestation of alang-alang. Previously this land was too costly to bring back into production and was abandoned in favor of fields that were dominated by *Chromalaena*.

Successful zero tillage food crop systems using herbicide are quite rare in the tropics. The fact that such a system was developed independently by a village of shifting cultivators is thus all the more remarkable. The glyphosate system does not replace slash-and burn. It is a complementary practice that enhances it. The herbicide is both a weed management practice in the cropping cycle, and a fallow management practice. Both aspects enhance the sustainability of the system.

In Belangian a private enterprise (herbicide company) interacting with another private enterprise (a village of shifting cultivators). The result was an unanticipated innovation: A way of manipulating fallow vegetation to save an agricultural system in crisis. Research could now be very effective in understanding how the system works, examine the benefits and costs, and explore where and how the principle of this practice might be used by other such communities. ICRAF and partners intend to look at this in depth in the context of an initiative on Indigenous Strategies for Intensification of Shifting Cultivation (part of the global program on Alternatives to Slash-and-Burn (ICRAF, 1996b). The extrapolation value of such a system is not trivial: *Chromalaena* is the preferred fallow species for slash-and-burn in most areas of Southeast Asia (e.g. western Indonesia, Philippines, Laos, Thailand. Other species of the*Compositae* family have been shown to play the same role in other environments.

Food crop/tree crop systems for grasslands without tillage

Growing crops or trees in *Imperata* grasslands is seriously difficult. Intensive and repeated tillage is usually essential to make it possible to maintain annually cropping, or to establish perennial crops or timber plantations. *Imperata cylindrica* regrows rapidly, competes vigorously, and creates a major fire hazard for young plantations. Recent research and extensive on-farm trials by the Agency for Agricultural Research and Development (A M Fagi, pers. comm.) has developed a promising system for food and tree crop establishment based on the judicious use of glyphosate herbicide. The grass is killed by an initial application of the herbicide, and upland rice or other crops are direct-seeded by dibbling into the thick residue mulch. Tree crops such as rubber, fruit trees, or timber trees, are established as intercrops with the food crops. Successive crops of annuals may be grown for two or three years while the canopy cover of the trees develops. Trials in Java, Kalimantan, and Nusa Tenggara have provided experience with the system on scores of farmers' fields. Currently, a national program is being developed to enable smallholders and large estates to use the system to reclaim blocks of sheet *Imperata* grassland. The Government of Indonesia is supports this approach as a key alternative to slash-and-burn farming, and to conventional methods of establishing tree estates.

Previously, the cultivation of food crops during the establishment phase of estate crops or reforestation was not encouraged or allowed in government-sponsored programs. In 1995 the policy was changed to strongly promote or even require that upland rice or other food crops be cultivated during the establishment phase of perennial plantations, and to use zero tillage methods to grow these crops. These changes will help intensify land use in ways that reduce the need for slash-and-burn, and are more conducive to smallholder livelihood on the forest margins, increasing food production and rural incomes of poor villagers and reducing the need to clear land for subsistence cropping. Mixed-species perennial gardens have also very recently been encouraged by policymakers in the Ministry of Agriculture.

National projects have been initiated to study the ecological sustainability of such systems, and the effects of the practices on biodiversity, particularly the populations of soil micro-flora responsible for greenhouse gas emissions or absorption. More research is needed on a number of aspects. The global Alternatives to Slash-and-Burn Program (ICRAF, 1996) is collaborating with Indonesian researchers to examine the constraints and potential solutions. Confidence is increasing that the use of glyphosate may be a key breakthrough in rehabilitating large parts of Indonesia's nine million hectares of sheet *Imperata*.

Improved Fallows

Clearly, there is considerable potential to improve the benefits of fallowing through manipulation of the natural succession, and through the establishment and management of selected fallow species. But improved fallows involve increased labour investment, management skills, and planting materials. The basis for an improved fallow is that these investments pay off by increasing the efficiency of the fallow phase in building the usable nutrient reservoir, suppressing weeds, and possibly providing other economic benefits (fodder, fuel, timber, fruits).

Cover crops for Conservation Tillage

Managed fallows: Herbaceous cover crops and improved pastures. Much agronomic work has been done to exploit the principle that leguminous cover crop species may accelerate the regeneration of the productivity of land. They have proven advantageous for short fallow periods of less than 2 years.

von Uexkull and Mutert (1995) have worked extensively with Indonesian researchers from the Centre for Soil and Agroclimatic Research on a cover crop system to rehabilitate unproductive degraded savannas in Indonesia. *Mucuna cochinchinensis* is established with an application of lime and P fertilizers (or one ton/ha of phosphate rock). After 6-7 months food crops are directly seeded into the dead Mucuna mulch. Results from on-farm trials in southern Sumatra during 12 crop seasons. gave average yields of 5-6 t/ha grain equivalents. The initial investment in the amendments is a constraint for smallholders, but the returns are generous: Annual farm income increased from from $400/ha in conventional cropping to $1300/ha with the *Mucuna* mulch system. They recommend public sector investment to enable smallholders to take advantage of these returns, and enable a sustainable farming system to be built on *Imperata* grasslands.

Including legume cover crops such as *Mucuna, Calopogonium, Centrosema* in a crop rotation for 3-6 months benefits soil fertility via its organic matter input (about 2-3 ton ha^{-1} aboveground) and N-input of about 60 -90 kg ha^{-1} (Hairiah *et al.*, 1992). Such legume cover crop fallows compared to a weed/grass fallow (including *Imperata*) led to about 1 Mg ha^{-1} of maize grain yield advantage in the subsequent crop (Van Noordwijk *et al.*, 1995a). The apparent N recovery for urea N fertilizer (at 60 kg N ha^{-1}) was about 30%, and for the three legume cover crops apparent N recovery per kg legume N was 80-90% of that value for urea N. In similar soil and climatic conditions on an Ultisol at Onne (Port Harcourt), Nigeria, a maize/covercrop rotation practiced during four consecutive years had a strong residual effect on a subsequent maize crop, while all N fertilizers failed to show any residual effect (Fig.2; Van der Heide and Hairiah, 1989).

Evidence from Benin (Versteeg and Koudokpon, 1993) underscores the ability of velvetbean (*Mucuna pruriens, cv utilis* and *cv cochichinensis*) to control *Imperata cylindrica*. Benin farmers now use velvetbean to smother *Imperata* on fallow land. After the cover crop senesces in about 9 months they dibble maize directly through the dead mulch. This drastically reduces labour investment in maize production by eliminating the need for primary tillage by hand hoe, and it also nearly eliminates the need for hand weeding the maize.

Burkill (1966), as cited in Buckles (1995), noted that *Mucuna* was cultivated in Java, Bali, and Sumatra as early as the seventeenth century to recover worn-out ground. The prospects for using legume cover crops as a green manure and to control *Imperata* have been widely recognized (Adiningsih and Mulyadi, 1993; Agboola and Fayemi, 1972). However, they have not been accepted by farmers due to their labour costs and the opportunity costs in utilizing land periods when food crops may be grown. In the N. Lampung site, leguminous cover crops definitely have a potential from a biological point of view, especially where *Mucuna pruriens* var. *utilis* or the more perennial *M. deeringiana* are used (Guritno *et al.*, 1992; Hairiah *et al.*, 1993). But farmers have adopted *Mucuna* only on small areas where the seeds are harvested for food. Cover crops such as *Mucuna* generally imply less intensive cropping patterns than continuous cultivation of food crops and consequently are best suited to fallow rotation situations where a portion of the farmer's land is not cultivated each year.

Several studies in the Philippines reveal that some forage legume species can significantly reduce rhizome mass and *Imperata* viability and at the same time enhance soil fertility. These species are: *Stylosanthes guyanensis* and *S. humilis*, *Pueraria phaseoloides*, *Centrosema pubescens*, *Calopogonium mucunoides*, *Macrophilium atropurpureum* ("siratro") and *Desmodium intortum* (Armachuelo *et al.*, 1989; FSDP-EV, 1986; Sajise, 1980; Florido, 1992). Such species may be utilized in fallow improvement systems. However, the introduction of these legumes in native pasture grasslands also requires the incorporation of certain soil amendments, like phosphorous fertilizer, lime and microbial symbionts *(Rhizobia* and *Azospirillum*) in order to obtain effective growth.

Although cover crops have often been considered as prospective candidates for managed fallows in the Philippines, empirical evidence of their practical utility is still sparse (Garrity *et al.*, 1993). Farmers in Batangas Province do commonly use *Lablab purpureus* L Sweet as a dual purpose component of their upland cropping patterns. It is interopped with maize and provides edible pods, fodder, and green manure for the next year's crop. Torres and Garrity (1990) measured the yield-enhancement of labab on subsequent maize crops. They noted that species likely to be most promising are those such lablab and siratro (*Psophocarpus palustris*) that are also used as human food. Three key constraints to greater use of cover crops that must be overcome are: Protection of the land from communal grazing, protection from dry season fires, and a dependable seed supply (Garrity *et al.*, 1993). The extraordinary success achieved by farmers with cover crops in Central America and Benin suggest that there is much progress to be made in adapting cover crop systems to farm conditions in Southeast Asia.

Fallow rotations with perennials

Improved fallows of leguminous trees. Shifting cultivators in many indigenous systems deliberately select and protect some of the trees remaining in the fallow. This maintains a desirable species diversity and enhances biomass accumulation. There are also cases where farmers deliberately stimulate the colonisation of fallowed land with tree species to create conditions that accelerate the regeneration of the land between cropping cycles. In the village of Naalad, Cebu (Lasco, 1991; Kung'U, 1993) farmers broadcast *Leucaena leucocephala* seed on steeply sloping land that is being fallowed after maize and tobacco cropping. Farmers claim that the *Leucaena* accumulates nutrients for the next cropping phase, improves soil fertility, and provides woody stakes for contour erosion structures. A broadcast-seeded *Leucaena* fallow system (called *amarasi*) is also practiced in parts of eastern Indonesia. MacDicken (1991) has developed a tree fallow rotation system suited to the circumstances of shifting cultivators on Mindoro island in the Philippines. He emphasised the suitability of these systems to upland cultivators in harsh environments, and the lack of research attention that has been given to them.

Tree fallow systems are particularly suited to communities that practice hand tillage, either because cultivation is on steep slopes, or animal draft power is unavailable. The random distribution of the woody vegetation complicates the use of the plow. There are many areas where shifting systems are practiced where animal power is not or cannot be used. Introduction of this type of system may be promising for such conditions, but why are such systems not practiced more widely?

Identification of appropriate tree species for local agroecological conditions is one constraint. Clearly, the *Leucaena*-based systems were broadly limited to soils that are not strongly acid. This may explain their use in central Philippines and eastern Indonesia. But elsewhere in Southeast Asia, strongly acid soils tend to dominate (IRRI, 1986). These areas tend to have been settled more recently and have lower population densities. There may have been less pressure to identify tree fallow solutions to declining soil quality.

A critical factor in selecting an appropriate tree species for managed fallows is re-establishing a tree population with minimal effort at the end of the cropping period. As a prolific seeder, *Leucaena leucocephala* was an exceptionally suitable species for this purpose. It is easy for farmers to harvest seed and broadcast it to re-establish adequate plant populations.

Tree species suitable for developing tree-based fallow systems on acid soils are urgently needed. But there has been very little work on identifying and testing species for such conditions. *Acioa barterii* is a non-leguminous species that farmers in south-eastern Nigeria have cultivated as a fallow regeneration species for strongly acid soils (Kang *et al*, 1990). But this species is planted in rows, and is pruned during the cropping period and allowed to regrow during the fallow period, rather than re-established from seed. The *Acioa* system is therefore a tree fallow, but with the trees in hedgerows.

Agroforests for Soil Conservation

One of the most promising solutions to transforming slash-and-burn systems is the development of 'complex agroforests'. These are farmer-evolved forests that contain a mixture of tree species in multi-story systems. Agroforests and many types of home gardens often resemble natural secondary forest systems in structure and ecology. The trees provide food, fuel, and cash income. The agroforest accumulates and sequesters carbon. This carbon pool often is maintained indefinitely, since only individual trees are replanted, and only when tree death or gaps occur. There are many examples of agroforests in the humid tropics. An outstanding example are the rubber agroforests of Indonesia that occupy over 2.5 million hectares (Gouyon, A, H de Foresta, and P Levang. 1993) In these systems, rubber trees are the main component, but many other species of fruit and timber trees are combined with rubber, either intentionally or through natural regeneration.The rubber seedlings are established as intercrops in a slash and burn cultivation system. After the 1-2 year cropping phase the plot is left alone and the rubber trees mature along with the secondary forest regrowth. Biodiversity levels that often approach those of natural secondary forest.In

Another case exemplifying the agroforest option is the 'damar' agroforest system in Lampung, Sumatra, Indonesia. Over the past century, local populations have extended the cultivation of the Dipterocarp tree *Shorea javanica* which is tapped to yield a resin that is sold for industrial products on the national and international markets. This man-made forest now extends over scores of kilometers along the western boundary of the national park. This agroforest harbours a major proportion of the natural rainforest flora and fauna species (Michon, G, and de Foresta, H. 1995). Torquebiau's (1992) review of the sustainability indicators of tropical home gardens, he found many indirect sources of evidence that soil fertility levels were maintained over long periods, and that soil organic matter levels increase.

In countries such as the Philippines, Vietnam, and Thailand, which are experiencing extreme encroachment pressures on the remaining natural areas, there is a concurrent trend toward major increases in the value of farm-grown timber. Smallholders, even shifting cultivators on the frontier, are now engaging in farm forestry for the first time in great numbers, in response to the strong price incentives (Garrity and Agustin, 1994). This situation dramatically increases the prospect of stimulating smallholder timber production systems as a major vehicle for rapidly increasing overall tree cover. Agroforestry practices provide a variety of ways in which agriculture can be intensified, tree cover can be increased, and soil and wate conservation enhanced.

The current view of agroforestry is that it is "the deliberate cultivation of woody perennials with agricultural crops on the same unit of land in some form of spatial mixture or sequence". This leads many people to see it merely as a set of distinct prescriptions for land use. Agroforestry is much more than this, and as such, it still often falls short of its ultimate potential as a way to mitigate deforestation and land depletion. When we see agroforestry as the increasing integration of trees in land-use systems we perceive the passage toward a more mature agroecosystem of increasing ecological integrity. Leakey (1996) has proposed that agroforestry be considered as a "dynamic, ecologically based, natural resource management system that, through the integration of trees in farm and range land, diversifies and sustains smallholder production for increased social, economic, and environmental benefits". This definition is currently being refined ICRAF as a more holistic conceptualization of agroforestry. It evokes the process of integrating the variety of current agroforestry practices into productive and sustainable land-use systems. The land uses become progressively more complex, biodiverse, and ecologically and economically resilient.

Conservation Tillage for Systems with Animal-Power

This part of the paper focuses on the problems and possibilities faced by that major segment of farmers that have draft power, and cultivate their land intensively. Prospective conservation tillage practices for these farmers must suit a very different set of conditions, and must cope with the greatly accelerated soil erosion of clean cultivation on slopes.

Contour hedgerow systems

The main conservation farming practice prescribed for open-field intensive cultivation systems in Southeast Asia has been contour hedgerow systems (Garrity, 1994). Contour hedgerow farming with leguminous trees has thus become a common feature of extension programs for sustainable agriculture on the sloping uplands in southeast Asia. These systems may do a very good job of erosion control, even on steep slopes (Kiepe, 1995; Garrity, 1995) Data from the IBSRAM Sloping Lands Network trials six countries have confirmed that annual soil loss with hedgerow systems is typically reduced 70 to 99 percent (Sajjaponse and Meyers, 1995).

There are also numerous reports of increased yield levels of annual crops when grown between hedgerows of leguminous trees. However, a number of observers have commented on limited farmer adoption of these systems. Constraints that limit the effectiveness of pruned-tree hedgerows include the tendency for the perennials to compete for growth resources and hence reduce yields of associated annual crops planted in adjacent rows, and the inadequate amounts of phosphorus cycled to the crop in the prunings. But the major problem is the enormous amount of labor needed to prune and maintain them.

We found that farmers' labor investment to prune their leguminous-tree hedgerows was about 31 days per hectare, or 124 days of annual labor for four prunings (ICRAF, 1996). This increased the total labor for an upland rice crop from 143 days to 64 days, or by an average of 64%. Labor for a maize crop increased 90% due to pruning operations. Such an increase in production costs seldom caused a commensurate increase in returns. The extra labor didn't pay off.

The case for natural vegetative strips

In Claveria, Philippines, tree legumes and fodder grasses were tried and adopted by farmers during the first years of research and farmer-to-farmer training project. Farmers that perceived soil erosion to be a problem were much more interested in vegetative barrier techniques that minimized labour (Fujisaka *et al* 1994). Some independently developed and experimented with the practice of laying out contour strips that were left unplanted, and were revegetated by native grasses and forbs. Researchers found that these natural vegetative strips had many desirable qualities (Garrity, 1993). They needed much less low pruning maintenance compared with fodder grasses or tree hedgerows, and offered little competition to the adjacent annual crops compared to the introduced species (Ramiaramanana, 1993). They were very efficient in minimizing soil loss (Agus, 1993). And they did not show a tendency to cause greater weed problems for the associated annual crops (Moody, 1992, pers. comm.).

Natural vegetative strips (NVS) were found to be an indigenous practice on a very limited scale in other localities, including Batangas and Leyte Provinces. Adoption is quite simple. Once contour lines are laid out there is no further investment in planting materials or labour. The vegetative strips do not need to conform closely to the contour; they act as filter strips rather than bunds. The biomass production, and economic value as fodder, is lower than many other hedgerow options, but labour is minimized. *Vetiver* grass fills a similar niche as a low value-added but effective hedgerow species. But for *vetiver* or any other introduced hedgerow species the planting materials must be obtained and planted out. A limitation of low maintenance hedgerow components is that they do not enhance the nutrient supply to the crops. In this respect they do not differ from many other hedgerow enterprises, including fodder grasses and perennial or cash crops. NVS or other low management hedgerow options can only be sustainable with continuous cropping if fertilization is practiced. They have proven to be popular in northern Mindanao and have been adopted by hundreds of farmers in recent years.

Terrace Development and Soil Sustainability

One of the most cited advantages of contour hedgerow systems is their tendency to create 'natural' terraces through a soil redeposition process. Visual evidence and field level soil loss measurements indicate that the soil moves within the alley, but not off the field. But there is clear evidence that the development of these terraces is not unequivicably good. There is also a downside risk due to the scouring of soil from the upper alleyway.

Skewed Distribution of Crop Yields in Sloping Alleys. There have been few long-term observations of crop yields in contour hedgerow systems on slopes. But where these are reported, the yield response tends to become skewed after a few years (Garrity et al, 1995). In 5-year old hedgerow systems of either leguminous trees (*Leucaena leucocephala* + *Cajanus cajan*) or grass (*Paspalum conjugatum*) on an Ustic Kandihumult of 21-35% slope in Thailand, Turkelboom *et al* (1993) reported reductions in rice yields of greater than 50% in the upper alleys, compared to the middle and lower areas. Solera (1993) nearly excluded both above-ground and below-ground hedgerow competition by intensive pruning and installation of 50-cm deep plastic barriers. He found that the spatial pattern of yields was unchanged. Surveys by Peden (1994, pers. comm.) and co-workers on hillsides in Uganda indicate that the effects may be quite long lasting. They have documented cases of steep front-facing terraces on slopes >50% in which upper alley crop productivity remains drastically lower than in the lower alleys, after under cultivation for at least 50 years (ICRAF, 1994).

Soil Spatial Fertility Gradients. Soil may be very rapidly redistributed across the alleyways, as is evident from several reports. Basri *et al* (1990) reported a 60-cm drop in soil level between the alleys after 2 1/2 years on a field with 25 % slope. Fujisaka (1993) observed similar rates of terrace development on several farmers fields in Claveria, Philippines. A tendency toward rapid terrace riser development was observed in trials on a range of other soil types (Sajjapongse, 1992). Rapid terrace development is associated with the upper alley yield depressions observed in many cases. Soon there was evidence as to why. In a *Cassia spectabilis* hedgerow experiment (Garrity *et al*, 1995), soil organic carbon was found to vary from 1.7% near the hedgerow in the upper alley to 2.8% near the lower hedgerow. Available P was twice as high in the lower zone compared to the upper. Soil pH was unchanged but exchangeable aluminium increased. These patterns were observed in the subsoil (15-30 cm) as well as in the topsoil. Agus (1993) sampled 5 points across the alleyways between *Gliricidia* contour hedgerows, and observed a linear soil fertility gradient. Exchangeable calcium, organic C, pH, and Bray-2 extractable P increased from the upper to the lower alleyway, exchangeable Al decreased, while K and Mg were unchanged. Samzussaman's (1994) row-wise study of soil properties elucidated linear increases in organic carbon (from 2%

to 3 %) and nitrogen (0.20% to 0.27%) on an Oxic Palehumult. Turkelboom *et al* (1993) monitored soil organic carbon on an entire slope transect. They observed a "saw-tooth" pattern, with much higher SOM levels in the lowest part of the alleyway and under the hedgerow, and a tendency for these differences across the alleys to be accentuated on the terraces located furthest downslope.

Upper alley scouring, and rapid soil displacement to the lower alley, seem particularly prominent where draft animal plow systems are used. But the scouring process also occurs with hand hoe farming in Thailand on steep slopes (Turkelboom*et al*, 1993). However, it is not always observed, particularly when no-tillage is practiced continuously, or when hand-hoeing is done superficially (as in shifting cultivation).

Crop Performance Across the Alleys. The row-wise performance of crops in alleyways subjected to scouring suggests a response surface that is determined by two phenomena (Figure 2): The classical hedge-crop inter-species competition for growth resources, and soil scouring during terrace formation. The conventional response function of crop yield or dry matter may be represented as the integrated effect of the two independent sets of processes. In future, as more work focuses on the disaggregation of the integrated effect we should be able to model the interaction between these gross effects as part of a more general understanding of the entire tree-crop system.

Is Farming on Natural Terraces Sustainable? The effects of scouring raise serious issues concerning the short-term and long-term agricultural sustainability of natural terraces. We urgently need to know: (1) Whether and under what conditions scouring effects are a short-term or a long-term phenomenon, and (2) How they can be effectively avoided or alleviated. There are three basic ways to try to cope with scouring: To avoid it, alleviate it, or change the cropping system to live with it. The research agenda for each is now briefly addressed.

Adjust biomass and nutrient inputs. To alleviate scouring it is logical to consider changing the spatial pattern of nutrient inputs. The application of crop residues, hedgerow prunings, animal manure, and fertilizers may be biased to the upper alley zones. Since scouring tends to redistribute topsoil nutrients downward naturally, application to the upper alley may ensure a more even distribution in the long run. In recent surveys we found that Claveria farmers who have experienced significant scouring have tried many of these options and many observed impressive success in rehabilitating their soils. Yields in the upper part of alleys once again approach those in lower zones (Stark, pers. comm.). We have initiated experiments to elucidate these fertility management issues, and gain a predictive knowledge about them.

Change the Cropping (or Hedgerow) System. Another strategy is to accept the scouring effect and to alter the cropping system to adjust to the changes (particularly if they are drastic). Substitution of perennials (e.g. bananas, timber trees, or MPTs) for annual crops, or more tolerant annuals (e.g. cassava), are practices that have farmers are experimenting with. Researchers and farmers must learn how to better exploit the degraded upper alley zone that a conservation technology may create.

Reducing the intensity of tillage. To avoid scouring a farmer must avoid frequent primary tillage. In zero-tillage systems there is little tendency for hedgerow risers to develop, or for soil scouring to occur. Unfortunately, they have not proven practical for annual crops in the tropics. But there are many variations of reduced tillage that smallholders can adopt. ICRAF is investigating permanent ridge tillage (see below). In ridge-tilled fields, unplowed strips are maintained indefinitely, and the annual crops are planted consistently in these strips.