Soil Fertility Constraints in Indonesia and Methods of Improvement

M. Sudjadi*
and Suryatna Effendi*²

ABSTRACT

The major soil orders found in Indonesia consist of Ultisols, Oxisols, Histosols, Inceptisols and Vertisols. The total area covered by these soil orders is about 130million hectares or slightly more than 68% of the total land area.

Soil fertility constraints have a major influence on distribution of the population in Indonesia.

Constraints associated with Ultisols and Oxisols result from a low level of plant nutrients, low cation exchange capacity and high acidity as well as phosphorus deficiency and aluminium toxicity. Liming is needed for bulldozer-cleared lands and lands cultivated for more than one year. Lime application at the rate of 0.3 to 1.0t/ha is needed for upland rice in bulldozed soils, while mungbaen requires as much as 5t lime/ha. The critical Al-saturation levels are: 5 % for mungbean, 15% for soybean, 28% for peanut, 29% for corn, 55% for cowpea and 70% for rice.

Phosphorus fertilizers are necessary to overcome the extremely low levels of available P in Ultisols and Oxisols. Applications of 20 to 80kg P/ha are sufficient to fertilize crops in rotation. The residual effect lasts at least two years and the economic return of phosphorus fertilization is high.

For the reclamation of Histosols, shallow drainage ditches at frequent intervals are more suitable than relatively few deep drainage canals. Lime application is needed when pH values are below 4. The application of nitrogen, phosphorus, potassium and trace elements gives striking results.

Andosols are high phosphate fixers. To achieve a high efficiency for P application, a high rate of P is suggested. Although in Vertisols the phosphorus availability is generally low, there is no fertilize each crop with phosphorus.

Introduction

The Indonesian archipelago consists of about 13,600 islands of which 990 are inhabited. From the 190million hectares of the land surface of Indonesia only 21million or 11% of the total area used for agricultural production, 5.3million for perennial crops and 15.7million hectares for annual crops. Of the latter area about 4.8million hectares are irrigated.

The soils which are the most intensively used for agriculture are Oxisols, Ultisols, Histosols, Inceptisols, and Vertisols. The least intensively used areas are covered with soils which are very extensive in Indonesia namely the Ultisols and the Histosols.

Wetland rice is cultivated on the fertile soils with adequate water availability and suitable relief in Java, Bali, Lombok, West Sumatra, North Sumatra, Aceh and South Sulawesi, or on other lowland areas where the water conditions are favourable.

The Outer Islands of Indonesia, Sumatra, Kalimantan, Sulawesi and Irian Jaya, are sparsely populated and largely covered by tropical rainforests on acid soils which according

*Principal Research Officer, CSAR, Jln. Juanda 98 Bogor, Indonesia.
*²Director, Center for Soil and Agroclimate Research, Indonesia.

to the FAO/UNESCO legend (1975) are called Acrisols and Ferrasols and named as Ultisols and Oxisols in the U. S. Soil Taxonomy. Agriculture on these soils consists primarily of either small-scale shifting cultivation or large-scale tree plantations. Ultisols, Oxisols and Histosols cover 55% of the total area of Indonesia when the population density is the lowest, in sharp contrast with the island of Java, which has a population of approximately 95million people.

This paper reports on the soil fertility constraints on some major soil in Indonesia and their methods of improvement.

The major soils of Indonesia

Indonesia has a wide diversity of soils as would be expected in a country with such a diverse range of geology, relief and climate. In this paper the description of major soils which have obvious constraints such as Ultisols, Oxisols, Histosols, Inceptisols and Vertisols is summarized.

Ultisols

Ultisols cover about 71.48million hectares or 37.5% of the total land area. Ultisols constraints are characterized by low nutrient levels, presence of exchangeable aluminum, and nitrogen losses through leaching under high rainfall. Characterization data of a very fine, kaolinitic, isohyperthermic Typic Paleudult are shown in Table 1. Shifting cultivation is often practiced on this soil type where acidity, aluminum saturation and low phosphorus content are limiting factors for use. Applications of fertilizer and lime are required for sustained production. Ultisols are sensitive to erosion and they are easily damaged by compaction and loss of surface soils, when heavy equipment is used for deforestation. With proper management they can be made productive but require careful handling. Ultisols occur extensively in Sumatra, West Java, Kalimantan, Sulawesi and Irian Jaya.

Table 1 Soil profile data and classification of soils in Sitiung (Wade, *et al.*, 1988)

Depth (cm)	Clay	Silt	Sand	Org. C	Free Fe	Bulk density	Exchangeable				ECEC	Al	pH	
							Ca	Mg	K	Al			H_2O	$CaCl_2$
Taxonomy : Clayey, Kaolinitic, Isohyperthemic Typic Haplortox.														
	……%……					g/cm³	……cmol/L……					%		
0—11	88	7	5	1.4	7.3	0.93	0.1	t	t	3.1	3.2	97	3.9	3.8
11—40	90	6	4	1.3	7.4	1.10	0.1	0.1	0.1	3.0	3.3	91	4.0	3.9
40—73	90	6	4	0.9	7.2	1.00	0.1	t	t	2.1	2.2	95	4.3	4.2
73—102	89	7	4	0.7	7.9	0.95	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	0.1	t	t	1.6	1.7	94	4.5	4.2
154—200	85	11	4	0.5	7.1	0.99	0.1	0.1	t	1.3	1.5	87	4.6	4.3
Taxonomy : Very fine, Kaolinitic, Isohyperthermic Palaeudult														
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	0.1	0.1	0.1	2.2	2.5	88	4.5	4.0
34—62	61	10	29	0.6	3.7	1.28	t	t	t	1.8	1.8	100	4.5	4.2
62—106	62	10	28	0.5	3.6	1.27	0.1	0.1	t	1.5	副.7	88	4.8	4.2
106—142	64	10	26	0.4	3.9	1.26	t	t	—	1.6	1.6	100	5.0	4.3
142—180	64	13	23	0.3	4.3	1.24	t	t	—	1.7	1.7	100	5.0	4.3

Oxisols

Oxisols are strongly and deeply weathered soils, with a clay fraction consisting of kaolinite and sesquioxides (low activity variable charged-clays). They have a low inherent fertility but good physical properties and a low erodibility index. Constraints of Oxisols include low level of plant nutrients, low cation exchange capacity and weak retention of bases applied as fertilizers or amendments, and strong fixation and deficiency of phosphorus on fine-textured soils (Dudel, 1980). Oxisols are found in Kalimantan, Northern Sumatra and parts of Sulawesi and Irian Jaya. Because of their low fertility status, Oxisols are often used for shifting cultivation. When fertility levels can be improved they are suitable for the cultivation of a wide variety of food and estate crops.

Histosols

Histosols are formed from organic material which accumulates under the influence of prolonged waterlogging. These soils cover an estimated ares of 24million hectares, and are distributed mainly along the southern coast of Irian Jaya, the southern, western and eastern coasts of Kalimantan and the eastern coast of Sumatra (Sudjadi, 1984). The natural fertility of the Histosols largely depends on their chemical composition and the extent of their decomposition. The nitrogen content of most Histosols is very high, but the N which is combined in lignoproteins is not directly available to plants. Table 2 shows the chemical characteristics of a Fibric Histosol from Sei Rasau (West Kalimantan).

Major constraints on agricultural production in these soils include waterlogging, low bearing capacity, weak foothold for plants, subsidence upon drainage, frequent microelement deficiencies-e.g. copper and irreversible shrinking of the organic matter upon drying (Soepraptohardjo and Driessen, 1976). Histosols can overlie sulphidic materials which make them susceptible to strong acidification when drained. Development of such kind of Histosols requires special management and constant control of the water level.

Table 2 Chemical characteristics of a Fibric Histosol from Sei Rasau, West Kalimantan, Indonesia (M. Sudjadi, 1984)

Depth below surface	Texture			pH		Org. C	N	P Sol.in 25% HCl	K Sol.in 25% HCl	Exchangeable Cations				CEC
	Sand	Silt	Clay	H_2O	KCl					Ca	Mg	K	Na	
……cm ……	………%………					………%………		mg/100g		………cmol/L………				
0—30	15	57	28	3.2	2.7	48.7	1.73	21	24	1.1	3.2	0.7	0.1	133.5
30—130	12	59	29	3.6	3.3	47.9	0.84	7	10	0.3	2.5	0.4	0.6	125.7
130—350	62	35	3	3.0	3.0	1.1	0.02	5	41	1.5	1.1	0.0	0.1	6.4

Inceptisols

Andosols (Great Soil Group of Inceptisol) are developed from volcanic ash under humid conditions ; they are characterized by the presence of amorphous hydrated oxides in the clay fraction ; they have a high cation exchange capacity and a high moisture retention, and often a high level of organic matter. Andosols strongly fix phosphates. They often occur at higher altitudes and are therefore suitable for crops which require cool climate conditions. Andosols are widely spread in Java, Bali, the central part of west Sumatra and Northern Sulawesi.

Vertisols

Vertisols are soils formed from heavy clay which swells and shrinks with changing moisture conditions. Constraints of vertisols are related to their physical properties and moisture regime. Their heavy texture and the presence of expanding-type clay minerals result in a very narrow range between moisture stress and water excess. Tillage is hampered by stickiness when the soils are wet and hardness when dry. Base saturation is high, with calcium and magnesium dominating in the sorptive complex (Dudal, 1980). Phosphorus availability is generally low. These soils are usually used for growing wetland rice and sugarcane. Vertisols found in Central and East Java and in Lombok are used for growing rice (Soepraptohardjo and Suhardjo, 1978).

Methods for improvement of constraints of Ultisols and Oxisols

Major soil fertility constraints on agricultural development in Ultisols and Oxisols are a high level of Al saturation, acidity, and low P-content.

Representative profiles (Table 1) show the low pH values and the presence of more than 60% Al saturation to a depth of 60cm. To study the crop tolerance acidity, a series of liming trials was conducted on Oxisols and Ultisols in Sitiung, West Sumatra. The four major upland food crops responded to applied lime on mechanically cleared soils. 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 peanuts (Fig. 1). Figure 2 illustrates the differences in the crop tolerance to Al saturation based on a number of experiments on Ultisols and Oxisols with the six crops.

Although specific critical Al-saturation values varied somewhat depending upon the crop

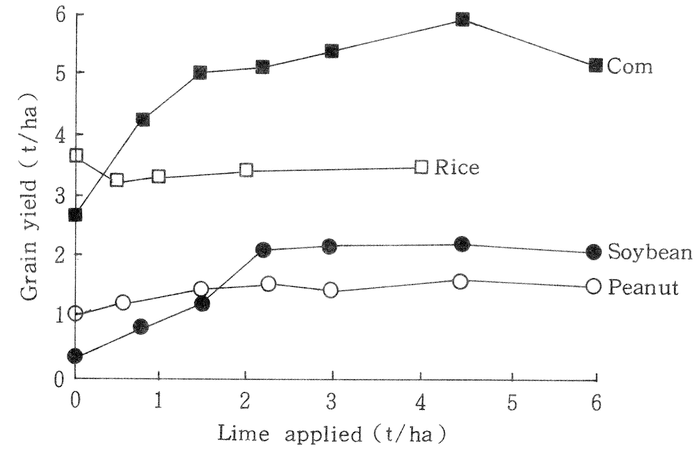

Fig. 1 Yield response to lime of four common food crops grown in bulldozer-cleared Oxisols and Ultisols of Sitiung (Wade, *et al.*, 1988).

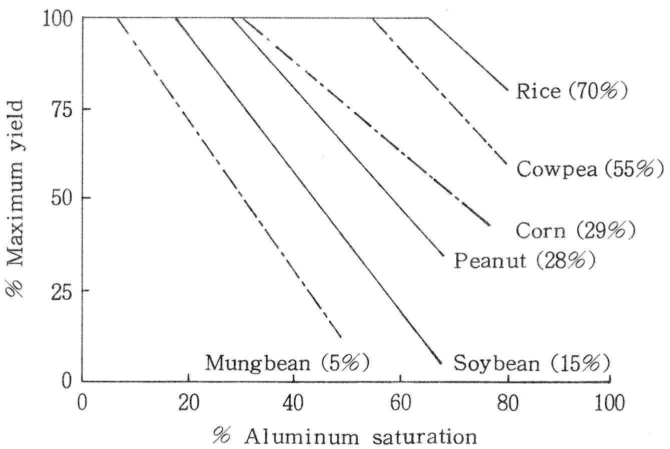

Fig. 2 Relationship between maximum grain yield of six crops and aluminum saturation in Oxisols and Ultisols in Sitiung. Numbers in parentheses are critical Al-saturation levels (Wade, *et al.*, 1988)

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 (Fig.2). Yields of those crops declined sharply once the critical level of Al saturation was surpassed, (Wade *et al.*, 1988).

No lime was needed even for acid-sensitive crops immediately 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.

Severely degraded, unproductive Oxisols resulting from improper bulldozer 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 (Fig. 3 and 4). Low levels of chemical inputs increased the basic cation level, decreased Al saturation to 43% and increased the amount of available P and K sufficiently to produce upland rice yields averaging 1.8t/ha. (Table 3). The total inputs levels were 1.5t/ha of lime, 120N, 39P, 73K,

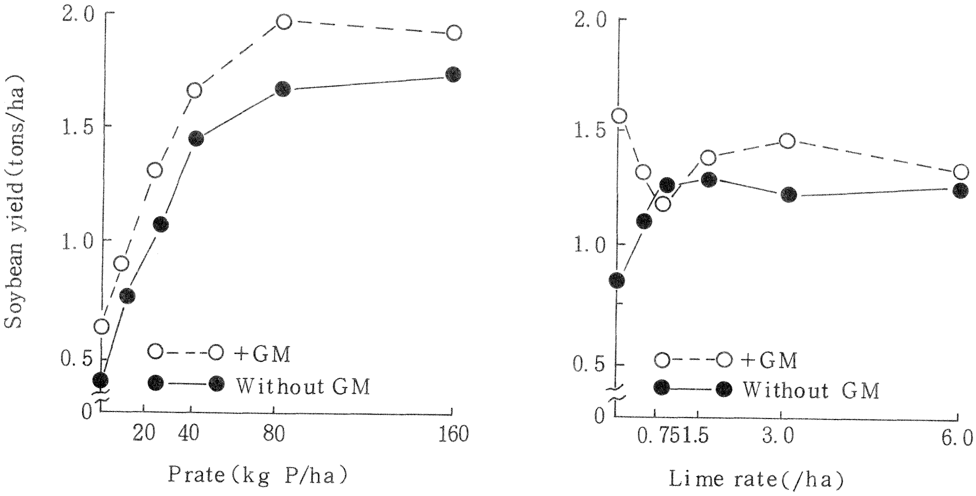

Fig. 3 Effect of green manures (GM) on the response of soybean to P and lime application on an Ultisol in Jambi, Sumatra.

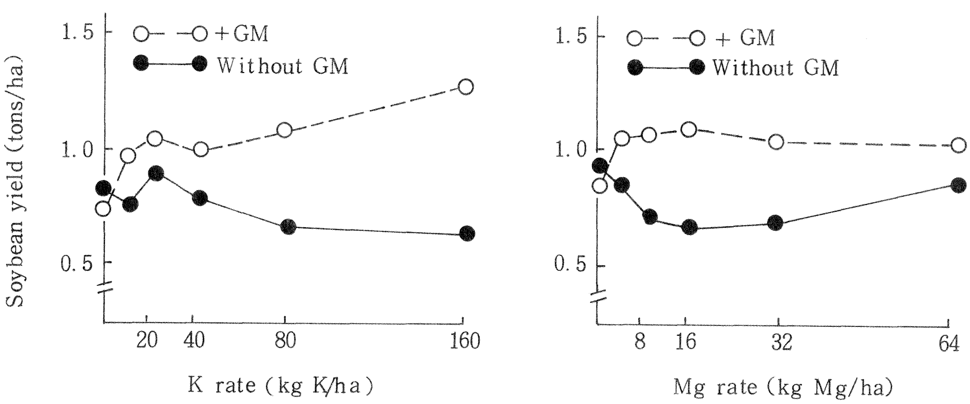

Fig. 4 Effect of green manures (GM) on the response of soybean to K and Mg application on an Ultisol in Jambi, Sumatra.

Table 3 Soil chemical properties (0-15cm) one year after beginning the land reclamation study

Chemical input treatment	pH	Exchangeable			ECEC	Al sat.	Avail. P
		Al	Ca+Mg	K			
		···meq/100ml···				%	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

Source : MaKarim, 1985.

70Mg, 93S, 1Cu and 4.5Zn in kg/ha as urea, triple superphosphate, KCl, $MgSO_4$, Cu SO_4 and Zn SO_4, respectively.

In contrast, soybean required a high chemical-input treatment to achieve maximum yields of 2.3t/ha. A high chemical treatment for an entire rice-soybean rotation during the first year consisted of 6.8t/ha of lime, 150kg N/ha (for rice), 567kg P/ha, 295kg K/ha, 140kg Mg/ha, 187kg S/ha and the same level of micronutrients as in Fl. These rates improved the chemical fertility of the soil. Soil pH reached a level of 5.7, exchangeable Al was neutralized, the content of Ca, Mg and K increased, and that of available P increased, perhaps to excessively high levels (Table 3).

Because this soil consists mainly of variable-charge minerals, raising pH from 3.9 to 5.7 increased the effective cation-exchange capacity by 30%.

Management of phosphorus deficiency

Phosphorus deficiency is one of the most widespread constraints of Oxisols and Ultisols in Indonesia. Table 4 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 160kg P/ha, but few farmers may have the cash or access to sufficient credit to buy that much fertilizer at one time (800kg P/ha of triple superphosphate). A more conservative approach might be to add 40kg P/ha initially and follow with 20kg/ha/crop as a maintenance. The most efficient P fertilization option is to broadcast an initial application of 40kg P/ha.

Table 4 Effect of selected P treatments on relative yield, net return, and rate of return to P fertilizer of four crops in a rotation (Wade, *et al.*, 1988)

P applied		Relative yield					Net return[1]	Rate of return
Initial + Maintenance	Total	Corn 1	Soy 1	Corn 2	Soy 2	Mean		
······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	20	70	75	86	91	80	1780	22
40+20	60	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.

Tables 5 and 6 show the results of experiments with different phosphate rocks as related to triple superphosphate, using upland rice and soybean as test crops on an Ultisols and an Oxisol in Sumatra. The results indicated that most of the phosphate rocks tested are more effective than triple superphosphate. Some also showed that they have a greater residual effect than TSP.

Table 5 Yield of upland rice grown on an Ultisol in Terbanggi using different sources of phosphorus

Kg P/ha	P Source				
	TSP	gNcPR		uNCPR	gJPR
	....	....	t/ha	....	....
0			1.5		
10	3.0	2.6		2.5	2.6
20	3.5	3.4		2.8	3.1
40	3.8	3.6		3.7	3.5
120	3.9	3.9		3.8	3.9

TSP = triple superphosphate
gNCPR = ground North Caroline PR
uNCPR = unground North Caroline PR
gJPR = ground Jordanian PR

Table 6 Yield of upland rice in rotation with soybean grown on an Oxisol in Lampung

P-Source	Yields of upland rice and soybean			
	Planting Season			
	I	II	III	IV
	....	.... t/ha	....	....
No-P	0.4	0.3	0.5	0.2
TSP	1.4	1.1	2.6	0.5
Tunisian-RP (g)	1.3	0.5	2.6	0.5
Tunisian-RP (n)	1.1	0.7	2.5	0.4
Tunisian-RP (f)	1.6	0.8	2.5	0.6
Christmas-RP	0.9	0.7	2.2	0.4

Cropping seasons I and III : upland rice
Cropping seasons II and IV : soybean
P aplied = 80kg P/ha at the beginning of growing season I
g = granular
n = natural
f = fine

Methods for improvement of constraints of Histosols

The transformation of virgin forest peat into high quality agricultural land involves a complex amelioration process which normally takes several years. According to Polak (1952) clearance of the forest vegetation should be followed by drainage, de-acidification and fertilization. However, she reported that these processes may produce subsidence of the land of 1m or more in the first year.

A generally applicable method for the reclamation of peat cannot be given, as it depends on the properties and thickness of the peat and the water regime. Burning is usually the first step, but this should be limited as much as possible, since it not only causes considerable peat losses, but field experiments have shown that the nutrients liberated by burning alone are not sufficient for good crop production. As a rule, the drainage depth should be as shallow as possible to reduce peat losses. Shallow drainage ditches at frequent intervals are more suitable than relatively few deep drainage canals. Lime should be applied where pH values are below pH 4, as liming increases not only the microbial activity, but also the availability of some micronutrients. The application of nitrogen, phosphorus, potassium and trace elements gives striking results.

Copper deficiency is common in newly reclaimed peat soils, and is often called "reclamation disease". Polak (1948 and 1952) reported that in her experiments, rice on reclaimed peat which received $CuSO_4$ developed well filled grains, in marked contrast to the rice which did not receive copper. Farmers in the Rokan watershed in Sumatra have reported that more than two-thirds of the panicles of irrigated rice grown on deep peat remained empty.

Several practices may improve the soil-water conditions in the root zone and do not necessarily require expensive and large reclamation work, including continuous leaching of the soil, temporary interruption of irrigation, covering or mixing the root zone with mineral soil and liming. Continuous leaching with fresh water, preferably river water, improves the oxygen supply and, if good quality water is used, lowers the level of soluble organic substances and adds macro-and micronutrients to the plant.

Covering the peat with a thin layer of mineral soil is a common practice in certain peat areas, and farmers in Tanjung Segumai, Kampar watershed, Sumatra, have claimed that they were able to obtain normal rice yields on deep peat covered with 10-20cm of levee soil (Driessen and Sudjadi, 1981).

Methods for improvement of constraints of Inceptisols

The presence of amorphous hydrated oxides in Andosols induces a very high phosphate-fixing capacity in Hydric Dystrandepts in West Java. Manuelpillai *et al.* (1981) reported the response to lime and potassium of soybean grown on Dystrandepts in West Java. The authors reported that experiments on three successive soybean crops initially supplied with P and lime averaged accumulated yields of 6t/ha over the three crops. An increasing response to P became significant with the third crop. Decreasing availability of P was perhaps due to P sorption on the soil complex.

Leiwakabessy *et al.* (1973) indicated that among the 15 soil groups tested, Andosols showed the highest fixation figure. The fixation capacity of a Brown Andosol from Bogor was 97% and was constant to an application of up to 600ppm P. The same authors suggested that to achieve a high efficiency of P application a higher rate of P should be applied at least at a rate which could saturate fixation capacity.

Methods for improvement of constraints of Vertisols

Aside from the physical constraints such as heavy texture, tillage which is hampered by stickiness when the soils are wet and hardness when dry, Vertisols used for rice and sugarcane have fertility constraints related to N and P deficiency.

Studies made on farmers' fields on Vertisols indicate that higher yield and economic returns are possible with deep-placed urea than with prilled urea applied in the conventional broadcast manner.

In the mid-seventies about 500,000ha of Vertisols in East Java were found to be P-deficient. However, recent trials conducted by the Center for Soil and Agroclimate Research on P-deficient Vertisols indicated that there is significant evidence of P "buildup" on the soils that had been subjected to P fertilization after more than 15years. As a consequence the recommended rate for P application can be reduced. Depending on the P status of the soil 50 to 125kg of triple superphosphate are recommended for lowland rice.

References

1) Dudal, R. (1980): Soil related constraints to agricultural development in the tropics. *In* : Properties for alleviating soil related constraints to food production in the tropics. Int. Rice Res. Inst. Los Banos, Laguna, Philippines.
2) Driessen, P.M. and Sudjadi, M. (1981): Soils and specific soils problems in tidal swamps. Int. Worksh. on Res. Priorities in Tidal Swamp Rice. IRII and AARD, Indonesia.
3) Leiwakabessy, F.M., Koswara,O. and Sudjadi,M. (1973): Preliminary study on P-fixation of major soil groups in Java. Proc. of the Second Asean Soil Conference Vol.II. Soil Res. Inst. Bogor, Indonesia.
4) Makarim, A.K. (1985): Effects of land reclamation management practices on crop production and physical and chemical properties on tropical soil Ph. D. thesis, North Carolina State University, Raleigh.
5) Manuelpillai, R. G., Sudjadi, M., Putu G, I., Widjaja-Adhi and Sholeh, M. (1984): Soybean (*Glycine max*) responses to applications of P, K and lime and the residual effects of P and lime in hydric dysterandepts of West Java. Trop. Agric. (Trinidad), 61, No. 1.
6) Polak, B. (1948): Landbouw op veengronden. Landb. 20.
7) Polak, B. (1952): Veen en veenontginning in Indonnesia. M. I. A. I. No. 5 and 6 Bandung, Indonesia.
8) Soepraptohardjo, M. and Driessen, P. M. (1976): The lowland peats of Indonesia, a challenge for the future. Proc. ATA. 106, Midterm Seminar, Soil Res. Inst. Bogor.
9) Soepraptohardjo, M. and Soehardjo, H. (1978): Rice soils in Indonesia, *In* Soils and Rice. The Int. Rice Res. Inst. Los Banos, Philippines.
10) Sudjadi, M. (1984): Problem soils in Indonesia and their management. F. F0 T. C. Book Series No. 27. Problem soils in Asia.
11) Wade, M. K., Gill, D. W., Subagjo, H., Sudjadi, M. and Sanchez, P. (1988): Overcoming fertility constraints in a transmigration area in Indonesia. Tropsoils Bull. No. 88-01 North Carolina State Univ. Raleigh.

Discussion

Young, A. (ICRAF) : I am certain that the farmers who take part in your resettlement (transmigration) schemes have a difficulty in applying high-input technologies and you stated that to do so requires a heavy and continuing government subsidy. On the sloping lands with Ultisols and Oxisols, do you believe that it is pnssible to develop low-input systems of land use?

Answer : I agree with you that it will be very difficult for the farmers to cultivate the sloping land using low inputs to maintain a sustainable system. In particular, when those farmers are originally coming from a flat area with hmited experience, care should be taken not to recommend the farmers to use low-input technology. In this regard, alley cropping may be a suitable practice.

Toledo, J. M. (CIAT) : The high-input level may be excessive for most of the crops, while the low-input fertilizer level may be deficient for most of them. Instead of considering high or low inputs, we should promote the efficient use of inputs both economically and ecologically. You have discussed technologies to change the soil properties. It may be preferable to change the plants to adapt them to acid poor soils in order to reduce the application of fertilizers.

Answer : I agree with your first comment. It would be a challenge for our plant breeders to develop crops that can adapt to acid soil conditions. Under the Indonesian conditions, there are old varieties that are tolerant to acidity. Breeding programs should aim at looking for better varieties with higher-yielding capacity.