Agroforestry Systems 36: 55–82, 1997.

Food-crop-based production systems as sustainable alternatives for *Imperata* grasslands?

M. VAN NOORDWIJK[1], K. HAIRIAH[2], S. PARTOHARJONO[3], R. V. LABIOS[4] and D. P. GARRITY[1]
[1] *ICRAF S.E. Asia, P.O. Box 161, Bogor 16001, Indonesia;* [2] *Universitas Brawijaya, Malang, Indonesia;* [3] *Central Research Institute for Food Crops, Bogor, Indonesia;* [4] *Upland Farming Systems Division, Farming Systems and Soil Resources Institute, University of the Philippines Los Baños, the Philippines*

Key words: erosion, *Imperata cylindrica*, Indonesia, the Philippines, rotational hedgerow intercropping, sustainability criteria, weed control

Abstract. Purely annual crop-based production systems have limited scope to be sustainable under upland conditions prone to infestation by *Imperata cylindrica* if animal or mechanical tillage is not available. Farmers who must rely on manual cultivation of grassland soils can achieve some success in suppressing *Imperata* for a number of years using intensive relay and intercropping systems that maintain a dense soil cover throughout the year, especially where leguminous cover crops are included in the crop cycle. However, labour investment increases and returns to labour tend to decrease in successive years as weed pressure intensifies and soil quality declines.

Continuous crop production has been sustained in many *Imperata*-infested areas where farmers have access to animal or tractor draft power. *Imperata* control is not a major problem in such situations. Draft power drastically reduces the labour requirements in weed control. Sustained crop production is then dependent more solely upon soil fertility management. Mixed farming systems that include cattle may also benefit from manure application to the cropped area, and the use of non-cropped fallow areas for grazing. In extensive systems where *Imperata* infestation is tolerated, cassava or sugarcane are often the crops with the longest period of viable production as the land degrades.

On sloping *Imperata* lands, conservation farming practices are necessary to sustain annual cropping. Pruned tree hedgerows have often been recommended for these situations. On soils that are not strongly acidic they may consistently improve yields. But labour is the scarcest resource on small farms and tree-pruning is usually too labour-intensive to be practical. Buffer strip systems that provide excellent soil conservation but minimize labour have proven much more popular with farmers. Prominent among these are natural vegetative strips, or strips of introduced fodder grasses.

The value of *Imperata* to restore soil fertility is low, particularly compared with woody secondary growth or *Compositae* species such as *Chromolaena odorata* or *Tithonia diversifolia.* Therefore, fallow-rotation systems where farmers can intervene to shift the fallow vegetation toward such naturally-occurring species, or can manage introduced cover crop species such as *Mucuna utilis* cv. *cochinchinensis,* enable substantial gains in yields and sustainability. Tree fallows are used successfully to achieve sustained cropping by some upland communities. A variation of this is rotational hedgerow intercropping, where a period of cropping is followed by one or more years of tree growth to generate nutrient-rich biomass, rehabilitate the soil, and suppress *Imperata.* These options, which suit farmers in quite resource-poor situations, should receive more attention.

Introduction

Imperata and deforestation

When forests are opened for food crop production throughout Southeast Asia the land becomes infested with *Imperata cylindrica* within a few years. People then often move on toward the new forest frontier, leaving the grasslands behind as an under-utilized resource, and contributing to the deforestation process (Figure 1). Can the initial degradation into *Imperata* be slowed down or avoided at the time that forest is first opened, either by the development of sustainable food-crop based production systems alone, or food crops in association with tree crops and/or animal production? A second issue is how and under what conditions could the grasslands can be reclaimed and used more intensively?

Links between shifting cultivation and the formation of *Imperata* grasslands were pretty well understood in Indonesia in the 1930s. Establishment of mixed farming units, in which animal husbandry is combined with food and tree crops, was seen as a basic solution to the problem of agricultural intensification (Hagreis, 1931). Community-level fire control was seen as an essential first step in the reclamation of *Imperata* grassland (Danhof, 1941). In many areas with previous *Imperata* problems land-use has indeed intensified, but meanwhile new *Imperata* grasslands were created elsewhere. This

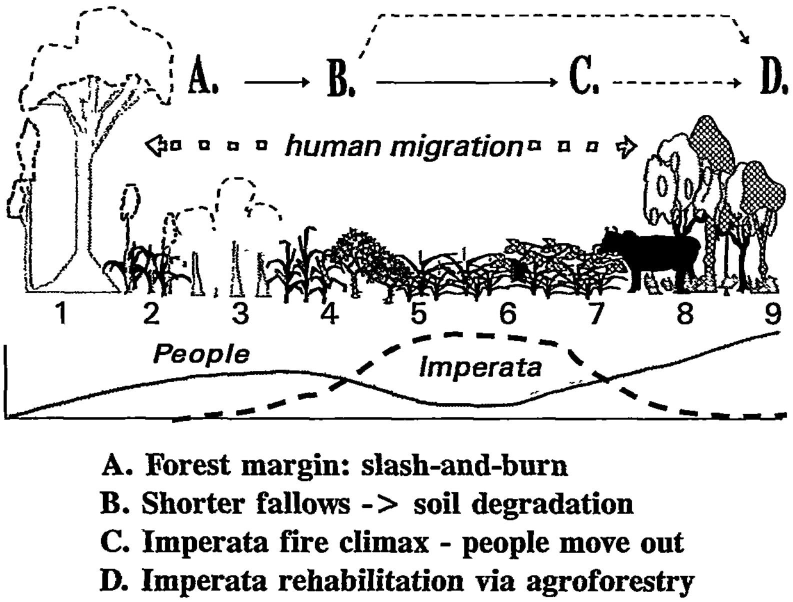

Figure 1. Schematic land use transformations from forests via *Imperata* grasslands to rehabilitated lands with various agroforestry options (van Noordwijk, 1994).

was often due to over-optimistic estimates of the potential productivity of *Imperata* land under continuous food cropping.

In the early 1970s, basic facts about *Imperata* grasslands were emphasized in Indonesia, after an apparent 30-year fallow period for this field of research. Eussen and Wirjahardja (1973) stated:

> It is primarily the shifting cultivation method of agriculture, practiced in many areas of Southeast Asia, which is responsible for the expansion of *alang-alang* fields in these areas. A clear example of this situation can be found in the province of Lampung Sumatra, Indonesia. . . . Due to lack of primary forest, people now clear these different stages of succession to a secondary forest. Because the soil is still infested with *alang-alang*, the farmers can have only one or two harvests, of, for instance corn or upland rice, before *alang-alang* reoccupies the land. This land is abandoned and another piece of secondary forest used. By this practice, the natural succession is always disturbed and the area occupied by *alang-alang* is increased.

Suryatna and McIntosh (1982) concluded that shifting cultivation can only be appropriate if there is enough land to cope with the population increase, and if a perennial-crop-based cropping system is used in the long run, with the food crops produced during the first and second years of establishment of the perennial crops. They made the point that

> Many people have assumed that *alang-alang* was the cause of degradation of opened land. This is not the case. It is fortunate that *alang-alang* can grow and thrive under the adverse conditions that exist. It is like a secondary infestation – an aggravation but not the initial cause. Without *alang-alang* or a similar plant, erosion and leaching would be disastrous.

Land degradation in the view of these authors is mainly a consequence of a cropping pattern based on maize, upland rice and cassava that does not supply enough organic inputs to the soil and does not provide a permanent cover of the soil surface. Without fertilizer inputs, after three years cassava is the only crop that will grow with any vigour, but even its production is reduced to a small fraction of its potential. Consequently, the land is virtually open in the early period of the rainy season and *alang-alang* seeds have an ideal place to germinate. Because the production is so low, the farmer has no incentive to weed the fields and *alang-alang* becomes firmly established before the cassava is tall enough to shade the ground.

Suryatna and McIntosh (1976, 1982) saw diversification of the farming operation as the major way out of this degradation cycle. Perennials such as coffee, pepper, cloves and rubber should provide the major farm income in the long run. A dependable food source must be established first, however, especially for spontaneous or government-sponsored (trans)migrants. They estimated that a farm size of about five ha would be needed to enable a sustainable farming system to be practiced, rather than the two ha which has for long been the standard amount of land allocated in Indonesian government settlement programs. Only one ha of this would be cultivated for food crops at a time, unless animal draught power was available. Experiments in central Lampung with intensive relay and intercropping patterns in combination with moderate fertilizer and lime rates confirmed that the major elements of a successful system were to 1) avoid nutrient deficiencies by judicious use of fertilizer, 2) maintain all crop residues in the field and if possible provide further organic inputs to maintain the soil organic mater content, and 3) provide a permanent soil cover to reduce weed establishment and minimize weeding labour.

Zaini and Lamid (1993) showed that intensive cropping systems based on sufficient fertilizer inputs and herbicides are technically feasible on *Imperata* land in West Sumatra, but that a productive tree component may be necessary to make them financially attractive in the long run. Even so, they noted that credit schemes may be needed to overcome the negative returns expected during in the first two years.

Imperata (*alang-alang, cogon*) grasslands cover a substantial area of former and potential agricultural lands. Garrity et al. (this issue) showed that *Imperata* occurs on a broad range of soil types (acid soils, recent volcanic soils, limestone soils), from plains to steep slopes, in climatic zones with different lengths of dry season and chances of fire, and at different scales, from small patches in a fine-grained mosaic of land uses to sheet *alang-alang* grasslands. There is also enormous variation in social and economic conditions of the populations across the region that are attempting to cope with farming the forest margins and *Imperata* grasslands. Therefore, generalizations about the sustainability of food crop systems on these lands are hazardous. The numerous differences among *Imperata* ecosystems ensure that a wide range of scenarios are expected. Therefore, generalizations must be made (and interpreted) with great care.

This paper will review the constraints and possibilities for sustained food crop production in *Imperata* environments, and whether or not it is feasible for farmers to attempt to reclaim grasslands. We will initially examine some broader issues related to *Imperata* and farming systems, and then procede to analyze the directions toward more sustained food crop systems under different farming situations. The analysis refers most directly to *Imperata* grassland ecosystems that are found on the large areas of strongly acidic soils (particularly Oxisols and Ultisols) on the more humid islands of Indonesia (most notably Sumatra and Kalimantan) and the Philippines. First, we seek a set of criteria by which we may view a sustainable farming system.

Sustainability criteria

The following issues are judged crucial for sustainable crop production in *Imperata* environments, based on general sustainability criteria (van der Heide et al., 1992; Table 1):

a) avoiding (re-)infestation by *Imperata* or having the ability to reclaim infested fields;

Table 1. Sustainability issues at different scales and levels of decision making (based on van der Heide et al., 1992).

I. *Criteria at field/farm level*

A. Maintaining resources for future production
* maintaining soil physical quality by controlling erosion and maintaining soil structure
* maintaining soil fertility, preventing a negative nutrient balance
* preventing build up of pests, weeds and disease population
* maintaining genetic diversity

B. Adequate profitability
* producing marketable products with adequate cashflow
* 'adequate' productivity per unit labour, land and inputs in view of existing alternatives, including migration

C. Risk control
* maintaining adequate 'buffering capacity' and/or risk sharing mechanisms
* maintaining meaningful diversity: different baskets for the eggs

D. Development potential
* Maintaining options for improvement, development and adjustment to new options and constraints (don't over-specialize)
* Technology within experimental scope for farmers: no 'fixed package' technology

II. *Criteria at watershed~eco-regional level*

E. No negative environmental effects 'downstream'
* no siltation of lakes and rivers by erosion products
* no pollution of ground-and surface water with agrochemicals and nutrients

F. No continued 'land hunger'
* no continued threat on natural resources such as forests, biodiversity reserves by causing outmigration

III. *Criteria at national/global level*

G. No 'upstream' pollution or resource depletion
* no (disproportionate) dependence on external inputs from polluting industries or from non-renewable resources (including energy)

H. No atmospheric pollution
* no excessive net emissions of greenhouse (CO_2, CH_4, N_2O) and other (NH_3) gasses

b) maintaining soil organic matter and soil structure, avoiding erosion;
c) maintaining the nutrient balance, compensating for nutrient exports with farm products plus unavoidable losses; and
d) achieving a reasonable yield per unit labour and external inputs.

Some conflicting demands have to be met: the presence of *Imperata* may help to prevent erosion and too rigorous weed control may cause erosion problems; intensive cropping systems, providing a near-continuous cover of the soil will help to prevent (re-)infestation by *Imperata*, but also cause a heavy drain on the nutrient balance. If components with a lower harvest index are included, such as trees and cover crops, short-term returns on the labour invested may be limited. Careful balancing is thus required in developing cropping systems adjusted to the local biophysical and socio-economic environment. No 'model farming systems' or recipes can claim to have universal applicability. Rather, research will help to understand basic relationships and trade-offs and thus help farmers in adapting new elements into their system, and assist the public sector to support this process more effectively.

Imperata *as a weed*

Nye and Greenland (1960) noted in their classical review *The Soil Under Shifting Cultivation* that 'There is no doubt that the increasing effort to keep the land free of weeds as the cropping period proceeds is often the primary reason for a patch of land being abandoned'. Yet, the major part of researchers' attention has always been directed to soil depletion and the organic matter balance as the key constraints. Alternatives to slash and-burn agriculture have often been sought through systems with improved soil organic matter maintenance (Nye and Greenland, 1960; Kang et al., 1986; Brady, 1996). Indirectly, the improvement of soil fertility may help to redress weed problems. Crops are generally less efficient competitors for soil resources than weeds, and increased total nutrient supply may especially benefit the crop.

Imperata is not only an effective competitor for water and nutrients, due to its extensive, but often shallow, root systems. It also may have allelopathic effects on crops such as maize or cucumber, due to specific compounds leached from the leaves and rhizomes (Eussen, 1978). The crop's sensitivity to these compounds, however, is reduced at higher N supply, and thus improved soil fertility may help to overcome these allelopathic effects, along with the effects via competition. Brook (1989) and Terry et al. (this issue) have reviewed the biological reasons of the success of *Imperata* as a weed and the options for control, by cultural, mechanical, biological and chemical means.

Imperata *land as degraded land*

Imperata cylindrica meets the requirements which are usually formulated for a cover crop: that is, it is fast growing, low cost, adapted to broad range of soil conditions, requires no effort to get started, has few pests or diseases, and provides good soil cover and erosion control. *Imperata* plays a positive role on sloping lands in reducing soil movement and providing a vegetative filter for runoff carrying sediment. Contour vegetative strips are advantageous for soil conservation when annual cropping on open sloping fields, although they may increase re-infestation of the cropped area by rhizomes and seeds. In climates with a pronounced dry season, however, *Imperata* grasslands are prone to burning, either on purpose or by accident. Regular fires followed by heavy rains result in substantial erosion. Soil organic matter (SOM) in regularly burnt *Imperata* grasslands tends to decline. Without fire reasonable SOM levels are maintained, although the 'quality' of the litter and the subsequent N mineralization rates are low. In the Philippines, fallow fields are often burned or subjected to intensive grazing. Farmers acknowledge that these practices are usually ineffective in regenerating fertility. This has also been corroborated by sampling the nutrient status of fields (Fujisaka, 1989). Farmers often observe relatively poor fertility regeneration on land in *Imperata* fallow after several years, even in the absence of burning (Cairns, 1994). This has led to more recent interest by ICRAF and other institutions in synthesizing information about farmer developed indigenous strategies to intensify fallows to avoid invasion by *Imperata*.

Some alternative grass species that are prospective candidate to replace *Imperata* for erosion control are *Pennisetum purpureum, Brachiaria decumbens, Brachiaria humidicola, Setaria sphacelata* cv. *Nandi, Setaria splendida*, and *Vetiver zizanoides*. These grasses have more direct value than *Imperata*, especially as fodder. Trees can also be used for such a purpose.

Imperata *land as nutrient-depleted soils*

The spread of *Imperata* is often linked to a decline in soil fertility, leading to reduced crop vigour. The process is exacerbated because the grass competes most effectively at lower fertility levels. This is particularly true after forest or long fallow (bush) clearance. Maintaining adequate soil nutrient status is thus one of the keys for stabilizing crop productivity and preventing *Imperata* encroachment.

Three key processes in nutrient cycling in agricultural systems are:

1) plant nutrient uptake and redistribution from stored as well as recently added organic and/or inorganic resources;
2) losses of available nutrients from the system by leaching, erosion, or volatilization, or fixation to less available forms;

3) removal of nutrients in the harvest products, their exchange for external inputs and the recycling of harvest residues in the system.

Most emphasis in the agronomic literature is often given to the first two processes. Aspect 3, however, may be at least as important in determining farmers' decisions on cropping systems. Keeping a positive nutrient balance in food-crop-based production systems is difficult because of the export of harvest products beyond the realm where recycling is possible. Waste recycling tends to decline as farming systems integrate with the cash economy. Unfavorable product/input price ratios and/or high costs for credit may prevent the use of external inputs to replace the exported nutrients.

Cassava is one of the most efficient nutrient scavengers among the crops (aspect 1); yet cassava-based systems are not efficient in obtaining cash (e.g. for purchasing inputs) per unit nutrient export (aspect 3). Table 2 indicates the nutrient removal of various products and the 'replacement costs' if fertilizer inputs are to balance these outputs. For cassava such fertilizer costs would represent more than 50% of the farmgate price of cassava tubers in years with average or below-average prices, leaving small rewards for labour and land if one wants to avoid 'mining' the soil.

Santoso et al. (this issue) discuss the investments in soil fertility, especially

Table 2. Comparison of nutrient replacement value of various agricultural products and their farmgate price; financial parameters relate to the situation in Lampung (Indonesia) in December 1995.

	A Nutrient removal[a] (R_i), g/kg product			B Nutrient replacement value[b] $\Sigma R_i * P_i$, Rp/kg	C Farmgate value of product, Rp/kg	D Relative replacement costs, B/C
	N	P	K			
Cassava (fresh tuber)	1.4	0.24	3.6	15	25–100	0.15–0.60
Rice (grain + husk)	12	2.4	2.0	49	400	0.12
Maize (grain)	16	1.8	3.2	49	250	0.20
Cowpea (grain)[c]	34*	3	15	80	300	0.27
Sugarcane (cane dry weight)	1.5	0.8	3.5	22	40	0.54
Rubber (kg latex (DRC))	6.3	1.3	4.3	35	2000	0.02
Oil palm (bunches)	2.9	0.4	3.7	19	60	0.31

[a] *Sources*: Ahn (1993) and Höweler (1991).

[b] Replacement costs, P_i, are based on a price of 260, 480 and 400 Rp/kg for urea, TSP and KCl (based on prices for December 1995, Suyanto pers. comm.), a nutrient content of 0.45 (N), 0.20 (P) and 0.46 (K), respectively, and a long term recovery (kg nutrient in crop/kg nutrient in fertilizer) of 0.5, 0.2 and 0.3, respectively; combined, these estimates lead to replacement costs P in Rp per g nutrient in the exported crop of 1.1, 12 and 2.9, for N, P and K, respectively.

[c] Assuming that the N harvest index equals the percent N derived from the atmosphere, so that no net N is exported from the field.

phosphorus, which may be necessary as part of a rehabilitation effort to grow food crops on *Imperata* grassland. To some extent, *Imperata* grasslands can be seen as a 'fallow' in a rotational cropping system. A major question, however, is whether it leads to any improvement of soil fertility, or merely stops further degradation. This depends on the specific function(s) of a fallow in overcoming the key constraint. They may be:

- mobilizing nutrients from occluded forms and/or deep layers into organic/available pools in the topsoil,
- reduction of specific pests and (soil borne) diseases,
- improving soil structure and soil organic matter content,
- accumulating nutrients from elsewhere (viz. sedimentation, atmospheric dust input, N_2 fixation).

Imperata is probably not very effective in fulfilling these functions, except for capturing material flowing in from higher positions in the landscape via erosion. An exception is the observed build up of VA mycorrhizal inoculum beneficial to crops. Efforts to replace *Imperata* by other fallow species often have the double target of improving soil fertility and reducing the resident stock of *Imperata* rhizomes in the soil that will re-infest during a subsequent cropping period.

Species of the *Compositae* family such as *Chromolaena odorata* can suppress *alang-alang* to some extent and facilitate further succession to a shrub/forest vegetation, as noted in a study in Lampung by Eussen and Wirjahardja (1973). On soils where this succession is effective, farmers often prefer *Chromolaena* as a fallow species and will take active steps to facilitate the spread of *Chromolaena* (Brookfield et al., 1995; Potter, this issue). The mechanisms by which *Chromolaena* improves soil fertility are not fully understood, but its superior biomass generation, and high rate of litterfall containing a fairly high nutrient content, probably contribute to the process (Slaats, 1995; Cairns, 1994). Natural fallows of bushy species such as *Chromolaena odorata* and *Tithonia diversifolia* are overwhelmingly preferred to *Imperata* as fallows by slash-and-burn farmers throughout Southeast Asia. In addition to their perceived soil fertility regeneration benefits, they are judged to be much less laborious to slash and prepare for cropping. Some farmers manipulate the fallow vegetation on their farms toward domination by these desirable components and their suppression of *Imperata* (M. Cairns, pers. comm.)

The beneficial effects of leguminous plants on accompanying or subsequent crops have been recognized for thousands of years in various cultures. The use of cover crops is particularly relevant in the humid tropics, as high rainfall often depletes soil nutrients, especially nitrogen. Under these conditions, sustainable semi-permanent agriculture should not only compensate for the nutrients removed by the harvest of products, but should also recycle nutrients that have leached to deeper layers in the soil profile during the growth of shallow-rooted food crops (Hairiah and van Noordwijk, 1989).

To be a viable option for small farmers, the cover crop should perform well over a considerable range of soil conditions where *Imperata* infestation is a problem. Several cover crop species were tested on an Ultisol in northern Lampung (Indonesia) and at Onne (Nigeria) (Hairiah and van Noordwijk, 1989). These included *Mucuna pruriens* var. *utilis*, *Calopogonium mucunoides*, *Centrosema pubescens*, *Crotalaria juncea*, *Pueraria phaseoloides*. *Mucuna pruriens* var. *utilis* produced the highest biomass and exhibited the fastest growth; its creeping and twining stems climbed over the grass canopy, pulling it down and smothering it. A longer life cycle cover crop such as *Mucuna deeringiana* (eight months) was more effective in suppressing *Imperata* than those with a shorter life cycle such as *M. pruriens* var. *utilis*. Under acid conditions, however, *Mucuna* may not perform well due to its shallow rooting system (Hairiah et al., 1993, 1995). MacDicken et al. (this issue) discuss cover crops and *Imperata* control more thoroughly.

Imperata *control as a labour problem*

Imperata control is primarily a problem of labour. It is possible to clear *Imperata* grasslands manually and plants crops or trees, but this may take up to 200 man days per ha, which is far more than it takes to open a new secondary forest by slash-and-burn methods. Ruthenberg (1976) gave estimates of 200–400 hours/ha for clearing forest and 800–1000 hours/ha for reclaiming grasslands. Solutions to the *Imperata* problem which are not efficient in labour use are not practicable for farmers.

Questions for this review

When classifying the possibilities for food crop production in former or potential *Imperata* areas, a major distinction can be made between systems with and without cattle. Cattle provide animal traction, which enables grassland reclamation by plowing. The initial tillage of *Imperata* sod with animal traction usually requires two or three plowing and harrowing operations, possibly accompanied by burning or removal of some of the large rhizome accumulation. These operations require less than one-fifth of the human labour time invested when tillage is done by manual methods. Animal tillage operations for subsequent crops require much less effort. Weed management during the crop cycle by interrow cultivation with animal power also requires a very small fraction of the effort required if weeding is done by hand. In animal (or tractor-powered) systems with multiple primary and secondary tillage operations per year, *Imperata* (and other perennial weed species) is rapidly supplanted by annual grass weeds. *Imperata* is not a problem weed during the cropping period, contrary to manual cultivation systems, where primary tillage is much more laborious and thus cannot be practiced as frequently.

Therefore, in farming systems with cattle the re-invasion of fallowed fields by *Imperata* is not the debilitating problem that it is when the household has to rely on manual cultivation. Fallowed fields may also provide economic benefits through grazing as well. Without cattle, alternative reclamation options to manual tillage are critical. Cover crops, manipulation of other species of natural vegetation (such as *Chromolaena*), or herbicides are key options to reduce the labour investment in reclamation.

Trees in a support role can help to maintain the soil organic matter content and through their shade help to control *Imperata*. Trees in a productive role can also be an important or even dominant part of the production system.

We will review cropping systems options under four broad headings (Table 3):

1) annual crop systems based on manual tillage,
2) annual crop systems with animal power,
3) annual crop systems with trees in a supporting role,
4) systems with trees in a productive role.

This review will focus on data from the Lampung area (Sumatra, Indonesia), the 'degraded lands' site for the Alternatives to Slash and Burn Program in Indonesia (van Noordwijk et al., 1995b), with additional information from the Philippines.

Table 3. Crop-based production systems for former/potential *Imperata* grasslands.

	Manual tillage	Animal (or mechanical) power
No trees	*Imperata* control very labour consuming or costly when based on herbicides and minimum tillage; multispecies intercrops with cover crops to prevent re-infestation	Frequent ploughing gives adequate *Imperata* control and can prolong cropping period; increased erosion on sloping lands leads to need for contour vegetative strips which can provide fodder
Trees in support role: – fallows – hedgerows	Fallow periods have to be long and consist of fire-tolerant trees to shade out *Imperata*; *rotational hedgerows* may be promising	Fodder trees on field boundaries, in contour hedgerows or in improved fallows can supply fodder to support the cattle needed for tillage
Trees in productive role	Perennials may start as intercrops during cropping period; spot application of herbicides may control *Imperata* regrowth due to patchy shade patterns	Animal role can be transitory during establishment of tree crops, or remains dominant with intensive continuous cropping on a portion of the farm.

Annual crop systems based on manual tillage

Food crops only

In Indonesia, large government sponsored re-settlement programs were initially based on opening logged-over forest land for food crop production and farming with manual tillage. Unless villagers could develop wetland ricefields in the valleys and depressions, land productivity fell below their requirements and people were tempted to move on into new forest margins, to the cities, or return to densely populated Java.

Suryatna and McIntosh (1982) showed that on the Ultisols (Red Yellow Podzolic Soils) intensive relay/intercropping systems based on cassava + upland rice + maize, followed by legume crops such as mungbean, groundnut or soybean could be productive and sustainable over a number of years (Table 4), and prevent *Imperata* infestation by providing a near-continuous crop cover. Progress has been made in selecting maize and rice varieties for such upland conditions, and in Indonesia improved cultivars of upland rice may be successfully grown on acid upland soils with yields of 3–4.5 Mg ha^{-1} (S.M. Sitompul, pers. comm.). Cassava is a major component of these cropping systems for acid upland soils. It serves both as a staple food for the poorest part of the rural population in transmigration areas, and as an industrial crop. Extensive cassava production, heavily infested by *Imperata* are still considered feasible in Lampung with yields of only 5–10 Mg $ha^{-1}$of tuber (Hayami et al., 1989).

Smallholder settlers on *Imperata* lands throughout Indonesia often practice multi-species intercropping systems that include upland rice, maize, and

Table 4. Yield (calories and protein) and gross returns of the cropping systems tested in Way Abung (Sumatera, Indonesia) during 1977/1978.

Cropping pattern	Gross return ($ ha^{-1})	Calories (Mcal ha^{-1})	Protein (kg ha^{-1})
Maize + rice/cassava/ groundnut or rice bean	1134	46	842
Maize + mungbean + rice/cassava	987	54	763
Maize + soybean – maize + sweet potato – cowpea	1011	23	957
Traditional maize + upland rice/cassava + inputs	461	25	391
Traditional maize + upland rice/cassava	336	20	284

Source: Suryatna and McIntosh (1982).

cassava. A succession of crops is harvested but only one primary tillage operation is practiced per year. Complex intercropping systems was hypothesized to better sustain crop production as the soil surface is protected from erosion and a higher organic matter input is achieved through crop residues. Organic inputs in cassava are largely based on litterfall during the growing season which amounts to about 2 Mg ha^{-1}, as stem material is often removed at harvest. In addition, the difference in plant geometry among intercrop plants and plant density in the intercropping systems was expected to reduce the light at the ground level and thus prevent invasion of *Imperata.*

Several cassava-based cropping systems were tested in the Nitrogen Management Project in North Lampung. Three cropping patterns tested were cassava monocrop or cassava intercropped with maize, upland rice or soybean in combination with three levels of N fertilizer (0, 30 and 60 kg ha^{-1}) and followed by *Mucuna* or cowpea (*Vigna unguiculata*) in the second season. Moderate inputs of P (20 kg ha^{-1} as TSP) and K were used and improved crop varieties with their associated insecticides. After 5 years of continuous cropping, the cassava tuber yield declined gradually in all treatments. Maize failed as an intercrop after 3–4 years, while rice and soybean still gave good yields. *Mucuna* was only successful as a cover crops during the dry season in relatively wet years; it had some visible effects on early crop development in the next cropping season, but it did not increase cassava tuber yield significantly (Sitompul et al., 1992a). On aggregate, the rice and soybean intercropping systems were more productive than cassava monocropping, but *Imperata* problems increased, especially where no N fertilizer was used.

Cassava monocultures could keep *Imperata* pressures at low levels in the fourth and fifth year of continuous cropping when cowpea or especially *Mucuna* were used as cover crop in the fairly dry period between cassava harvest (August) and the next planting time (November/December) (Table 5). Contrary to the hypothesis formulated, cropping systems with maize, rice or soybean as intercrops in the beginning of the cassava period had significantly more *Imperata,* especially when no or a low rate of N fertilizer was used. The first season food crops apparently competed with cassava and slowed down the development of the cassava canopy, sufficient for *Imperata* to get established. *Imperata* infestation doubled from the fourth to the fifth year.

A neighbouring experiment (Table 6) included a bare fallow after the cassava harvest, which is similar to the farmers' practice, and a treatment with a cowpea crop during that period. The bare fallow for two or three months allowed a substantial increase in *Imperata* cover, but not in the treatments with a surface mulch of maize stover remaining from an intercrop during the early growing season. Nitrogen fertilizer was not as effective in reducing *Imperata* cover in this second experiment as it had been in the first. The overall *Imperata* infestation level was higher in this second experiment than in the first, and after three years continuous cropping became difficult.

Combining the results from the two experiments, we see that a continuous

Table 5. Imperata cover at the end of the fourth (1990) and fifth (1991) year of cassava-based cropping systems after clearing of a secondary forest in North Lampung (Indonesia); results for a factorial design with main-crop * dry-season cover crop * N fertilizer level as treatments in four blocks.

Main effects	F	Pr > F	Interactions	F	Pr > F
Main crop	11.06	<0.001	Main-crop * N level	2.74	0.015
Cover crops	2.96	0.087	Main-crop * year	2.49	0.063
N level	11.75	<0.001	Other interactions	NS	>0.10
Year	28.45	<0.001			

Mean percentage *Imperata* cover

	1990				1991				*Grand*
	NO	N30	N60	avg	NO	N30	N60	avg	*avg*
Cassava	5.2	2.4	4.0	**3.9**	9.9	4.0	6.4	**6.8**	***5.3***
C + maize	14.6	10.8	7.5	**10.9**	33.1	24.1	11.8	**23.0**	***17.0***
C + rice	26.0	11.5	6.9	**14.8**	42.0	20.7	15.6	**26.1**	***20.5***
C + soybean	10.2	16.7	4.5	**10.5**	34.0	38.7	16.8	**29.9**	***20.2***
Average	**14.0**	**10.3**	**5.7**	**10.0**	**29.8**	**21.9**	**12.7**	**21.4**	***15.7***

S.E.D.'s main crop 3.0; N level 2.6; Year 2.1; MC * N * Y 7.4

cover crop:	Cowpea	*Mucuna*	S.E.D.
	17.6	13.9	2.1

Data: S.M. Sitompul, unpub.; details of experiment: Sitompul et al., 1992a. S.E.D. = standard error of differences.

soil cover is indeed important for slowing down *Imperata* infestation, but a surface mulch cover of maize stover may be about as effective as a legume cover crop. Intercropping maize, rice or soybean between the young cassava gives a good cover in the beginning of the wet season, but may inhibit cassava development to the extent that overall *Imperata* infestation increases after the harvest of the first season's crops. Use of (N) fertilizer can reduce this effect. Thus, although complex intercropping may reduce manual weeding, weeding is still important in the early years and the *Imperata* problem intensifies over time.

Including legume cover corps

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 Mg 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%,

Table 6. Imperata cover at the end of the third year (1991) of cassava-based cropping systems after clearing of a secondary forest in North Lampung (Indonesia); results for a factorial design with main crop * dry season cover crop * N fertilizer level as treatments in four blocks (data: S.M. Sitompul, unpub.; details of experiment: Sitompul et al., 1992a).

Main effects	F	Pr > F	Interactions	F	Pr > F
Main crop	1.24	0.274	Main crop * Cover crop	4.27	0.047
Cover crops	5.56	0.024	Other interactions	NS	
N level	1.67	0.203			
Year					

Mean percentage *Imperata* cover

	Cover crop			
Main crop	Cowpea	Bare fallow	Average	S.E.D.
Cassava crop	30.7	57.3	44.0	
Cassava + maize	36.5	38.2	37.3	
Average	33.6	47.6	40.7	8.49

N level	NO	N30	N60	S.E.D.
	48.4	36.9	36.7	7.35

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 (Figure 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 nine 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 Muladi, 1992; 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 North 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

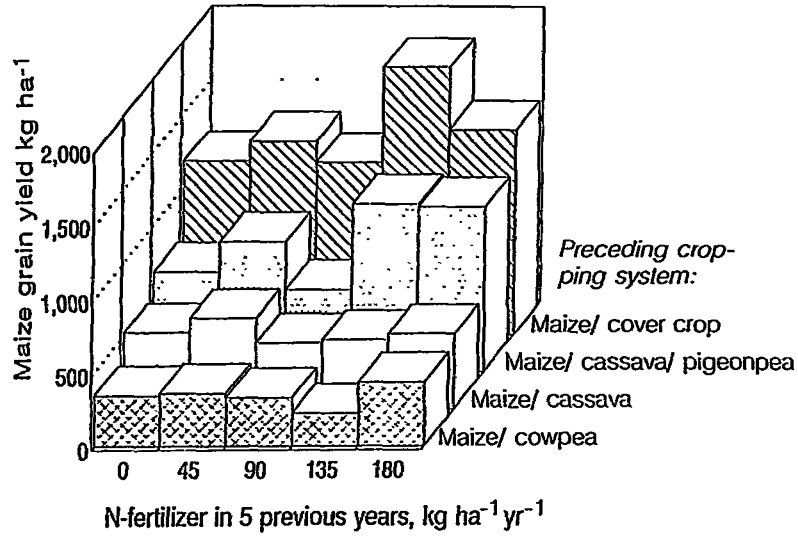

Figure 2. Maize grain yield as affected by residual soil fertility from four cropping systems at five N fertilizer rates in the preceding five years; experiment at IITA's High Rainfall Station at Onne, Port Harcourt, Nigeria (van der Heide and Hairiah, 1989).

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 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 *Lablab* on subsequent maize crops.

They noted that species likely to be most promising are those such as *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).

Annual crop systems with animal power

Most farmers in grassland environments highly value ruminant animals as a component of their farming system (and tend to have them whenever they can afford them). Cattle, in particular, not only enable the household to convert the abundant grass in their environment to income through the periodic sale of beef animals, but their use as draft animals dramatically increases labour productivity in crop cultivation. Managing livestock for manure production is another distinct advantage of building a mixed farming system with ruminants, particularly when the manure can provide a means for concentrating the nutrients consumed from fallow grass areas on or off the farm. Fodder availability then becomes an issue and the *Imperata* grassland area may become a 'resource', although fodder quality of *Imperata* is low, except for the early regrowth after fire. Introducing animals (one cow, 3 goats and 11 chicken per family) in transmigration areas in Batumarta (South Sumatra) has substantially increased farmers income (Anwarhan et al., 1991), both by providing direct income and by allowing more intensive use of the crop land. In the farming systems experiments in Batumarta, *Gliricidia sepium* and *Flemingia congesta* were introduced as fodder trees.

In the Philippines animal traction is widely used in the uplands, and *Imperata* grasslands are reclaimed by plowing without great difficulty. The availability of draft power tends to enable the household to crop larger areas, and to clean-till these areas more frequently during the year than is feasible with manual tillage. One down-side risk of this, however, is the tendency for accelerated soil erosion on farms with animal power. Contour hedgerow farming is particularly suited to counter this problem, since such systems are more conveniently managed with draft power, though they use clean-tillage rather than mulching. Leguminous fodder trees have particular value on mixed farms, either in border plantings or as a component of the hedgerows. The economic value of the prunings as fodder, particularly during the dry season, has been shown to be much more lucrative than direct use for green manure.

Farmer participatory research in communities with animal power in the Philippines with farm sizes averaging about three hectares, has shown that there is great interest by smallholders in establishing contour hedgerow systems. However, these systems often produce volumes of fodder exceeding the household is needs. This is particularly common when fodder trees or exotic forage grasses such as napier (*Pennesitum purpureum*) are planted in the hedgerows. Labour requirements to prune these systems are demanding.

Under such circumstances farmers strongly prefer installing hedgerows of natural vegetative strips (NVS). These are established by laying out the contours and leaving unplowed strips that revegetate with *Imperata* and other annual and perennial grasses (Garrity et al., 1993). They require very little work to install, and little maintenance thereafter. They reduce soil losses up to 99% on slopes of 20% and rapidly develop natural terraces that farmers find easier to cultivate than open slopes. Competition between the NVS and associated food crops is less than with fast-growing, taller, species of introduced grasses or trees. Tung and Alcober (1991) observed that natural strips composed of *Imperata* may provide three types of benefits: reduced soil losses, mulching material, and roofing material. They noted that Vetiver grass (*Vetiver zizanoides*) strips can also be a suitable alternative to *Imperata.*

On farms with higher cattle populations, and/or with a higher labour/land ratio, there is the potential and the need for a larger volume of high quality fodder. It is then practicable to progressively increase the area of field borders and hedgerows devoted to exotic fodder grasses and leguminous trees. But care must be taken when hedgerow prunings are siphoned off the field for ruminant feed. Mercado and Garrity (1994) reported that when napier grass was exported as fodder from a hedgerow system, maize yields declined 86% after three years due to competition for nutrients (and possibly water) with the grass. Basri et al. (1990) noted a similar effect when leguminous tree prunings were removed rather than applied as green manure. Clearly, intensive fodder harvesting in hedgerow systems requires higher levels of fertilization to replace the accelerated nutrient·offtake.

Burke et al. (1995) reviewed several farming system models practiced in eastern Indonesia where farms have a number of cattle. These may have relevance in *Imperata* areas elsewhere. One model is an agro-silvo-pastoral practice: The cropland is devided into a number of compartments (perhaps 0.5 ha or less in size) by enclosing them with live fences of leguminous fodder trees. The animals are kept in these corrals of fallowed land for up to a year, and removed just prior to cropping. The manure is therefore concentrated on the land and favorably regenerates soil fertility. This boosts yields in the succeeding crops. They also described a more intensive 3-strata system practiced in Bali in which the crop field is surrounded by a band of fodder grass, enclosed by a field border of fodder trees and full canopy fruit and timber trees.

Annual crop systems with tree in supporting role

Alley cropping (or hedgerow intercropping) has received considerable attention from researchers throughout the tropics in the past decade, after the first publications in which it was presented as a 'stable alternative to shifting cultivation' (Kang et al., 1986). The enthusiasm generated by alley cropping as a sustainable alternative to shifting cultivation systems has now been tempered by disappointing results in 'implementation' programs due to the specific form of system chosen (Fujisaka et al., 1995). There is some danger that this disappointment may lead toward the other extreme of assuming that crop fields and woodlots must be entirely separated. But there are many agroforestry systems developed and used by farmers that apparently do meet their criteria. Many of these systems are far more complex and less tidy than the neat sequence of hedgerows and crops in alley cropping. Therefore researchers face a much more challenging task in quantifying such systems and exploring the range of options to improve them, in order to support what resource-poor farmers actually need.

The alley-cropping system is related to the bush-fallow system practiced by farmers all over the world during a certain stage in the intensification of land use. The bush fallow alternates in time with a cropping phase. In many traditional versions of this system, the stumps of the trees survive during the cropping phase and help to re-establish a woody vegetation which can partially restore soil fertility during the fallow period. Alley-cropping is an attempt to replace this temporal sequence by a spatial zonation, in which the trees play their role in strips between the crops. In the specific way in which alley-cropping has been most widely promoted (*Leucaena leucocephala* hedgerows at 4 m spacing, pruned regularly at 0.5–1 m height), it has not met expectations. This is partly due to biophysical reasons: A single 'miracle tree' may be vulnerable to pest infestation as shown by the *Heteropsylla* invasion of *Leucaena*, where water supply is limiting and tree-crop competition for moisture is too severe, or because the tree species is poorly adapted to acid soils. It is also partly due to the relatively high labour requirements to prune and maintain the hedgerows (often 80–100 person-days per year). This may represent a large fraction of the total amount of annual household labour available for farming (ICRAF, 1996)

In many areas in Southeast Asia researchers have attempted to use the hedgerow intercropping concept to maintain or improve productivity of crop land, with mixed results on the biophysical side, and often low farmer adoption rates. A less recognized aspects is that over time the adoption of alley farming may reduce the labour requirement for land clearing and weeding at least in manual tillage systems. If so, this may be a more important reason for farmer adoption than increases in the production of staple food crops (Fischer, 1995).

Weed suppression by hedgerow intercropping with *Leucaena leucocephala* in Nigeria was greater in plots that were cropped every other year than in continuously cropped plots (Akobundo et al., 1995). *Gliricidia sepium* hedgerows were more effective in *Imperata* control than *Leucaena leucocephala* (Anoka et al., 1991). Biophysically, the prunings of the hedgerow trees give a substantial organic input (4–12 Mg ha^{-1} of dry biomass for a 4 m hedgerow spacing; Hairiah et al., 1992) as well as nutrient inputs, based on N_2 fixation, and nutrients captured from the crop root zone and below. Further analysis of the tree–soil–crop interactions in this system shows that soil improvement by the mulch is clear, but that competition for light (unless a very rigorous and time consuming pruning regime is maintained), water (in dry periods) and/or nutrients often outweighs the advantages.

Data of the first five years of a long term experiment in north Lampung with several leguminous hedgerows trees showed that the highest maize production within the alley was obtained in hedgerow intercropping with *Peltophorum dasyrrachis* (previously wrongly identified as *P. pterocarpum*) and its combination with *Gliricidia sepium* (Hairiah et al., 1992; van Noordwijk et al., 1995a). These two trees are also the strongest species as regards long term pruning tolerance (*Erythrina orientalis* and *Calliandra calothyrsus* died back after about three and six years, respectively). Maize yield in the alleys with the best trees were increased by 0.5–1.0 ton ha^{-1} over the control (van Noordwijk et al., 1995a). The local tree *Pelthophorum* is reasonably fire-tolerant and this probably explains its local dominance the secondary forest vegetation; it is one of the few trees establishing spontaneously in *Imperata* grasslands, along with *Schima wallichii*, *Vitex pubescens* and *Dillenia obovata*.

Table 7 shows recent data from the Philippines where crop yields per unit cropped area increased, but yields per ha decreased by the inclusion of hedgerows. This pattern is very common. Only on very poor soils with low open-field yields can clear benefits be expected for hedgerow intercropping.

At the moment, attention is shifting towards systems which are a bit closer to the bush-fallow system, and which can be termed 'rotational alley-cropping'. The trees are still grown in hedgerows, but cropping is not continuous; a tree phase alternates with a crop phase. During the crop phase, the trees are severally set back by pruning to near ground level, to reduce competition as well as labour demands for pruning; yet the tree stumps are supposed to survive and allow a quick regrowth of trees after one to three years of cropping (Figure 3). Candidate trees for this system must survive the setback pruning and develop a proper tree canopy when left to grow. If such a system is able to control weeds such as *Imperata* in the fallow stage, the labour costs of pruning may be more then off-set by the time gained from less weed control.

Table 7. Maize yields Mg ha^{-1} from SALT plot and control plot (sloping land).

	1985	1986	1987	1988	1989	1990
Control	4.7	4.3	4.2	3.1	2.6	2.1
SALT plot: per ha	3.9	4.1	2.7	2.1	2.4	2.6
Per cropped area	4.9	6.8	6.3	5.2	5.7	5.9

The proportion of maize area in the SALT plot varied as follows: 1985 = 85%, 1986 = 60%, and during 1987–1990 = 43% of the total land area of SALT.
Source: Partap and Watson (1994).

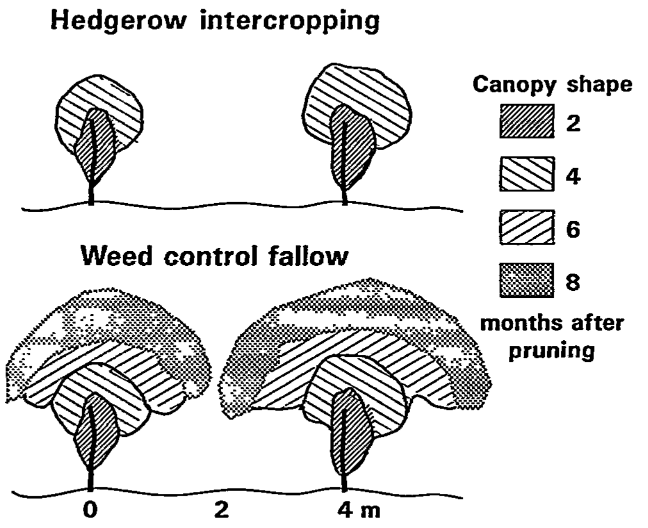

Figure 3. Schematic canopy shape of hedgerow trees for rotational alleycropping (van Noordwijk et al., 1992).

Current experiments in North Lampung test a prototype of this system, based on *Gliricidia sepium* and the local tree *Peltophorum dasyrrachis*. In 1992 an experiment was started to get the trees growing in an *Imperata* grassland, with a minimum of labour and other inputs (transplanted local tree seedlings, a bit of P fertilizer) in a small strip which was manually cleared of *Imperata* (van Noordwijk et al., 1992). In the next two years trees were left to grow. After one year the trees had started to reduced *Imperata* vigour, but did not suppress it sufficiently. In the *Gliricidia* plots the weed *Chromolaena odorata* partially replaced the *Imperata*. During the second year, tree canopy development continued, but not enough to eliminate the *Imperata*. Tree growth showed considerable variability – in the patches were the tree grew best adequate *Imperata* control was reached after two years, but not on the majority of the plots. A fire raged through the plot in the exceptionally dry season of 1994 and provided a true test of the fire tolerance of the trees. All trees of both species resprouted after the fire, but only the *Peltophorum* trees on the best patches (were the fire intensity was probably less due to less *Imperata* biomass) resprouted from higher stem positions. In the next season food crops (rice, maize, groundnut) were grown. One half of the plots were pruned at ground level, the other half at 0.75 cm height, as in the conventional alley cropping system. Fruit trees (*Mangifera* and *Parkia*) were introduced into the system on the farmer's wish to gradually transform the field into a permanent agroforestry system.

The experience so far suggests that either more effort has to be made to speed up tree establishment, or a higher initial tree density is needed for this system. Results after the first cropping year and a five months recovery

Table 8. Biomass of *Imperata* cylindrica (Mg ha^{-1}) in October 1995 at the start of the second cropping year in a rotational hedgerow cropping trial in North Lampung (Indonesia).

Pure crop control	*Pelthophorum dasyrrachis*	*Gliricidia/Peltophorum* alternating hedgerows	*Gliricidia sepium*	S.E.D.
1.755	0.252	0.137	0.045	0.218

S.E.D. = standard error of differences.

period of the hedgerows after the harvest of the second food crop, show a substantial reduction in *Imperata* infestation in the plots (Table 8). There thus appears to be scope to further explore rotational hedgerows intercropping as midpoint in the continuum from 'improved fallows' as a sequential agroforestry system to permanent 'hedgerow intercropping' as spatial zoned, completely simultaneous system.

Most alley cropping research has focused on the soil fertility aspects; the N contribution of tree prunings rarely exceeds the equivalent of 60 kg N as urea per crop (two pruning cycles) (van Noordwijk et al., 1995a). If we take a conservative estimate of the labour costs of pruning as 20 man-days per ha per pruning cycle, the rewards for this labour are only 1.5 kg Urea N per day or, at current prices (Table 2) US$0.38 per day, about a third of the official minimum wage in Indonesia.

However, on the basis of available data labour costs of pruning (80 days per ha for four pruning cycle and two crops per year) compare favourably with labour saving by less weeding and especially by avoiding the reclamation of heavily *Imperata*-infested lands (200 man-days per ha for a two-year cropping period). A more complete economic evaluation is needed, but there is a lack of basic data on labour requirements under on-farm conditions.

Work on rotational hedgerow systems has also been initiated in Claveria, Philippines on several farmers' fields with contour hedgerows of *Senna* (*Cassia*) *spectabilis* that were fallowed two years previously. The hedgerows had developed intense shade across the alleyways. We are currently comparing the systems productivity of these plots (crop yields and pole yields) and the labour investments, against those for adjacent plots in bush fallow for the same time period.

A farming system that exhibits some similar characteristics has been widely adopted by smallholder crop and cattle farmers in Timor, Indonesia. In this 'amarasi system' blocks of land are planted to *Leucaena* when they are fallowed from maize production. The dense population of trees provide fodder during the fallow, and are slashed and burned when the land is re-opened for crop production (Burke et al., 1995).

Trees in a productive role

Although trees can be successful in a 'supportive' role from the a biophysical point of view, farmer acceptance of such technologies is much more likely if the trees have a productive role as well. Some of the popular fruit trees in home gardens have such a dense foliage (e.g. jackfruit and other *Artocarpus* species) that *Imperata* is shaded our, but possibilities for food crop production are small as well. Other popular trees such as coconut or *Paraserianthes falcataria* planted as fast growing timber, have such an open canopy at normal plant spacings, that *Imperata* is a problem; intercropping with food crops may be beneficial, even if food crop yields are reduced by the trees, as the chances for tree survival are enhanced due to lower fire risks and lower competition than an *Imperata* sward would exert. The food crops here take a 'supportive role' towards the productive trees. Most tree crops, such as oil palm and rubber are intermediate between these two situations and may benefit from intercropping in the early years, but not after they established a closed tree canopy. As was the case with the cassava intercropping systems, the transition period between the food intercrops and tree canopy closure is the most vulnerable stage.

Fast-growing trees may be employed as nurse trees in establishing timber and cash perennials. Their inclusion is intended to create a favorable microclimate, reduce soil erosion, and suppress *Imperata*. A model based on this concept is promoted by NGOs in eastern Indonesia. Species that benefit from partial shade such as cacao, coffee, vanilla, and high-quality timber species are established between hedgerows of nitrogen-fixing trees for early protection. This 'family forest model' evolves into an permanent agroforest (Burke et al., 1995). Contour rows of N-fixing trees have been widely used in establishing forest plantations in Indonesia.

Likewise, systems that start out as dominantly food crop-based contour hedgerow systems may evolve into perennial cash crop systems. Leucaena contour hedgerow systems have been widely practiced on Flores island in eastern Indonesia since the 1930s. They were promoted for their conservation and soil fertility regeneration features in food-crop systems. Djogo et al. (1990) describe how cash perennials were integrated into these systems in some areas, eventually resulting in the development of a dominantly tree-crop system. The Sloping Agricultural Land Technology (SALT) model promoted in the Philippines also emphasizes the evolution of perennial tree crops in alternating alleyways.

The development of agroforests is still generally uncommon in grassland areas. However, a few cases have been identified where communities have successfully developed agroforests on a large scale in the midst of sheet *Imperata* grassland. These have been observed in eastern Indonesia (L. Fisher, pers. comm.) and in Riam Kanan, South Kalimantan (D.P. Garrity, pers. comm.) These cases need further determined study to elucidate the factors that stimulated their success, so that extrapolation of these systems can be efficiently promoted.

Colfer (1991) described the change in research culture which is needed to shift from a food-crop based bias focused on (trans)migrant farmers to efforts to more fully exploit the opportunities of diverse, tree-based production systems. The Ministry of Transmigration in Indonesia has recognized the limitations of a pure food-cropping approach and is now advocating agroforestry models. This is a positive development, if it is sufficiently flexible to allow for the wide range of prospective perennial choices for specific local circumstances, and the need of smallholders to diversify their tree crop enterprises. Levang (1995) discussed the change in perceptions surrounding the shift of transmigration villages from 'food-crop based' to systems integrating crops, animals and rubber trees in Batumarta (South Sumatra). Agroforestry systems with trees in a productive role as an alternative to *Imperata* grassland are further reviewed by Bagnall-Oakeley et al. (this issue), de Foresta and Michon (this issue), and Menz and Grist (this issue).

Conclusions and priority areas for research

Crop-based production systems without animals, or without trees in a productive role, are not likely to give a sustainable alternative to migration into new forest margins. Crop-based production systems are essential during a transition period, while tree-based systems or mixed farming systems get established, especially for new migrant families.

The priority areas for research include:

1) more coordinated studies of how the grasslands are farmed by communities in a wide range of situations to identify new sources of technical practices and institutional innovations that may prove useful on a wider scale;
2) rotational alley cropping as 'improved fallow' with shade-based *Imperata* control; choice of suitable tree species which regrow slowly after pruning but which eventually form a dense canopy;
3) relay-and inter-cropping systems which reduce gaps in soil cover after the harvest of component crops;
4) slash-and-mulch systems based on self-regenerating cover-crops, which avoid the costly re-establishment of a fallow vegetation;
5) how to build on indigenous strategies to stimulate the succession to *Chromolaena/Eupatorium* in fallow periods; these species may evolve into a self-regenerating cover crop, which can be relatively easily controlled during cropping periods;
6) cheap methods for maintaining soil fertility to reduce *Imperata* infestation;
7) the compatibility of food crops and the establishment phase of tree crops.

References

Adiningsih S and Mulyadi J (1993) Alternative technology for rehabilitation and utilization of *alang-alang* land. In: Syarifuddin Karama et al. (eds) Prosiding Seminar Lahan Alang-alang, pp 29–49. Pusat Penelitian Tanah dan Agroklimat, Bogor, Indonesia

Agboola AA and Fayemi AA (1972) Fixation and excretion of nitrogen by tropical legumes. Agronomy Journal 64: 409–412

Ahn PM (1993) Tropical Soils and Fertilizer Use, Longman Group, Harlow, UK, 264 pp

Akobundo IO, Ekelme F and Agyakwa CW (1995) Effect of alley farming on weed infestation and floral composition. In: Kang BT, Osiname AO and Larbi A (eds) Alley Farming Research and Development, pp 137–143. Afneta, IITA, Ibadan, Nigeria

Anoka UA, Akobundo IO and Okonkwo SNC (1991) Effects of *Gliricidia sepium* (Jacq.) Steud and *Leucaena leucocephala* (Lam.) De Wit on Growth and Development of *Imperata Cylindrica* (LK.) Raeuschel. Agroforestry Systems 16: 1–12

Anwarhan H, Supriadi H and Sugandi D (1991) Kontribusi pakan ternak di lahan kering Batumarta Sumatera Selatan [Contribution of livestock in dryland farming in Batumarta, South Sumatra]. In: Proc Simposium Nasional Penelitian dan Pengembangan Sistem Usahatani Lahan Kering yang Berkelanjutan, 29–31 August, 1991, Malang, Indonesia, pp 268–283 [in Indonesian]

Armachuelo CG, Corre MD, Hipe RB, Logo TJ, Costilo E, Sotto E and Gonzalez N (1989) Cogon viability as affected by cover crops. Eastern Visayas Development Project. Report No. 88, 11 pp

Bagnall-Oakeley H, Conroy C, Faiz A, Gunawan A, Gouyon A, Penot E, Liangsutthissagon S, Nguyen HD and Anwar C (1997) *Imperata* management strategies used in smallholder rubber-based farming systems. Agroforestry Systems 36: 83–104 (this issue)

Basri I, Mercado A and Garrity DP (1990) Upland rice cultivation using leguminous tree hedgerows on strongly acid soils. Agronomy Abstracts, 1990, American Society of Agronomy, Madison, WI, USA

Brady NC (1996) Alternatives to slash-and-burn: a global imperative. Agriculture, Ecosystems and Environment 58: 3–11

Brookfield H, Potter L and Byron Y (1995) In Place of the Forest, Environmental and Socio-economic Transformation in Borneo and the Eastern Malay Peninsula. United Nations University Press, Tokyo, Japan, 310 pp

Brook RM (1989) Review of literature on *Imperata cylindrica* (L.) Raeschel with particular reference to South East Asia. Tropical Pest Management 35: 12–25

Buckles D (1995) Velvetbean: a 'new' plant with a history. Economic Botany 49: 13–25

Burke T, Rachmawati I, Agung K, Marthina Pa S (1995) Investigations on Traditional and Introduced Agroforestry Systems Used in Timor. Rote, and East Sumba. Forest Research Centre, Kupang, Timor, Indonesia, 56 pp

Burkill IH (1966) A Dictionary of the Economic Products of the Malay Peninsula Governments of Malaysia and Singapore, Kuala Lumpur, Malaysia

Cairns M (1994) Stabilization of upland agroecosystems as a strategy for protection of national park buffer zones: a case study of the coevolution of Minangkabau farming systems and the Kerinci Seblat National Park. Masters thesis, York University, Ontario, Canada

Colfer CJP (1991) Toward Sustainable agriculture in the humid tropics, building on the TropSoils experience in Indonesia Tropsoils bulletin No. 91–92, North Caroline State University, Raleigh NC, USA, 86 pp

Danhof GN (1941) Tweede bijdrage tot oplossing van het alang-alang vraagstuk in de Lampongse Districten [Second contribution to the solution of the *Imperata* problem in the Lampung Districts]. Tectona 34: 67–85 [in Dutch]

De Foresta H and Michon G (1997) The agroforest alternative to *Imperata* grasslands: when smallholder agriculture and forestry reach sustainability. Agroforestry Systems 36: 105–120 (this issue)

Eussen JHH (1978) Studies on the tropical weed *Imperata cylindrica* (L.) Beauv. var. major. PhD Thesis, Utrecht University, Utrecht, the Netherlands

Eussen JHH and Wirjahardja S (1973). Studies of an *alang-alang* (*Imperata cylindrica* (L.) Beauv.) vegetation. BIOTROP Bulletin No. 6, SEAMEO-BIOTROP, Bogor, Indonesia

Fisher LA (1995). Alley farming in the uplands of southeastern Indonesia. In: Kang BT, Osiname AO and Larbi A (eds) Alley Farming Research and Development, pp 519–532. AFNETA, IITA, Ibadan, Nigeria

Florido LV (1992) Agri-silviculture in relation to livestock production in the Philippines. In: Proceedings of Regional Expert Consultation on Agro-Silviculture to Support Animal Production in Asia and Pacific Region, pp 131–148. FAO-RAPA, Bangkok, Thailand

FSDP-EV (1986) Farming Systems Development Project – Eastern Visayas. A diagnostic survey on understanding farmers' indigenous techniques in cultivating cogonal fallow areas and to design and test cogon control measures. Working Paper No. 9. Ministry of Agriculture and Food, Region III, Tacloban City, the Philippines, 15 pp

Fujisaka S, Mercado A and Garrity DP (1995) Farmer adaptation and adoption of contour hedgerows for soil conservation. In: Kang BT, Osiname AO and Larbi A (eds) Alley Farming Research and Development, pp 547–555. Afneta, IITA, Ibadan, Nigeria

Guritono B, Sitompul SM and van der Heide J (1992) Reclamation of *alang-alang* using cover crops on an Ultisol in Lampung. Agrivita 15: 87–89

Garrity DP, Kummer DM, and Guiang ES (1993) The Philippines. In: Sustainable Agriculture and the Environment, pp 449–624. National Academy Press, Washinton, DC, USA

Garrity DP, Soekardi M, van Noordwijk M, De La Cruz R, Pathak PS, Gunasena HPM, Van So N, Huijun G and Majid NM (1997) The *Imperata* grasslands of tropical Asia: area, distribution, and typology. Agroforestry Systems 36: 3–29 (this issue)

Hagreis BJ (1931) Ladangbouw [Shifting Cultivation]. Tectona 24: 598–631 [in Dutch]

Hairiah K and van Noordwijk M (1989) Root distribution of leguminous cover crops in the humid tropics and effects on a subsequent maize crop. In: van der Heide J (ed) Nutrient Management for Food Crop Production in Tropical Farming Systems, pp 157–169. Institute for Soil Fertility, Haren, the Netherlands and Brawijaya University, Malang, Indonesia

Hairiah K, Utomo WH and van der Heide J (1992) Biomass production and performance of leguminous cover corps on an Ultisol in Lampung. Agrivita 15: 39–44

Hairiah K, van Noordwijk M and Setijono S (1993) Tolerance to acid soil conditions of the velvet beans *Mucuna pruriens* var. utilis and *M. deeringiana* II. Aboveground growth and control of *Imperata cylindrica*. Plant and Soil 152: 187–199

Hairiah K, van Noordwijk M and Setijono S (1995) Aluminum tolerance and avoidance of *Mucuna pruriens* at different P supply. Plant and Soil 171: 77–81

Hayami Y, Kawagoe T, Morroka Y, Mayrowani H and Syukur M (1989) Agricultural marketing in a transmigration area in Sumatra. CGPRT Centre, Bogor, Indonesia. Report No. 19, 73 pp

Höweler RH (1991) Long term effects of cassava cultivation on soil productivity. Field Crops Research 26: 1–18

ICRAF (1996) Annual report for 1995, pp 180–185. International Centre for Research in Agroforestry, Nairobi, Kenya

Kang BT, Wilson GF and Lawson (1986) Alley Cropping a Stable Alternative to Shifting Cultivation. IITA, Ibadan, Nigeria, 22 pp

Levang P (1995) Tanah Sabrang, la Transmigration en Indonésie: permanence d'une politique agraire contrainte ORSTOM, Montpellier, France, 461 pp

Menz K and Grist P (1997) Economic opportunities for smallholders to combine pulpwood trees and food crops. Agroforestry Systems 36: 221–232 (this issue)

MacDicken KG, Hairiah K, Otsamo A, Duguma B and Majid NM (1997) Shade-based control of *Imperata cylindrica*: tree fallows and cover crops. Agroforestry Systems 36: 131–149 (this issue)

Mercado A and Garrity DP (1994) Nitrogen fixation capacity in contour hedgerow systems: how important? Agroforestry Systems 27: 241–258

Nye PH and Greenland DJ (1960) The Soil under Shifting Cultivation. Commonwealth Bureau of Soils, Harpenden, UK

Partap T and Watson HR (1994) Sloping agricultural land technology (SALT): a regenerative option for sustainable mountain farming. ICIMOD Occasional Paper No. 23, Kathmandu, Nepal, 140 pp

Potter LM (1997) The dynamics of *Imperata*: historical overview and current farmer perspectives, with special reference to South Kalimantan, Indonesia. Agroforestry Systems 36: 31–51 (this issue)

Ruthenberg H (1976) Farming Systems in the Tropics, 2nd ed. Oxford University Press, Oxford, UK, 366 pp

Sajise P (1980) *Alang-alang* (*Imperata cylindrica* (L.) Beauv.) and upland agriculture, pp 35–46. In: Proceedings of the BIOTROP Workshop on *Alang-alang*. BIOTROP Special Publication No. 5, Bogor, Indonesia

Santoso D, Karama S, Adiningsih S, Wigena IGP, Purnomo J and Widodo S (1994) The management of sloping lands for sustainable agriculture in Indonesia. Reports and Papers on the Management of Sloping Lands in Asia (IBSRAM/ASIALAND), pp 53–86. Network Document No. 8. IBSRAM. Bangkok, Thailand

Santoso D, Adiningsih S, Mutert E, Fairhurst T and van Noordwijk M (1997) Soil fertility management for reclamation of *Imperata* grasslands by smallholder agroforestry. Agroforestry Systems 36: 181–202 (this issue)

Sitompul SM, Setijono S, van der Heide J and van Noordwijk M (1992) Crop yields and sustainability of cassava-based cropping systems on an Ultisol in Lampung. Agrivita 15: 19–28

Slaats JJP (1995) *Chromolaena odorata* fallow in food cropping systems, an agronomic assessment in South-West Ivory Coast. Tropical Resource Management Papers, No. 11. Wageningen Agricultural University, Wageningen, the Netherlands, 177 pp

Suryatna ES and McIntosh JL (1976) Food crops production and control of *Imperata cylindrica* (L.) Beauv. on small farms. Proceedings of the BIOTROP Workshop on *Alang-alang*, pp 28–29. BIOTROP, Bogor, Indonesia

Suryatna ES and McIntosh JL (1982) Weed control in a shifting cultivation and permanent agriculture. In: Weed Control in Small farms, Biotrop Spec. Publ. 15, pp 63–73. BIOTROP, Bogor, Indonesia

Terry PJ, Adjers G, Okezie Akobundu I, Anoka AU, Drilling ME, Tjitrosemito S and Utomo M (1997) Herbicides and mechanical control of *Imperata cylindrica* as a first step in grassland rehabilitaton. Agroforestry Systems 36: 151–179 (this issue)

Torres RO and Garrity DP (1990) Evaluation of batao (*Lablab purpureus* L. Sweet) as a dual purpose component of upland cropping patterns. Agroecology Unit, International Rice Research Institute, Los Baños, the Philippines

Tung L and Alcober D (1991) Natural grass strips are preferred. ILEIA Newsletter 7(2): 27–28

Utomo WH, Sitompul SM and van Noordwijk M (1992) Effects of leguminous cover crops on subsequent maize and soybean crops on an Ultisol in Lampung. Agrivita 15: 29–44

van der Heide J, Setijono S, Syekhfani M, Flach EN, Hairiah K, Ismunandar S, Sitompul SM and van Noordwijk M (1992) Can low external input cropping systems on acid upland soils in the humid tropics be sustainable? Backgrounds of the UniBraw/IB Nitrogen management project in Bunga Mayang (Sungkai Selatan, Kotabumi, N. Lampung, S. Sumatra, Indonesia). Agrivita 15: 1–10

van Noordwijk M (1994) Agroforestry as reclamation pathway for *Imperata* grassland use by smallholders. pp 2–10 In: Proceedings of the Panel Discussion on Management of *Imperata* Control and Transfer of Technology for Smallholder Rubber Farming System. Balai Penelitian Sembawa, Pusat Penelitian Karet Indonesia

van Noordwijk M, Tomich TP, Winahyu R, Murdiyarso D, Suyanto, Partoharjono S and Fagi AM (eds) (1995) Alternatives to Slash and Burn in Indonesia, Summary Report Phase I. ASB-Indonesia Report No. 4, Bogor, Indonesia, 154 pp van Noordwijk M, Sitompul SM, Hairiah K, Listyarini E and Syekhfani (1995) Nitrogen supply from rotational or spatially zoned inclusion of Leguminosae for sustainable maize production on an acid soil in Indonesia. In: Date RA et al. (eds) Plant Soil Interactions at Low pH, pp 779–784. Kluwer Academic Publishers, Dordrecht, the Netherlands

van Noordwijk M, Sitompul SM, Hairiah K and Syekhfani M (1992) Rotational hedgerow intercropping + *Peltophorum pterocarpum* = new hope for weed-infested soils. Agroforestry Today 4(4): 4–6

Versteeg MN and Koudokpon V (1993) Participative farmer testing of four low external input technologies to address soil fertility decline in Mono Province (Benin). Agricultural Systems 42: 265–276

Zaini Z and Lamid Z (1993) Alternative technology for food crop cultivation on *alang-alang* land. In: Pemanfaatan Lahan Alang-alang untuk Usahatani Berkelanjutan, pp 71–94. Centre for Soil and Agroclimate Research, Bogor, Indonesia