Overcoming Soil Fertility Constraints

in a Transmigration Area of Indonesia

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Foreword

TropSoils field research in Indonesia is a collaborative program involving the Centre for Soils Research, the University of Hawaii and, until 1986, North Carolina State University.

North Carolina State University's component focused primarily on overcoming soil fertility constraints to crop production. This bulletin summarizes, synthesizes and interprets the results of these investigations.

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Summary

From 1983 to 1986, TropSoils conducted a field research program aimed at overcoming severe soil fertility constraints in Sitiung, West Sumatra, Indonesia, where large-scale bulldozing of primary tropical rainforests had severely affected soil productivity. Soils in Sitiung are classified mainly as Red-Yellow Podzolics (very fine, kaolinitic isohyperthermic families of Typic Haplorthox and Typic Paleudults). They have excellent structure but high acidity, extreme aluminum toxicity, low effective cation-exchange capacity, and low nutrient reserves (especially phosphorus, potassium, magnesium and calcium).

The goal of the program was to make sustained production of basic food crops possible in the transmigration area. Experience elsewhere in the humid tropics had indicated that such a strategy could succeed. Although some of these soils were so affected by improper land clearing that not even weeds could grow, they were readily transformed into successful upland rice-soybean production systems with the judicious use of lime and fertilizer. Unlike similarly affected sandy Ultisols and Alfisols in South America and Africa, where physical land reclamation is needed, only chemical reclamation was necessary for these well-structured clayey Oxisols and Ultisols.

Soil acidity is probably the most important constraint in Sitiung soils, where pH values hover around 4.0 and aluminum saturation exceeds 60 percent. The main crops grown by transmigrant farmers were found to differ widely in their tolerance to aluminum saturation. Upland rice tolerated 70 percent aluminum saturation; cowpea, 55 percent; peanut, 28 percent; soybean, 15 percent; and mungbean, 5 percent.

Less than one ton of lime per hectare is needed for upland rice in order to overcome calcium deficiency, while mungbean requires as much as 5 t/ha. No lime is needed for the first crop planted after slashing and burning due to calcium and magnesium additions in the ash and temporary aluminum complexing by decomposing organic matter. However, lime is required after the first crop. Liming is highly profitable, and lime is locally available. The lime requirements of specific crops were predicted using a modified Cochrane equation. Rapid downward movement of calcium was detected in the subsoil within a year, improving its chemical properties. Most crop rotations require annual lime applications from the second year after clearing.

Phosphorus management is not difficult in Sitiung soils, but phosphorus fertilizers are necessary to overcome extremely low levels of available soil phosphorus. Sitiung soils are not high phosphorus-fixers, as predicted by the Fertility Capability Classification System. Broadcast applications of 20 to 80 kg P/ha are sufficient to fertilize most rotations, and the residual effects last for at least two years. The economic return of phophorus fertilization is high in Sitiung soils.

Potassium fertilization also produces strong yield responses, and most crops require about 80 kg K/ha. These rates can be reduced if crop residues are returned to the soil. Critical soil test levels for phosphorus, potassium and magnesium were developed for most of the food crops grown at Sitiung. No responses to sulfur fertilization were detected during a three-year period.

Green manure incorporation, with material imported from outside the field, resulted in consistently strong growth and yield responses under a variety of conditions at Sitiung. Green manuring

may complex aluminum and supply phosphorus, potassium and other nutrients.

The results show that

1) reclamation of soils damaged by mechanical land clearing is successful;
2) lime and fertilizers are the key to reclaiming these degraded soils and maintaining soil productivity;
3) an efficient lime and fertilizer delivery system is crucial to sustainable production;
4) fertilizer and lime recommendations can be made according to soil tests for specific crops in rotation with similar fertility requirements; and
5) the use of organic inputs, such as crop residues and *in situ* green manure crops, can help decrease lime, fertilizer and weed control requirements.

Recommendations for further research include

1) identifying crop rotations for low-input or high-input systems of management, including green manures and managed fallows;
2) establishing a soil testing service for farmers;
3) integrating information into distinct soil-management options;
4) selecting crop varieties for aluminum tolerance; and
5) starting comprehensive research on pastures and agroforestry.

Setting

The Outer Islands of Indonesia, Sumatra, Kalimantan, Sulawesi and Irian Jaya, are sparsely populated and largely covered by tropical rainforests on acid soils classified as Red Yellow Podzolics in the Indonesian system and as Oxisols and Ultisols in Soil Taxonomy (Dent 1980). Agriculture consists primarily of either small-scale shifting cultivation or large-scale tree plantations. This contrasts sharply with the island of Java, which has a population of approximately 95 million people in an area about the size and shape of the states of North Carolina and Tennessee in the United States (approximately 750 people/km^2). Java has a high proportion of fertile, volcanic soils with a well-developed infrastructure for lowland rice production.

In an attempt to relieve the high population pressure on Java and develop the sparsely populated Outer Islands, the Indonesian government has undertaken vast transmigration projects. The earliest transmigration projects were begun by the Dutch in 1905; approximately 200,000 people had been relocated when Indonesia gained independence in 1945. The transmigration program is currently administered by the Department of Manpower and Transmigration. The third five-year plan (1979-1984) called for the transmigration of 500,000 households, or about 2.5 million people (Christanty et al. 1982; Whitten et al. 1985).

Typical transmigrants are farm families from Java who express their desire to become transmigrants by registering for the program with local officials. Transmigrants are selected according to several criteria—poverty, health, youth and marital status (adult transmigrants must be married). Occasionally, an entire community may be relocated, resulting in a transmigrant population that includes a cross section of community members and not just poor and landless farmers.

Sitiung contains about 12,000 families who moved into the area between 1975 and 1985. The area is divided into six administrative units (Sitiung I-VI), which are divided into blocks of about 2,000 hectares, each containing approximately 3,000 settlers. Sitiung I and II were established in 1976 and 1977, respectively, by farmers relocated from the community of Wonogiri, Central Java, due to construction of a dam which flooded their lands. In contrast, the other Sitiung sites (III-VI) were populated by Javanese from Central Java, Sundanese from West Java, and some Minang from West Sumatra. The Minang are an indigenous ethnic group and are scattered among the various transmigration sites.

Location

The transmigration sites of Sitiung are in an area of approximately 100,000 hectares along the Trans-Sumatran Highway and the Batang Hari

River in West Sumatra, about 200 km southeast of Padang, capital of the province of West Sumatra (Figure 1). Sitiung is located just south of the equator at an altitude of approximately 100 m above sea level, east of the volcanic highlands of West Sumatra Province. The topography is lowland but quite variable, as part of the area is on subrecent, relatively flat river terraces, while the larger part is an old, well-dissected peneplain. Many parts of Sitiung have short slopes ranging from 8 to 15 percent, which are similar to those of Yurimaguas, Peru, where North Carolina State University has its primary TropSoils research site.

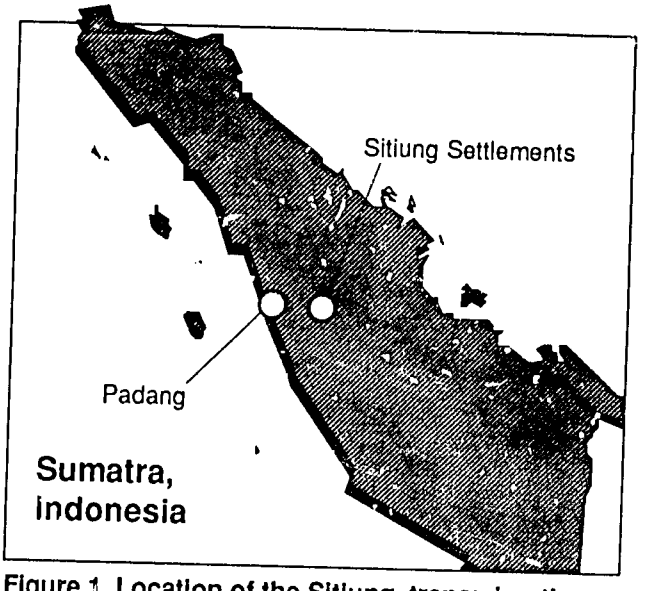

Figure 1. Location of the Sitiung transmigration settlements.

Climate

Sitiung's climate is humid tropical, very similar to the main locations of North Carolina State University's Amazonian work in Yurimaguas, Peru, and Manaus, Brazil. Annual rainfall in the three areas ranges from 2100 to 2600 mm with a relatively weak dry season during the months of June, July and August (Table 1). Temperatures average about 26°C with little seasonal variation. In Soil Taxonomy terms, the predominant soil moisture regime is udic and the soil temperature regime is isohyperthermic. Short-term droughts are common at the three sites.

Vegetation

Primary rainforest is the dominant native vegetation in well-drained sites, with leguminous dipterocarps being very important. After land clearing and abandonment, many fields around Sitiung become derived savannas dominated by *alang-alang* grass (*Imperata cylindrica*). This is in contrast to the Amazon, where secondary forest fallows are the main form of abandoned vegetation, and where *Imperata cylindrica* is not found. Many of the same weed species are common to both continents. The *Axonopus scoparius-Paspalum clandestinum* complex, known as *torourco* in Peru, is also found in Sitiung.

Soils

Soils of the Sitiung region have been mapped at the semidetailed level (1:45,000 scale) for 20,035 hectares and at the detailed level (1:5,000 scale) for selected blocks ranging from 33 to 178 hectares each (Centre for Soils Research 1979). That report also includes detailed physical, chemical and mineralogical properties for 55 profiles, their interpretation and classification into the Indonesian and Soil Taxonomy systems, plus climate, geology, potential productivity ratings, and engineering interpretations. The Centre for Soils Research also has a similar soils data base for many other transmigration projects. Furthermore, the Soil Management Support Services (SMSS) has several Sitiung soil profiles included in its Lincoln, Nebraska, soil data base (John Kimble, personal communication). Spatial variability of particular sites has been studied (Trangmar et al. 1987), and two soil transects from the volcanoes to the lowlands have been investigated (Subagjo, in prep.; Subagjo and Buol, in press). The soil data base is therefore very good.

Sitiung soils fit near the point where Oxisols, Ultisols and Inceptisols meet in the Soil Taxonomy system. Detailed characterization data from four main experimental sites, with two of them being classified as Oxisols (very fine, kaolinitic, isohyperthermic Typic Haplorthox) and two as Ultisols (very fine, kaolinitic, isohyperthermic Typic Paleudults), are shown in Table 2. Other soils in the region, particularly in Sitiung I, have mixed

mineralogy, rather than kaolinitic. Such soils have a higher cation-exchange capacity and a higher lime requirement, and roads remain waterlogged for longer periods of time than with the kaolinitic Oxisols (Sanchez and Buol 1980). Organic carbon levels less than 2% in the surface layer are usually indicative of topsoil removal by bulldozer clearing.

Soil Constraints

The Fertility Capability Classification (FCC) system was used to identify the main soil constraints to plant growth (Sanchez et al. 1982 *Geoderma*). The FCC classification for the four profiles listed in Table 2 is the same: *Caek*. This classification indicates that soils are clayey throughout their profile, are aluminum toxic, have low effective cation-exchange capacity (ECEC), have low-activity clays, and have a low supply of weatherable minerals. The FCC class also indicates no severe constraints in terms of waterlogging, prolonged droughts, high phosphorus fixation, shrink-swell properties, salinity, alkalinity, or high soil erodibility under normal management. Such soil constraints are somewhat different from those encountered in sandy Ultisols (fine loamy, siliceous, isohyperthermic, Typic Paleudults) at Yurimaguas, Peru, classified mainly as *Leak* or *Sleak* soils. These FCC classes indicate similarly low native fertility but higher susceptibility to compaction and erosion. Sitiung soils are more similar to those of the main experimental Oxisol site at Manaus, Brazil, which are classified as very fine kaolinitic, isohyperthermic Typic Acrorthox and also as *Caek* in the FCC system.

Farming Systems

The traditional farming systems in the area are shifting cultivation, practiced by the local Minang people, and large-scale estate crops (rubber or oil palm). The transmigration program, however, has developed a farming system of its own due to the policies and subsidies given to the settlers. A description of the clearing process and post-clearing management follows.

The Sitiung settlements are situated near the paved, Trans-Sumatran Highway. Each block has

Table 1. Long-term mean monthly precipitation and air temperature at Sitiung, Indonesia; Yurimaguas, Peru; and Manaus, Brazil. Sources: Centre for Soils Research 1979, Cochrane and Sanchez 1982.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Sitiung, West Sumatra, Indonesia (2° S, 102° E, 60 m elevation)													
Rainfall (mm)	216	283	200	334	232	122	148	38	166	216	258	362	2,575
Mean temp (°C)	25.6	25.9	26.1	26.3	26.7	26.7	25.7	25.3	25.3	25.9	25.8	25.6	25.9
Yurimaguas, Loreto, Peru (5°54' S, 76°5' W, 182 m elevation)													
Rainfall (mm)	214	225	212	249	177	99	90	93	159	209	210	199	2,136
Mean temp (°C)	26.1	26.4	26.1	26.2	26.0	25.8	25.8	26.6	26.9	26.6	26.6	26.7	26.3
Manaus, Amazonas, Brazil (3°15' S, 49°15' W, 90 m elevation)													
Rainfall (mm)	276	277	301	287	193	99	61	41	62	112	165	228	2,102
Mean temp (°C)	25.9	25.8	25.8	25.8	26.4	26.6	26.9	27.5	27.9	27.7	27.3	26.7	26.7

schools, a network of well-built but unpaved secondary roads, and a village center with various shops and services. Some blocks have irrigation and electricity. Primary forest was cleared by the same bulldozers used for road construction and other infrastructure development. After pushing down trees, bulldozers removed most of the largest logs and stumps, and settlers burned the remaining biomass. In Sitiung III, we saw small areas where ash was present on the soil surface and upland rice was growing well, while one meter away where there was no ash, rice was growing very poorly. Obvious gully erosion was common (Sanchez and Buol 1980).

Another transmigration area visited in February 1980 was Rimbobujang, about 70 km east of Sitiung in Jambi Province, where the land-clearing process was beginning. Logging crews went first, chain sawing commercial timber in 100-meter-wide swaths on both sides of a tertiary road, and hauling it away for sale. Bulldozers were next, pushing the rest of the trees down. They made a mess of the land, creating mounds of topsoil, and leaving heaps of logs without well-defined windrows. Carpenters built a simple house and an outhouse for each family, and the transmigrants

Table 2. Soil profile data and classification of soils at experimental sites in Sitiung. t=trace. Source: Soil Management Support Services data bank.

Profile 1: High-input phosphorus study—Sitiung I-A
Taxonomy: Clayey, kaolinitic, isohyperthermic Typic Haplorthox. FCC: *Caek.*

Depth (cm)	Clay	Silt	Sand	Org. C	Free Fe	Bulk density	Avail. water	Exchangeable Ca	Exchangeable Mg	Exchangeable K	Exchangeable Al	ECEC	Al sat	pH H_2O	pH $CaCl_2$
	%					g/cm³	cm/cm	cmol/L					%		
0-13	72	21	7	3.0	3.4	0.94	0.14	0.3	0.1	0.2	5.0	5.6	89	4.1	3.9
13-37	75	19	6	1.0	4.2	1.04	0.23	0.1	t	0.1	2.9	3.4	85	4.9	4.3
37-68	73	21	6	0.5	3.8	0.98	0.24	t	t	t	2.7	2.7	100	5.0	4.3
68-100	68	26	6	0.3	4.2	0.97	0.24	t	t	t	2.9	2.9	100	4.9	4.3
100-127	59	33	8	0.3	4.1	0.94	0.23	t	t	t	3.3	3.3	100	5.1	4.3
127-170	54	37	9	0.3	4.1	1.04	0.21	t	t	t	3.3	3.3	100	5.2	4.3

Profile 2: Lime study—Sitiung IV-D
Taxonomy: Very fine, clayey, kaolinitic, isohyperthermic Typic Paleudult. FCC: *Caek.*

Depth (cm)	Clay	Silt	Sand	Org. C	Free Fe	Bulk density	Avail. water	Exchangeable Ca	Exchangeable Mg	Exchangeable K	Exchangeable Al	ECEC	Al sat	pH H_2O	pH $CaCl_2$
	%					g/cm³	cm/cm	cmol/L					%		
0-5	64	14	22	4.6	3.6	-	-	0.6	0.2	0.1	4.3	5.2	83	3.6	3.5
5-20	70	13	17	1.5	4.4	1.18	0.12	0.1	t	t	3.3	3.4	97	4.3	3.9
20-48	74	12	14	1.1	4.8	1.12	0.13	t	t	t	2.8	2.8	100	4.7	4.1
48-102	77	10	13	0.6	4.7	1.07	0.12	t	t	t	2.4	2.4	100	4.6	4.2
102-157	78	12	10	0.4	5.4	1.12	0.09	0.1	t	t	2.0	2.1	95	4.4	4.2
157-194	77	13	10	0.3	5.2	1.13	0.10	0.1	0.1	t	1.6	1.8	89	4.6	4.3

moved into their new one-hectare farm. Little burning had taken place before the settlers arrived.

In Sitiung each transmigrant family house is surrounded by a 0.25 ha home garden and 1.0 ha of field crops at a distance of 1-2 km from the house. In addition, all the families are entitled to another 0.75 ha of land presently under forest about 5 km away. The government has not officially allocated the additional 0.75 ha yet, but farmers are optimistic that this will happen in the near future.

The government stipulates that transmigrant farmers must reside on their allotted holdings for ten years before receiving title to the land. If a farmer and his family leave before this period, the local transmigration officer is authorized to allocate such land to young married couples who have no land of their own.

In the earlier settlements of Sitiung I-IV, the allocated land holdings were mainly cleared by bulldozing, resulting in compaction and exposure of subsoils. Government agencies recognized this damage and, in recent settlements (Sitiung V and VI), elected to use the slash-and-burn method of land-clearing. Bulldozers were used only to clear the sites for house construction and where desired by farmers.

Table 2. (Continued)

Profile 3: Lime maintenance trial—Sitiung II-E
Taxonomy: Clayey, kaolinitic, isohyperthermic Typic Haplorthox. FCC: *Caek.*

Depth (cm)	Clay	Silt	Sand	Org. C	Free Fe	Bulk density	Avail. water	Exchangeable Ca	Mg	K	Al	ECEC	Al sat	pH H_2O	$CaCl_2$
	%					g/cm³	cm/cm	cmol/L					%		
0-11	88	7	5	1.4	7.3	0.93	0.06	0.1	t	t	3.1	3.2	97	3.9	3.8
11-40	90	6	4	1.3	7.4	1.10	0.12	0.1	0.1	0.1	3.0	3.3	91	4.0	3.9
40-73	90	6	4	0.9	7.2	1.00	0.13	0.1	t	t	2.1	2.2	95	4.3	4.2
73-102	89	7	4	0.7	7.9	0.95	0.11	0.1	0.1	t	2.0	2.2	91	4.3	4.2
102-154	88	8	4	0.6	7.5	0.96	0.11	0.1	t	t	1.6	1.7	94	4.5	4.2
154-200	85	11	4	0.5	7.1	0.99	0.10	0.1	0.1	t	1.3	1.5	87	4.6	4.3

Profile 4: Low-input phosphorus study—Sitiung V-C
Taxonomy: Very fine, kaolinitic, ischyperthermic Typic Paleudult. FCC: *Caek.*

Depth (cm)	Clay	Silt	Sand	Org. C	Free Fe	Bulk density	Avail. water	Exchangeable Ca	Mg	K	Al	ECEC	Al sat	pH H_2O	$CaCl_2$
	%					g/cm³	cm/cm	cmol/L					%		
0-4	46	12	42	3.8	2.6	-	-	0.8	0.4	0.2	3.9	5.4	72	3.5	3.5
4-34	52	11	37	1.1	3.2	1.28	0.09	0.1	0.1	0.1	2.2	2.5	88	4.5	4.0
34-62	61	10	29	0.6	3.7	1.28	0.09	t	t	t	1.8	1.8	100	4.5	4.2
62-106	62	10	28	0.5	3.6	1.27	0.09	0.1	0.1	t	1.5	1.7	88	4.8	4.2
106-142	64	10	26	0.4	3.9	1.26	0.10	t	t	-	1.6	1.6	100	5.0	4.3
142-180	64	13	23	0.3	4.3	1.24	0.08	t	t	-	1.7	1.7	100	5.0	4.3

The government provided each transmigrant family with a free subsidy of food, seeds, basic farm implements, lime, fertilizer and pesticides for the first year. A list of the subsidy received by farmers in Sitiung V compiled by Fernandes and Fernandes (1986) is as follows:

50 kg rice per month
35 kg rice seed
5 kg peanut seed
5 kg soybean seed
3.5 tons lime
600 kg phosphate rock
100 kg urea
100 kg triple superphosphate
1 hoe
1 machete
1 sickle
6 coconut seedlings
2 rambutan seedlings
2 citrus seedlings

After the first year, farmers can buy fertilizers at highly subsidized prices, although difficulties in coordinating an efficient distribution sometimes result in unavailability at peak periods. The 1986 subsidized price of urea and triple superphosphate fertilizers to farmers was Rp. 125,000 (U.S. $112) per ton (Ray Diamond, IFDC, personal communication). This implies a government subsidy of about U.S. $66 and $260 per ton for urea and triple superphosphate, respectively.

Upland rice and cassava are the main food crops and both tolerate acid soils reasonably well. Diligence, patience and use of the government-supplied fertilizers, animal manure and crop residues have allowed the farmers to feed their families. Farmers tend to use the free fertilizer for tree seedlings around their home gardens. More recently, crop-intensification programs include credit for purchasing 23 to 46 kg N, 20 kg P and sometimes 25 kg K/ha/crop. A recent liming program, primarily to stimulate soybean production, includes 3 to 4 t/ha of lime free of charge. A large lime deposit exists in mountains about 50 km west of Sitiung on the Trans-Sumatran Highway. It is now commercially exploited with a lime crusher producing agricultural-quality lime.

Farmers use various sources of inputs for soil improvement on small areas on which they grow vegetables and grain legumes in an attempt to provide variety to their diets. They choose areas of burned windrows to grow crops demanding higher fertility. The more recent land clearing has been done mostly by chain-saw and by hand, eliminating bulldozer-induced soil problems, and providing nutrients via the ash, and, thus, a much better initial crop.

There is a large irrigation scheme designed to provide water for paddy rice at Sitiung I and II. This program is under way, and a few hundred hectares are currently under irrigation. If completed as planned, there will still be substantial areas of upland crops, even in Sitiung I and II. Although flooded rice has been the mainstay of Javanese agriculture, upland rice predominates in the Outer Islands, especially in Sitiung III-VI.

Local Minang farmers have developed a pattern which utilizes relatively fertile, recent alluvial areas for dryland crops, lowland areas for paddy rice, and upland areas for tree crops, with some shifting cultivation. This has been quite successful and constitutes the truly indigenous system. However, the transmigrants, with only two hectares of preselected land, do not have such an option.

There are also considerable areas of rubber around Sitiung. These are large plantation-type tracts, although the land is actually owned by hundreds of local Minang farmers in one- to three-hectare units or by the government. Such managed plantations are quite successful, providing good income for the participating farmers (Fernandes and Fernandes 1986). However, this plan has been mainly implemented with indigenous farmers. Rubber does well on these soils and is particularly appropriate for the rolling hillsides. Like many export crops, its viability is dependent on the widely fluctuating prices of the world market, which happen to be high at present. There is evidence that many fruit and plantation-type cash crops are well suited to these infertile, sloping lands. However, the immediate problem of increasing and stabilizing the basic food supply still remains.

Pests and diseases are major constraints to

crop production in Sitiung. The main pest of peanut, maize and cassava is the wild pig, which is capable of totally destroying unprotected fields. Rice blast (*Pyricularia oryzae*), seedling fly (*Atherigona exiqua*), brown planthopper (*Nilaparvata lugens*) and stem borer (*Chilo* sp.) are major pests of upland rice. Soybean plants are attacked by seedling fly (*Agromyza* sp.) soon after germination and a pod borer (*Etiella zinckenella*) at the pod-filling stage. *Imperata cylindrica* (*alang-alang*), a grass, is also a problem. Most farmers lack the cash resources to purchase pesticides and adopt avoidance strategies. Thus, upland rice is planted early in the rainy season, when the incidence of blast is low. Corn and peanut are not planted in areas prone to damage by pigs.

According to interviews by Fernandes and Fernandes (1986), the major food problem as perceived by the farmers is an inadequate production of rice to meet year-round family needs, resulting in the need to purchase rice. This causes competition for scarce cash resources that are also required for the purchase of lime, fertilizers and pesticides in order to ensure adequate production in the next season.

None of the farmers interviewed mentioned lack of labor as a constraint. This is probably due to the availability of cooperative labor (*gotong royong*). This system involves groups of 20 to 25 farmers working in rotation on each other's fields. The farmer whose land is being worked pays for this labor by providing meals for the group. Despite this system, however, some labor bottlenecks occur, especially at planting and harvesting when all the farmers are involved at approximately the same time.

Strategy

The problems and constraints described are not new, nor unique, to Indonesia, except for the large numbers of people affected. Since 1972, the Tropical Soils Research Program at North Carolina State University has studied humid tropical soils in Latin America with some of the same problems. The detrimental effects of straight-blade bulldozer clearing have been established (Seubert et al. 1977) and widely confirmed (Sanchez 1979; Lal et al. 1986; Alegre et al. 1986a, 1986b). Temperate-region soils in the southeastern United States have similar chemical and physical properties, and principles learned there are applicable to similar soils in the tropics. In past years, popular opinion among some temperate-zone scientists was that humid tropical soils could not be subjected to continuous cultivation and remain productive. However, research in Peru has shown that continuous cultivation utilizing sound soil-management practices can sustain high yields for many years (Sanchez et al. 1982 *Science*, Sanchez et al. 1983). In fact, most soil research in the tropics has given results similar to, or at least explainable by, principles investigated in nontropical regions.

The basic premise for North Carolina State University's strategy for upland tropical soil research is that all soils adhere to certain principles which can be investigated, and that viable management options can be hypothesized from existing information, including the socioeconomic makeup of a region. The TropSoils/Indonesia team decided to capitalize on what was learned elsewhere. Indonesian scientists visited Hawaii, North Carolina and Yurimaguas before project initiation. When the TropSoils program was funded and agreements signed with AARD, the overall strategy consisted of major research to utilize the principles and practices developed elsewhere within an Indonesian farming-system context. The primary subjects investigated included soil characterization, reclamation of bulldozed lands, liming, green manuring, and phosphorus, potassium and sulfur fertilization for annual crops. Given the importance of tree crops, a study of agroforestry potential in the region was also included. The available information was then interpreted within the context of specific soil-management options.

Land Clearing

The TropSoils team visited Gadjah Mada University in Jogjakarta and Bogor Agricultural University in Bogor to develop a land-clearing study and to review literature on this subject. Superior clearing techniques and post-clearing management practices developed for transmigration (Ross 1986; Suwardjo 1986; Rumawas 1987) are similar to methods developed in Peru (Seubert et al. 1977; Alegre et al. 1986a, 1986b). Destructive clearing in Indonesia is apparently not due to a lack of appropriate technology.

The Centre for Soils Research began to play an increasingly assertive role in promoting appropriate land-clearing techniques. In several locations, land-clearing operations have improved. For example, manual slash-and-burn, the most appropriate method, was used in Sitiung by 1983, in contrast to bulldozer clearing at Sitiung I and II in 1980. Also, mechanical clearing operations in the Jambi Province have improved. Trees are felled by hand, and windrows are planted with root rakes, reducing soil movement. After the windrows are burned and the ashes redistributed, the land is tilled, using large offset disks, and 500 kg of rock phosphate/ha are broadcast. A leguminous cover crop of *Centrosema pubescens*, *Calopogonium mucunoides*, and *Pueraria phaseoloides* is planted, following a recommendation of the Potash-Phosphate Institute of Singapore (von Uexkull 1985). Steep slopes and draws are left forested to prevent erosion. This much-improved clearing method appears to be properly managed.

Because appropriate land-clearing techniques had already been developed for Indonesia, the TropSoils program chose to focus on reclamation of already degraded soils and fertility-related problems.

Reclamation of Bulldozed Land

The first field experiment established in 1983 consisted of combinations of physical, chemical and biological methods to bring into crop production a clayey Oxisol on a ten percent slope, which was severely eroded after straight-blade bulldozing in a farmer's field at Sitiung II-D (Makarim 1985).

The soil surface had little vegetative cover even though the transmigrant farmer had tried to grow crops from time to time since the land was cleared six years before. Small gulleys, 10 to 15 cm deep, indicated severe soil erosion. Initial topsoil (0-15 cm) properties were very acid (pH of 3.7 in water), with high clay content (74%), low-bulk density (1.09 g/cm^2), low organic matter (1.22% C), extremely low available-P values (0.4 ppm by the modified Olsen test), low exchangeable K (0.12 cmol/L), high exchangeable Al (3.75 cmol/L), very high Al saturation (81%), and a very rapid water infiltration rate (20 cm/hr). Physical properties were therefore quite good, but chemical properties were extremely poor. Low soil fertility and high acidity probably impeded the development of a sufficient plant canopy to prevent erosion even in this well-structured (albeit bulldozed) very fine kaolinitic, isohyperthermic Typic Haplorthox.

Experimental Design

Three main chemical-input treatments were established to test crop responses to various rates of fertilizer and lime. Treatment F0 received no lime or fertilizers. Treatment F1 (low-input) included small additions of lime and fertilizers to maintain an Al saturation level near 40% and to maintain nutrients at critical levels. Treatment F2 (high-input) was designed to neutralize all exchangeable Al in the soil, and to overcome what was initially thought to be a high P-fixation capacity, and, thereafter, to maintain macronutrients at optimum levels without excess. Treatment F0 was terminated after the first year because it produced essentially no yields.

Each main treatment was split into six plots to test tillage methods and organic inputs for their effectiveness in combination with the chemical input differentials. Subplot treatments were:

1. Hoeing to 15 cm depth, a standard practice among upland farmers in Sitiung.
2. Hoeing, then mulching with *Calopogonium mucunoides* at 12.5 t/ha of fresh weight for the rice crop and 8 t dry matter/ha of imported rice straw for each subsequent soybean and mungbean crop. The organic input was left on the surface as mulch.
3. Hoeing to incorporate *Calopogonium*, as a green manure, at the same rates as above. In this treatment, as well as in the previous one, the organic input was imported from adjacent fields and not grown *in situ*.

4. Forking with a spading fork to uniformly till the soil to 30 cm depth.
5. Strip-forking to till the soil to 30 cm depth in alternate strips spaced 20 cm apart.
6. Using a hand rototiller to uniformly till the soil to 10 cm depth.

The cropping sequence consisted of a rotation of upland rice (*Oryza sativa* 'Sentani'), soybean (*Glycine max* 'Orba') inoculated with *Rhizobium*, and mungbean (*Vigna radiata* 'Betet'), followed the second year by rice and then soybean. These three species are basic food crops used by transmigrant farmers.

Crop Performance—First Year

The effects of fertilization and tillage on rice and soybean yields are shown in Table 3. Mungbean failed due to drought stress. During the

Table 3. Effects of various reclamation treatments on continuous annual crop production for 18 months on a bulldozed Oxisol in Sitiung II-B. Source: Makarim 1985.

Reclamation treatment	Grain yield			
	First year		Second year	
	Rice	Soybean	Rice	Soybean
	t/ha			
No chemical inputs (F0)[1]				
Hoe	0.02	0.00		
Hoe & mulch	0.04	0.02		
Hoe & green manure	0.67	0.11		
Dry Spading fork (30 cm)	0.02	0.00		
Strip-forking (30 cm)	0.04	0.00		
Rototiller	0.01	0.00		
Mean	**0.13**	**0.02**		
Low chemical inputs (F1)				
Hoe	1.54	0.57	1.88	0.15
Hoe & mulch	1.80	0.79	2.63	0.31
Hoe & green manure	2.71	0.63	2.76	0.39
Spading fork (30 cm)	1.79	1.33	2.06	0.26
Strip-forking (30 cm)	1.36	0.47	1.67	0.19
Rototiller	2.04	0.80	2.41	0.17
Mean	**1.87**	**0.77**	**2.23**	**0.24**
High chemical inputs (F2)				
Hoe	2.17	2.24	2.09	0.62
Hoe & mulch	2.33	2.44	3.17	0.58
Hoe & green manure	2.94	2.40	2.93	1.18
Spading fork (30 cm)	2.19	2.16	1.49	0.71
Strip-forking (30 cm)	1.27	2.40	2.01	0.53
Rototiller	2.09	2.27	2.32	0.74
Mean	**2.16**	**2.31**	**2.33**	**0.73**
$LSD_{0.05}$ (interactions)	**0.52**	**0.27**	**0.60**	**0.20**

[1]Abandoned after second crop.

first year the highest fertility inputs produced the highest rice yields, with one treatment approaching 3 t/ha. Plants in the control plots (F0) died unless they received green manure. Green manure incorporation had a marked effect on rice production at all fertility levels. At the low-input level, green manures increased grain yields by as much as 76%, and unexpectedly raised yields in the high-input treatment as well, even though all limiting factors for rice growth were thought to have been eliminated. Direct supply of Mn or additional N, P and K contained in the green manure may be responsible for this difference.

For soybean, the high-input treatment increased the average yield 202% over the low-input treatment. Soybean plants without lime and fertilizer grew poorly or died, while tillage or green manure treatments did not overcome the lack of chemical inputs.

Crop Performance—Second Year

Yields for the second year are also shown in Table 3. Mulching increased rice yields on the low-input treatment by 40% as compared to conventional hoeing. This significant increase may be related to alleviation of drought stress, which was more pronounced during the second rice crop, or to the residual effects of the previous crop-residue mulch, which may have increased nutrient levels. Green manure incorporation produced the highest yield of rice on F1, and rototilling increased rice yield significantly.

High chemical inputs (F2) did not produce rice grain yields significantly higher than those in the low-chemical input treatment. Many upland rice varieties are very Al tolerant and do not respond to lime, as observed in Peru by Nicholaides and Piha (1987). Mulching and green manure increased yields again in the second year.

Soybean yield in the second year was much lower than in the first, due to the leaf-rolling insect, *Lamprosema indicata*. Many plants were killed, but those growing on the more fertile soil, as in treatment F2, were somewhat more resistant to the insect attacks.

Soil Chemical Properties

Low levels of chemical inputs increased basic cation levels, decreased Al saturation to 43%, and increased available P and K sufficiently to produce upland rice yields averaging 1.8 t/ha (Table 4). The total input levels were 1.5 t/ha of lime, and 120 N, 39 P, 73 K, 70 Mg, 93 S, 1 Cu and 4.5 Zn in kg/ha as urea, triple phosphate, KCl, $MgSO_4$, $CuSO_4$ and $ZnSO_4$, respectively.

In contrast, soybean required the high chemical-input treatment to achieve maximum yields of 2.3 t/ha. The high chemical treatment for the entire rice-soybean rotation during the first year consisted of 6.8 t/ha of lime, 150 kg N/ha (for rice), 567 kg P/ha, 295 kg K/ha, 140 kg Mg/ha, 187 kg S/ha and the same level of micronutrients as in F1. These rates improved the chemical fertility of the soil. Soil pH reached a level of 5.7, exchangeable Al was neutralized, Ca, Mg and K increased, and available P increased, perhaps to excessively high levels (Table 4). Because this soil consists mainly of variable-charge minerals, raising pH from 3.9 to 5.7 increased its effective cation-exchange capacity by 30 percent.

Table 4. Soil chemical properties (0-15 cm) one year after beginning the land reclamation study. Source: Makarim 1985.

Chemical input treatment	pH	Exchangeable Al	Exchangeable Ca + Mg	Exchangeable K	ECEC	Al sat.	Avail. P
		meq/100 ml				%	ppm
F0 (Zero)	3.9	3.93	0.3	0.04	4.30	92	2
F1 (Low)	4.6	1.69	2.1	0.12	3.93	43	9
F2 (High)	5.7	0.08	5.4	0.16	5.59	1	67

Soil Physical Properties

The soil showed no significant change in either bulk density or mechanical impedance due to chemical, biological or tillage inputs one year after cropping (Table 5). Infiltration rates remained high in all treatments, ranging from 20 to 30 cm/hr. The spading fork treatment (to 30 cm) tended to have a higher mechanical impedance but also a higher infiltration rate than the other tillage treatments. No significant effects of green manure incorporation were observed on soil physical properties, despite the fact that this treatment produced the highest crop yields at all chemical input levels (Table 3). It is clear, therefore, that the physical properties of this soil were excellent even though it had been bulldozed, and that these properties changed little with reclamation treatments.

Conclusions

1. Severely degraded, unproductive Oxisols resulting from improperly bulldozed clearing can be brought into full crop production. Inputs required to do so are primarily lime and fertilizers, and their effect is enhanced by green manure incorporation.
2. None of the tillage practices were effective unless accompanied by fertilizer and lime applications.
3. Upland rice did not respond to high levels of soil fertility, unlike soybean.
4. Green manure incorporation increased crop yields. Mulching was effective only during periods of moderate drought.
5. Deep tillage and strip forking were not beneficial for rice but were slightly beneficial for soybean. Rototilling was good for rice but only slightly beneficial for soybean.

This trial demonstrated several aspects of soil management that influenced the direction of the research. The response to green manures encouraged more studies on green manures and residue management. After the first crop, available P, determined by the modified Olsen method, exceeded 100 ppm (15 is sufficient), indicating a gross overestimation of P-fixation by the sorption isotherm. This supports the absence of a high P-fixation modifier in the FCC classification of this particular Oxisol.

The differential response of rice and soybean reinforced the need to develop separate management systems and crop rotations consistent with crop acid-tolerance levels, i.e.. if low rates of inputs are used, then Al-tolerant crops such as rice and cowpea should be grown. Soybean crops do not produce well in these soils without sufficient lime to neutralize most of the exchangeable Al. This confirmed South American findings on crop selection for high- vs. low-input systems (Sanchez and Salinas 1981; Sanchez and Benites 1983).

Table 5. Selected soil physical properties before and one year after cropping began. Source: Makarim 1985.

	Bulk density	Mech. impedance[1]	Infiltr'n rate
	g/cm³	mm	cm/hr
Before cropping	1.09	92	19.5
Treatment			
No fertilizer	1.07	98	25.6
Low-input	1.07	99	29.0
High-input	1.06	93	47.0
Hoeing	1.07	93	21.1
Hoe + mulch	1.05	89	21.2
Hoe + green manure	1.08	98	20.4
Spading fork (30 cm)	1.05	100	30.1
Strip forking (30 cm)	1.05	92	25.2
Rototilling	1.07	88	28.6
LSD $_{0.05}$ (inputs)	**0.03**	**12**	**18.6**
LSD $_{0.05}$ (tillage)	**0.03**	**9**	**17.6**

[1]Depth that penetrometer reaches into the soil after five blows.

Soil Acidity and Liming

Acidity is a major constraint in Sitiung soils. Representative profiles (Table 2) show low pH values and more than 60% Al saturation to a depth of 60 cm, the criteria by which these soils are classified as Al toxic in the FCC system. Acid tropical soils under rainforest vegetation usually have a thin (10 cm or less) organic-rich A horizon, where Al-saturation levels are low due to recycling of basic cations.

Such is the case in Yurimaguas and Manaus (Cochrane and Sanchez 1982). Acidity in the topsoil is temporarily decreased by the liming effect of the ash, if the slash-and-burn system is used (Seubert et al. 1977; Smyth and Bastos 1984). In the bulldozed soils at Sitiung, these ameliorating factors are largely absent because of topsoil removal and the absence or sporadic nature of burning. Al-saturation values were above 80% throughout the profile (Table 2). Severe Al toxicity and Mg-deficiency symptoms were identified in upland rice and cassava, species considered highly tolerant to soil acidity, during an initial visit to the region.

As part of a governmental effort to increase soybean production within Indonesia, Sitiung farmers participating in a soybean program were provided with up to four tons of a calcitic limestone containing only traces of Mg. However, little research had been done in the region to determine what levels of lime were appropriate for growing soybean and other upland crops, when lime would need to be reapplied, and what effects lime would have on crop requirements for other nutrients.

There were two reasons why the TropSoils team conducted a series of trials designed to answer questions about liming: first, Al toxicity was identified as a major constraint, and second, a large governmental lime project was beginning in the area.

Approach

A laboratory was established on site to measure KCl-extractable Al, as well as exchangeable Ca and Mg, plus exchangeable K and available P by the modified Olsen extraction used routinely by the North Carolina State University Tropical Soils Program in Raleigh and Latin America. The 1*M* KCl procedure extracts both Al^{+++} and H^{+} ions, but the vast majority of the ions are Al^{+++} because H^{+} is unstable in mineral soils. This parameter is called exchangeable Al, although some H^{+} is included in the measurement. Exchangeable Al expressed in cmol/L determines the amount of lime needed in tons of $CaCO_3$ equivalent per hectare by applying conversion factors of 1.5 or 2 as recommended by Kamprath (1970).

Another key property is percent Al saturation.

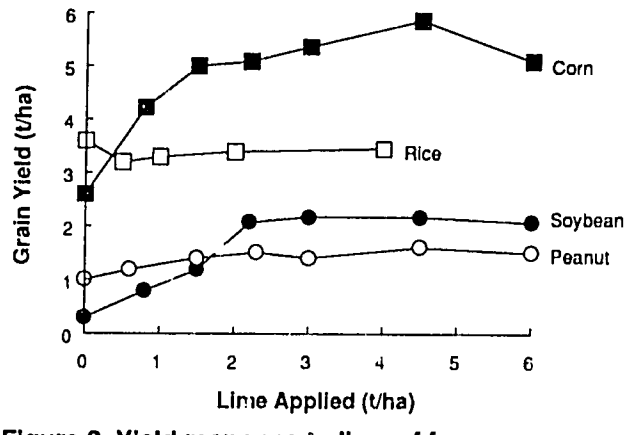

Figure 2. Yield response to lime of four common food crops grown in bulldozer-cleared Oxisols and Ultisols of Sitiung.

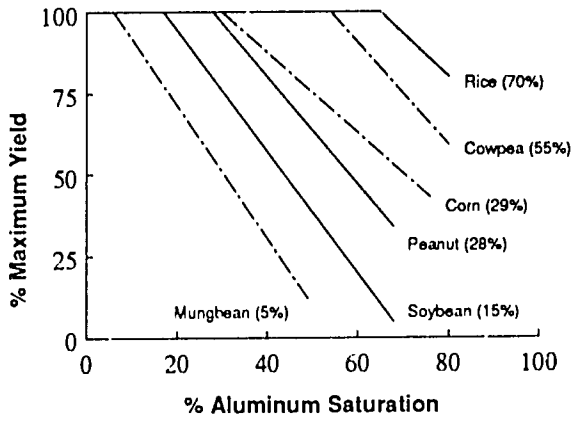

Figure 3. Relationship between maximum grain yield of six crops and aluminum saturation in Oxisols and Ultisols in Sitiung. Numbers in parentheses are critical Al-saturation levels.

It is calculated by dividing exchangeable Al values by the effective cation-exchange capacity (ECEC), which is the sum of exchangeable Ca + Mg + K + Na (if any) + Al. Although this parameter is sometimes referred to as "acid saturation" to recognize the presence of H^+ in KCl extractable Al, it will be referred to as percent Al saturation in this publication.

Plant roots are sensitive to the ratio of certain cations to the total of those on the exchange complex of the soil and in the soil solution. Aluminum-saturation percentage is such a ratio, and it can be used to decide whether liming is needed or not, based on the crop's tolerance to Al saturation. The amount of lime to be added is calculated from the actual exchangeable-Al levels expressed in absolute terms (meq/100 ml or cmol/L) multiplied by the factor of 1.5 or 2.

Crop Tolerance to Acidity

A series of liming trials was established in farmers' fields throughout Sitiung. The four major upland food crops responded to applied lime on mechanically cleared soils (Figure 2). Relatively low rates of lime, ranging from 2 to 4 t/ha were sufficient to approach maximum yields of Al-sensitive crops such as corn, soybean and peanut. These rates are low due to the relatively low amounts of exchangeable Al in these eroded topsoils with low ECEC levels. The lack of response with rice also confirms the high Al tolerance of this crop in acid Sitiung soils.

Since individual soils vary in exchangeable Al levels, a relationship was sought between crop yields and Al-saturation levels. Al saturation was found to be well correlated with yield response. Figure 3 illustrates differences in crop tolerance to Al saturation based on a number of experiments in the area with the six crops. Upland rice yields remained high across much of the range of Al saturation, while corn, peanut, mungbean and soybean tolerated much less Al. Yields of these crops declined sharply once the critical level of Al saturation was surpassed.

Although specific critical Al-saturation values varied somewhat depending upon crop varieties grown, the critical Al-saturation level for each crop averaged 5% for mungbean, 15% for soybean, 28% for peanut, 29% for corn, 55% for cowpea, and 70% for rice (Figure 3). These critical levels are somewhat lower for soybean, peanut, cowpea, corn and rice than those found in Yurimaguas (North Carolina State University 1976), and for corn and soybean in Manaus (Cravo and Smyth 1987). This comparison suggests that the Asian varieties used in Sitiung may be more susceptible to Al than their South American counterparts. Mungbeans are not grown in South America, and they are extremely susceptible to Al at Sitiung.

Lime Requirements

A major purpose of our work was to establish successful prediction of lime requirements for various soil and crop combinations at Sitiung. The relationship between added $CaCO_3$ and exchangeable Al remaining in three soils was calculated. The slopes of the lines indicate the efficiency of applied lime in neutralizing Al (Figure 4). An important point is that the three soils have similar slopes, suggesting similar chemical behavior and, therefore, similar predictability in the effect of the lime. The slopes change at higher lime rates, indicating that lime is more efficient in neutralizing the first few cmol of Al (2 cmol $CaCO_3$ were able to neutralize 1 cmol Al), and then the efficiency of neutralization falls to more than 10 cmol $CaCO_3$ needed to neutralize 1 cmol Al.

This sharp decrease in neutralization efficiency occurred at approximately 10% Al satura-

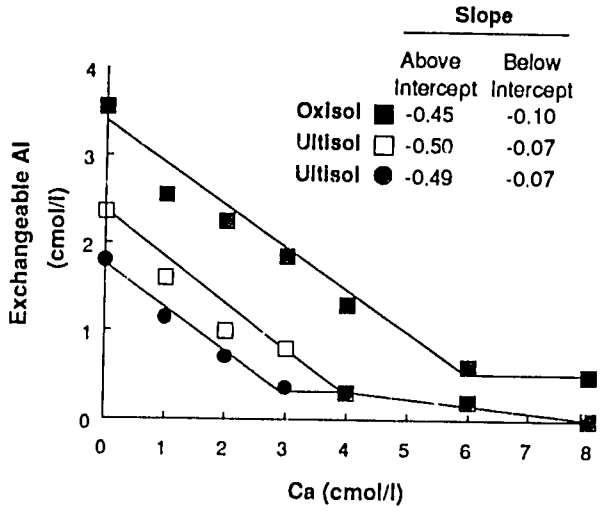

Figure 4. Effect of increasing exchangeable calcium as a consequence of liming on exchangeable-Al levels of three Sitiung soils. Oxisol is located at Sitiung I-A, first Ultisol at Sitiung IV-B, and second Ultisol at Ragusa, near Sitiung.

tion in all the soils, suggesting it is inefficient to lime soils to less than 10% Al saturation. Recalling from Figure 3 that the critical levels for corn, soybean and peanut range from 15 to 29% Al saturation, there is no apparent need to lower Al-saturation values to the 10% level where the neutralizing effect of lime becomes less efficient. Since only one crop, mungbean, is extremely Al sensitive, an appropriate strategy is to aim for 10% to 15% Al saturation to allow mungbean crops to approach their yield potential. Although upland rice did not respond to high levels of lime, it did respond to lower levels which added $CaCO_3$ as a fertilizer without neutralizing much Al. An application of 375 kg/ha of lime was sufficient to supply the needed $CaCO_3$, only slightly decreasing Al saturation in one experiment (Gill et al., in press). In another trial, upland rice did respond to 1 t/ha of lime. A critical level of approximately 70% Al saturation is therefore suggested to account for the low lime level required.

A lime-prediction equation that takes into account crop tolerance to soil acidity was proposed by Cochrane et al. (1980). The original Cochrane et al. (1980) equation uses a factor of 1.8 for lime incorporated to a depth of 20 cm. However, most tillage methods incorporate lime to approximately 15 cm. The adjusted factor becomes 1.5. Thus, the lime-requirement equation for Sitiung becomes:

LR = 1.5 [(Al-(RASxECEC/100)]

Where:

LR = lime required in t/ha of $CaCO_3$ equivalent

Al = cmol/L soil by 1*M* KCl extraction

RAS = maximum % Al saturation tolerated by a specific crop (Figure 3)

ECEC = effective CEC (Al+H+Ca+Mg+K), in cmol/L soil

Applying this equation to the above crops growing on the Sitiung IV-D Oxisol, which has 3.6 cmol/L of exchangeable Al and an ECEC of 4.0 cmol/L in the top 15 cm (Table 2), the equations for the different crops are as follows:

Corn: LR = 1.5 [3.6-(29x4.0/100)] = 3.7 t/ha
Peanut: LR = 1.5 [3.6-(28x4.0/100)] = 3.7 t/ha
Rice: LR = 1.5 [3.6-(70x4.0/100)] = 1.2 t/ha
Soybean: LR = 1.5 [3.6-(15x4.0/100)] = 4.5 t/ha
Cowpea: LR = 1.5 [3.6-(55x4.0/100)] = 2.1 t/ha
Mungbean: LR = 1.5 [3.6-(5x4.0/100)] = 5.1 t/ha

The recommended rates will differ in different soils because exchangeable Al and Al-saturation levels are different. For example, the lime requirements for corn for the four soils described in Table 2 are:

Profile 1: 5.1 t/ha
Profile 2: 3.7 t/ha
Profile 3: 3.1 t/ha
Profile 4: 2.6 t/ha

The characterization data in Table 2 is by genetic horizons; many of the A horizons are quite shallow, less than 5 cm thick. Since lime should be incorporated to 15 cm, the exchangeable Al and ECEC values are prorated to a depth of 0 to 15 cm in the above calculations.

Liming Recently Cleared Soils

The above equation worked very well in bulldozed soils, but not in fields newly cleared from forest. One such field was slashed and burned, with partially burned forest litter and ashes remaining on the plots. Before liming, this soil was still quite acid with a pH of 4.2 and Al saturation

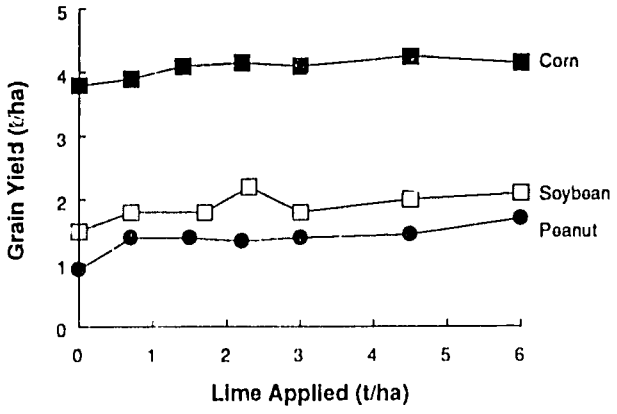

Figure 5. Yield response to lime of three food crops grown immediately after slash-and-burn clearing in Sitiung.

of 55%, but none of the first three crops grown showed a significant response to applied lime (Figure 5). In experiments in areas which had been cleared longer or cleared by bulldozer, this level of Al saturation was sufficient to decrease crop yields where no lime was applied. That did not happen in land newly cleared by slash-and-burn.

One possibility is that rapidly decomposing organic matter is forming complexes with Al, temporarily rendering Al non-toxic to plants (Foy 1984). Hue et al. (1986) have found that oxalic, citric and tartaric acids are particularly effective in complexing Al, and that forested soils have much higher concentrations of these acids before clearing. Complexing by organic acids may temporarily block Al toxicity, and, thus, no crop response to lime occurs during the first planting. With time, topsoil organic matter levels drop, Al complexing by organic constituents decreases, Ca levels drop and then acid-sensitive crops begin to respond to lime (Sanchez et al. 1983; Smyth et al. 1987). This has happened 14 to 18 months after burning in South America (Lopes et al. 1987). It may be necessary to lime newly cleared acid soil starting with the second or third crop.

Lime Reaction and Timing of Application

Scientists from temperate regions commonly recommend that lime be applied two or three months prior to planting in order for sufficient time to neutralize soil acidity (Adams 1984). Figure 6 shows that lime reacted very rapidly in Sitiung. Three days after lime application, there was nearly a unit increase in pH and a correspondingly sharp decrease in Al and an increase in Ca+Mg. Afterwards, pH and Al levels essentially did not change over the next year. Exchangeable Ca+Mg values tended to gradually increase for several months, indicating dissolution of larger and more slowly reacting particles over time. The data show no tendency for reacidification during the year the soils were monitored (Table 6). These results indicate that up to the first year, no reapplication of lime is necessary to maintain neutralization levels

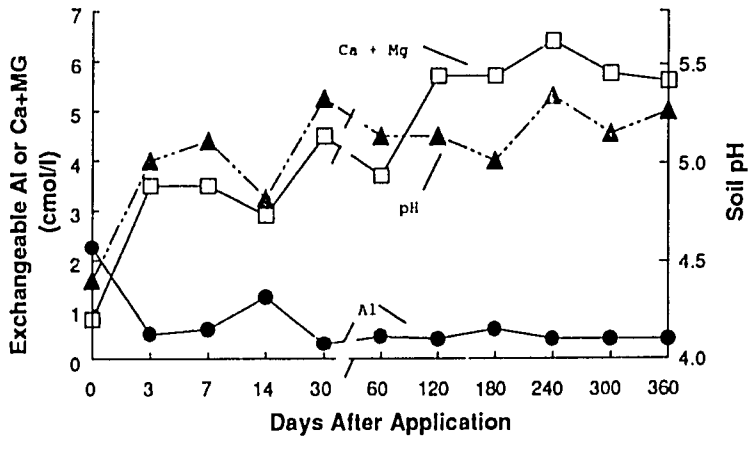

Figure 6. Effect of lime applications over time on soil pH, exchangeable Al, and Ca + Mg. Data are means of three locations and lime rates resulting in less than 20% Al saturation.

attained with the original application. The second year and thereafter, an annual maintenance rate of 1/3 of the initial rate seems to be sufficient to maintain Al saturation below the critical levels for soybean, peanut and corn (Table 7).

Subsoil Improvement

One of the advantages of liming Oxisols and Ultisols is the gradual improvement in subsoil properties caused by the downward movement of Ca applied as lime. A year after 2.25 to 5 t/ha of lime were applied to an Oxisol of Sitiung II (Figure 7), subsoil Al saturation decreased considerably within the top 50 cm. In comparison, a treatment with a low application rate of 0.38 t/ha did not show any Ca movement. These results are similar to South American data (Ritchey et al. 1980; Sanchez et al. 1983; Cravo and Smyth 1987), where the gradual improvement in subsoil fertility increased root proliferation and made the crops more tolerant to drought stress because they had access to a larger volume of soil water.

Is Lime Economical?

Lime is definitely profitable under Sitiung conditions. Partial budget analysis (Table 8) shows that for every rupiah invested in lime, farmers could obtain from 2.5 to 9 rupiahs, depending on the rate of application.

Conclusions

A lime-management program at Sitiung, using readily available limestone crushed to agricultural size, should take into account the following considerations:

1. Lime application of 0.3 to 1.0 t/ha is probably needed for upland rice in bulldozed soils, both to neutralize soil acidity and to satisfy the crop's need for Ca.
2. No lime was needed even for acid-sensitive crops right after slashing and burning a forest, even when soil analysis before land clearing indicated otherwise. The fertilizer value of the ash and temporary Al complexing by rapidly decomposing organic litter decreased Al toxicity for several months. Liming may be needed for the second or third crop.

Table 6. Effect of initial liming only (residual) and initial liming with maintenance applications of lime on Al saturation over time.

		Residual effect of lime				With maintenance	
		(Months after initiation)					
Initial rate	Goal	4	12	24	33	24	33
t/ha	% Al saturation						
0	60	66	66	62	72	54	53
0.5	40	42	42	48	54	36	38
1.0	20	20	40	36	39	22	22
2.0	10	6	22	25	31	12	9
4.0	0	0	5	5	5	4	2

Table 7. Initial and annual maintenance rates of lime used for the experiment reported in Table 6.

	Maintenance application rates			
Initial rate	Months after initiation 12	24	36	Total
	t/ha			
0	0.17	0.06	0.08	0.31
0.5	0.28	0.06	0.16	0.50
1.0	0.56	0.15	0.33	1.04
2.0	0.52	0.52	0.67	1.71
4.0	1.40	1.40	1.33	4.13

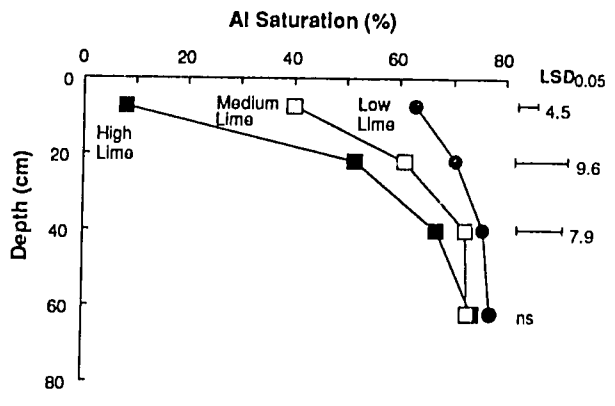

Figure 7. Percentage of Al saturation of a Typic Haplorthox in Sitiung II, measured one year after application of lime. Three lime rates were used: low (0.375 t/ha), medium (2.25 t/ha), and high (5 t/ha). Source: Gill 1988.

Table 8. Effect of liming at various rates on gross income and return on investment for an upland rice-soybean-upland rice rotation at Sitiung, 1984-1985.

Lime rate	Grain yield increases			Increased revenues[1]	Lime cost	Rate of return
	Rice '84	Soybean '84	Rice '85			
	t/ha			1000 Rp/ha		Rp/Rp
0.5	0.4	0.3	0.8	312	35	8.9
1.0	0.6	0.5	0.9	440	70	6.3
2.0	0.4	0.9	1.1	600	140	4.3
4.0	0.4	1.2	1.0	704	280	2.5

[1]Prices: rice = Rp. 160/kg, soybean = Rp. 400/kg, lime = Rp. 70,000/t. Exchange rate (1985): $1 U.S. = 1058 Rp.

3. Liming is definitely needed for bulldozer-cleared lands or lands cultivated for more than one year in order to grow acid-sensitive crops. The critical Al-saturation levels found were 5% for mungbean, 15% for soybean, 28% for corn, 29% for peanut, 55% for cowpea, and 70% for rice. These levels may vary somewhat, depending upon the cultivar being grown.
4. The modified Cochrane equation reliably predicted lime requirements on Sitiung soils for upland crops with critical Al-saturation levels higher than 10 percent.
5. No lime incubation time was required at this humid tropical location when finely ground agricultural lime was used. Therefore, liming and planting may occur on the same day with no adverse effects. By the time the seeds germinate, the majority of the lime will have reacted and sufficiently neutralized toxic Al.
6. Rapid downward movement of Ca into the subsoil occurred in an Oxisol within a year, decreasing Al saturation and probably improving root development.
7. An annual lime application of 1/3 the initial rate appeared to be sufficient to maintain Al saturation below the critical level for soybean, peanut or corn for three years.
8. Lime was definitely profitable for an upland rice-soybean rotation. For every rupiah invested in lime, the farmer could potentially obtain from 2.5 to 9 additional rupiahs in crop yields.
9. Upland crop-rotation systems should consider liming for the most acid-sensitive crop. Rotations involving only Al-sensitive crops, such as corn, soybean and peanut, are likely to fully capitalize on the effects of lime. Including Al-tolerant crops in the rotation, such as upland rice or cassava, may be necessary because of farmer priorities and market or pest control considerations. In such cases the lime investment is not well utilized for part of the rotation, although upland rice did show yield response to small increments of lime in several trials.

This liming work is being incorporated into a worldwide expert system for lime management by R. S. Yost and collaborators of the University of Hawaii TropSoils Program.

Phosphorus Fertilization

Approach

Soil tests using the modified Olsen extractant indicate that nearly all soils of Sitiung have serious P deficiencies. This extractant, widely used in Oxisols and Ultisols of South America, shows critical levels of 10 to 20 ppm P for annual food crops, while most Sitiung soils have less than 5 ppm P. Two approaches were utilized in developing phosphorus-fertilization research at Sitiung. A low-input approach was based on choosing acid-tolerant crops and recycling crop residues, especially on soil recently cleared by slash-and-burn, where phosphorus would be the primary limiting factor. Low-input management is currently the most immediate avenue available to cash-poor transmigration farmers. A high-input approach sought maximum economic returns. It included high-yield, high-income crops, sufficient lime and fertilizers to eliminate fertility constraints, and appropriate credit and market infrastructure. Results from each of these approaches follow.

Low-Input Rotation

A rotation of peanut and upland rice was grown on an Ultisol on a recently cleared field (by slash-and-burn) in Sitiung V-C for two consecutive years. Phosphorus fertilizer was the only input except for a topdressing of 46 kg N/ha per rice crop and 325 kg $Ca(OH)_2$/ha per peanut crop as a supplemental source of Ca for pod development. Both are modest inputs and consistent with the low-input philosophy (Sanchez and Salinas 1981). The response of the two crops to triple superphosphate (TSP) is shown in Figure 8. Both species responded strongly to P fertilizer. Peanut needed 80 kg P/ha to reach plateau yields the first year, and 20 kg the second, whereas rice needed only 20 kg P/ha both years.

Methods of applying P fertilizer were also investigated in this trial. Five methods (broadcasting, banding every row, banding between every other row, placing in the seed hole, and dibbling beside the seed) were tested with very similar

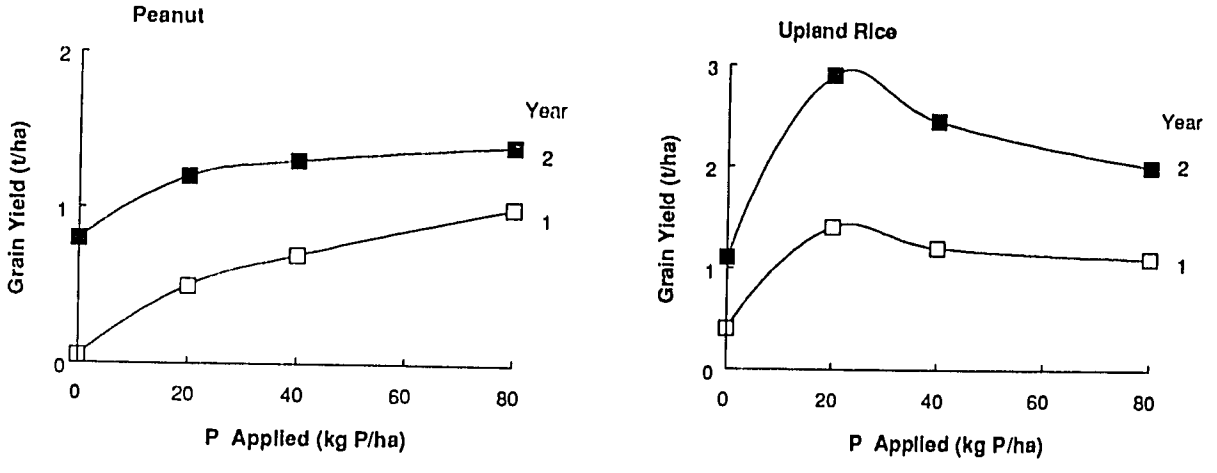

Figure 8. Yield response over two years to an initial broadcast triple superphosphate application on a peanut-upland rice rotation after slash clearing in a clayey Typic Paleudult at Sitiung V-C.

Table 9. Effect of various methods of phosphorus application (20 kg P/ha) on peanut and rice yield.

Application method	Peanut Year 1	Peanut Year 2	Rice Year 1	Rice Year 2
	t/ha			
Broadcast	0.5	1.1	1.5	2.9
Band every row	0.4	1.2	1.4	2.0
Band every other row	0.5	1.1	1.8	2.4
Dibble near seed	0.5	1.2	1.2	2.2
Dibble with seed	0.5	1.2	1.5	2.9
	ns	ns	ns	ns

Table 10. Soil test P and Al-saturation values over time in the peanut-upland rice low-input system. Mean of all treatments.

Months after planting	Al saturat'n	Available P (mod. Olsen)	Time of P application
	%	ppm	
0	55	4	1st crop
4	25	12	2nd crop
7	17	14	None
12	34	13	"
16	28	14	"
24	23	-	"

results (Table 9). Therefore, broadcasting, which requires about a tenth of the labor of the other methods, is considered the most appropriate application method.

A major research goal was to improve the prediction of P-fertilizer requirements. Figure 9 shows the relationship between crop yield and P soil test levels according to the modified Olsen method. Rice shows a lower critical level than peanut (10 vs. 17 ppm P, respectively). Such critical levels can be used to identify when P fertilization is needed. If a given soil analysis is below the indicated crop critical level, then a prediction based on yield response curves can be made concerning the amount of P fertilizer needed to raise the soil test P value up to or above the critical level.

This experiment gave evidence of stability in the low-input system over a two-year period in terms of the key fertility parameters of Al saturation and soil test P levels (Table 10). Proper land clearing, residue return and Ca application to peanut appear to adequately suppress soil acidity development. Also, there was a strong residual effect of P application under this management. Phosphorus was applied only to the first two crops, yet soil test P levels remained stable for at least 16 months.

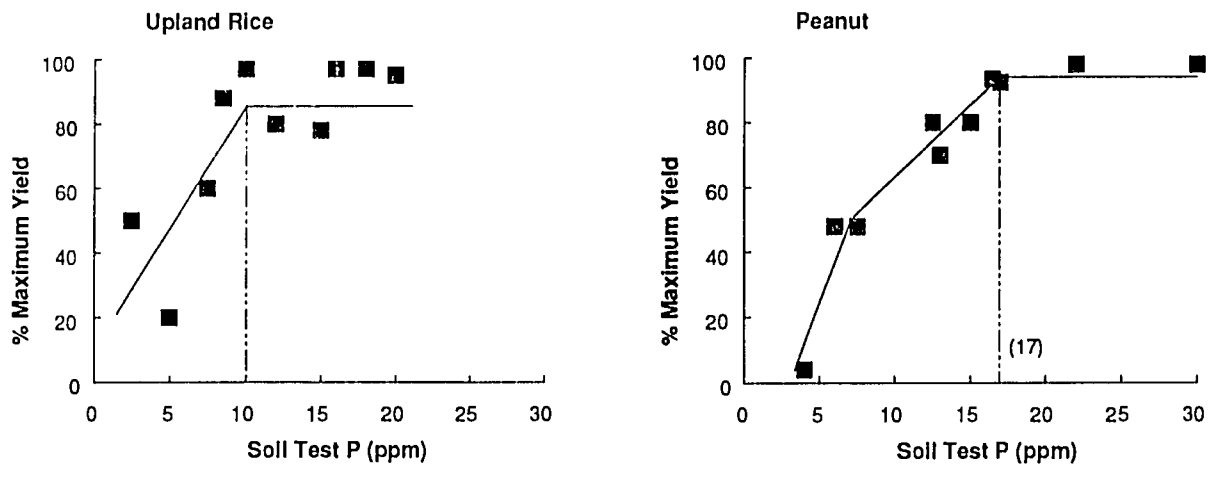

Figure 9. Critical levels of P by modified Olsen for upland rice and peanut in an Ultisol of Sitiung V in a low-input crop rotation. Two years' data. Source: Wade and Santoso 1985b.

High-Input Rotation

A high-input trial was conducted with a crop rotation of corn and soybean for two years at Sitiung I-A. Lime was applied at the rate of 6.5 t/ha of lime as basal applications to all plots, followed by application of 135 kg N (corn only), 75 kg K/crop, 16 kg Mg/crop, and 23 kg S/ha/crop. The soil was a Haplorthox with higher P fixation than the Paleudult utilized in the low-input experiments. Incremental additions of P fertilizer resulted in small increases in extractable P (Figure 10).

Further investigation into P fixation was conducted in the laboratory using P-sorption isotherms according to the Fox and Kamprath (1970) method. The Haplorthox used in this trial, as well as the Paleudult in the low-input experiment, were studied and compared with soils from Brazil and Peru. Results can be seen in Figure 11. The Sitiung I-A Oxisol showed extremely high P sorption, higher than Oxisols of Brasilia and Manaus, Brazil. The Sitiung Ultisol from the low-input trial showed relatively moderate P sorption, although still much higher than the Peruvian Ultisol, probably due to its much higher clay content. In contrast with the sorption isotherm data, neither the Sitiung Oxisol nor the Ultisol were classified as high P fixers by the Fertility Capability Classification system, as shown in Table 2.

Because the sorption isotherms indicated high P fixation in the Oxisol, high initial P rates were selected for this trial. Also, a maintenance factor was included to test the effect of adding a low rate (20 kg P/ha) to each crop in addition to the various initial rates. There were two maintenance treatments: one banding the 20 kg P/ha and the other broadcasting it. None of the four crops showed a differential response to these two methods of application; thus, the mean of the maintenance methods is reported.

The first crop, corn, responded strongly to the initial P rates (Figure 12). Thereafter, soybean in year 1 and both crops in year 2 continued to show a strong residual effect to the initial P rates. When the per crop maintenance of 20 kg/ha was included, the crops' response to initial rates declined progressively. This is shown by the flatter slopes of the response to maintenance P (Figure 12).

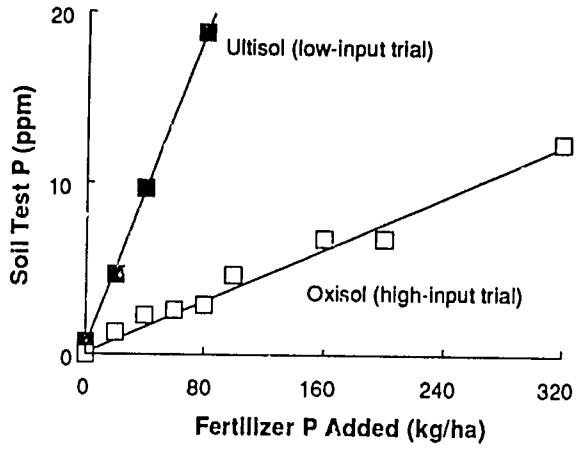

Figure 10. Differences in P-fertilization requirements to achieve levels of soil test P (modified Olsen) between the Ultisol of Sitiung V-C used in the low-input trial and the Oxisol of Sitiung I used in the high-input trial.

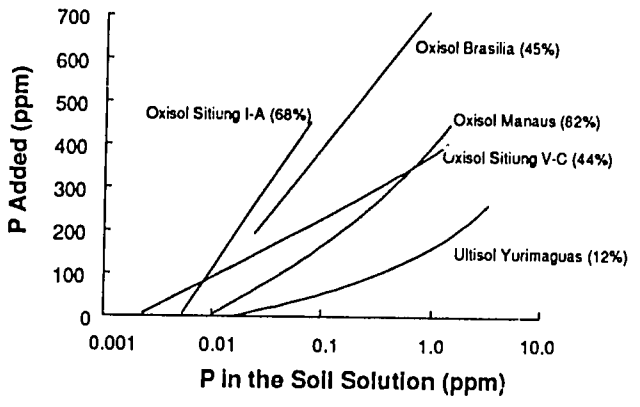

Figure 11. Phosphorus fixation isotherms of an Oxisol of Sitiung I and an Ultisol of Sitiung V in comparison with soils from Brasilia and Manaus, Brazil, and Yurimaguas, Peru. Numbers in parentheses are percent clay content.

These results, therefore, are not consistent with those of high P-fixing soil. The residual effect should have declined over time in a high P-fixing soil, yet soil test P values remained stable. A modest rate of 20 kg P/ha/crop was not expected to increase yields as much as it did. This soil has 68% clay in the A horizon and, therefore, has a high surface area which could fix large amounts of P, as indicated by the P-sorption isotherm (Figure 11) and the small increase in extractable P when

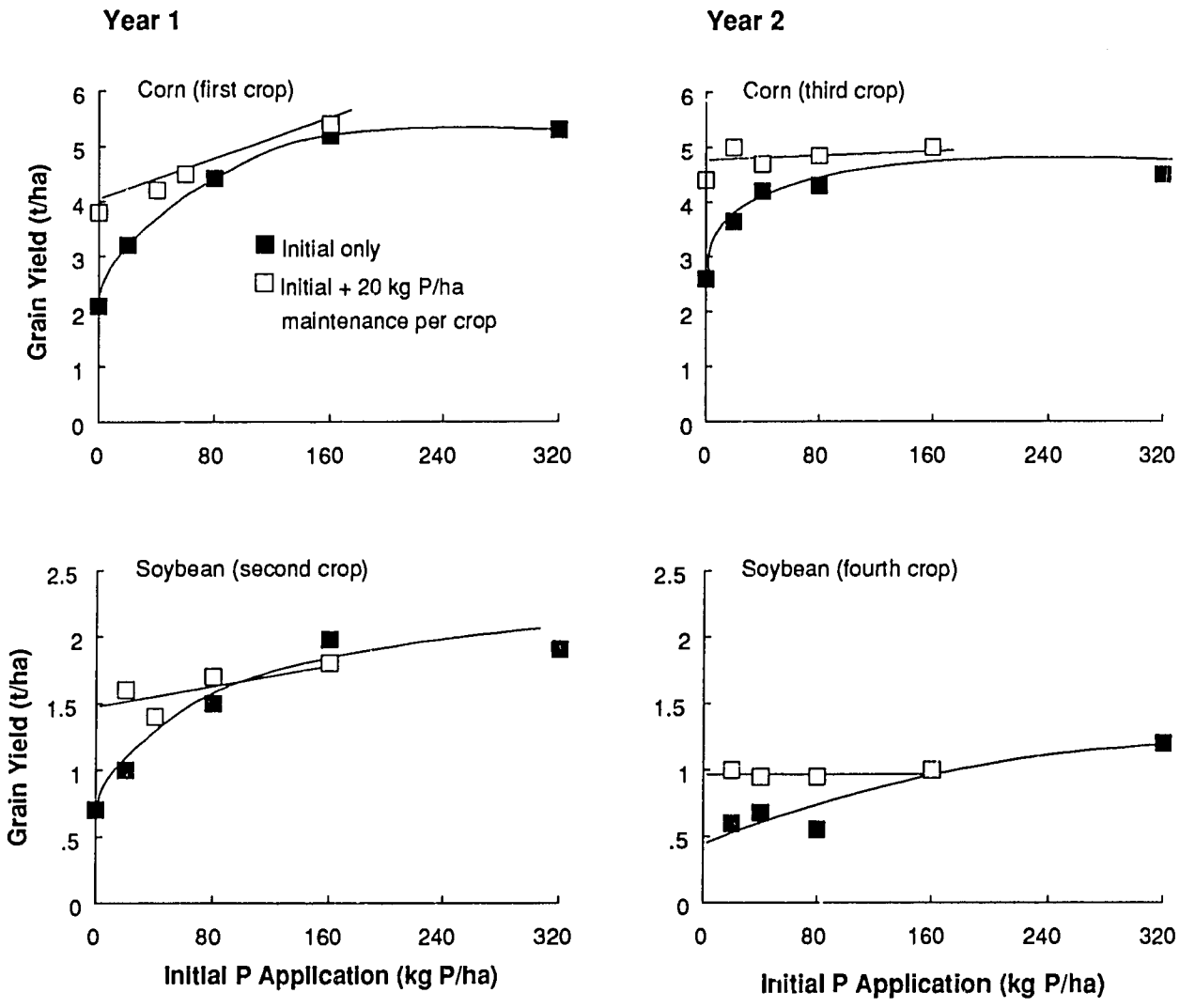

Figure 12. Corn and soybean yield response to initial and 20 kg P/ha maintenance fertilizer application in high-input rotation at Sitiung I-A.

fertilizer was added (Figure 10). However, clays in this and other Sitiung soils are almost entirely low activity, crystalline kaolinite, which does not tightly bind P. There is little free Fe that would strongly bond with P (Table 2). Therefore, the so-called fixed P remains labile, or available, to growing crops. Appropriately, the soil is not classified as a high P fixer in the FCC system, as the free Fe/clay ratio is less than 0.2.

Is Phosphorus Fertilization Economical?

Table 11 shows the relative crop yields of different P-management options. Economic returns to P fertilization are very high. For every rupiah invested in P fertilization, farmers obtained from 16 to 38 extra rupiahs. The highest return on investment was achieved with an initial rate of 160 kg P/ha, but few farmers may have the cash or access to sufficient credit to buy that much fertilizer at one time (800 kg/ha of triple superphosphate). A more conservative approach might be to add 40 kg P/ha initially and follow with 20 kg/ha/crop as maintenance. The most efficient P fertilization option is to broadcast an initial application of 40 kg P/ha.

It is also relevant to note that significant crop yields (2 t/ha of corn; 0.5 t/ha of soybean) were obtained without any P fertilization (Figure 12).

Table 11. Effect of selected P treatments on relative yield, net return, and rate of return to P fertilizer of four crops in a rotation.

P applied		Relative yield						
Initial + Maintenance	Total	Corn 1	Soy 1	Corn 2	Soy 2	Mean	Net return[1]	Rate of return
kg P/ha		% maximum					Rp 1000/ha	Rp/Rp
0+0	0	39	35	51	45	42	950	-
40+0	40	81	70	82	64	74	1680	38
0+20	80	70	75	86	91	80	1780	22
40+20	120	78	80	98	91	87	1910	20
160+0	160	96	100	100	91	97	2150	16

[1]Exchange rate (1985): $1 U.S. = 1058 Rp.

This represents an average of 42% of the maximum yield, attained with an initial application of 160 kg P/ha. This is a very different response from that obtained on Oxisols of Brazil, where essentially no corn or soybean can be produced without P fertilization (Yost et al. 1979; Smyth et al. 1987). The response pattern at Sitiung is similar to the one in Yurimaguas, Peru, where some yield is obtained without P fertilization, but there is a crop response to P application (Sanchez et al. 1983).

No research was conducted with phosphate rock as a P source. This is particularly important and should be included in future plans for investigation in the region.

Critical Level

Prediction of response was an important goal of this research. Figure 13 shows soil test critical levels (by the modified Olsen method) derived from the research for both corn and soybean. This must be considered preliminary data, since a large data base should be developed for the major soil types in order to give greater confidence to the data. Nevertheless, the soil test correlation data, as exhibited in Figure 13, can be used to define critical levels and reliably predict soil phosphorus-sufficiency/deficiency status.

Conclusions

1. Phosphorus-fertilization management is not difficult on Sitiung soils. Whether under high- or low-input management, relatively low rates are needed to obtain good yields, and the P fertilizer has residual effects for at least two years.
2. No differences were observed due to method of P application, and broadcasting is therefore recommended since it requires less labor than banding.
3. Soil analysis can define critical levels for annual food crops in the region and should be effective in predicting soil P deficiencies and corrective rates of fertilization. Critical levels for corn and soybean were 10 and 13 ppm P, respectively, by the modified Olsen method.
4. The economic return to phosphorus-fertilizer application is very high in Sitiung soils.

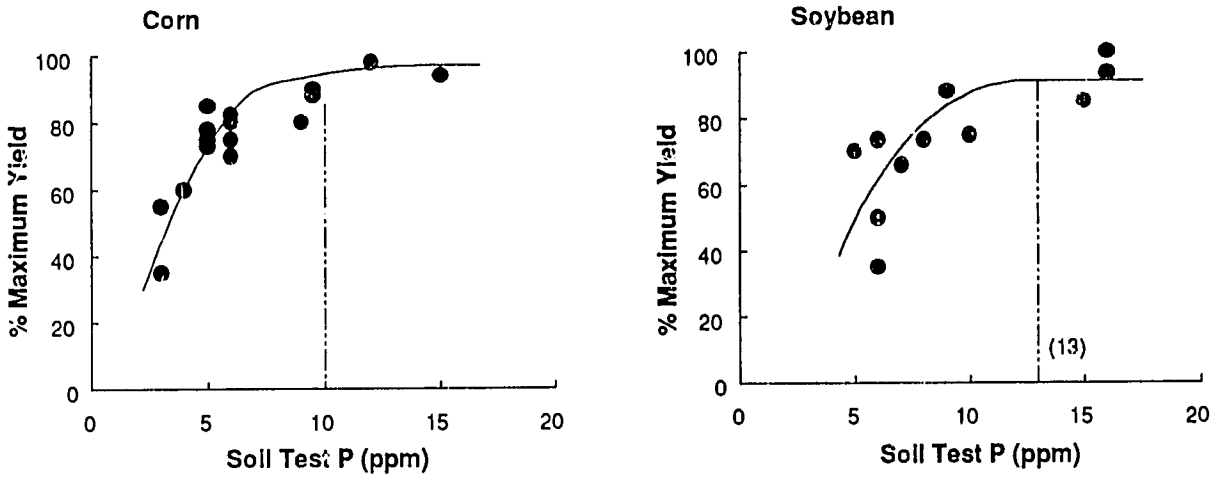

Figure 13. Critical levels of P by modified Olsen for corn and soybean in an Oxisol of Sitiung I-A in a high-input crop rotation.

Green Manures

In addition to inorganic chemical fertilizers, organic inputs were tested at Sitiung as surface-applied mulches or incorporated into the topsoil as green manures. Mulches and green manures were grown outside the field, brought in and applied, in contrast to the practice of growing them *in situ*.

First Observation

The first experience was in the land reclamation study where 12.5 t/ha of fresh *Calopogonium mucunoides* harvested from a nearby rubber plantation was added as mulch or incorporated as a green manure. Crop yields increased with green manure applications regardless of the level of fertilizer input used (Table 3).

Although green manures are viewed primarily as a source of nitrogen, additions of other elements present in the plant tissue may also be important. In the land reclamation study, rice developed foliar Mn-deficiency symptoms except in plots with where green manures were incorporated. This problem was corrected by applying Mn to the deficient plots. The effect of green manures on increases in available soil Mn and plant tissue Mn contents are shown in Table 12. However, this effect was not observed with green manures in other studies in the area.

Table 12. Effect of imported green manure (fresh *Calopogonium mucunoides*) on available Mn (modified Olsen) and plant Mn content. Source: Makarim 1985.

Green manure	Extractable soil Mn	Leaf Mn	
		Rice 1	Rice 2
t/ha	ppm		
0	1.1	50	157
12.5	3.4	205	428

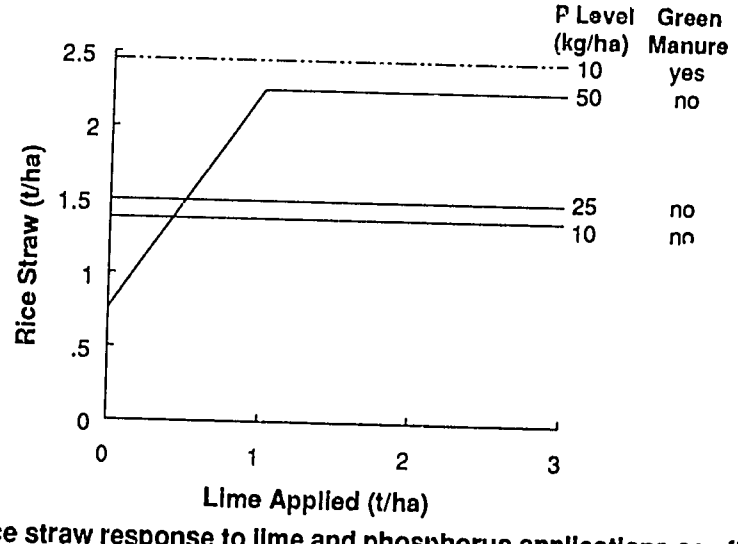

Figure 14. Rice straw response to lime and phosphorus applications as affected by incorporation of 20 t/ha of fresh *Calopogonium* green manure in an Oxisol at Sitiung II-E.

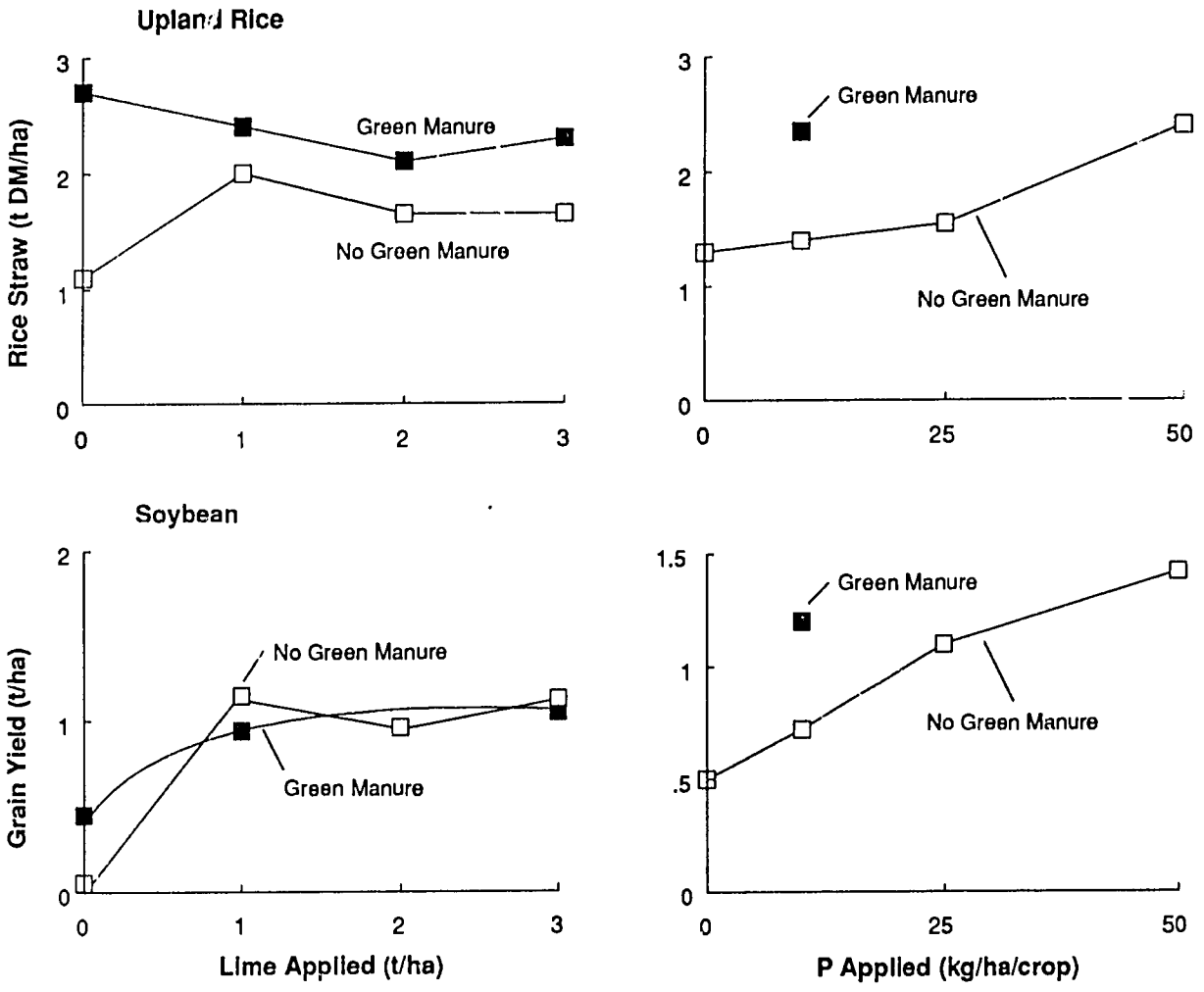

Figure 15. Effects of lime and P applications and 20 t/ha of imported fresh *Calopogonium* application on upland rice and soybean yield. Source: Heryadi and Wade 1985.

Interactions with Lime and Phosphorus

A green manure experiment was conducted on a Haplorthox at Sitiung II-E, cleared by bulldozer six years before and planted to upland rice every year. Soil pH was 4.1, Al saturation was very high (82%), and available P levels were low (5 ppm). Treatments included four lime rates (0, 1, 2 and 3 t/ha) and four P rates (0, 10, 25 and 50 kg/ha) in a factorial design. In addition, 20 t/ha (fresh weight) of imported *Calopogonium* were incorporated into additional plots which had received the various lime rates, but only at the rate of 10 kg/ha of P. Lime and green manure were applied at initiation of the rice-soybean rotation only, while P was reapplied to the soybean crop.

Rice was severely attacked by blast (*Pyricularia oryzae*) and no reliable grain yield estimates could be made; therefore, aboveground dry matter at harvest was the growth parameter measured. With low P rates (10 or 25 kg P/ha), there were no responses to lime, since P, not lime, was apparently limiting yields (Figure 14). At the higher P rate (50 kg P/ha), a dramatic response to lime was evident in the dry matter yield. With green manure and only 10 kg fertilizer P/ha, dry matter yield was high, and there was no response to lime. This suggests that the green manure was detoxifying soil Al, perhaps by mechanisms similar to those previously discussed. There also appears to be an enhancement of P availability by the green manure

treatment. The green manure + 10 kg P/ha treatment added an estimated 9 kg P/ha from green manure and 10 kg P/ha from fertilizer. It produced as much dry matter as with 50 kg fertilizer P/ha (Figure 14).

The beneficial effect of the green manure application was short-lived. Effects of green manure on lime response was observed in a subsequent crop of soybean at the zero rate of lime only (Figure 15). P response, however, to the residual effect of green manure was significant. Soybean yield with a combined application of green manure and 10 kg P/ha/crop was equivalent to that obtained with 25 kg P/ha/crop (Figure 15). During the first rice crop, the treatment with green manure + 10 kg P/ha gave a response similar to that of the 50 kg P/ha treatment. It appears, therefore, that the Al-complexing effect of the green manure was effective for only one crop, but the positive effects on P availability carried over to the second crop. This latter effect cannot be explained simply by the P contained in the green manure (9 kg/ha). Perhaps the green manure complexed some soil Al which would have interacted with P, thus increasing P availability to the crop.

Table 13. Extractable P (by modified Olsen) and Al saturation as affected by lime rates, P rates, and imported green manure incorporation at time of harvest of the first rice crop. Source: Heryadi and Wade 1985.

Lime rate	Rate of applied P (kg/ha) 10	25	50	10 + green man.
t/ha	Extractable P ppm			
0	7	6	12	7
1	8	8	17	8
2	4	4	14	11
3	5	6	8	6
	Al saturation %			
0	78	79	78	72
1	58	58	49	53
2	45	42	38	40
3	34	34	21	36

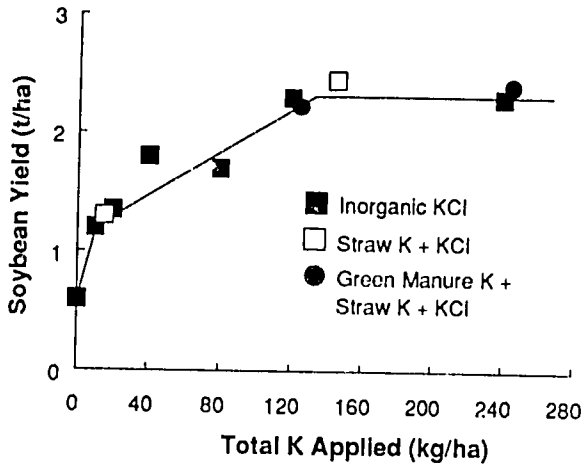

Figure 16. Effects of K added 1) as KCl only, 2) as straw from the previous rice crop plus KCl, and 3) as green manure plus rice straw plus KCl. Source: Gill and Sri Adiningsih 1986.

The positive effects of green manures on alleviating Al toxicity or increasing P availability to the rice crop were not detected by soil tests after the rice harvest (Table 13). This indicates that in-depth studies are needed to understand the effects of green manures on soil fertility parameters.

Interaction with Potassium

A similar trial with potassium was conducted at Sitiung V-C using a rice-soybean rotation in which different rates of KCl fertilization were studied in incomplete factorial combination with three organic input levels. KCl treatments were 0, 20, 40, 80, 120 and 240 kg/ha of K. The three organic input levels were the following: 1) removal of residues of the previous crop in the rotation, 2) return and incorporation of previous crop residue, and 3) return and incorporation of previous crop residue plus 10 t/ha of fresh *Calopogonium mucunoides-Pueraria phaseoloides* mixture added to the soil. Organic input treatments were combined with the 0 and 80 kg/ha KCl treatments.

Crop residues, as well as green manures, supplied significant amounts of K, with both crops responding strongly to applications of K, either in the form of inorganic KCl or in organic form

Table 14. Effect of returning residues from previous crops and applying imported green manures on upland rice grain yield response to K fertilization at Sitiung V-C. Source: Gill and J. Sri Adiningsih 1986.

KCl fert. applied	Residues removed	Residues returned	Residues returned + green man.
kg K/ha	Rice yield (t/ha)		
0	0.5	2.1	2.5
80	3.4	3.2	3.0

within the residues and green manures (Figure 16). Yields were very low where no K was added and residues were removed (Table 14). Simply returning residues from the previous crop improved yields dramatically even without KCl application, and, when the imported green manure was applied, yields increased further. When total additions of K (both organic and inorganic sources) are plotted against soybean yield, a single regression curve fits the data, suggesting that the response to green manures and residues is due to the K supplied organically by these inputs (Figure 16).

Conclusions

1. Imported green manure additions have given consistently strong growth and yield responses under a variety of conditions at Sitiung.
2. The primary benefits include temporarily alleviating Al toxicity (for one crop), enhancing P availability, and supplying K, Mn and possibly other nutrients to the crops.
3. The effects of green manures on ameliorating soil acidity and increasing P availability were not detected by routine soil test procedures.
4. Returning crop residues to the field instead of carrying them away provides large quantities of K and, thus, reduces the need for K fertilization. Farmers in Sitiung seldom leave crop residues in place, and encouraging the return of crop residues to the field should be an important extension practice unless the residues are used for fodder or some other necessary product.
5. No green manures were grown in place. Incorporation of green manures into the crop rotation cycle should be attempted in order to save the labor involved in importing green manures from other fields and to investigate the effects of growing them *in situ*. Further research is being done by University of Hawaii scientists to develop cropping systems where inclusion of green manures is economically feasible.

Potassium Fertilization

Soils in Sitiung are low in exchangeable K, with levels of 0.1 cmol/L or less (Table 2). The government of Indonesia recently initiated a program to increase soybean production by providing up to 4 t/ha of lime to many farmers in the region. There was concern that addition of lime to these soils, although necessary for neutralization of toxic Al, would further decrease the K levels in the soil and cause such serious K deficiencies in the crops that little or no yield increases would be realized by the lime applications. Two experiments to investigate crop and soil response to K applications at three lime rates were initiated on Typic Haplorthox soils at Sitiung I and II.

Both experiments were complete factorials with six rates of KCl (0, 20, 40, 80, 120 and 240 kg K/ha) and three lime rates establishing approximately 70, 40 and 10% Al saturation. The lowest rate of lime was not zero, since previous research showed that without lime, Al saturation was above 75% and no soybean growth occurred. Thus, 0.4 t of lime/ha was applied in order to decrease Al saturation to about 75%, to increase Ca in the soil, and to ensure crop survival at the low lime rate. For the medium lime treatment, 1.5 t/ha were applied to the first crop, and a further 0.75 t/ha was applied previous to planting the second crop, in order to decrease Al saturation closer to the initial goal of 40%. The initial rate for the high lime treatment was 5 t/ha, but since Al levels remained higher than desired for the experiment at Sitiung I, 1.5 t/ha of lime were added to plots in the high lime treatment after growing the first crop.

Since farmers generally do not return crop residues to the field (Sudjadi et al. 1985), all crop residues were removed for each crop. Base levels of P, Mg and S were applied to all crops, and N was applied to the cereal crops. Many farmers in the region grow a two-crop rotation every year, with perhaps the most common being rice-soybean. Thus, in one experiment, a rice-soybean rotation was grown, while in the other, a corn-peanut rotation was grown, with mungbean and cowpea grown on split plots during the dry season. KCl was applied before planting every crop, except for the mungbean and cowpea crops.

Upland Rice

Upland rice did not respond to applications of lime greater than 0.4 t/ha due to the tolerance of this species to Al. Apparently this rate decreased Al sufficiently and supplied enough Ca for rice. Response to applied K, however, was quite strong in both years (Figure 17). In 1985, yields did not reach a maximum until 100 kg K/ha were applied.

Potassium applications were effective in

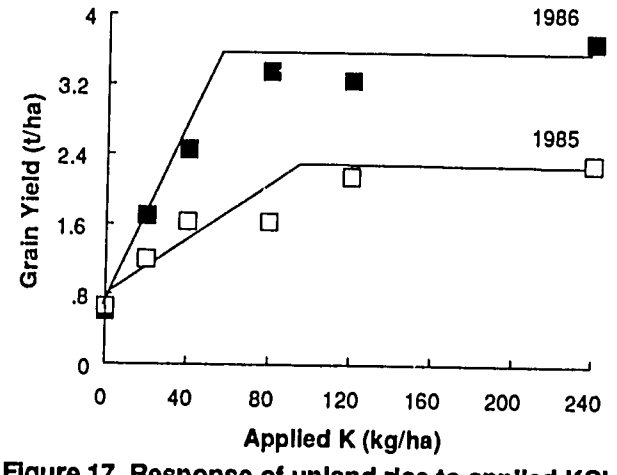

Figure 17. Response of upland rice to applied KCl at Sitiung in 1985 and 1986. Source: Gill, Kasno and Kamprath, in press.

decreasing incidence of rice blast disease caused by *Pyricularia oryzae* (Table 15). This added resistance to disease was at least partially responsible for the grain yield response to applied K.

Better rainfall distribution, as well as higher total rainfall during 1986, led to relatively high yields. However, yields approached maximum at an application rate of 60 kg K/ha, in contrast with the 100 kg K/ha required the previous year (Figure 17). A total of 11.3 and 33.3 kg of rice grain were produced per kg of applied K in 1985 and 1986, respectively, for the portion of the curve showing a positive response.

Grain yield in 1985 was related to percentage of K in the straw at harvest (Figure 18). The higher the K levels in the straw, the greater the grain yield. Potassium uptake in the grain for the first crop of rice varied from about 2 kg/ha with 0 kg of applied K to a maximum of about 8 kg K/ha at high rates of applied KCl (Figure 19). Total K uptake ranged from 9 to 124 kg K/ha, indicating that the majority of the K taken up by the plant was in the straw.

Apparent K-fertilizer recovery is defined as (A-B/C)100, where A = total crop K uptake under treatment X, B = total crop K uptake with 0 applied KCL, and C = K applied as KCl under treatment X. At the lower rates of applied K, the rice crop actually accumulated more K than that applied (Table 16), apparently because the addition

Table 15. Rating of rice crop grown in the Sitiung region in 1985 for rice blast (*Pyricularia oryzae*) incidence at levels of KCl applications. (0 = no blast;10 = all plants killed). Source: Gill 1988.

Treatment	Blast rating
kg K/ha	
0	4.9
20	2.9
40	2.2
80	2.1
120	1.8
240	2.0

Table 16. Apparent K-fertilizer recovery for the rice crop grown in the Sitiung region in 1985. Source: Gill 1988.

Treatment	Total K uptake	Apparent K recovery
kg K/ha	kg K/ha	%
0	9	—
20	31	107
40	54	111
80	78	86
120	92	69
240	124	48

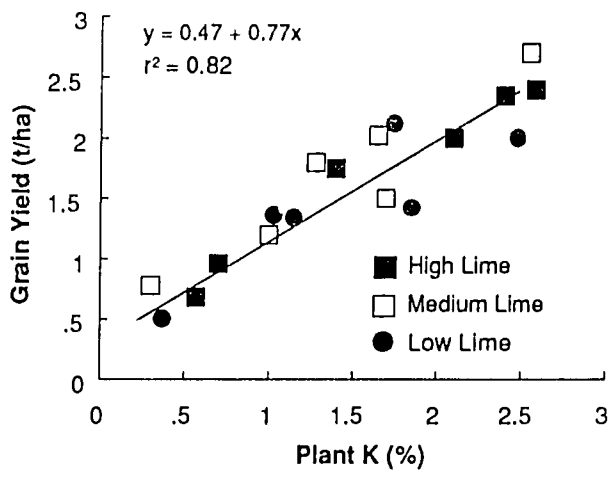

Figure 18. Relationship of percentage of K in straw at harvest to upland rice grain yield at three lime levels (0.4, 1.5 and 5 t/ha). Source: Gill 1988.

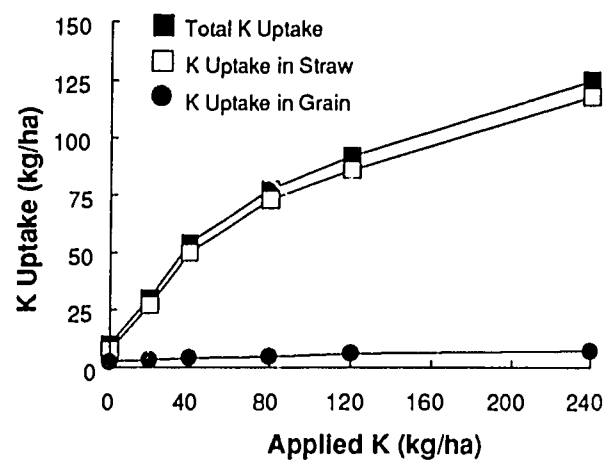

Figure 19. Potassium uptake of a rice crop at varying KCl rates. Sitiung, 1985. Source: Gill 1988.

of small doses of K permitted roots to develop more vigorously and take up more soil K than they would have without the addition of KCl. Apparent K-fertilizer recovery remained relatively high for rates of 120 kg of applied K/ha or less.

The linear response and plateau (LRP) model for grain yield and soil test K showed a critical level or break point at 0.20 cmol/L of K extracted by Mehlich I (Figure 20).

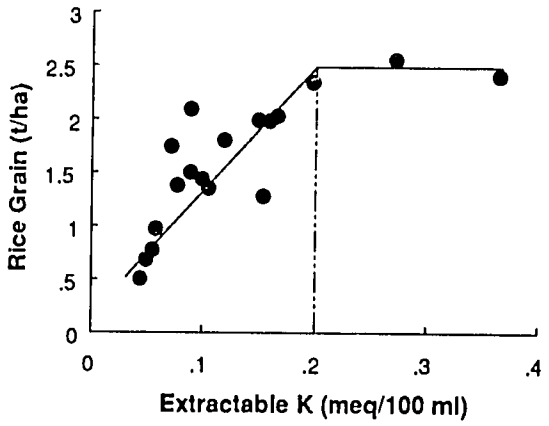

Figure 20. Rice grain yield as influenced by Mehlich I extractable-K levels in Sitiung in 1985. Source: Gill 1988.

Soybean

Soybean grain response to K, unlike that of the rice, depended on the level of lime applied (Figure 21). In 1985, no response to K was observed at the low rate of lime. A response to 20 kg K/ha at the medium lime rate was detected, but yields approached maximum only with 60 kg K/ha under the high lime treatment. This response is related to soybean sensitivity to soil Al, as previously shown in Figure 3.

Apparent K-fertilizer-recovery values for soybean at the three lime levels are shown in Table 17. At the low lime rate, Al inhibited K uptake and recovery was low. At the medium rate of lime, recovery was higher at low K rates, but dropped off rapidly at the higher K rates since root growth was still restricted by Al toxicity.

The apparent recovery of K fertilizer remained relatively high over a wider range of K-application rates (to 80 kg K/ha) in the high lime treatment, because most of the exchangeable Al in the topsoil was neutralized, and the potential for

Table 17. Apparent K-fertilizer recovery for the soybean crop grown at various lime levels in the Sitiung region in 1985. Source: Gill 1988.

	Lime level (t/ha)		
Treatment	Low (0.4)	Medium (2.25)	High (5.0)
kg K/ha	% Apparent fertilizer recovery		
0	-	-	-
20	40	65	60
40	25	50	50
80	4	26	56
120	13	22	33
240	5	14	16

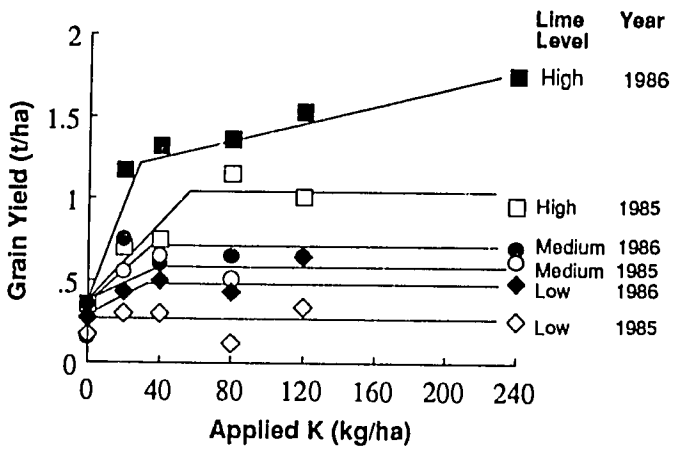

Figure 21. Effect of applied KCl at three lime levels on soybean grain yield in Sitiung in 1985 and 1986. Source: Gill 1988.

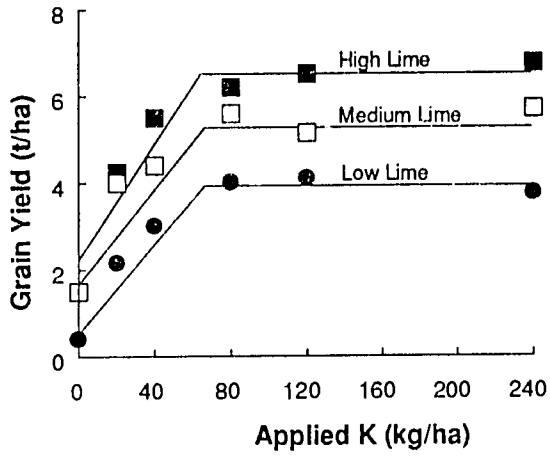

Figure 22. Effect of applied KCl at three lime levels on corn grain yield in Sitiung in 1986. Source: Gill 1988.

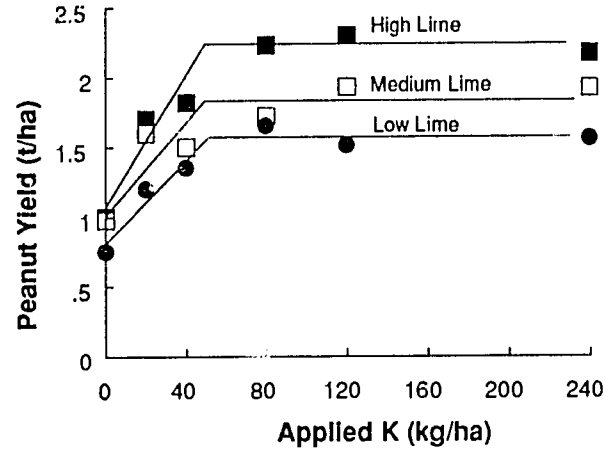

Figure 23. Effect of applied KCl at three lime levels on peanut grain yield in Sitiung in 1986. Source: Gill 1988.

crop yield and K uptake substantially increased.

Soybean yields during 1986 were higher than in 1985 (Figure 21), primarily due to increased rainfall. Responses to K were obtained up to approximately 30 kg K/ha at both low and medium lime rates, while grain yields at the high lime rate did not reach a plateau, but showed a response with two ascending curves. Sixty kg K/ha, however, accounted for 85% of the response to applied K.

Corn

In the experiment with the corn-soybean-cowpea/mungbean rotation, all crops responded to potassium applications. Corn showed a significant response to lime applications, with greater yields achieved as more soil Al was neutralized (Figure 22). Overall grain yields were relatively high, surpassing 6 t/ha. Differences in yield due to lime treatments became greater as the rate of K increased, with an increase of 2.5 t/ha of grain between the low and high lime treatment when adequate levels (60 kg K/ha or more) were applied. Response of corn to K was rather dramatic, with yields increasing four-fold or more from zero to 60 kg K/ha. A soil test critical level of 0.22 cmol K/L using the Mehlich I extractant was recorded.

Potassium applications were very effective in decreasing lodging incidence in corn (Table 18). A high proportion of corn plants in the low K plots fell to the ground, resulting in some grain loss.

Peanut

Peanut response to lime and K, though not as dramatic as that of corn, was highly significant (Figure 23). A response up to 60 kg K/ha was observed at each lime rate in 1986, with yields doubling when compared to that obtained without KCl additions. A 0.75 t/ha increase in nut yield was obtained by the high lime treatment, as compared to the low lime treatment, when sufficient K (60 kg/ha) had been applied.

Cowpea and Mungbean

Responses of the cowpea and mungbean crops are shown in Figure 24. There was no lime

Table 18. Effect of applied KCl on lodging of corn grown in Sitiung in 1986. Source: Gill 1988.

Treatment	Lodging
kg K/ha	no. plants/plot
0	43
20	26
40	11
80	5
120	4
240	2

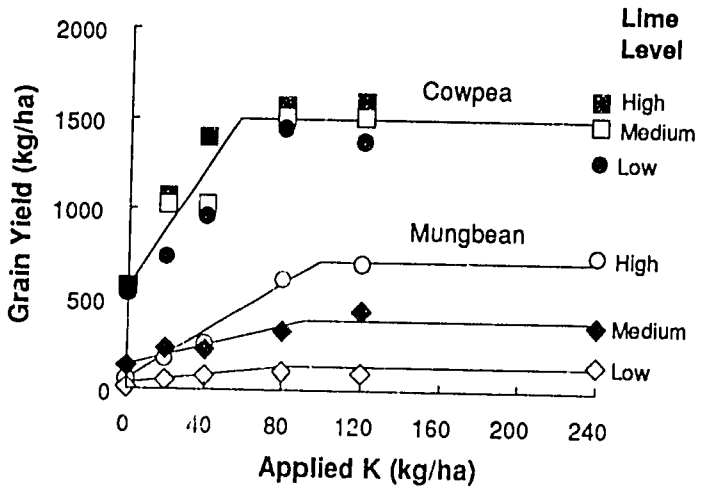

Figure 24. Response of mungbean and cowpea to KCl and lime applications after two previous crops in rotation. Source: Gill 1988.

response in cowpea, and thus all the data points fit one curve. In contrast, there was a strong lime response in mungbean. These crops were grown during the dry season without the addition of any further fertilizers, using only the residual nutrients left after growing the corn and peanut. Mungbean grew well only on those plots which had received high rates of lime and 80 kg K/ha or more, demonstrating that this crop is poorly adapted to Al-toxic, low base status soils.

Large portions of the plots receiving the low rate of lime were bare, and plants grew poorly even at the medium lime rate. Cowpea, which is more tolerant to Al, grew relatively well, producing more than 0.5 t/ha of grain even at the low lime rate. This crop also responded significantly to applied K, with plateau yields obtained only with 60 kg K/ha at all lime rates. Both crops had critical Mehlich I soil test levels of about 0.20 cmol/L.

Conclusions

1. Upland rice, soybean, corn, peanut, cowpea and mungbean responded strongly to applications of KCl. The degree of response to K was related to what factors were limiting each crop's yield potential. When Al toxicity limited yields, little or no response to K was observed.
2. Before lime was applied, toxic Al in the soil limited the yield potential of crops. After liming, low K levels in these soils began to be the primary limiting factor, and crops showed greater responses to applied KCl.
3. KCl applications to Al-sensitive crops, such as soybean or mungbean growing on soils with high levels of Al, were wasted. No response was obtained, and most of the applied K was not taken up.
4. A Mehlich I critical level of approximately 0.2 cmol/L was tentatively established for all six upland crops grown in these experiments.
5. The majority of the K taken up by these crops was found in the stover, emphasizing the importance of crop-residue return in development of any potassium-management program for the region. Some uses of crop stover, such as for cattle feed, may give greater profit, but farmers should be made aware of the high levels of K contained in crop stovers.

Magnesium Fertilization

Observations made while conducting trials and visiting farmer fields indicated apparent Mg deficiency as a fairly common problem in Sitiung. These observations were confirmed by soil and plant analyses, which indicated marginal Mg levels. Since the lime being delivered to the region had only traces of Mg in it, two experiments were initiated to study crop response to rates of Mg applied as $MgSO_4$. In one experiment, a rotation of rice-peanut was grown with rates of Mg ranging from 0 to 48 kg/ha applied to the rice crop, while in the other, a corn-soybean rotation was grown with Mg rates of 0 to 64 kg/ha applied to the corn crop. Before growing the second crop in each rotation, two of the lower rates of Mg were reapplied as a means of comparing maintenance vs. residual effects on crop growth.

Differences in S application due to the rates of $MgSO_4$ were balanced by additions of elemental S. Base fertilizers of N, P and K were applied to all plots, except that N was not applied to the legumes. Lime was applied at a rate of 2.5 t/ha to the rice-peanut rotation (to decrease Al to below 40%), while 5 t/ha were applied to the corn-soybean rotation, since soybean plants are more Al sensitive. There were Mg-deficiency symptoms on leaves of young corn plants growing without Mg, and a response in plant height was also observed (Figure 25), but no grain yield response was recorded because of a late-season drought. Rice responded similarly to corn in terms of plant height.

The two grain legume crops responded strongly to $MgSO_4$ fertilization (Figure 26). Soybean reached plateau yields with the residual of 24 kg Mg/ha, whereas peanut did so with the residual of only 8 kg Mg/ha. Soybean also responded positively to maintenance applications of 8 and 16 kg Mg/ha, but peanut did not respond to the second applications of 4 and 8 kg/ha.

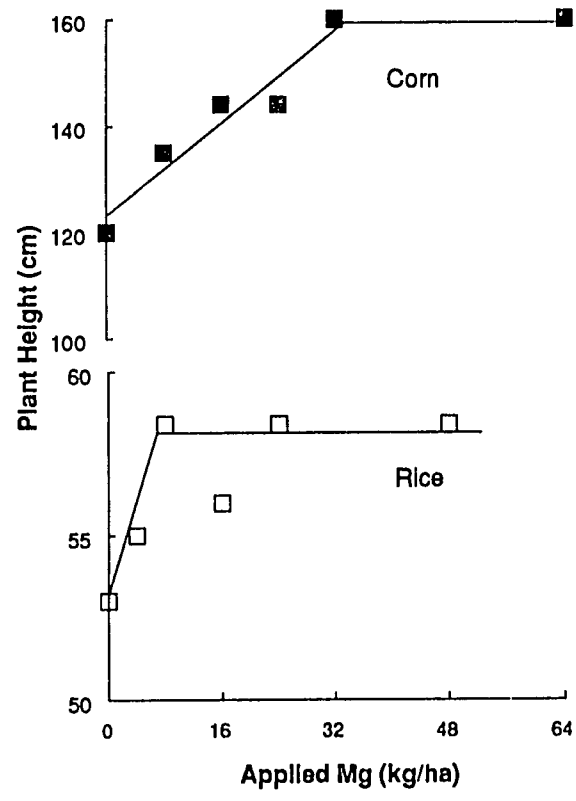

Figure 25. Effect of Mg fertilizer on corn and rice plant height at 36 days after planting.

Two experiments were conducted to observe the effect of Mg-fertilizer applications on exchangeable Mg in the soil (Figure 27). The added $MgSO_4$ linearly increased soil Mg in both the low-input (rice-peanut) and the high-input (corn-soybean) experiments. However, the rice-peanut system showed consistently higher levels of exchangeable Mg across the range of fertilizer

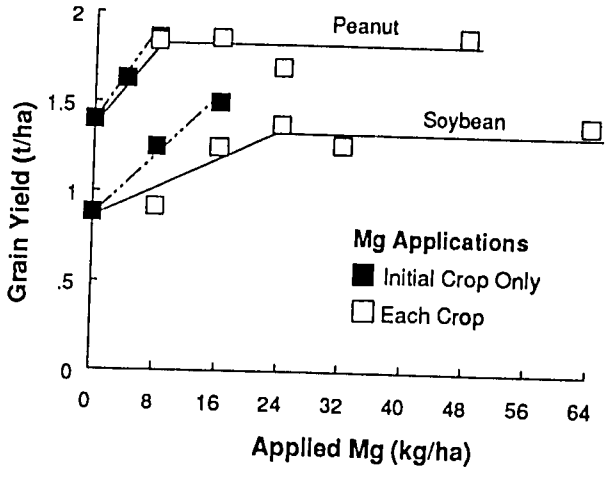

Figure 26. Response of peanut and soybean to Mg fertilization in Sitiung.

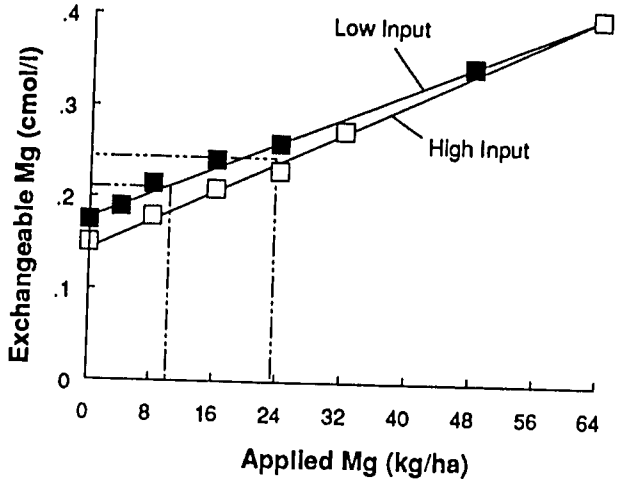

Figure 27. Effect of Mg fertilizer on soil exchangeable Mg, with high and low base applications of lime and fertilizer.

rates. Apparently the 5 t/ha rate of lime in the corn-soybean rotation reduced the amount of Mg retained on the exchange sites relative to the other rotation, which received less lime.

Crop yield as related to exchangeable Mg also was studied (Figure 28). A linear-plateau model fits each crop's response to Mg-application levels. Grain yield response to exchangeable Mg indicated critical levels of 0.21 cmol/L and 0.24 cmol/L for peanut and soybean, respectively. Although the difference in these values is small, it is sufficient, when coupled with the possibly reduced Mg retention with higher lime rates, to explain the three-fold difference in optimum Mg-fertilizer rates between the two crops (Figure 26). The higher lime rate of the corn-soybean system resulted in lower exchangeable Mg and increased the soybean response to Mg rates. Thus, differences are probably not simply a case of soybean being more demanding of soil Mg than peanut.

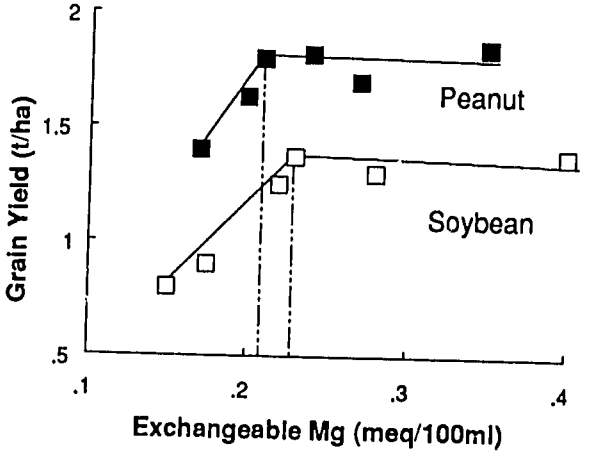

Figure 28. Critical levels of exchangeable Mg on grain yield in soybean and peanut at Sitiung.

Sulfur Fertilization

Soil analysis for sulfur is difficult and often unsuccessful in predicting the availability of that nutrient to crops. Climatic and soil conditions in Sitiung suggest that S may be limiting in these soils. The commonly used fertilizers, urea and triple superphosphate, do not have significant amounts of S, and, therefore, S deficiency seems likely, especially under continuous cultivation.

A trial to test this hypothesis was established at two locations, one on an Oxisol under cultivation for five years and one on a recently cleared Ultisol. Lime and base fertilizers to overcome possible crop growth limitations were applied at both locations. Three successive crops were grown, but none responded to S fertilization at either location (Table 19). The lack of response to S was not as surprising on the newly cleared soil with its higher organic content. However, it was expected that in the bulldozer-cleared soil which had been cultivated for five years and had no obvious source of S, any available sulfates would have been lost by leaching, crop uptake, or both. No response was obtained at this site either, indicating that there were still sufficient levels of available S in the soil.

Two possible explanations for this lack of response are that the soil may contain some sorbed S, which is not held very strongly and which readily resupplies the depleted soil solution, and that there may be S being deposited from fires in the region. Indonesian farmers commonly use fire to dispose of plant material, e.g., rice straw and stubble after harvest, overgrown and unpalatable grasses (especially *alang-alang*), and dried logs and forest products. Thus, off and on throughout the year, airborne S deposits are possible. No attempt was made, however, to measure either of these potential sources of S.

Table 19. Yield response of three successive crops to sulfur fertilization applied as $CaSO_4$ and $MgSO_4$ on both a recently cleared Ultisol and an Oxisol that had been cultivated for five years.

		Mungbean		Corn		Soybean	
Source	Rate	Recently cleared	Cultivated	Recently cleared	Cultivated	Recently cleared	Cultivated
	kg S/ha	t/ha					
—	0	0.176	0.028	5.85	3.65	2.70	1.91
$CaSO_4$	10	0.171	0.043	5.48	3.47	2.46	1.90
$CaSO_4$	20	0.160	0.037	4.94	3.62	2.50	1.90
$CaSO_4$	40	0.158	0.066	4.92	3.21	2.76	1.74
$MgSO_4$	20	0.236	0.037	5.48	·	1.96	2.30
$LSD_{0.05}$		ns	ns	ns	ns	ns	ns

Conclusions and Recommendations

Our original premise was that soils at Sitiung would respond to management in a predictable way, based on previous experience in the humid tropics and elsewhere. This premise was largely correct, with no surprises, after soil properties were characterized and interpreted. Instead of relying on data from other countries, this project generated the site-specific information that constitutes the backbone for management recommendations for sustainable and productive farming systems. Not all issues were tackled during the three-year period. Nevertheless, the available research information, coupled with the rich experience of farmers in whose fields most of the data were generated, permit the following conclusions and recommendations.

Reclamation of Soils Is Successful

Research results clearly demonstrate that the catastrophic devastation caused by improper land clearing in Sitiung can be readily reversed by judicious application of chemical inputs, turning massive soil degradation into sustainable food-crop production systems. The excellent clayey Oxisols and Ultisols of Sitiung, with their excellent granular structure, required only the addition of chemical inputs. Soil physical properties did not constrain crop growth even after straight-blade bulldozer land clearing. These results contrast sharply with experiences in reclaiming sandy Ultisols in the Amazon, where bulldozing created compacted soil layers, and both physical and chemical reclamation methods were needed to put soils back into food-crop production (Alegre et al. 1986a, 1986b). Similar difficulties have been experienced in sandy Alfisols of West Africa (Opara-Nadi et al. 1986). Clayey kaolinitic families of Oxisols, Ultisols and associated Inceptisols (Oxic Dystropepts) are less difficult to reclaim than other soils with different textures or mineralogies because of their strong granular structure. This consideration must be kept in mind when extrapolating the Sitiung findings to other regions where soils may be different.

Lime and Fertilizers Are the Key

The experimental work showed very clearly that lime and fertilizers are indispensable for sustained crop production. This is the case for bulldozed lands, where most of the low native fertility was removed along with the topsoil. This is also the case within a year after clearing the land by slash-and-burn. During the first year or so, bases added as ash decrease the need for lime. After this initial period, little, if any, yield of upland rice, corn, soybean, peanut or mungbean was possible without chemical inputs. Economic

returns to lime, phosphorus and potassium applications are very high. Magnesium is also needed unless dolomitic limestone is used. Javanese farmers are accustomed to applying fertilizer, and Indonesia has developed one of the most extensive fertilizer-manufacturing industries in the Third World. Liming, on the other hand, is relatively new in Indonesia because soil acidity has not been a major constraint. Flooding eliminates soil acidity in paddy rice systems; the main estate crops (rubber and oil palm) are acid-tolerant, and most upland crop production has been concentrated on non-acid soils.

Efficient Lime and Fertilizer Delivery Systems Are Needed

The physical infrastructure for providing local farmers with lime and fertilizers is in place in Sitiung, thanks to efforts by the Indonesian government to assist farmers in the region. Although the delivery system does not always function as well as it could due to a variety of problems, including impassable roads during continuous rains, authorities have attempted to remedy these problems. Recently, many of the roads and bridges in the region have been improved in an attempt to maintain traffic even during the most rainy periods of the year.

The use of lime and fertilizers would be unrealistic if there were no supply and distribution infrastructure. Like most tropical regions with acid soils, Sitiung has nearby lime deposits. There are mountains of limestone about 50 km from Sitiung along the Trans-Sumatran Highway. Lime crushers are now in operation in that area, making agricultural lime readily available. Indonesia is also a major producer of urea and triple superphosphate, and the transmigration program makes these, as well as potassium fertilizers, available to Sitiung farmers either free or at highly subsidized prices. With a large market in the capital city of Padang, and a governmental price support system, crop production beyond subsistence needs can readily be sold for cash income. Even when adequate fertilizer and lime supplies exist, however, farmers lack cash to purchase inputs and are reluctant to participate in credit programs. Therefore, although the physical infrastructure is there, it is sometimes not as effective as it could be.

Cash income is limited by low yields and by low prices for cash crops. The low yields of soybean, peanut and corn are due primarily to the acid, infertile soils, which require adequate liming and fertilizer inputs, pests (pigs, insects, rats, monkeys), and drought. Current low income from tree crops (cloves, coconut, coffee, rambutan) is due mainly to the low prices of these crops in the local markets. Farmers are unable to transport their produce to the large markets at Padang and often fall victim to exploitation by middlemen. Most farmers are reluctant to participate in government credit programs for fear of crop failure, which would result in their inability to repay loans.

Guidelines for Lime and Fertilizer Use

While efforts must be directed to improving fertilizer, lime and crop delivery systems, there are several management practices that can be implemented to increase the efficiency of the fertilizer and lime available to transmigrant farmers.

The initial free fertilizer allotment each new family received in Sitiung V was 3.5 t lime, 100 kg urea (46 kg N), 600 kg phosphate rock, and 100 kg triple superphosphate, providing a total of about 70 kg P. The farmers have one to two hectares of upland fields and home gardens they can use the fertilizer on. What is the best allocation of these resources?

A summary of critical soil test levels for the six upland crops is presented in Table 20. Such soil test levels indicate whether or not a specific nutrient or amendment should be applied, not how much is needed.

The six crops in the table can be grouped in three categories in terms of lime requirements: acid-tolerant (rice and cowpea), acid-sensitive (corn, peanut, soybean), and very acid-sensitive (mungbean). The critical levels of phosphorus fell within a relatively narrow range (10-17 ppm P), as did critical K levels (0.15-0.22 cmol/L) and critical Mg levels (0.21 to 0.28 cmol/L). Typical soil test values of Sitiung soils are also shown in Table 20. They clearly show the need for P, K and Mg

Table 20. Summary of soil test critical levels for the required lime and fertilizer nutrients for six main food crops in clayey Oxisols or Ultisols of Sitiung. Soil test for P and Mg by modified Olsen extraction, and for K by Mehlich I.

Soil test parameter	Typical Sitiung analysis	Critical levels					
		Upland rice	Soybean	Corn	Peanut	Mungbean	Cowpea
Al saturation(%)	88	70	15	29	28	5	55
P (ppm)	5	10	13	10	17	n.d.	n.d.
K (cmol/L)	0.10	0.20	0.16	0.22	0.22	0.20	0.20
Mg (cmol/L)	0.15	0.21	0.24	0.28	0.21	n.d.	n.d.

n.d. = not determined

fertilization and for liming of areas cropped with soybean, corn, peanut and mungbean.

Indicative lime and fertilizer recommendations per crop are shown in Table 21, based on the interpretation of critical soil test level and yield responses in field experiments (Table 20). A lime rate of about 0.5 t/ha was necessary for upland rice, both to reduce Al saturation slightly as well as to increase soil Ca levels. Lime rates for the other crops show a range, depending on actual exchangeable Al levels.

No nitrogen fertilization studies were conducted at Sitiung by North Carolina State University scientists. The requirements presented in Table 21 are based on other experiments, some done by Centre for Soils Research scientists and some by Food Crops Research Institute scientists. Soybean plants often need *Rhizobium japonicum* inoculation, while peanut and cowpea usually do well with indigenous rhizobia, but more research is needed in these areas.

All crops require phosphorus and potassium fertilization. The P requirement for rice is substantially lower than that of the other crops, while K requirements are approximately the same for all crops.

Magnesium fertilization varies with crop species. This need can be supplied by dolomitic limestone if available. If not, a fertilizer source such as $MgSO_4$ should be applied. Although no response to S was obtained, insufficient information exists to obviate the need for S fertilization, especially if crop yields are high. Deficiencies of Mn were observed in one experiment, and it is possible that other micronutrient deficiencies might occur in the region as well.

The above requirements should be viewed as general guidelines. Soil testing of specific sites in the local laboratory should be used for specific fertilizer recommendations.

Assemble Crop Rotations According to Fertility Requirements

Fertilizer recommendations for individual crops are not additive in crop rotations. Given the year-round growth conditions in Sitiung, crop rotation is not only advantageous but would help avoid weed buildups that may occur when no crop is grown. The results show that two crops per year are clearly feasible, with a fallow period during the June-August dry season. Often a short-duration crop, such as cowpea or mungbean, can be grown during the dry season, but due to the risk of drought, it is recommended that no fertilizers be applied to this crop.

The rotation should ideally consist of crops with similar lime requirements. However, one of the most common rotations used presently (rice-soybean) consists of an acid-tolerant and an acid-sensitive crop. In such a case, the lime program must be aimed at overcoming the needs of the acid-sensitive crop—soybean. Although the investment in lime will not be utilized very efficiently by the rice crop, farmer preference and government

Table 21. Initial inputs needed to satisfy lime and fertilizer requirements of six main food crops grown in clayey Oxisols and Ultisols at Sitiung. (Based on Table 20.)

Input	Upland rice	Soybean	Corn	Peanut	Mungbean (residual moisture)	Cowpea (residual moisture)
Lime (t/ha)[1]	0.5-1.5	4-5	3-5	3-5	5	1-3
N (kg N/ha)[2]	45	0	135	0	0	0
P (kg P/ha)[3]	20	80	80	80	80	80
K (kg K/ha)[4]	60	40	60	60	80	60
Mg (kg Mg/ha)[5]	8	24	32	8	n.d.	n.d.
S (kg S/ha)	0	0	0	0	0	0

n.d. = not determined

[1] Applying modified Cochrane formula for Sitiung (see liming chapter).

[2] Not based on local research; actual rates used in experiment.

[3] These are initial rates. Maintenance applications of 20 kg P/ha/crop were sufficient thereafter.

[4] These are both initial and maintenance rates for crops where residue was removed. Return of residues would permit these rates to be reduced.

[5] Unless dolomitic lime is utilized.

policies of soybean promotion result in this rotation. If started immediately after slash-and-burn clearing, the ash will supply sufficient Ca and Mg for rice growth. Lime applications should begin one year after clearing the forest, being applied before the Al-sensitive crops in the rotation are grown. Annual applications of lime at approximately 1/3 of the initial rate are required to keep soil acidity levels relatively constant.

A corn-soybean rotation would probably be more appropriate for a limed field. Mungbean would fit well into such a pattern, since it is the most acid-sensitive crop used in the area.

A true low-input cropping system that does away with the lime requirement would be very welcome in Sitiung. The rotation most nearly accomplishing this is rice-peanut, but peanut requires a lower Al saturation—28%, which definitely includes liming. Besides upland rice, the two other truly Al-tolerant crops are cowpea and cassava. Upland rice-cowpea is an obvious rotation which has been very successful in the Amazon. In Peru, when combined with crop-residue return and managed fallows, this rotation eliminated the need for liming and reduced phosphorus and potassium requirements substantially (Sanchez and Benites 1987). The major problem with this rotation is that transmigrant families prefer the more Al-sensitive legume crops, such as soybean, peanut or mungbean, to cowpea. Also, it is likely that some lime will be needed to supply Ca and Mg for rice and cowpea in bulldozed soils of Sitiung, because of the much lower levels of exchangeable Ca and Mg in these soils than those found in Yurimaguas, Peru (about 1.1 cmol/L of Ca and 0.6 of Mg). Upland rice-cassava is another possible rotation, but it probably necessitates some Ca and Mg fertilization as well.

Intercropping upland rice with cassava is sometimes practiced in Sitiung. More complex intercropping patterns, however, have been found to be of little interest to farmers as compared with a rotation of two crops per year.

Consequently, the following rotations can be recommended, depending on levels of inputs the farmers employ: rice-cowpea or rice-cassava for low-input systems; rice-peanut for medium-input systems; and corn-soybean, rice-soybean, corn-

peanut, corn-soybean-mungbean for high-input rotations. Corn, peanut and cassava, however, can only be grown in areas where wild pigs are not a major problem.

Decreasing Fertilizer Requirements with Organic-Input Management

The general fertilizer requirements on a per-crop basis can be decreased when considering the entire crop rotation. Several management practices can improve nutrient recycling and fertilizer-use efficiency. Research at Sitiung, plus recent information gathered in the Amazon and elsewhere, suggests the following possibilities: planting a legume fallow immediately after land clearing, returning all crop residues, improving nitrogen carryover from a grain legume to the subsequent cereal crop, and using green manures and managed fallows. Agroforestry and pasture options will be discussed separately.

Immediate Fallow Planting

Clearing of new lands should be done in a way that maximizes nutrient retention in the field. Slash-and-burn clearing or bulldozer clearing with a floating blade followed by burning are most effective because they least disturb the topsoil and provide nutrients in the ash. When large clearing operations are done several months before the settlers arrive, planting legume cover crops is recommended to protect the soil from erosion and weed encroachment, as well as to capture the nutrients released by the ash and decomposing vegetation. The system proposed by von Uexkull (1985) has now become part of the land-clearing specifications for land-clearing contracts awarded by the Indonesian government. It is a sound management practice to plant a legume cover on newly cleared soils that are not going to be immediately used by farmers.

Maximum Crop-Residue Return

Successful cropping systems, whether high- or low-input, include returning crop residues to the soil as a way of recycling nutrients accumulated by the straw or stover. This is not a common practice in Asia because rice straw is either removed or burned in paddy fields, and many crop residues are used for stall-feeding of animals kept in home gardens. When residues are removed, the fertility requirement of subsequent crops increases because nutrient recycling is then limited to root decomposition, which constitutes a small fraction of the crop's nutrient uptake.

The effect of residue return on potassium response can be seen in Table 14. Rice yielded 0.5 t/ha without K applications or crop-residue return, but when residues were returned, rice yields increased to 2.1 t/ha without K-fertilizer applications. According to response curves (Figure 17), this yield difference is equivalent to a K-fertilization rate of 40 kg K/ha. Consequently the K-recommended rates shown in Table 21 can be decreased by perhaps half with proper crop-residue return, thus increasing the efficiency of fertilizer K applications.

Potassium is not the only nutrient that is recycled by leaving the previous crop residue on the soil surface. Sanchez and Benites (1987) found that more than half the crop's biomass, N and Mg, about 90 percent of the K and Ca, and 37% of the P accumulated by a low-input upland rice-cowpea rotation were recycled to the soil.

Incorporating Green Manures in Rotations

Our experience with green manures showed many positive results, including temporary complexing of Al, increasing the availability of P, and supplying K and Mn to subsequent crops. Similar effects were also recorded in work in Peru (Wade and Sanchez 1983). All experiments were performed with plant materials gathered from outside the field. Realistic use of green manures require that they be grown *in situ* as part of the rotation. The obvious time is at the end of the rainy season, after harvest of the second crop, allowing the green manure crop to grow on residual moisture at a time when it is less desirable to grow other crops. Green manure species must be selected to fit the 90- to 100-day period available, as well as for Al-tolerance in low-input systems. One possibility is dense planting of cowpea, without a major consideration of grain yield. Other possibilities include Al-tolerant legumes such as *Calopogonium* sp., *Centrosema pubescens* or *C. macrocarpun*, *Pueraria phaseoloides*, or mucuna (*Stizolobium atter-*

rimum). A successful fit of a green manure crop in the various high-input or low-input rotations may decrease the need for lime, phosphorus, potassium and nitrogen considerably, as well as decrease weed control problems.

Managed Fallows

The recommended crop rotations—upland rice-soybean, upland rice-peanut, corn-soybean and corn-peanut—can probably be practiced indefinitely with the recommended initial and maintenance fertilizer applications coupled with maximum utilization of crop residues and green manures. Although the systems were studied for only three years at Sitiung, similar experience in Yurimaguas and Manaus in the Amazon suggests that such systems can be productive on a long-term basis. One factor that was not studied at Sitiung is weed encroachment. In Yurimaguas, Peru, it has been found that weed populations shift with continuous cropping, and some of the new weed species are very difficult to control by conventional herbicides or manual labor (Mt. Pleasant and McCollum 1987). Farmers may have other reasons for discontinuing production as well. In such cases, a managed fallow might be highly advantageous. In Yurimaguas, a one-year kudzu fallow eliminated the weed problem, kept the soil covered, and recycled some nutrients (Sanchez and Benites 1987). One year after the kudzu was planted, it was cut and burned, and low-input crop production was resumed. This practice may be an important option in Sitiung as well.

Fertility Management of the Rotations

The lowest-input rotation is probably rice-peanut, ideally with a green manure crop in the dry season. Phosphorus fertilization is highly recommended for the low-input system. Between 40 and 80 kg P/ha on previously unfertilized soil (in the absence of soil analysis) should be a sufficient amount. If rock phosphate has been applied, as has been done at some transmigration locations, this initial application could be omitted. Thereafter, 20 kg P/ha/year should be adequate maintenance if residues are recycled. An annual application of 250 to 500 kg/ha of dolomitic lime would also be recommended. Potassium fertilizer may be needed, depending on soil condition and residue management. A relatively small application of 20 to 40 kg K/ha/crop should suffice unless K depletion has been serious. Rice would probably be more responsive to K than peanut, both in growth and in disease (rice blast) resistance, whereas peanut would be more responsive to lime. Nitrogen fertilization is needed for rice (approximately 50 kg N/ha), but the amount could decrease if a green manure were grown and incorporated before the rice crop.

The high-input rotation could very well start with upland rice as the first crop after manual clearing and burning, without chemical inputs. Then a soybean-corn rotation could follow with two crops per year, with either a mungbean or a green manure crop during the dry season. Liming to decrease Al saturation to 15% would be necessary prior to planting soybean. A broadcast application of 80 kg P/ha and 60 kg K/ha should be used. No fertilizers should be applied for the dry season crop. Corn would then be planted the next rainy season with a maintenance application of 20 kg/ha of P and K, plus an amount of N fertilizer dependent on estimates of N carryover from the previous dry season crop. Liming should not be necessary the second year, but prior to the third soybean planting, lime should be applied at 1/3 the original rate.

Establishing a Soil Testing Service

The above recommendations are guidelines to be used in the absence of soil analysis. Experience elsewhere has shown that such services are extremely cost effective; thus, we recommend the establishment of a soil testing service which, if performed on a selected basis and combined with records kept by farmers, could be a very effective method of determining proper fertilizer needs. The actual credit for fertilizer and lime inputs could be tied to soil analysis results. Recommendations based on periodic soil testing will make maximum use of available lime and fertilizer resources and, if combined with the appropriate use of organic inputs, give realistic hope for sustained crop production in Sitiung.

Research Needs

Management Options

Figure 29 illustrates the main landscape-soil combinations found in upland transmigration areas of the Outer Islands, with several management options for sustained productivity. Wherever there are poorly drained soils or possibilities of irrigation, rice paddies will receive top priority, even if terracing is required in undulating areas. Crop- and soil-management practices for *sawah* (paddy rice) production are well advanced in Indonesia.

Upland food-crop rotation, both high-input and low-input, occupies several landscape positions, including rolling terrain where terraces of some sort are needed. The work described in this report focuses on these two options. Estate crops, particularly rubber, are also well established with available soil-management technology in the region.

Two important options, pastures and agroforestry, have not been studied in detail at Sitiung

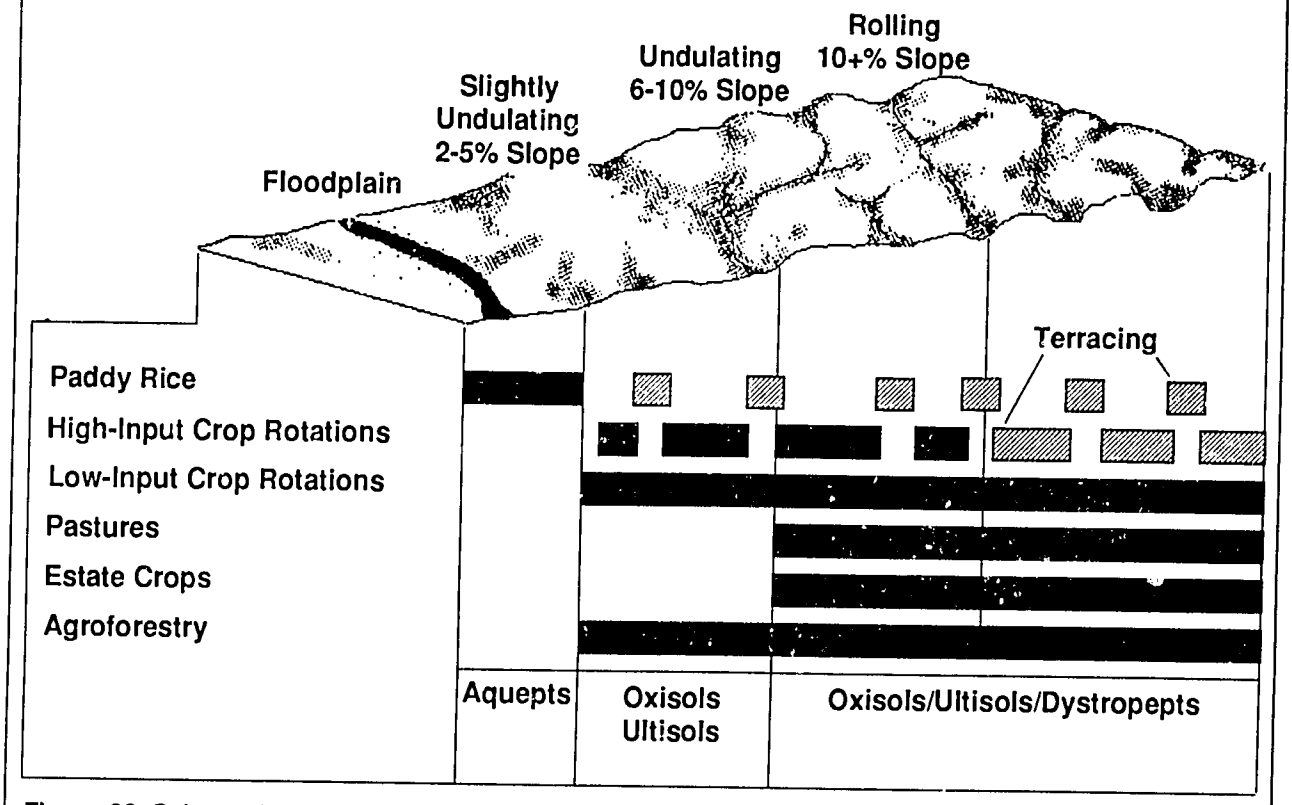

Figure 29. Schematic view of topography and associated soils common to outer islands of Indonesia, with management options appropriate to each group. Concept by H. Subagjo and P.A. Sanchez.

from the soil-management standpoint. There are also gaps in our knowledge of upland cropping. Further research is needed on the following:

High- and Low-Input Cropping

Field selection of soybean, corn and peanut cultivars for acid-soil tolerance. Germ plasm should be collected from a wide variety of sources and tested in the field at low and high levels of soil acidity (20 and 80% Al saturation, for example). A simple method for such field testing has been developed by Nicholaides and Piha (1987).

Determine nutrient requirements of other acid-tolerant crops. Cassava is a major crop in the region, and its nutrient requirements should be quantified. Acid-tolerant sorghums are beginning to become a reality in Latin America (Gourley and Salinas 1987). They may provide another low-input crop and an important source of feed for poultry.

Establish fertilizer nitrogen requirements for cereal crops. Little research on N fertilization has been conducted to date. Nitrogen requirements for upland rice (at low lime levels) and corn (at high lime levels) should be established, in rotation with grain legume and green manure crops. The N carryover of the grain legume crops and green manures should be determined in order to quantify fertilizer N requirements.

Determine rhizobium inoculation needs of grain legume crops. Soybean plants are very specific in rhizobium requirements, while peanut and cowpea are less specific. It is important to ensure that biological N fixation is effective in the various green legume crops grown in Sitiung.

Determine the long-term residual effects of lime and phosphorus fertilization. This can be achieved by continuing some of the ongoing trials. Further observation on subsoil fertility improvement through downward movement of Ca and Mg is strongly recommended. This should be linked with research on water stress. Phosphate rock is now being used in Sitiung. On-site comparisons with superphosphates should be conducted.

Green manures should be included in crop rotations. Appropriate species must be selected, and their effects on soil-fertility parameters in subsequent crops should be determined.

Crop-residue management will require further study to quantify the potential for nutrient cycling and to adjust fertilizer recommendations accordingly.

Weed control problems should be quantified and appropriate control recommendations made. Practices to prevent the spread of *alang-alang* that have proven successful in other parts of Indonesia should be validated at Sitiung.

Managed fallows should be studied, selecting candidate species for acid soil tolerance, speed of ground cover development, root production, and litter quality.

Sulfur and micronutrient problems are likely to appear sporadically. Studies should be conducted in areas where symptoms develop, most likely on the most fertility-demanding crops, soybean and corn.

After crop rotations are assembled, including residue return, green manures and perhaps managed fallows, the *long-term sustainability should be documented* along with changes in soil physical, chemical and biological problems.

Pastures and Forages

Although most farmers in Sitiung I have cattle, farmers in recent settlements have yet to receive their cattle from the government. Currently each farmer is given a cow with the condition that two calves be returned to the government within five years. The advantages of livestock over food and cash crops include lower production costs in terms of labor and inputs, and reduced risks, since livestock production is less affected by rainfall variability and timely inputs.

Farmers in Sitiung I appreciate the advantages of their cattle, which are used for land preparation and as an investment. In addition, most farmers use the manure on their home gardens and crop lands. Animals are sold to generate cash for school fees, medical expenses, purchase of inputs, and food. It is interesting to note that of the ten farmers interviewed by Fernandes and Fernandes (1986), the only farmer who did not mention lack of cash and fertilizers as constraints to productivity had a small herd of five cows. He used manure to

supplement fertilizer inputs, and over the years had sold several animals from his gradually expanding herd. Improved fodder grasses had been planted in and around the boundaries of the home garden.

Although disease is apparently not a problem, most of the cattle in Sitiung appear to be in poor condition. This is not surprising considering the scarcity of fodder resources, which consist mainly of grasses and weeds harvested from the roadsides and croplands.

Grazing of pastures by ruminants is an important management option in the humid tropics. It is particularly attractive in areas with acid soils because (1) there are many grass and legume species very well adapted to acid soils under low inputs, (2) the grazing animal feeds and transports itself, and (3) the grazing animal recycles most of the nutrients to the soil, producing valuable meat and milk products for farmers. Because of land constraints in Java, most transmigrants have adopted the system of stall-feeding cattle, goats and tropical sheep, which are kept enclosed virtually throughout their lives. Feeding forage to caged ruminants depletes nutrients in the soils on which the forage is grown. Large quantities of nitrogen and potassium are removed, carried away by considerable manual labor, with little, if any, return to the soil. The long-term result is a gradual decrease in the quality of the forage and a subsequent decline in animal nutrition. The main beneficiary of this system is the home garden, where the manure is applied.

Cattle-grazing in pastures is found in other parts of Indonesia, such as Bali, but not in Sitiung. Although farmers are given one cow as part of the original settlement package, it is unrealistic to expect grazed pastures when the farmer has only two to three hectares to cultivate. The idea of communal grazing areas apart from the individually alloted land has been mentioned by AARD scientists as a possible option. If such an intention exists, a pastures research program could be developed with germ plasm and management guidelines from CIAT's Tropical Pastures Program. Such guidelines have resulted in highly productive and persistent pastures in the Amazon, where no N is needed and more than 80% of the P,

Ca and K applied as fertilizer is recycled back to the soil (Ayarza et al., in press). CIAT germ plasm screening, begun at Sitiung by Thompson et al. (1987), constitutes the initial step in a pastures research program.

Agroforestry

Agroforestry, the use of woody perennial species in conjunction with crop and livestock production, is a very attractive concept for the humid tropics. Agroforestry research in acid soils of the humid tropics is in its infancy. In 1986, the TropSoils Management Entity requested a study of agroforestry research needs in Sitiung. This study was conducted by Fernandes and Fernandes (1986). The following comments are taken from their report.

Agroforestry is important in both the farmers' home gardens, as well as their cultivated fields. All the transmigrant farmers at Sitiung have spontaneously developed agroforestry-based home gardens, involving multistoried mixtures of trees, annual crops and stall-fed livestock. This diversity in the home gardens not only supplements the production from the cropland but also minimizes risk of crop failure. Recent studies have shown that home gardens account for 44% of total agricultural production (Colfer et al. 1986; Chapman 1984) and provide between 28 and 60% of total cash value of agricultural produce in the various communities in Sitiung. It is important to note that the develop-

ment of these home gardens has been based mainly on the farmers' previous experience. Scientists observed that most of the home gardens are producing well below their potential. There are few plants available that are adapted to acid soils. In addition, many farmers were landless and inexperienced before their arrival in Sitiung.

In general, the home gardens (*pekarangan*) comprise a complex, multistoried mixture of perennials, annuals and livestock. Their proximity to the house facilitates intensive management, including the application of manure, ashes and kitchen waste, and most are an important source of both food and income (Colfer et al. 1986). These home gardens are a classic example of the agroforestry approach to home gardens in the tropics (Fernandes and Nair 1986). An inventory of plant species in the home gardens of ten farm families interviewed identified 36 woody perennials and 19 herbaceous species (Table 22). Although mature home gardens (8-10 years old) are characterized by a predominance of perennials and fewer species of intercropped annuals, large sections of younger home gardens may be planted in upland rice, peanut, cowpea and cassava (Colfer et al. 1986).

Five major potential areas of agroforestry research in Sitiung were identified by Fernandes. Four were at the farm level: alley-cropping, live fences, fodder production, and high-value tree-crop enterprises. The fifth area involves community-level projects. Alley-cropping work has been initiated by Carl Evensen and associates of the University of Hawaii (Evensen et al. 1987).

Alley-cropping with fast-growing, Al-tolerant, N-fixing woody perennials in hedgerows along the contours will address one or more of the following issues: reducing Al toxicity via complexing of Al by freshly added leaf and woody material; recycling leached nutrients from fertilizers added to crops by the more deeply rooted woody species; minimizing cropland erosion, especially on slopes, via formation of natural terraces; providing a high-protein fodder supplement for livestock; providing fuelwood, all of which is currently obtained from surrounding natural forests.

Albizia falcataria and *Calliandra calothyrsus* have been tested at Sitiung and show potential for use as alley-cropping species (Evensen et al. 1987). The good performance of *Inga edulis* on acid soils in Yurimaguas, Peru, warrants its inclusion in trials at Sitiung. *Inga* appears to be more suitable where fuelwood production is a major function of the woody hedgerows. One benefit of growing these species is that, should an invasion of *alang-alang* (*Imperata cylindrica*) occur, the alley crops could be permitted to grow and shade out the grass, since it is quite shade intolerant.

Live fences can be used on field boundaries to minimize wild pig damage to crops such as corn, cassava, and peanut. Apart from the labor to establish the live fences, little maintenance would be required, and the fences could be managed to produce green manures, mulch, or fodder.

Closely planted, easy-to-grow species such as *Gliricidia sepium*, *Albizia falcataria*, and *Calliandra calothyrsus* should be tried. In addition to being an excellent live fence, *Peronema canescens* (known locally as *sungkai*) could be managed to produce good-quality poles. Other potential live-fence species include *Ceiba pentandra* and *Jatropa curcas*. These can be propagated vegetatively from cuttings, similar to *Gliricidia*, but they are not as suitable for green manure.

Pasture production in home gardens and on upland fields can be intensified. Most transmigrant home gardens are currently devoted to woody perennials for food and cash and a few annual crops. There is, however, good scope for pasture production on currently underutilized boundary areas. Although shade-tolerant grasses could also be used in the understory, local farmers prefer to keep the ground bare in home gardens because of a deep-rooted fear of snakes.

Woody species with potential for fodder production on farm boundaries include *Gliricidia sepium*, *Codariocalyx gyroides* (*Desmodium gyroides*), and *Desmodium rensonii*.

Cash-crop enterprises using trees in home gardens could be enhanced. Species with potential, but currently used only on a limited scale, include

clove (*Syzigium cumini*), rambutan (*Nephelium lappaceum*), coconut (*Cocos nucifera*), durian (*Durio zibethinus*), and mangosteen (*Garcinia mangostana*). Moderately shade-tolerant high-value species, such as vanilla and black pepper, should also be investigated.

At the community level: If farmers in each Sitiung community agreed to pool their promised 0.75-ha plots, their cash crop and livestock feed needs could be addressed by a tree crop/grazing system.

A promising option appears to be a community rubber plantation with grazing of the cover crops (*Pueraria phaseoloides*, *Calopogonium mucunoides*, *Calopogonium caeroleum*, and *Centrosema pubescens*). Additional land would be required for grass/legume pastures. The possibility of the government allocating adequate additional land to each community for such a plantation should not be overlooked.

Small ruminants such as goats are very suitable sources of animal protein. Goats have several advantages including high milk production, sturdiness, and an ability to thrive on a wide variety of feeds. With goats, as compared to cattle, there are also more animal units per unit of feed, thus spreading risk and increasing sales opportunities over cattle enterprises. The annual demand for goats for the celebration of Ramadan by the predominantly Muslim population offers good scope for an economically profitable goat-rearing enterprise. If they are left unmanaged, however, goats can become a nuisance in agricultural areas.

A latex processing plant already exists near Sitiung, and the economic returns from rubber appear promising. Each administrative unit could have its own rubber plantation, planted and tapped on a communal basis. Tapping could be undertaken by women, thereby increasing their involvement in cash-generating off-farm labor. A communal herd of goats or sheep could be allowed to graze the cover crops in a rotation. Rotational grazing coupled with greater than normal spacing of the rubber trees would be required to ensure adequate persistence of the cover crops.

There is good potential for the development of community-owned, rotationally grazed pastures containing a mixture of woody legumes and pasture grasses. The government could allocate a suitable amount of land to each community. Although this is a different approach than Javanese farmers normally use, the potentially high returns to labor would be a powerful incentive. Legume-based pastures developed at Yurimaguas should be tested at the grazing level.

Agroforestry has great potential for regions such as Sitiung. Integrated correctly into a farming system, these species offer a variety of benefits, such as greater erosion control, control of weeds like *alang-alang* (*Imperata cylindrica*) by shading, and improved nutrient cycling, in addition to the many products they produce. Perennial species which are well adapted to the climate and soils of the area can be highly productive without the use of large inputs and can improve prospects for long-term sustainability.

Table 22. Common plants in Sitlung home gardens. Source: Fernandes and Fernandes 1986.

Species	English name	Indonesian name	Uses
Woody perennials			
Albizia falcataria	albizia	jeungjing	green manure, fuel
Anacardium occidentale	cashew	jambu-mete	fruit
Anona muricata	soursop	sirkaya	fruit
Areca catechu	beetle nut	jambe	masticant
Artocarpus heterophyllus	jackfruit	nangka	fruit, vegetable, boundary
Averhoa bilimbi	bilimbi	bilimbing	fruit, vegetable
Averhoa carambola	carambola	karambola	fruit
Bambusa spp.	bamboo	bambu	building material
Cajanus cajan	pigeon pea	-	food seed
Calliandra calothyrsus	calliandra	kaliandra	green manure, fuel
Camellia sinensis	tea	teh	beverage
Carica papaya	papaya	papaya	fruit
Ceiba pentandra	kapok	kapok	fiber, fuelwood, boundary
Citrus spp.	citrus	jeruk	fruit, cash crop
Cocos nucifera	coconut	kelapa	food nut, fiber
Coffea robusta	coffee	kopi	cash crop, beverage
Crotalaria sp.	crotalaria	krotolaria	green manure
Durio zibethinus	durian	durian	fruit
Elettaria cardamomum	cardamom	kapulaga	spice, cash crop
Erythrina spp.	erythrina	dadap	live fence, local medicine
Eugenia aquea	water apple	jambu air	fruit
Eugenia caryophyllus	clove	cengkeh	cash crop, spice
Garcinia mangostana	mangosteen	manggis	fruit
Gliricidia sepium	gliricidia	gamal	live fence, fodder, green manure
Gnetum gnemon	-	melinjo	food seed, vegetable
Jatropa curcas	jatropa	jarak, pagar	live fence, local medicine
Lansium domesticum	duku	duku	fruit
Leucaena leucocephala	leucaena	lamtoro	green manure, boundary, fodder
Mangifera foetida	mango	mangga	fruit, condiment
Nephelium lappaceum	rambutan	rambutan	fruit
Parkia javanica	parkia	petai	vegetable pods, fodder, green manure
Pithecellobium jiringa	stinkbean	jengkol	vegetable seeds
Psidium guajava	guava	jambu biji	fruit
Sesbania grandiflora	-	turi	vegetable, green manure, fuel
Peronema canescens	-	sungkai	live fence, poles
Tamarindus indica	tamarind	pohon asam	condiment
Herbaceous annuals and perennials			
Ananas comosus	pineapple	nenas	fruit
Arachis hypogeae	peanut	kacang, tanah	food seed, cash crop
Capsicum spp.	chili	cabe	spice, vegetable
Colocasia esculenta	taro	talas	food
Curcurma domestica	turmeric	kunyit	spice
Glycine max	soybean	kedelai	food seed, cash crop
Ipomoea aquatica	swamp cabbage	kangkung	vegetable
Ipomoea batatas	sweet potato	ubi jalar	food
Manihot esculenta	cassava	ubi kayu	food
Musa spp.	banana	pisang	fruit
Oryza sativa	paddy rice	padi sawah	food
	upland rice	padi gogo	food
Pachyrrizus erosus	yam bean	bengkuang	vegetable
Phaseolus aureus	mungbean	kacang, hijau	vegetable
Piper betel	betel leaf	sirih	chewed with *Areca*
Saccharum officinarum	sugar cane	tebu	food
Solanum melongena	eggplant	terung	vegetable
Vigna sesquipedalis	long bean	kacang, panjang	vegetable
Vigna unguiculata	cowpea	kacang, tunggak	food
Zea mays	maize	jagung	food

References

Adams, F. 1984. Crop response to lime in the Southern United States. In *Soil acidity and liming*, ed. F. Adams, 211-259. Madison, Wisconsin: Am. Soc. Agronomy.

Agus, F., M. K. Wade, and J. Prawirasumantri. 1985. *Effects of post-clearing methods on soil properties and crop production*. TropSoils/ Indonesia Field Research Brief, no. 18. Bogor, Indonesia: Centre for Soils Research.

Alegre, J. C., and D. K. Cassel. 1986. Effects of land clearing methods and post-clearing management on aggregate stability and organic carbon content of a soil in the humid tropics. *Soil Sci.* 142:289-295.

Alegre, J. C., D. K. Cassel, and D. E. Bandy. 1986a. Effects of land clearing and subsequent management on soil physical properties. *Soil Sci. Soc. Am. J.* 50:1379-1383.

Alegre, J. C., D. K. Cassel, and D. E. Bandy. 1986b. Reclamation of an Ultisol damaged by mechanical land clearing. *Soil Sci. Soc. Am. J.* 50:1026-1031.

Alegre, J. C., D. K. Cassel, and A. K. Makarim. Strategies for restoration of degraded lands. In *Land clearing and development for sustainable agriculture: An inaugural workshop*. IBSRAM, Bangkok, Thailand. In press.

Al-jabri, and M. K. Wade. 1985. *Lime reaction rate and effectiveness*. TropSoils/Indonesia Field Research Brief, no. 10. Bogor, Indonesia: Centre for Soils Research.

Ayarza, M. A., R. Dextre, and P. A. Sanchez. Persistence of grass legume mixtures under grazing. In *TropSoils technical report 1986-1987*, ed. N. Caudle, and C. B. McCants. Raleigh: North Carolina State University. In press.

Bandy, D. E., and P. A. Sanchez. 1986. Post-clearing soil management alternatives for sustained production in the Amazon. In *Land clearing and development in the tropics*, ed. R. Lal, P. A. Sanchez, and R. W. Cummings, Jr., 347-367. Rotterdam: Balkema.

Cassel, D. K., A. K. Makarim, and M. K. Wade. 1987. Reclamation of bulldozed lands. In *TropSoils technical report 1985-1986*, ed. N. Caudle, and C. B. McCants, 122-124. Raleigh: North Carolina State University.

Centre for Soils Research. 1979. Soil survey of the irrigation project area, Sitiung-S. Jujuhan (West Sumatra). Ministry of Agricultural Research and Development, Indonesia.

Chapman, B. 1984. *Diet and production survey of Sitiung, West Sumatra*. TropSoils/Indonesia Field Research Brief, nos. 2 and 3. Bogor, Indonesia: Centre for Soils Research.

Christanty, L., J. Iskandar, and O. Abdoelah. 1982. Homegarden and its possibilities for implementation in transmigration areas. Paper presented for the TropSoils CRSP Lecture Series, University of Hawaii, August 1982.

Cochrane, T. T., J. G. Salinas, and P. A. Sanchez. 1980. An equation for liming acid mineral soils to

compensate for crop aluminum tolerance. *Trop Agric. (Trinidad)* 57:133-140.

Cochrane, T. T., and P. A. Sanchez. 1982. Land resources, soils and their management in the Amazon region: A state of knowledge report. In *Amazonia: Agriculture and land use research*, ed. S. B. Hecht, 137-210. Cali, Colombia: Centro Internacional de Agricultura Tropical.

Colfer, C. J., C. Evensen, S. Evensen, F. Agus, D. Gill, and M. K. Wade. 1986. Transmigrants' homegardens: A neglected research opportunity. Laporan Tahunan 1984-85. Bogor, Indonesia: Centre for Soils Research.

Cravo, M. S., and T. J. Smyth. 1987. Lime requirements and downward movement of calcium and magnesium. In *TropSoils technical report 1985-1986*, ed. N. Caudle, and C. B. McCants, 102-106. Raleigh: North Carolina State University.

Dent, F. J. 1980. Major production systems and soil-related constraints in Southeast Asia. In *Priorities for alleviating soil-related constraints to food production in the tropics*, 79-106. Los Banos, Phillippines: International Rice Research Institute.

Evensen, C., R. S. Yost, and M. K. Wade. 1987. Management of organic materials in Indonesia farming systems. In *TropSoils technical report 1985-1986*, ed. N. Caudle, and C. B. McCants, 184-186. Raleigh: North Carolina State University.

Fernandes, E. C. M. Agroforestry research needs. In *TropSoils technical report 1986-1987*, ed. N. Caudle, and C. B. McCants. Raleigh: North Carolina State University. In press.

Fernandes, E. C. M., and E. M. Fernandes. 1986. *Agroforestry research needs at transmigration sites in Sitiung, West Sumatra, Indonesia.* Raleigh: North Carolina State University, Soil Science Dept.

Fernandes, E. C. M., and P. K. R. Nair. 1986. An evaluation of the structure and function of some tropical homegardens. *Agricultural Systems* 21:179-310.

Fox, R. L., and E. J. Kamprath. 1970. Phosphate sorption isotherms for evaluating the phosphate requirement of soils. *Soil Sci. Soc. Am. Proc.* 34:902-906.

Foy, C. D. 1984. Physiological effects of H, Al and Mn toxicities in acid soils. In *Soil acidity and liming*, ed. F. Adams, 57-86. Madison, Wisconsin: Am. Soc. Agronomy.

Friesen, D. K., A. S. R. Juo, and M. H. Miller. 1982. Residual value of lime and leaching of calcium in a kaolinitic Ultisol in the high rainfall tropics. *Soil Sci. Soc. Am. J.* 46:1184-1189.

Gill, D. W. 1988. Response of upland crops to potassium at three levels of aluminum saturation in the humid tropics of West Sumatra. Ph. D. thesis, North Carolina State University, Raleigh.

Gill, D. W., E. J. Kamprath, J. J. Nicholaides III, and M. K. Wade. 1985. Potassium dynamics in cropping systems of weathered soils of West Sumatra, Indonesia. In *TropSoils triennial technical report 1981-1984*, ed. C. B. McCants, 45-50. Raleigh: North Carolina State University.

Gill, D. W., A. Kasno, and E. J. Kamprath. Response of upland crops to potassium and lime applications. In *TropSoils technical report 1986-1987*, ed. N. Caudle, and C. B. McCants. Raleigh: North Carolina State University. In press.

Gill, D. W., A. Kasno, and J. Sri Adiningsih. 1985a. *Response of upland rice and soil K levels to K fertilization and green manure applications at Sitiung V.* TropSoils/Indonesia Field Research Brief, no. 8. Bogor, Indonesia: Centre for Soils Research.

Gill, D. W., A. Kasno, and J. Sri Adiningsih. 1985b. *Response of soybeans and soil K levels to K fertilization and green manure applications at Sitiung V.* TropSoils/Indonesia Field Research Brief, no. 13. Bogor, Indonesia: Centre for Soils Research.

Gill, D. W., and J. Sri Adiningsih. 1986. Response of upland rice and soybeans to potassium fertilization, residue management and green manuring in Sitiung, West Sumatra. *Pembr. Penel Tanah dan Pupuk* 6:26-32.

Goodland, R. J. A., and H. S. Irwin. 1975. *Amazon jungle: Green hell to red desert?* Amsterdam: Elsevier.

Gourley, L. M., and J. G. Salinas, eds. 1987. *Sorghum for acid soils.* Cali, Colombia: CIAT.

Heriyadi, and M. K. Wade. 1985. *Effects of green manures on food crop response to lime and P fertilization.* TropSoils/Indonesia Field Research Brief, no. 2. Bogor, Indonesia: Centre for Soils Research.

Hue, N. V., G. R. Craddock, and F. Adams. 1986. Effect of organic acids on aluminum toxicity in subsoils. *Soil Sci. Soc. Am. J.* 50:28-34.

Kamprath, E. J. 1970. Exchangeable aluminum as a criterion for liming leached mineral soils. *Soil Sci. Soc. Am. Proc.* 34:252-254.

Kamprath, E. J., M. K. Wade, and Heriyadi. 1985. *Sulfur responses and reaction in soils of Sumatra.* TropSoils/Indonesia Field Research Brief, no. 17. Bogor, Indonesia: Centre for Soils Research.

Lal, R., P. A. Sanchez, and R. W. Cummings, Jr., eds. 1986. *Land clearing and development in the tropics.* Boston: A. A. Balkema Press.

Lopes, A. S., T. J. Smyth, and N. Curi. 1987. The need for a soil fertility reference base and nutrient dynamics studies. In *Management of acid tropical soils for sustainable agriculture*, ed. P. A. Sanchez, E. R. Stoner, and E. Pushparajah. IBSRAM Proc. 2:147-166. Bangkok, Thailand.

Makarim, A. K. 1985. Effects of land reclamation management practices on crop production and physical and chemical properties on a tropical soil. Ph. D. thesis, North Carolina State University, Raleigh.

Makarim, A. K., D. K. Cassel, and J. J. Nicholaides III. 1963. Reclamation of unproductive, abandoned land. In *TropSoils triennial technical report 1981-1984*, ed. C. B. McCants, 37-40. Raleigh: North Carolina State University.

Makarim, A. K., D. K. Cassel, and M. K. Wade. Effects of land reclamation and management practices on physical properties of a tropical soil. In press.

Mt. Pleasant, J., and R. E. McCollum. 1987. Weed population shifts under continuous cropping systems. In *TropSoils technical report 1985-1986*, ed. N. Caudle, and C. B. McCants, 65-66. Raleigh: North Carolina State University.

Nair, P. K. R., and E. C. M. Fernandes. 1986. La agrosilvicultura como alternativa a la agricultura migratoria. In *Sistemas mejorados de producción como alternativa a la agricultura migratoria*, 183-197. Servicio de Recursos, Manejo y Conservación de Suelos. Dirección de Fomento de Tierras y Aguas. Rome: Food and Agriculture Organization.

Nicholaides, J. J., and M. I. Piha. 1987. A new methodology to select cultivars tolerant to aluminum and with high yield potential. In *Sorghum for acid soils*, ed. L. M. Gourley, and J. G. Salinas, 103-116. Cali, Colombia: CIAT.

North Carolina State University. 1976. Agronomic-economic research on soils of the tropics. Annual Report for 1975. Raleigh: North Carolina State University, Soil Science Dept.

Opuu-Nadi, O. A., R. Lal, and B. S. Ghuman. 1986. Effects of land clearing methods on soil physical and hydrological properties in Southwestern Nigeria. In *Land clearing and development in the tropics*, ed. R. Lal, P. A. Sanchez, and R. W. Cummings, Jr., 215-226. Rotterdam: Balkema.

Ritchey, K. D., D. M. G. Sousa, E. Lobato, and O. Correa. 1980. Calcium leaching to increase rooting

depth in a Brazilian savanna Oxisol. *Agron. J.* 32:40-44.

Ross, M. S. 1986. The development and current status of landclearing for transmigration in Indonesia. In *Land clearing and development in the tropics*, ed. R. Lal, P. A. Sanchez, and R. W. Cummings, Jr., 119-130. Boston: A. A. Balkema Press.

Rumawas, F. 1987. Reclamation of degraded acid tropical soils in Indonesia. In *Management of acid tropical soils for sustainable agriculture*, ed. P. A. Sanchez, E. R. Stoner, and E. Pushparajah. IBSRAM Proc. 2:205-216. Bangkok, Thailand.

Sanchez, P. A. 1979. Soil fertility and conservation considerations for agroforestry systems in the humid tropics of Latin America. In *Soils research in agroforestry*, ed. H. O. Mongi, and P. A. Huxley, 79-124. Nairobi, Kenya: International Council for Research in Agroforestry.

Sanchez, P. A. 1987. Management of acid soils in the humid tropics of Latin America. In *Management of acid tropical soils for sustainable agriculture*, ed. P. A. Sanchez, E. R. Stoner, and E. Pushparajah. IBSRAM Proc. 2:63-108. Bangkok, Thailand.

Sanchez, P. A., D. E. Bandy, J. H. Villachica, and J. J. Nicholaides. 1982. Amazon Basin soils: Management for continuous crop production. *Science* 216:821-827.

Sanchez, P. A., and J. R. Benites. 1983. *Opciones tecnologicas para el manejo racional de suelos de la Selva peruana.* Estacion Experimental de Yurimaguas, Serie de Separatas, no. 6. Yurimaguas, Peru: INIPA.

Sanchez, P. A., and J. R. Benites. 1987. Low-input cropping for acid soils of the humid tropics. *Science* 238:1521-1527.

Sanchez, P. A., and S. W. Buol. 1980. Trip report to Indonesia and Sri Lanka by the Soil Management CRSP Planning Team, February 19-March 5, 1980. Raleigh: North Carolina State University, Soil Science Dept.

Sanchez, P. A., W. Couto, and S. W. Buol. 1982. The fertility-capability soil classification system: Interpretation, applicability and modification. *Geoderma* 27:283-309.

Sanchez, P. A., and J. G. Salinas. 1981. Low-input technology for managing Oxisols and Ultisols in tropical America. *Advances in Agron.* 34:279-406.

Sanchez, P. A., J. H. Villachica, and D. E. Bandy. 1983. Soil fertility dynamics after clearing a tropical rainforest in Peru. *Soil Sci. Soc. Am. J.* 47:1171-1178.

Santoso, D., and A. Sofyan. 1984. Penelitian pangelolaan tanah Podsolik. Program TropSoils. Laporan Tahunan 1982-83. Bogor, Indonesia: Pusat Penelitian Tanah.

Seubert, C. E., P. A. Sanchez, and C. Valverde. 1977. Effects of land clearing methods on soil properties on an Ultisol and crop performance in the Amazon jungle of Peru. *Trop. Agric. (Trinidad)* 54:307-321.

Smyth, T. J., and J. B. Bastos. 1984. Alterações na fertilidade em un latossolo amerelo álico pela quema da vegetaçao. *R. Bras. Ci. Solo* 8:127-132.

Smyth, T. J., M. Cravo, and J. B. Bastos. 1987. Soil nutrient dynamics and fertility management for sustained crop production on Oxisols of the Brazilian Amazon. In *TropSoils technical report 1985-1986*, ed. N. Caudle, and C. B. McCants, 88-94. Raleigh: North Carolina State University.

Subagjo, H. Soil characterization along a transect away from volcanic ash sources in Sumatra. Ph. D. thesis, North Carolina State University, Raleigh. In preparation.

Subagjo, H., and S. W. Buol. Volcanic ash influence in transmigration areas of Sumatra. In

TropSoils technical report 1986-1987, ed. N. Caudle, and C. B. McCants. Raleigh: North Carolina State University. In press.

Sudjadi, M., J. Sri Adiningsih, and D. W. Gill. 1985. Potassium availability in soils of Indonesia. In *Potassium in the agricultural systems of the humid tropics*, 157-168. 19th Colloquium of the International Potash Institute, Bangkok, Thailand. Berne, Switzerland: International Potash Institute.

Suwardjo, A. 1986. Land development for transmigration areas in Sumatra and Kalimantan. In *Land clearing and development in the tropics*, ed. R. Lal, P. A. Sanchez, and R. W. Cummings, Jr., 131-140. Boston: A. A. Balkema Press.

Thompson, J. R., C. Evensen, R. S. Yost, R. Guyton, I. P. G. Widjaja-Adhi, and F. Agus. 1987. Pasture grasses and legumes for the humid tropics. In *Tropsoils technical report 1985-1986*, ed. N. Caudle, and C. B. McCants, 181. Raleigh: North Carolina State University.

Trangmar, B. B., R. S. Yost, M. K. Wade, G. Uehara, and M. Sudjadi. 1987. Spatial variation of soil properties and rice yield on recently cleared land. *Soil Sci. Soc. Am. J.* 51:668-674.

von Uexkull, H. R. 1985. Managing Acrisols in the humid tropics. In *Problem soils in Asia*. Food and Fertilizer Technology Center Book Series 27:382-397. Taipei, Taiwan.

Wade, M. K., and Al-jabri. 1985a. *Phosphorus fertilization and maintenance*. TropSoils/Indonesia Field Research Brief, no. 9. Bogor, Indonesia: Centre for Soils Research.

Wade, M. K., and Al-jabri. 1985b. *Phosphorus fertilization and maintenance*. TropSoils/Indonesia Field Research Brief, no. 10. Bogor, Indonesia: Centre for Soils Research.

Wade, M. K., C. J. P. Colfer, and D. Santoso. 1985. Farmer and researcher designed and managed cropping systems. In *TropSoils triennial technical report 1981-1984*, ed. C. B. McCants, 67-70. Raleigh: North Carolina State University.

Wade, M. K., Heriyadi, and D. W. Gill. 1987. Effect of green manure applications on soil fertility and crops. In *TropSoils technical report 1985-1986*, ed. N. Caudle, and C. B. McCants, 134-137. Raleigh: North Carolina State University.

Wade, M. K., Heriyadi, and Martono. 1985. Soybean variety evaluation. In *TropSoils triennial technical report 1981-1984*, ed. C. B. McCants, 63-65. Raleigh: North Carolina State University.

Wade, M. K., E. J. Kamprath, Heriyadi, Al-jabri, E. Joniarta, and F. Agus. 1987. Liming in transmigration areas. In *TropSoils technical report 1985-1986*, ed. N. Caudle, and C. B. McCants, 125-131. Raleigh: North Carolina State University.

Wade, M. K., E. J. Kamprath, and D. Santoso. 1985a. Residual and maintenance rates of lime. In *TropSoils triennial technical report 1981-1984*, ed. C. B. McCants, 55-58. Raleigh: North Carolina State University.

Wade, M. K., E. J. Kamprath, and D. Santoso. 1985b. *Residual and maintenance rate of lime.* TropSoils/Indonesia Field Research Brief, no. 15. Bogor, Indonesia: Centre for Soils Research.

Wade, M. K., and P. A. Sanchez. 1983. Mulching and green manure applications for continuous crop production in the Amazon Basin. *Agron. J.* 75:39-45.

Wade, M. K., and D. Santoso. 1985a. *Phosphorus rates and methods of application.* TropSoils/ Indonesia Field Research Brief, no. 3. Bogor, Indonesia: Centre for Soils Research.

Wade, M. K., and D. Santoso. 1985b. *Phosphorous rates and methods of application.* TropSoils/Indonesia Field Research Brief, no. 14. Bogor, Indonesia: Centre for Soils Research.

Wade, M. K., D. Santoso, Al-jabri, and I. P. G.

Widjaja-Adhi. 1987. Phosphorus management in transmigration areas. In *TropSoils technical report 1985-1986*, ed. N. Caudle, and C. B. McCants, 131-134. Raleigh: North Carolina State University.

Wade, M. K., and A. Sophian. 1985. Source and method of lime application. In *TropSoils triennial technical report 1981-1984*, ed. C. B. McCants, 51-54. Raleigh: North Carolina State University.

Whitten, A. J., S. J. Damanik, J. Anwar, and N. Hisyam. 1985. *The ecology of Sumatra.* Yogyakarta, Indonesia: Gadjah Mada University Press.

Yost, R. S., E. J. Kamprath, E. Lobato, and G. C. Naderman. 1979. Phosphorus response of corn to an Oxisol as influenced by rates and placement. *Soil Sci. Soc. Am. J.* 43:330-343.