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Soil fertility management for reclamation of *Imperata* grasslands by smallholder agroforestry

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Abstract. *Imperata cylindrica* grasslands are widely believed to indicate poor soil fertility. Soil fertility improvement may have to be an important component of a reclamation strategy. Data for Sumatra, Indonesia indicate, however, that *Imperata* occurs on a broad range of soil types and is not confined to the poorest soils. A direct role of *Imperata* in soil degradation cannot be ascertained. In many instances, however, *Imperata* soils are low in available P and effective N supply. The use of rock phosphate in combination with erosion control ('fertility traps') and legume cover crops can be effective in restoring soil fertility. Case studies for a number of sites in Sumatra have confirmed the practical possibility of reclaiming grasslands for food and tree crops.

Introduction

Imperata grasslands cover large areas in Southeast Asia, but are far from uniform in soil type and the soil-related constraints to alternative land use systems. Three contrasting points of view on *Imperata* are:

a) *Imperata* is a weed which is difficult to eradicate and which causes large land areas with considerable potential for other land uses to remain under-utilized; *Imperata* control should be the first and major step of a reclamation effort; once *Imperata* is eradicated, the land can be used profitably;
b) *Imperata* is hardly a problem weed by itself but simply an indicator of poor, degraded soils. Hence *Imperata* reclamation without improving soil fertility does not solve the problem. When essential nutrient shortages, such as P deficiency are addressed, other land uses will be possible and other plants will outcompete *Imperata*;
c) *Imperata*, especially when frequently burnt, is itself a cause of soil degradation

We will refer to these points of view as the 'trouble weed', the 'poor soil indicator' and 'soil degrader' hypotheses, respectively. Although the three hypotheses indicate different entry points for reclamation, they are not mutually exclusive and hybrid strategies may be needed, addressing both the weed aspects and soil fertility. The relative importance of the 'poor-soil indicator' and 'trouble weed' hypotheses is likely to vary between the various classes of the *Imperata* grassland typology developed by Garrity et al. (this issue) and van Noordwijk et al. (this issue).

In the second section we will review the available evidence for the 'poor soil indicator' and 'soil degrader' hypotheses, by comparing data on the inherent soil fertility (which includes chemical, physical and biological constraints to plant growth) of current *Imperata* grassland to test hypothesis B, and by reviewing changes in these factors by the presence of *Imperata* (hypothesis C). In the third section we will discuss how soil fertility improvement should be integrated in rehabilitation efforts.

Constraints to other land use of current *Imperata* grasslands

Effects of land use on soil carbon content on Sumatra

Soil data to partially test the 'indicator hypothesis' are available for Sumatra, an island which contains about 25% of Indonesia's *Imperata* grasslands (Garrity et al., this issue). In the 1980's a coherent set of 1:250,000 soil maps of Sumatra were prepared by the Center for Soil and Agroclimate Research, Bogor, in the context of the LREP (Land Resources Evaluation and Planning Project) project. The data are stored in a computerized soil database and were recently analyzed for their soil organic matter content, as influenced by soil type and land use (van Noordwijk et al., 1997). The soil data were grouped into five classes: Histosols (peat), all wetland soils (classified as aquic subgroups of various soil orders; previously classified as Gleysols), Andisols (recent volcanic soils), a group of fairly fertile soils (Alfisols, Entisols, Inceptisols, Mollisols and Spodosols; this group very roughly corresponds with the 'Alluvial' soils of earlier soil maps and a group of acid soils of low fertility (Oxisols and Ultisols, including most of the previous 'Red Yellow Podzolics'). The 70 land use types of the LREP database were combined into five groups: swamp vegetation (mostly forest), primary forest, secondary forest (including 'jungle rubber' systems), a group tentatively indicated as Slash-and-Burn (S & B) series (including shrub-land, *Imperata* (*alang-alang*) grasslands and land currently used for annual crops) and a group with permanent crops (various tree crop plantations and sawah rice fields).

The Andisols form only 4%, the Histosols 10%, the wetland soils 24% and both of the upland soil groups about 31% of the data set. Secondary forest is the most important land use group overall (41.3%). This group includes large areas of 'jungle rubber' and 'fruit-tree enriched agroforests', which were not separately classified in the LREP study. Primary forest covers only 8% of the three upland soil groups. The S & B series is remarkably evenly distributed over the soil types (16–27% of all non-swamp land use, with the lowest value for the Histosols and the highest for the two main upland soil types). Nearly half of the Andisols (43%) are used for permanent cropping (mostly tree crops). On the other soils permanent crops represent 13–20% of the data set, with the lowest value for the Oxisols and Ultisols and the highest for the wetland soils (mostly rice fields).

The group indicated as Slash-and-Burn consists of annual crops and two vegetation types which may be interpreted as fallow land: shrub and *Imperata* grasslands. This interpretation is only a first approximation, as some of the shrubland, especially on the wetland soils may be natural. Crops are 14% of the S & B series on the Oxisols and Ultisols (indicating an overall crop: fallow ratio of 1:7, a very rough estimate), 21% on the alluvial upland group (tentative crop: fallow ratio 1:5) and 29% on the Andisols (1:3.5). These ratios correspond with a trend of increasing soil fertility from the Oxisols and Ultisols to the Andisols.

On all soils studied the fraction of *Imperata* grasslands is similar to the area used for annual crops. The ratio of currently cropped land and the Slash-and-Burn series is lowest on the Oxisols and Ultisols (1:2), highest on the Andisols (2:1), and intermediate (1.2:1) on the other soil orders.

The C_{org} content decreases from primary forest, to secondary forest to areas used for tree crops and the Slash-and-Burn series. On the major upland soils, the difference in soil organic carbon (C_{org}) content between land use types is about 0.5% C. At an average bulk density of 1.25 g cm^{-3}, this represents a difference of 10 Mg ha^{-1} for a 15 cm top soil layer. Changes in deeper layers may be expected to be less, and the total change is probably less than twice the change estimated from the top layer only.

A multiple regression analysis included soil pH, texture, altitude, slope, land use and soil type. All these factors were entered step-wise into the equation (Table 1). The quantitative factors: pH, clay and silt, had a slope which differs significantly ($P < 0.001$) from zero. The relative weighting factors for clay and silt are 1.4 and 1.0, respectively. The regression coefficient for altitude ($P < 0.01$) and for slope ($P < 0.05$) also differed significantly from zero. In this regression, the effects of altitude are studied separately from the different altitudinal distribution of soil groups. They indicate a positive effect on C_{org} of lower temperatures. The effect of slope suggests that erosion leads to *in situ* losses of soil organic matter. The regression equation leads, for example, for an Inceptisol with pH 4.0, 25% clay + 25% silt, altitude 200 m a.s.l., slope 10% and under *alang-alang* is:

$$\begin{aligned} C_{org} &= \exp(+1.333 - 0.0245 - 0.624 + 0.424 + 0.085 - 0.026 + 0.011) \\ &= e^{1.179} = 3.25\%. \end{aligned}$$

Compared to the average contents per soil type and land use, the C_{org} content will decrease 15% per unit increase in pH; increase 1% and 0.7 for each percent increase in clay and silt content, respectively; increase by 4% per 100 m increase in altitude; and decrease by 0.3% per percent increase in slope. No indication was obtained that tree-based production systems in plantations differ in C_{org} content from land used for annual crops.

Table 1. Multiple linear regression of $\log(C_{org})$ for Sumatra soil database; Histosols were excluded from the analysis.

$\mathrm{Log}(C_{org}) = 1.333 + 0$ (if soil is Oxisol or Ultisol) +
0.011^{NS} (if soil is inceptisol) +
0.834^{**} (if soil is Andisol) +
0.363^{**} (if soil is Fluvaq suborder) +
$0.00994^{**} * \mathrm{Clay\%} + 0.00699^{**} * \mathrm{Silt\%} +$
$-0.156^{**} * \mathrm{pH} +$
$0.000427^{**} *$ Altitude +
$-0.00264^{*} *$ Slope +
$+ 0$ (if LU is swamp forest) +
-0.077^{NS} (if LU is primary forest) +
-0.082^{NS} (if LU is secondary forest) +
-0.169^{NS} (if LU is upland crops) +
-0.245^{*} (if LU is *alang-alang*) +
-0.267^{*} (if LU is perennial crops) +
-0.288^{*} (if LU is shrub) +
-0.335^{*} (if LU is sedge) +
-0.433^{*} (if LU is riceland)

Source: van Noordwijk et al. (1997).
LU = land use group.

Shiddieq (1993) observed no differences in C_{org} of the topsoil between *Imperata* grasslands, the dominant vegetation type in the area, and young (25 years) or old (75 years) secondary forest on Ultisols on the peneplain of South Sumatra. He documented reduced C_{org}, cation exchange capacity and soil physical conditions on soils converted to coffee or rubber plantations (both 25 years old, average $C_{org} = 1.5\%$) and a low value for the third (and last) year of growing maize and rice in a slash-and-burn system (average $C_{org} = 1.8\%$). A reduction of C_{org} by 1.8% at the end of the cropping phase in a slash-and-burn system is at the high end of the range found in the larger data set, but not in contrast with a 1% difference between forests and crop land averaged over time, or over larger areas. Such a reduction in C_{org} content may have drastic effects on physical and chemical properties of the soil and on current N mineralization, as it involves the most active fractions of soil carbon, but it does not represent a very large amount of C in an absolute sense. A reduction in total soil C stock of 10 Mg ha^{-1}, equivalent to a decrease of C_{org} of 0.5% in the top 15 cm, will release 1000 kg ha^{-1} of mineral N (based on a C/N ratio of 10), which is a substantial amount in view of crop needs.

Similarly, Ohta et al. (1995) found no consistent difference between soil C stocks of primary or secondary forest and *Imperata* grasslands in East Kalimantan, after correction for effects of soil texture on C stocks. Total soil C stocks range from 35–110 Mg C per ha in the top 1 m.

The data thus give little evidence for a clear role of *Imperata* as a 'poor soil indicator': *Imperata* occurs on a broad range of soil types which typically have soil organic matter contents close to those of currently cropped soils.

Total soil organic matter is not a very sensitive indicator, however, of changes in 'active' soil organic matter pools. Evidence with a new size-density fractionation scheme for soil organic matter (Hairiah et al., 1995b) indicate that frequently burnt *Imperata* grasslands tend to have lower pool sizes of organic matter than grasslands without recent burning. The latter are close to systems including tree crops.

Soils under Imperata *compared to other fallow vegetation*

Soil conditions differed between three types of fallow vegetation in the Air Dingin area (West Sumatra, Indonesia; data of Cairns, 1994; Table 2). The fern fallows were found mostly on acid Andisols, with their typically high soil carbon content, linked to the mineralogy. Both *Imperata* and *Austroeupatorium* (formerly *Eupatorium*) *inulifolium* were found on red-yellow podzolics (Ultisols?), but the pH of the *Imperata* fallows was lower than that of the *Austroeupatorium* land. No major differences were found in available P or exchangeable cation content. Soil C content was higher under *Imperata* than under *Austroeupatorium*, which is in line with its more acid conditions. The soil data confirm a certain indicator value of the vegetation.

No direct evidence was obtained for any improvement in indicators of chemical soil fertility for the top 15 cm; the data showed no significant regression or trend of soil parameters on fallow duration, within a two-year period. Although this may be partly due to the limited size of the data set, it may also reflect the insensitivity of classical soil fertility parameters to changes

Table 2. Average soil chemical conditions of the topsoil (0–15 cm) under three types of fallow vegetation in the Air Dingin area, West Sumatra.

	Ferns	*Imperata cylindrica*	*Austroeupatorium inulifolium*
No. of samples	5	5	6
pH(H_2O)	4.8	4.9	5.5
pH(1M KCl)	3.8	3.8	4.5
C_{org} %	11.2	2.8	2.4
N_{tot} %	0.65	0.25	0.24
P_{Bray} mg kg^{-1}	0.4	0.9	2.0
Exchangeable cations:			
K $cmol_c$ kg^{-1}	0.22	0.32	0.53
Ca $cmol_c$ kg^{-1}	1.04	6.85	10.26
Mg $cmol_c$ kg^{-1}	0.48	2.01	2.96
Na $cmol_c$ kg^{-1}	0.31	0.29	0.34
Al $cmol_c$ kg^{-1}	2.91	2.19	0.39
H $cmol_c$ kg^{-1}	0.29	0.25	0.23
ECEC* $cmol_c$ kg^{-1}	5.26	11.91	14.71
Al/ECEC, %	55	19	26

Source: Cairns (1994).

* Effective cation exchange capacity.

which are relevant for crop growth and/or the importance of soil physical and soil biological factors, rather than soil chemical ones in the improved crop growth after a fallow. A further possibility is that the main improvement occurs upon reclamation of the fallow vegetation. After two years the aboveground biomass of *Austroeupatorium* contains about 20 kg ha^{-1} of P and the litter layer about 10 kg P ha^{-1}. For *Imperata* and the fern vegetation the aboveground biomass P content was 6.3 and 3.4 kg ha^{-1}, respectively, without an appreciable litter layer.

Weed, indicator, or soil degrader hypothesis?

Our data thus indicate that *Imperata* occurs on a broad range of soil types and is not confined to the poorest soils. A direct role of *Imperata* in soil degradation cannot be ascertained either. This means that the direct evidence for both the 'indicator' and the 'causal agent' hypotheses is weak. The presence or absence of *Imperata* on a particular plot of land is as much determined by aboveground factors (amount of shade, opportunities for germination of *Imperata* seeds) as it is by soil characteristics. Unless *Imperata* is frequently burnt, there is no indication that it reduces soil fertility, but it is not a very effective fallow species in improving fertility either. A large share of the short term fertility gained after opening a forest or fallow vegetation is based on ash derived from the burning of the aboveground biomass. Indirect effects of biomass burning by inducing changes in soil pools may have been underestimated in the literature so far (R.L. Sanford, pers. comm.). *Imperata* grasslands are poor in both aspects, and their fertility after conversion is largely restricted to the current soil pools. In many instances *Imperata* soils are low in available P and effective N supply. Unless such soil fertility constraints are addressed, poor crop growth following *Imperata* reclamation will facilitate re-infestation by *Imperata*.

Three case studies on site improvement and reclamation in Sumatra

Reclamation of degraded land with rock phosphate in South Sumatra

Extensive research was carried out by the Potash and Phosphate Institute (PPI) in cooperation with the CSAR between 1988 and 1994 to study site improvement techniques for *Imperata* grasslands. This research was supported by funds from American Phosphate Foundation (APF) and the World Phosphate Institute (IMPHOS).

The basic concept of the project was to weaken or eradicate the existing *Imperata* grass through burning and/or use of a chemical spray (glyphosate), then correct the phosphate and calcium deficiency through a one-time heavy surface application of a reactive rock phosphate (1 ton/ha) or its equivalent (in cost) in the form of triple superphosphate (TSP) and lime. Finally, plant a fast growing leguminous creeper (preferably *Mucuna pruriens* var. *cochinchinensis, M. p.* var. *utilis* or *Mucuna (Stizolobium) deeringianum.* (Uexkull and Mutert, 1995). *Mucuna* species are known to be efficient mobilizers of rock P (Bako Baon and Van Diest, 1989) and can shade out *Imperata* if given enough time (Hairiah et al., 1993).

The function of P application is to provide the most limiting plant nutrient, ameliorate P adsorption in the soil, and enhance cover crop growth. The legume covers were found to be effective in: (a) suppression of *alang-alang* regeneration, (b) rapid surface coverage, (c) prevention of soil erosion, (d) transformation of mineral P into organic P, (e) biological nitrogen fixation, (f) provision of mulch, (g) improvement of soil organic matter, moisture retention, and microclimate, and (h) stimulation of soil flora and fauna (Uexkull et al., 1991, 1992).

The soils at the experimental sites in Terbanggi and Gunung Madu in Southern Sumatra are derived from acid volcanic tuff sediments on an old coastal plain and developed under tropical humid conditions (mean annual temperatures: 23–32 °C , mean annual precipitation: 2,400–2,500 mm) and were originally covered by tropical rainforest but are presently under *Imperata cylindrica* (*alang-alang* grass) vegetation. Acidification and illuviation of predominantly kaolinitic clay minerals determine the present poor nutrient status (Al-saturation 30–50%) and a relative low permeability (many fine and medium pores) of the fine sandy to silty clay loam. The soils are classified as Kanhapludults (USDA).

During the first phase after initial burning of the grass vegetation in 1988, the 4–5,000 m^2 main trial plots were treated with a broadcast P application (two reactive rock phosphates in comparison with TSP and lime and zero P fertilization) and planted with *Mucuna pruriens* var. *cochinchinensis.* In 1989 the main plots were subdivided for three contrasting cropping systems (subplots), namely farmer practice (monocropping), alley cropping and a rotation between food and cover crops. The subplots were further subdivided for treatments of nitrogen and potassium fertilization. The N plots were treated with 46 kg N ha^{-1} yr^{-1} as urea, the K plots with 60 kg K_2O ha^{-1}, respectively. All treatments were tested in four replications.

The dry matter yield of the cover crop was larger under P application. Up to three times more dry matter was harvested from P-treated plots when compared with the control after six to seven months growth (Table 3). The increased vigour and the much improved growth of *Mucuna* on all P treated plots not only enriched the soil of the sites with nutrients and organic matter but also reduced runoff, erosion, and leaching, and supported the transformation, storage and release of nutrients for the succeeding food crops (Table 4).

The yields (expressed as MJ ha^{-1}) of intercropped maize and rice in the first cropping season were significantly higher in the P-treated plots (Table 3). This positive effect of residual P and *Mucuna* mulch on yield was subsequently maintained during 11 cropping seasons. While N and K fertilizer was

Table 3. The effect of different P sources on the yields of *Mucuna pruriens* var. *cochinchinensis* (dry weight = DW; N and P concentration in abovergound biomass), and effects on the 1st and 10th season crops (maize and rice).

Treatment		Location				
		Gunung Madu			Terbanggi	
		Mucuna yield (DW in Mg ha^{-1}; N and P as %)				
	DW	N	P	DW	N	P
Without P	2.1 a	2.16	0.24	6.8 a	2.16	0.12
TSP & Lime	5.7 bc	2.31	0.20	14.9 b	2.25	0.21
NCRP	7.2 b	2.32	0.23	12.4 c	2.55	0.25
MRP	4.7 c	2.42	0.21	13.6 d	2.35	0.21
		1st season maize and rice yield (Mj ha^{-1})				
Without P		13.4 a			29.7 a	
TSP & Lime		74.5 c			71.2 b	
NCRP		67.0 b			69.9 b	
MRP		68.2 b			71.6 b	
		10th season maize and rice yield* (Mj ha^{-1})				
Without P		23.1			18.5	
TSP & Lime		47.4			57.3	
NCRP		56.9			67.5	
MRP		52.7			61.6	

Source: Sri Adiningsih and Mulyadi (1993 and unpub. data).
TSP = Triple super phosphate (400 kg ha^{-1}).
NCRP = North Carolina Rock Phosphage (1,000 kg ha^{-1}).
MRP = Moroccan Rock Phosphate (1,000 kg ha^{-1}).
Lime = 1,000 kg ha^{-1}.

provided for each crop, phosphorus was only applied once again before the 8th cropping season (200 kg ha^{-1} for TSP, and 500 kg ha^{-1} for rock phosphate). Yields of maize and rice in the 10th season (Table 3) illustrate that a significant response to P occurred during all cropping seasons. Nitrogen and potassium application increased food crop production though not always significantly.

The response of *Mucuna* to P applications is not always as pronounced as described here (Hairiah et al., 1995a). The efficiency of added P depends to a considerable extent on the quantity of residual P in soils (Fox, 1988). When phosphate fertilizer is added to soils, the labile pool of available P is increased and in addition, the capacity of soils to adsorb additional phosphate is decreased. Thus, high initial P addition on tropical soils may result in stable or even increasing yields during subsequent cropping seasons, in contrast to the more usual effect of the 'law of diminishing returns' which acts at higher application levels. The sigmoid overall response function can lead to increasing economic returns from a one time application compared to regular

Table 4. The effect of the reclamation (combination of different P sources and establishment of legume cover crop *Mucuna* sp.) on some soil chemical properties on Ultisols in Gunung Madu and Terbanggi, Lampung, Sumatra, Indonesia.

	pH	C-org %	Extractable P ppm		CEC cmol$_c$ kg^{-1}	Al cmol$_c$ kg^{-1}	Acid saturation %
			HCl 25%	Bray II			
Gunung Madu							
Before rehab.	5.4	1.65	30	6	8.05	0.79	14
After rehab.							
Without P	5.0	2.69	30	3	14.33	0.73	19
TSP + lime	4.9	2.57	180	14	12.84	0.31	12
NCPR	5.0	2.70	160	18	13.79	0.17	5
Morocco PR	5.0	2.60	120	13	12.81	0.19	6
Terbanggi							
Before rehab.	5.3	1.70	60	4	6.1	0.48	11
After rehab.							
Without P	4.9	1.91	70	6	9.74	0.25	11
TSP + lime	5.0	1.78	160	19	9.25	0	0
NCPR	4.6	2.02	200	21	9.74	0.33	11
Morocco PR	4.8	2.31	460	23	12.22	0.16	4

Source: Anonymous (1994).

small amounts. The difference in residual effect between TSP and rock phosphate is in line with the model of Wolf and Janssen (1989).

The effect of the reclamation using different sources of P, and the establishment of *Mucuna* sp., on soil chemical properties is presented in Table 4. The results show that just after reclamation there is a significant increase in C-organic, total P (extracted in HCl 25%), available P (Bray II) content, and CEC, and a decrease in exchangeable Al and acid saturation. The increase in C-organic and CEC may be due to the incorporation of the *Mucuna* residues. C-organic and CEC decreased at both locations (Gunung Madu and Terbanggi) during subsequent cropping. The application of P fertilizer had a slight effect in sustaining the organic matter content as well as the CEC of the soil. This is explained by the effect of P application on the production of biomass in the hedgerows of *Flemingia congesta*, as well as by crop residues. The application of P sustained the amount of soil-P and decreased aluminium saturation significantly. PR was more effective compared to the TSP and lime application.

'One Ton Rock Phosphate' approach in an upland area of critical land in East Pasaman, West Sumatra

Background information on the target areas and project set up. The Area Development for the Rehabilitation of Critical Land and the Protection of Natural Resources and Environment (Pro RLK) is an Indonesian project, support by GTZ GmbH, working in three districts in the Province of West Sumatra, with a probable time span of nine years. Results are presented here for one of the three target areas, the East Rao Sub-district in the Pasaman District.

The Pasaman district comprises mainly heavily dissected and steep land. Soil types are Kandiudults, Hapludults and Dystropepts, all constrained by the combined effects of high Al saturation, very small amounts of available P, and low pH (Arya, 1990). Small pockets exist of flatter and more fertile soils (Eutropepts and Tropaquents) in low lying areas and valley bottoms (Subardja, et al., 1990). The farming system consists mainly of jungle rubber and some coffee which are grown as cash crops, and upland rice which is grown as the staple food (Brauns, 1993a, b). The complex local land ownership system means that land is variously share-cropped, rented, pawned, or 'borrowed' by and between the farmers. Production of upland rice does not satisfy local consumption which is supplemented by rice from the market.

Until recently the sole means of transport was by foot along winding tracks over some 20 km to the nearby town of Rao, or by powered canoe along the turbulent river Sumpur. All farm produce and household requirements were transported on pack horse or by canoe. In the last two years, new roads have connected this very isolated location to the surrounding area which is already supplied with excellent sealed roads.

At present, no bank credit *per se* is available in the sub-district. However, a small number of large traders in Rao borrow capital from the banks and relay it to farmers via local traders who provide credit to farmers for household goods secured against their rubber production. The project set up is aligned with the regional and district planning boards (BAPPEDA) who coordinate activities carried out by the respective line agencies (DINAS).

Characteristics of the upland farming system in East Pasaman. Just as the lowland rice areas are a rather homogenous farming system in Indonesia, the upland areas have great diversity in terms of soil properties, topography and local climate and farmer practice. This means that while it is practical and even sensible to formulate packets of technology for the lowland rice system, such a packet approach is inappropriate and anyway difficult to develop for the uplands (Hayami, 1994).

Soil surveys (for which the results are not yet available) which were carried out in cooperation with local farmers have revealed the extent of farmers' awareness of the great local variability of soil quality. Farmers are also able to use local plants as indicators of soil fertility. In the farmers' eyes, *Imperata cylindrica*, *Melastoma malabathricum*, and *Dicranopteris linearis* stand for poor soil fertility. In contrast *Austroeupatorium* (formerly *Eupatorium*) *inulifolium* (syn. *Eupatorium pallescens*) fallows are considered to be capable of faster fertility regeneration than the 'natural' vegetation (Cairns, 1994).

However, farmers are not generally aware of the underlying principles of soil fertility so that there is frequent misunderstanding when extension staff point out the poor inherent fertility of the soil (problems of acidity and aluminium saturation, and small amounts of available P) to farmers who are as yet unaware of the possibilities to improve productivity by modern farming methods.

Our experience also suggests that while farmers do not see soil erosion and degradation as fundamental problems, they are aware that upland rice yields have consistently declined over the past forty years, as fallow periods have been progressively shortened and cropping intensity increased. The land reserved for upland rice is now cropped every five to six years, even though Ultisols generally require a fallow period of 15 years to restore soil fertility (Young, 1989), suggesting that the present annual cropping systems are unsustainable. Since all the land under cultivation is tribal communal land, investments in soil fertility improvement are not a priority for individual farmer households, who are effectively tenants.

The system of land tenure does provide security of tenure to farmers who have established tree crops. Rubber continues to form the backbone of the farmer's cash income. Rubber planting was encouraged by the colonial government in the early 1900's who provided cash incentives to farmers based on a tree count. At that time, there was probably little pressure on land, and farmers planted this high income-earning crop on their best soils. With the increase in population, farmers are now left with their best land (in terms of soil quality and topography) planted to rubber, and cultivate their subsistence crops (mainly upland rice) on steep land which is degraded.

Almost no mineral fertilizer was either used or available prior to intervention by the project. There is very little manure available to apply to annual crop fields. Therefore, almost all fertility is supplied by the ash provided by burning felled vegetation, and this will continue as long as farmers do not have access to commercial fertilizers.

In contrast to rubber, which was introduced this century, the upland rice system has remained almost unchanged since it was first documented in West Sumatra two hundred years ago (Marsden, 1811), except that fallows have been very considerably shortened. However, there has been general awareness of the problems and potential solutions in the upland farming system since the 1920's when agriculturalists were already expressing concern about the effects on the natural resource base (Chin a Tam, 1993).

In some areas, the land has become a barren landscape of *Imperata cylindrica* dominated savanna, with small pockets of secondary bush forming gallery forests along the river sides and in the valley bottoms. In other parts, the land is either under jungle rubber (producing at most 0.5 t dry rubber ha^{-1}) or forest. Since the construction of the new road system, sections of the remaining forest land are now being felled for upland rice cultivation. GIS maps of the area have been produced (Daryanto and Sinurat, 1994) which, after field verification, provide a very powerful tool to help with land use planning.

Critical land: what can be done? Critical land, a term which includes both *already degraded land and land in danger of degradation* is important in Indonesia because these are the areas where there is the greatest concentration of the rural poor who bring about environmental destruction through their farming activities. These areas remain the last and largely under-exploited land reserve to provide future food requirements. Six main basic causes of land degradation have been identified in the project's three districts: (1) overgrazing, (2) burning, (3) slash and burn, (4) soil mining, (5) soil erosion, and (6) land tenure systems. Project interventions are only justified when they result in increased productivity which leads to a substantial increase in farm income. Only then will the farmer be inclined to consider investment in soil conservation and be able to invest in the necessary mineral fertilizers and conservation to maintain the soil in good condition.

The project is attempting to take advantage of the many technological developments that have already been worked out for upland areas. The aim is to assemble different techniques to form a site-specific technological package, taking into account the local farmer's situation with regard to skills, infrastructure, markets (for both inputs and outputs), and soil and climatic conditions. Examples of component rehabilitation technology that have been developed through applied research and tested in West Sumatra (Fairhurst, 1996) include the following:

1) the use of a large (1 t ha^{-1}) one-time application of rock phosphate to overcome basic soil constraints;
2) the use of legumes either as fertility-regenerating cover crops such as *Mucuna pruriens* (flat land), or contour strips (e.g. *Flemingia congesta*) on sloping land;
3) the use of improved rubber planting materials (e.g. BLIG polyclonal rubber);
4) the use of fertilizer responsive and blast-resistant upland rice varieties.

Taking into account the topography, soil types, and farming skills of the population in Rao, self-sufficiency in rice is not an option that should be promoted. Rather the approach should comprise the elements listed in Table 5.

In order to prepare the land for cropping, *Mucuna pruriens* should be planted after land clearing but before any cropping activity. *Mucuna* has a number of distinct advantages as a legume cover crop. These include production of a large biomass of up to 14 dry matter ha^{-1} (Sri Adiningsih and Mulyadi, 1993; Table 3), large seed and therefore fast establishment, and an annual habit so the farmer does not have to clear the land before planting, and a large N content of at least 70 kg N ha^{-1} (Hairiah and van Noordwijk, 1989). However, farmers are often unwilling to plant *Mucuna*, which has little direct value, on land which has just been fertilized with 1 t ha^{-1} fertilizer. For this reason, farmers are encouraged to plant legume contour strips to function as 'nutrient traps' at the same spacing as the eventual rubber planting lines,

Table 5. Potential project interventions in East Pasaman and their justification.

	Intervention	Justification
1.	The establishment of wet rice cultivation wherever topography and water supply permits.	One hectare of wet rice substitutes for 100 ha land reserved for upland rice which is then released for tree crop cultivation. The system is sustainable.
2.	The intensification of rubber production (replanting using polyclonal seed, rehabilitation of existing stands).	Rubber is the crop best adapted to the farming traditions (e.g., flexible labour input). High yields can be obtained with modern planting materials. Generates income to allow farmers to buy in rice.
3.	The introduction of 'low input' oil palm cultivation on pockets of suitable land.	A ready market exists for loose fruits which have a high value-to-weight ratio.
4.	The cultivation of annual crops using SALT* technology on the small pockets of more fertile, gently sloping land.	Maize, peanuts, green bean are profitable cash crops, and high yields have been achieved on demonstration plots.

Source: Pro-RLK (unpub.).
* SALT stands for Sloping Agriculture Land Technology.

to make sure that the applied fertilizer is not simply washed off the slope. The farmer is also quick to see the potential of feeding cut forage to livestock.

It is difficult to quantify all the inputs involved in establishing improved rubber plots which are intercropped during the immature phase until the canopy closes. Farmers have different preferences for annual crops, and weather conditions dictate the number of annual crops which can be grown per year. However, Table 6 summarizes the differences in terms of external inputs and farm produce in term of 'with and without project intervention'. Reclamation is only worthwhile if subsequent farming activities are attractive. The main options for this area are:

Rubber intensification. Wherever farmers are establishing upland rice outside the land reserved only for rice production, they interplant the rice with tree crops. Most farmers are planting rubber seedlings gathered from existing rubber fields. They do not use any fertilizer on either the upland rice or the rubber. Table 7 summarizes the different component parts of the improved technology.

Low input oil palm production. Up until now, oil palm has always been considered as a large-scale-development crop. The traditional approach is to set up large-scale intensively-managed plantings close to a processing mill. However, with the expansion of milling capacity and a ready market for the fruit, the possibility exists to introduce oil palm as a truly small-holder crop. The approach presently considered is to encourage the development of 10–20

Table 6. Comparison of establishment of new rubber plots with and without project intervention.

Aspect	Project intervention	
	Without	With
Planting materials for annual crops	Local rice produces poor yields and is prone to blast when fertilized Yield: 0.5 t ha^{-1} yr^{-1}	Improved rice is higher yielding and less prone to blast under fertilization Yield: 1.5 t ha^{-1} yr^{-1}
Planting materals for tree crops	Unimproved planting materials used Yield: 0.5 t ha^{-1} yr^{-1}	Modern, well adapted, high yielding planting material used. Yield: 1.0 t ha^{-1} yr^{-1}
Fertilizer	No fertilizer is used	1 t ha^{-1} rock phosphate (RP) is applied
Cost of additional inputs	Wild rubber seedings used	1 t RP @ Rp 220,000/t 500 BLIG rubber seeds @ Rp 45,000 Rp 285,000
Proceeds for farm products in the immature phase (Rp/yr)	Income: 0.5 t rice @ Rp 360/kg Rp 180,000	Income: 1.5 t rice @ Rp 360/kg Rp 540,000
Proceeds for farm products in the mature phase (Rp/yr)	Income: 0.5 t rice @ Rp 1,200/kg Rp 60,000	Income: 1.5 t rice @ Rp 1200/kg Rp 180,000

Source: Pro-RLK (unpub.).
Exchange rate: Rp 2,300 = US dollar 1.00.

ha plantings under farmers' management. Instead of selling fresh fruit bunches, the farmers would collect loose fruit only which contains 40% oil (FFB 22% oil). The farm gate price for this product is thus higher. Since this oil product contains very little nutrient content (i.e. N, P, K, Mg) the requirement for fertilizer is greatly reduced if not eliminated. Substantial fertilizer inputs would be required in the 30-month period up to maturity, but with the distribution of dead fronds and empty bunches (approximately 15 t ha^{-1} yr^{-1} dry matter, rich in N, P, K, Mg, and Ca) in the inter row, a closed nutrient cycle may be maintained, which might even progressively enrich the soil (Uexkull and Fairhurst, 1992). With present prices, and a conservative estimated yield of 15 t ha^{-1}, a two hectare plot would provide a monthly income of Rp 500,000 (USD 217). Such a plot would require a labour input of 10 days or less per month.

Table 7. Measures to improve the productivity of new rubber plots.

<table>
<tr><th>Measure</th><th>Rationale</th></tr>
<tr><td>Use of rock phosphate to overcome small amounts of available P, low CEC, small amounts of exchangeable Ca, low pH and high Al saturation.</td><td>Rock P is available on the local market, at present used only by tree crop estates.
Cost per unit P is smaller than for TSP.
<table>
<tr><td>Material</td><td>Rp kg^{-1}</td><td>% P_2O_5</td><td>Rp kg $P_2O_5^{-1}$</td></tr>
<tr><td>TSP</td><td>460</td><td>46</td><td>1000</td></tr>
<tr><td>Rock P</td><td>220</td><td>31</td><td>710</td></tr>
</table></td></tr>
<tr><td>Use Bah Lias Isolated Garden (BLIG) polyclonal seedling rubber instead of clones.</td><td>Easy to transport seed to farmers who can make their own nurseries.
More competitive against weeds during establishment.
No problems to distinguish between the true scion and the rootstock.</td></tr>
<tr><td>Use modern upland rice varieties.</td><td>More responsive to fertilizer.
More disease resistant and higher yielding.</td></tr>
<tr><td>Plant strip contours with *Flemingia congesta* or establish *Mucuna puriens* as a pioneer soil rehabilitation measure.</td><td>Function as nutrient traps.
Provide mulch.
Prevent soil loss in erosion.
Provide fodder for goats.</td></tr>
</table>

Source: Pro-RLK (unpub.).

Annual crop production. A demonstration of the '1 ton per hectare rock phosphate treatment' was carried out on gently sloping land. After clearing and burning the sparse secondary bush, the remaining branches were aligned along the contour and *Flemingia congesta* was planted in contour strips. Rock phosphate was broadcast on, but not incorporated into, the bare soil before planting peanuts. At planting, a starter dose of urea was applied 50 kg ha^{-1}, and after establishment a small amount of potash (100 kg ha^{-1}) was applied. The crop was harvested after three months and produced a comparatively high yield of 1.6 t ha^{-1} (Table 8). Three months after harvesting peanuts, green bean was planted, yielding 800 kg ha^{-1}. The gross margin for this one-year period is shown in Table 8. The enterprise was profitable, even with working capital borrowed at 20% interest.

A three-pronged approach to critical land rehabilitation has been adopted in the Rao Subdistrict in the District of Pasaman. This comprises the introduction of wet-rice production in low lying areas with the potential for irrigation, tree-crop production on steep areas comprising poor, acid, infertile upland soils, and small pockets of annual crop production on the flatter areas in valley bottoms. There is a major requirement for the provision of truly integrated extension advice if these components are to be implemented by farmers as a series of mutually complementary interventions.

Table 8. Gross margin calculation for the cultivation of peanuts and green bean on an acid Oxisol in East Pasaman.

Crop	Season	Yield (kg ha^{-1})	Price (Rp $unit^{-1}$)	Income (Rp ha^{-1})
Peanuts	2/94–6/94	1,800	1,500	2,400,000
Green bean	10/94–1/95	800	1,000	800,000
Gross farm income ha^{-1}				3,200,000
Variable costs	Md ha^{-1}	kg/ha^{-1}	Rp $unit^{-1}$	Rp ha^{-1}
Rock phosphate		1,000	300	300,000
Urea		50	360	18,000
KCl		100	400	40,000
Seed		120	1,500	180,000
Herbicide		5	20,000	100,000
Pesticide		2	30,000	60,000
Labour	113		5,000	565,000
Total costs				1,263,000
Gross margin				1,937,000
Interest				189,450
Margin over variable costs and interest				1,747,550

Source: Pro-RLK (unpub.).
Rp 2,300 ≈ USD 1.00.

Erosion control as part of reclamation on sloping lands

In searching for soil and crop management techniques which can consistently produce high crop yields, and at the same time also minimize runoff and soil loss, the combination of alley cropping systems with proper crop residues management should be considered. Under the harsh climate of the humid tropics, decomposition of crop residues is very rapid. The recycling of crop residues and application of hedgerow prunings, either as mulch or incorporated into the soil during soil preparation, have shown a significant effect in maintaining soil productivity at the Kuamang Kuning Unit XIX site.

In an attempt to develop more productive, sustainable farming systems for degraded and sloping lands, an experiment on the management of sloping lands was conducted by the Center for Soil and Agroclimate Research (CSAR) in collaboration with the International Board for Soil Research and Management (IBSRAM) and Swiss Development Cooperation (SDC) at the Kuamang Kuning Unit XIX site, Jambi Province, Indonesia. Twelve treatment combinations (four soil-crop management treatments and three levels of fertilizer application) were tested: alley-cropping system with *Flemingia congesta* as the hedgerow crop; cover crop using *Mucuna* as the third crop in the cropping system; incorporation of crop residues; and burning of crop residues, with minimum tillage and hand-pulling for weed control (farmers' practice). The fertilizer treatments were: no input without fertilizer; low input: 45 kg N and 20 kg P ha^{-1} for upland rice, and 22.5 kg N, and 20 kg P ha^{-1} for peanut; and high input: 90 kg N, 40 kg P, and 25 kg K ha^{-1} for upland rice; and 45 kg N, 40 kg P, 25 kg K, and 2 t lime ha^{-1} for peanut. The twelve treatment combinations were arranged in a randomized complete block design with three replications. The cropping pattern was upland rice-peanut-mungbean or *Mucuna*. There was no fertilizer application for mungbean or the *Mucuna* cover crop. Due to the inherently low fertility status of the soil, a high level of fertilizer application was needed to obtain good crop growth and better reduction in runoff and soil loss (Table 9; Santoso et al., 1994a). The application of the high rate of N and P fertilizer combined with lime and K fertilizer was needed to increase the yields of the crops being fertilized, and to balance the removal of plant nutrients in the crop yield. As expected, the no-input treatments resulted in a negative balance for all nutrients being studied. These results agree well with the decrease in the levels of all nutrients in the soil (Table 10; Santoso et al., 1994b).

The low-input treatments where only N and P fertilizer was applied resulted in negative balances for K, Ca, and Mg, and these were also substantiated by changes in nutrient status of the soil. In five years the potassium (K) content of the soil decreased by about 0.5 cmol kg^{-1}, calcium (Ca) content decreased between 0.27 and 1.23 cmol_c kg^{-1}, and magnesium (Mg) decreased between 0.14 and 0.21 cmol_c kg^{-1}. For nitrogen, the low input treatments gave negative N balances when combined with incorporating or burning of crop residues.

Table 9. Total run off and soil loss from July 1992 to June 1993 at the Kuamang Kuning XIX site.

Soil–crop management	Fertilizer input			Main effect of management
	No	Low	High	
		Runoff (m^3 ha^{-1})		
Alley, mulch	5818 bc	1944 d	1688 d	3150 C
Cover, mulch	5834 bc	5708 bc	5251 bc	5597 B
Residues incorp.	7062 a	6370 ab	5000 c	6144 AB
Residues burnt	7080 a	6242 ab	5597 bc	6306 A
Main effect of input	6448 A	5066 B	4384 C	
		Soil loss (t ha^{-1})		
Alley, mulch	50.7 de	1.6 e	1.4 e	17.9 D
Cover, mulch	133.3 cde	128.3 cde	98.1 cde	119.9 C
Residues incorp.	437.4 a	262.9 b	230.8 bc	310.4 A
Residues burnt	366.7 ab	152.3 cd	125.2 cde	214.7 B
Main effect of input	247.0 A	136.3 B	113.9 C	

Source: CSAR (unpub.).

The low input treatments in combination with alley cropping or cover crop gave positive N balances, due to the contribution of nitrogen from *Flemingia* hedgerows and the *Mucuna* cover crop. However, these results were not consistently corroborated by changes in N status of the soil.

The high-input treatments resulted in positive balances for N, P, K and Ca, but negative balances for Mg. Application of 90 kg N ha^{-1} for rice and 45 kg N ha^{-1} for peanut was apparently just sufficient to meet the nutrient requirements of the crops. The positive N balances were small, considering that in the estimation of the balances not all possible mechanism of N lossess have been taken into account, such as through leaching and volatilization. The soil analytical data showed that during five years of continuous cropping the N status of the soil did not change, except under high N input combined with incorporation of crop residues. This negative balance is mainly due to the large N losses through runoff and soil erosion.

Concluding remarks: implementation strategy

There are millions of hectares of former forest land in Indonesia that are now covered by unproductive grasslands and savanna. A large proportion of this land has only slight topographic limitations. Climate (solar radiation, rainfall and temperatures) is nearly optimal for high yield. The only constraint to sustained high yield is low fertility and the lack of management techniques that minimize soil erosion.

Thus, at least 10 million hectares of degraded land in Indonesia could be made highly productive and could yield at least five tons of grain equivalent per ha per year, or 50 million tons grain equivalent in total, if this potentially available land was improved. Hence a major part of Indonesia's future food grain demands, according to the International Rice Research Institute (IRRI, 1994), of approximately 64 million tons of (rough) rice alone in the year 2025, could be provided from presently unproductive land. This can be a major land resource, to be used as an alternative to on-going slash-and-burn agriculture in the remaining forest margins. However, current farm-level costs and benefits favour a continuation of the *status quo*.

A three step development approach is suggested for the reclamation of *Imperata* grasslands. During an initial phase the establishment of leguminous cover crops supported by liming and P application will enrich the biological and nutrient cycle of topsoils and prevent the soil from erosion, crusting and compaction. This is an expensive and 'unproductive' phase in the sense that no income is generated from the harvested materials. A second phase will concentrate on deepening and enriching the root zone for marketable crops, and thus generate farm income but at the same time will still require investment. During the third phase, a fully established ecologically

Table 10. Nutrient balance and change in nutrient status of top soil (0–15 cm) at the Kuamang Kuning Unit XIX site, Indonesia during five years (1990–1994).

Code	Nutrient balance (kg ha^{-1})					Change in nutrient status of the soil					
	N	P	K	Ca	Mg	C (%)	N (%)	P (mg kg^{-1})	K	Ca (cmol kg^{-1})	Mg
A-1	–18	–105	–88	–46	–274	–0.42	–0.01	–3.6	–0.04	–2.02	–0.16
A-2	568	165	–32	–63	–30	–0.11	0.03	39.6	–0.05	–1.23	–0.14
A-3	999	367	199	317	–23	–0.10	0	80.1	–0.03	5.42	–0.07
B-1	–292	–26	–149	–31	–72	–1.14	–0.01	–2.6	–0.05	–0.61	–0.14
B-2	–60	92	–123	–93	–62	–1.26	0	37.0	–0.05	–0.50	–0.12
B-3	918	301	101	232	–529	–1.15	0	63.4	–0.04	2.34	–0.12
C-1	–860	–57	–323	–64	–139	–0.70	–0.04	–0.4	–0.07	–0.59	–0.15
C-2	–232	255	–243	–95	–93	–0.56	–0.03	32.5	–0.05	–0.84	–0.17
C-3	140	564	18	1338	–1033	–0.18	–0.03	37.3	–0.05	2.43	–0.18
D-1	–641	–110	–311	–146	–178	–0.71	–0.01	–0.8	–0.04	–0.10	–0.39
D-2	–129	315	–195	–58	–85	–0.57	0	40.7	–0.04	–0.27	–0.21
D-3	261	635	31	1807	–819	–0.49	–0.01	52.0	–0.03	3.68	–0.30

Source: Santoso et al. (1994a).

and economically viable system will have to be sustained by balanced nutrition and efficient management (Uexkull and Mutert, 1995).

Only where sufficient funds and assistance are provided during the first two steps will wealth be introduced on landscapes where poverty would otherwise exist. Of course, the primary requirement for any such investments are a stable land tenure situation and good road accessibility. The option of successful reclamation of 'waste lands' exists, and can be profitable if evaluated on a sufficiently long time frame. However, the option will only help to slow down the annual destruction of more than 5 m ha tropical forest if it is part of an integrated effort to conserve those forests for the non-renewable values they represent. In the words of Marsden (1811):

> The expiring wood, beneficent to its ungrateful destroyer, fertilizes for his use, by its ashes and their salts, the earth which it so long adorned. . . . I could never behold this devastation without a strong sentiment of regret . . . it is not difficult to account for such feelings on the sight of a venerable wood, old, to appearance, as the soil it stood on, and beautiful beyond what pencil can describe, annihilated for the temporary use of the space it occupied.

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