Nutrient Balance and Economic Analyses of P Fertilization on an Acid Upland Soil in Sumatra

Neraca hara dan analisis ekonomi dari pemupukan P pada tanah kering masam di Sumatera

SANTOSO, D.[1], I G.P. WIGENA[1], J. PURNOMO[1], AND R.D.B. LEFROY[2]

ABSTRACT

Soil and crop responses to P fertilization were assessed for seven seasons, from rainy season 1997/1998 until rainy season 2000/2001, in a field experiment at Pauh Menang village of Jambi province, Indonesia. An incomplete factorial combination of six levels of inorganic P (0, 19, 38, 57, 76 and 95 kg P ha^{-1} as SP-36), two sources organic matters (FYM and stylo), and lime, was laid out in a randomized complete block design with four replicates. The soil in this site was very P deficient and application of 38 kg P ha^{-1} increased corn yields significantly from less than 1.0 to about 3.5 t ha^{-1} for the first four crops. The higher rates of applied P didn't increase further corn yields, indicating that external P requirement was fulfilled. A build-up and maintenance rate of banded application of SP-36 that required in this soil was 38 and 19 kg P ha^{-1}, respectively. Broadcast application for the entire topsoil layer in a plot or farmland would require considerably larger amount of P fertilizer for building up of P level than the banded application. The balances of P treatments were all positive and substantiated by the increasing Colwell P content of the soil with increasing rate of applied P. Although no apparent symptom of Zn deficiency was observed, the Zn content in plant leaf decreased with increasing rate of applied P. By assuming all labour costs as cash costs in conducting economic analyses to calculate the B/C ratios, in general only the SP-36 treatments gave beneficial returns. Although many of the B/C ratios were less than 1.0, the amount of total benefits that could be earned by farmers were considerably high because the total production costs included all labour costs.

ABSTRAK

Respon tanah dan tanaman terhadap pemupukan P dipelajari selama tujuh musim, dari musim hujan 1997/1998 sampai musim hujan 2000/2001, dengan sebuah percobaan lapang di Desa Pauh Menang Propinsi Jambi, Indonesia. Kombinasi faktorial tidak lengkap dari enam tingkat P anorganik (0, 19, 38, 57, 76 dan 95 kg P ha^{-1} sebagai SP-36), dua bahan organik (FYM dan stylo), dan kapur, telah digunakan dalam rancangan acak lengkap dengan empat ulangan. Tanah di lokasi ini sangat defisien P dan pemberian 38 kg P ha^{-1} meningkatkan hasil jagung sangat nyata dari kurang 1,0 menjadi 3,5 t ha^{-1} untuk empat musim tanam pertama. Takaran-takaran pupuk P yang lebih tinggi tidak meningkatkan hasil jagung lebih lanjut, menandakan bahwa keperluan P eksternal telah terpenuhi. Untuk meningkatkan dan memelihara kandungan P tanah yang tinggi, takaran pupuk SP-36 dengan penempatan dilarik adalah berturut-turut 38 dan 19 kg P ha^{-1}. Peningkatan kandungan P yang merata untuk seluruh tanah lapisan atas akan memerlukan jauh lebih banyak pupuk P dibandingkan dengan penempatan dilarik. Neraca hara P untuk semua perlakuan adalah positif dan hasil ini diperkuat dengan peningkatan kandungan Colwell P tanah sejalan dengan meningkatnya takaran pupuk P. Meskipun tidak ada gejala-gejala defisiensi Zn teramati di lapang, kandungan Zn dalam daun jagung menurun dengan peningkatan takaran pupuk P yang diberikan. Dengan menganggap semua upah buruh sebagai upah tunai dalam melakukan analisis ekonomi untuk menghitung rasio B/C (*benefit-cost* = keuntungan dibanding biaya), pada umumnya hanya perlakuan-perlakuan dengan SP-36 yang memberikan keuntungan. Meskipun banyak perlakuan yang memberikan rasio B/C kurang dari 1,0, sebenarnya keuntungan yang dapat diterima petani cukup besar karena biaya produksi dihitung secara keseluruhan, dimana semua upah buruh dihitung termasuk untuk tenaga kerja dalam keluarga tani sendiri.

Keywords : Nutrient balance, Economic analysis of P, Acid upland soil, Pauh Menang-Jambi.

INTRODUCTION

Despite successes achieved by Indonesian people in increasing food production, attempts continuously have to be sought to increase further food production to compete with the ever-growing population. The prevailing high total population of Indonesia (about 210 million people in 2000) and combine with its relatively high annual growth rate (about 1.7%) presents a big challenge to meet its food requirements. The need to increase agri-cultural production has driven Indonesia to extent its agriculture developments to the outer islands, predominantly in Sumatra, Kalimantan, and Sulawesi. Fortunately, Indonesia still has large lands. It is estimated that about 49.8 million ha or 26% of the total land area of Indonesia is available for agriculture expansion. However, most of these lands predominantly are acid mineral soils, Ultisols, Oxisols, and Inceptisols (Djaenudin and Sudjadi, 1987). In Jambi, these acid mineral soils are also

[1] Center for Soil and Agroclimate Research and Development, Bogor, Indonesia
[2] International Board for Soil Research and Management, Bangkok, Thailand

ISSN 1410-7244

important, with a total area of 3.6 million ha or 71% of the total land area of Jambi province (Mulyani *et al.*, 1994).

Being highly weathered, these soils are infertile, acidic and associated with aluminum toxicity. Moreover, these soils have high risk of erosion and many that have been used for agriculture are degraded. Fertilizers have been widely used in Indonesia, but mostly were for food crops, mainly irrigated lowland rice. On the other hand, fertilizer use for upland crops is still limited, although upland crops have great potential as alternative sources of carbo-hydrate and protein. With inadequate fertilizer, these acid upland soils could make only limited contributions to agricultural production. Beside nitrogen management, a proper phosphorus fertility management is very important to improve productivity of these soils. Phosphorus (P) deficiency is a major limiting factor in these soils, and most of the applied P fertilizers are not available to the plant because it is adsorbed by the high sesquioxide contents of the soils.

Proper P management on upland acid soils can improve soil properties and increase food crops yield. For example, an application of rock phosphate (RP) at 500 kg ha^{-1} increased soil pH from 5.0 to 5.2; Bray I extractable P from 3.9 to 41.2 ppm; extractable Ca from 0.54 to 0.81 cmol kg^{-1}; and decreased exchangeable Al from 1.10 to 0.46 cmol kg^{-1} (Utomo and Sunyoto, 1995). Meanwhile, soybean yield increased during the four-crop season's compared to control without P. Soybean yields of RP treatment were 1.53; 1.61; 1.80; and 0.93 t ha^{-1}, and for control without P were 0.86; 0.73; 1.32; and 0.59 t ha^{-1} for the first, second, third, and fourth season, respectively. Dev *et al.* (1999) found that application of 500 kg ha^{-1} of RP increased available P in soil from 9.3 to 21.2 ppm and from 9.5 to 24.4 ppm P for the fifth and sixth crop seasons of rice. Meanwhile, rice yield increased from 3.0 to 3.51 and from 1.15 to 1.45 t ha^{-1} at the same crop seasons.

The low productivity of acid mineral soils are also due to their low organic matter (OM) content. Interesting results on investigating of OM to increase productivity of these soils were observed. Three years seasonal application of OM at a rate of 6 t ha^{-1} on mineral acid soils in Niger increased pearl millet yield from 0.75 to 4 t ha^{-1}. The same rate of OM combined with 13 kg P ha^{-1} showed a higher increase of pearl millet yield from 1 to 5 t ha^{-1} (Marschner *et al.*, 1995). While Siem and Phien (1995) reported that application of 30 t of farmyard manure increased yield of corn, upland rice, and cassava from almost zero to 0.2; 0.4; and 4.1 t ha^{-1}, respectively. In combination with 60 kg N, 26 kg P and 50 kg K ha^{-1}, the same rate of this OM increased the crops yield to 0.9; 1.2; and 8.1 t ha^{-1}. Although the important roles of OM in soils are widely known, attempts to maintain or increase OM content under tropical rain forest climate are difficult due to intensively weathering conditions in this region.

The long-term impacts of phosphate application in improving soil properties and increasing food production in acid upland soils are very important. This report describes the results of a long-term field experiment conducted in an acid upland soil in Sumatra to assess soil and crop response to P fertilization, compare inorganic and organic sources of P and assess the interactions between these sources. This paper emphasizes on the results of the fifth to seventh crops with overviews of the results of the whole experiment, whereas the results of the first four cropping seasons have been reported elsewhere (Santoso *et al.*, 2001).

MATERIAL AND METHOD

A field experiment was conducted from the rainy season 1997/98 until the rainy season 2000/2001 on a Typic Dystrudept in Pauh Menang village, Pamenang Sub-District, of Merangin District, Jambi Province. An incomplete factorial combination of three factors, inorganic phosphorus, OM, and lime, were laid out in the field using a randomised complete block design with four replicates. Six rates (0, 19, 38, 57, 76, and 95 kg P ha^{-1}) of inorganic P in the form of SP-36 were applied to study site responses to P fertilization. To assess alternative and cheaper sources of P fertilizer, Christmas Island Rock Phosphate (CIRP) was used directly at rate of 42.6 kg P ha^{-1}.

The sources of OM were cattle farmyard manure (FYM) and fresh biomass of stylo (*Stylosanthes guyanensis* cultivar CIAT 184) as mulch. FYM was applied at 3 tons to one-third of the land area and incorporated along the corn rows. Stylo was intercropped between the corn rows in continuous lines. The stylo was pruned periodically and recycled *in situ* as mulch between corn rows. Depending on the treatment, the amount of stylo biomass in each cutting varied from 1 to 5 t ha^{-1}. Calcite lime ($CaCO_3$) was applied at equivalent to 3 t ha^{-1} to all treatments, except for one SP-36 treatment without lime and all of the rock phosphate treatments. Each plot received blanket applications of 125 kg N as Urea, 145 kg K as KCl, and 150 kg Mg as Kieserite ha^{-1}. Kieserite was reapplied before planting, while Urea and KCl were reapplied separately, namely one-half dosage before planting and the rest at 4 weeks after showing (WAS) of the succeeding crop. The details of the treatments were described in the earlier report (Santoso *et al*., 2001).

The balance of P under each treatment was calculated using the following equation: *P balance = [P added in fertilizer – (P taken up in corn's grain + cob + husk)]*. This balance is a simple partial balance to estimate the difference between the amount of P added in fertilizer -either as inorganic or organic fertilizer- and the amount of P taken out from the system by harvest. During the harvesting times, corn stover was directly returned *in situ* onto each respective plot. The estimation of P balance did not include other mechanisms of P losses from the system, such as losses due to leaching or soil erosion. Economic analyses were carried out to compare benefit-cost (B/C) ratio of different treatments studied in this experiment. The gross income subtracted by the total labour cost plus material inputs were considered as the total benefit for a certain treatment.

RESULTS AND DISCUSSION

Changes in soil P status

The repeated, seasonal application of inorganic P as SP-36 before every planting of corn crop resulted in large increases in Colwell P content of the topsoil sampled at 4 WAS (Figure 1). The increase in soil P was higher with higher rate of applied P. The first application of inorganic P has considerably increased P content of the soil, and the subsequent applications increased soil P even further. As expected, these data suggest that the crop did not take up all of the applied inorganic P and repeated application of P resulted in accumulation of residual P, and thus built up P status of the soil. Field experiment on Oxisols in Central Brazilia showed the same trend where P accumulation was higher with higher rate of applied P. In this experiment, extractable P (Colwell) were observed about 15 ppm at the treatment of 70 kg P ha-1 and about 30 ppm at the treatment of 280 kg P ha^{-1} after 30 months of P applied (Yost *et al*., 1981). While Garrity *et al.* (1990) reported that extractable P (Bray I) application of 10 kg P ha^{-1} was about 5.6 ppm, and application of 40 kg P ha^{-1} about 7.0 ppm after 4 years of applied P.

The inspiring question is: "What is the P rate to be recommended to the farmers?" The SP-36 (2) treatment at the rate of 38 kg P ha^{-1}crop^{-1} was presumed to be the *central* treatment as a recommended rate. However, application of this treatment by the third crop has increased P content of the soil to more than 100 mg P kg^{-1} soil, a level far above the known critical soil P level. This result maybe interpreted that this rate of P application is too high. However, such a conclusion is inappropriate because of the following considerations.

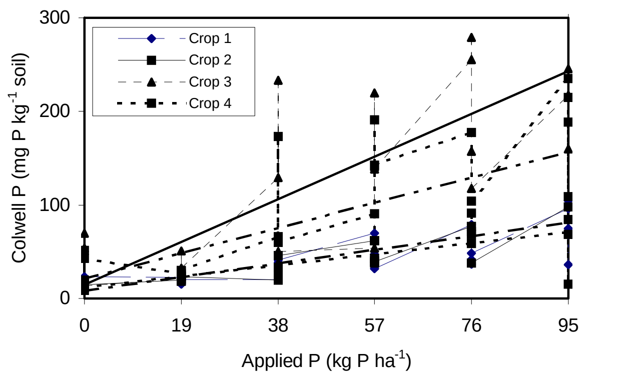

Figure 1. Effect of P application on Colwell P content of the topsoil at WAS of corn crop 1 to 4, Pauh Menang, Indonesia

Firstly, it should be noted that the method of applying inorganic, soluble P fertilizer (SP-36) in this experiment was locally banded in about 15 cm deep along the 30 cm corn-planting rows. This placement method was intended to reduce P sorption by the soil and, hence increase fertilizer use efficiency. Therefore, the achieved high P status was not the P status of the whole soil in each respective treatment's plot. Nevertheless, in practice the farmers also do not apply SP-36 onto the entire soil in his or her farm, but localised in holes made by planting stick near to corn seed holes. Alternatively, farmers place SP-36 in strips adjacent to corn seeds. Planting is usually done during the same day of the last ploughing, and corn seeds are just dropped along the burrows left by the plough.

Secondly, one could argue that inorganic P fertilizer could be applied repeatedly to build up P status in soils. After a high P level achieved, the subsequent applications are at a lower rate as a maintenance rate to replace the amount of P that may lost from the system, either by harvest or other mechanisms such as leaching or soil erosion. A less soluble P fertilizer, i.e. reactive rock phosphate (RRP), can be used directly in one application approach with a considerably high rate of about 1 t ha^{-1} to build up P status in the soil. Provided the fertilizer is made readily available to the farmers, its direct use for upland food crops is a promising strategy, and presumably RRP is cheaper than SP-36, to improve upland agriculture on acid mineral soils.

Crop response to P fertilization

By excluding crop 2, due to exceptional drought stress experienced during that particular season, comparison of the relative yields of crop 1, 3 and 4 demonstrated nicely the cumulative effects of residual P (Santoso *et al.*, 2001). Further comparison of grain yields of crop 1 to 7 in this study confirmed the effect of residual P (Figure 2).

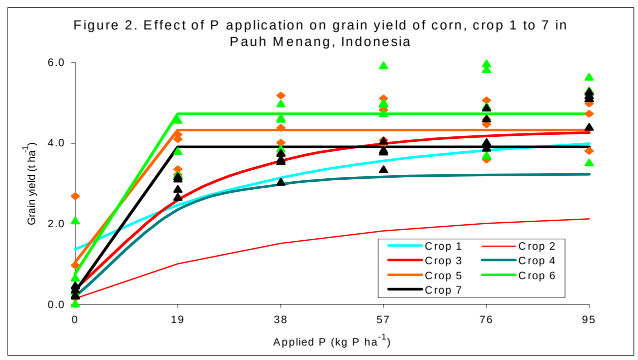

Figure 2. Effect of P application on grain yield of corn, crop 1 to 7 in Pauh Menang, Indonesia

With more inorganic P in the form of SP-36 applied every season, residual P in the soil accumulated. Yield data showed that starting from the fifth crop, the yield response curves to the increasing rate of applied P is no longer a curvilinear but a linear-plateau type. The cut-off point is not at the central treatment of 38 kg P ha^{-1} but at a lower level of 19 kg P ha^{-1}. This applies for all crops after the fourth crop (crops 4, 5 and 6). These results suggest that until the fifth crop, a phosphorus fertilization rate greater than 19 kg P ha^{-1}, let say 38 kg P ha^{-1}, was needed to fertilize the crop and at the same time built up P content of the soil. After a high P status in the soil has been established, a lower fertilization rate of about 19 kg P ha^{-1} is sufficient as a maintenance rate.

A question that remains to be studied is the critical level of P in the soil that associates with a plateau yield level of a corn variety. While in this study the establishment of a high level of P in the soil that associated with yield plateau was achieved in five cropping seasons, and in other soils it will be achieved differently. A laboratory experiment on upland acid soils with pH 4.0 showed that the maintenance rate of P fertilizer was achieved at the fourth of crop about 1.25 gram P pot^{-1} (Barrow and Campbell, 1972). Some of the factors that determine the building up of P in soils are: amount of P added, P sorption characteristics of the soil, yield level of the crop or the amount of P harvested out from the system, management of crop residue and leaching losses of P.

P balance

The simple partial balance of P under each treatment was calculated to estimate the difference between the amount of P added in fertilizer -either as inorganic or organic fertilizer- and the amount of P taken out from the system by harvest (Figure 3).

Except the control and the stylo treatments, which have negative balances, all other treatments showed positive P balances for all crops (1, 3, 4 and 5). The balances were higher with increasing rate of applied inorganic P. Clearly these estimates indicate that the amounts of P added in each season were much higher than the amount of P taken out by harvest. Consequently, P from fertilizer which was not taken up by the crop would remained in the soil and this residual P increased P content of the soil. The diagrams of the relationship between P balances and Colwell P content of the soil provide the evidence (Figure 4). At the same rate of applied P, the rock phosphate treatments also showed considerably high positive P balances but resulted in lower Colwell P contents in the soil than the SP-36 treatments. This diagram showed the less soluble characteristic of the rock phosphate.

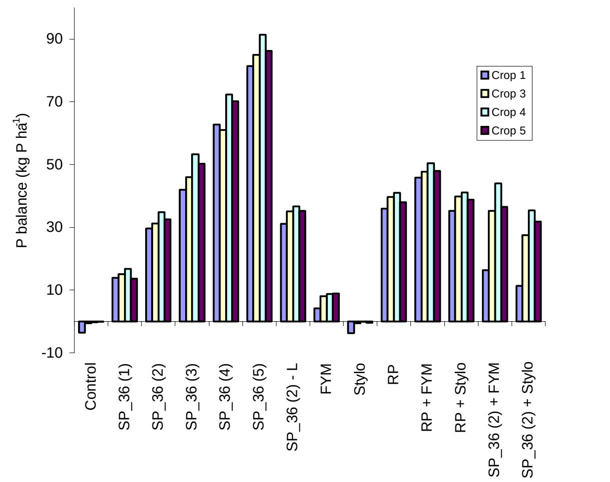

Figure 3. Balance under different treatments for crop 1 to 4 in Pauh Menang, Indonesia

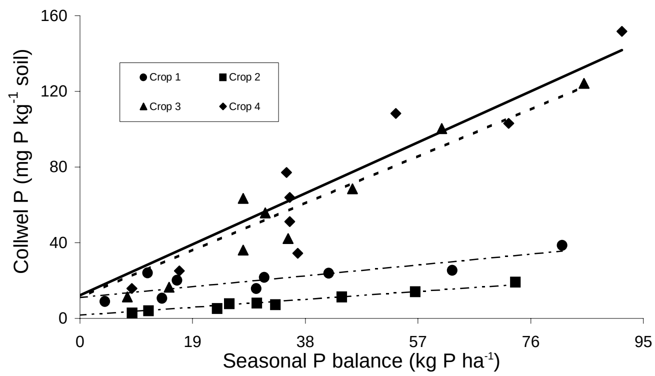

Figure 4. Relationship between seasonal P balance and Colwell P content of the soil of crop 1 to 4, Pauh Menang, Indonesia

The positive balances of all P application treatments in this experiment were corroborated with increasing Colwell P contents of the soil, where P balances were greater with higher rates of P fertilizer. Similar trend of positive P balance was also reported by Lefroy *et al.* (1988) where application of 32 kg P ha^{-1} on an upland acid soil resulted in a positive P balance of about 22 kg P ha^{-1}. In addition to the rate of fertilizer, P balances were also affected by soil-crop management practices. In a two-year alley cropping systems experiment on an Epiaquic Kandihumult in Jambi

Province, application of 20 kg P ha^{-1} under different hedgerow crops showed different P balances. The alley cropping system with *Flemingia sp*. as hedgerow gave the highest P balance of about 97 kg P ha^{-1}, while that with king grass as hedgerow gave lower P balance (59 kg P ha^{-1}), and followed by banana plus native grass as hedgerow (57 kg P ha^{-1}) (Wigena *et al*., 1997).

Effect of P application on Zn Uptake

As noted, application of increasing rates of soluble P fertilizer as SP-36 increased grain yields of corn. The effects of P fertilization were also observed in the increasing P contents in the leaves of the first corn crop taken at four weeks after showing (WAS). On the other hand, the application of P fertilizer resulted in decreasing zinc (Zn) contents in the leaves (Figure 5). It could be due to reduce Zn uptake hindered by increasing P level in the soil with increasing rate of applied P. Alternatively, it could also reflect *dilution* effect; namely decreasing Zn concentration in leaves due to increasing growth of crop. The decreasing concentration of Zn in plant tissue in this study may indicate the existence of other limiting factor other than P deficiency that was being studied. This could be one of the reasons of the less optimal yields that were achieved in this experiment (about 3.5 t ha^{-1}).

The mechanism of decreasing Zn content in the leaf in this study is not known and visual symptoms of Zn deficiency in the field were not apparent. Multinutrient deficiency is common in highly weathered acid soils, where inherent content of many nutrients in these soils is generally very low. If the most limiting nutrient was overcome by applying fertilizer, the second most limiting nutrient would appear to become deficient. Therefore, advice to farmers for improving these soils is by application of N, P, and K fertilizers alone, and occasionally with lime, undoubtedly would increase soil productivity. However, in the long-term attempts should be made to test whether or not other nutrients especially micro-nutrients have become a problem for continuously achieving a high level of crop yields.

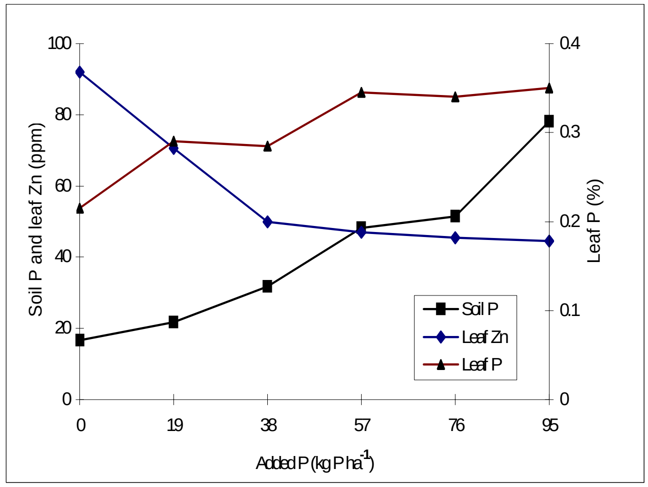

Figure 5. Relationship between soil P, leaf P and leaf Zn of the 1st corn at 4 WAS in Pauh Menang, Indonesia

Economic analysis

The high P requirement of acid mineral soils is a major economic constraint in cultivating these soils. Economic analyses of the different treatments studied in this experiment were carried out to compare benefit-cost (B/C) ratio (Table 1).

The labour cost and material inputs consist of two groups of items, unrelated and related with treatments. For example, there was no cost for applying inorganic P fertilizer for the control treatment since there was no SP-36 or rock phosphate to be applied under this treatment. On the other hand, labour cost has to be allocated for applying inorganic P for the SP-36 treatment. Likewise, cost of transporting yield under the control treatment was lower than the SP-36 treatment because of its lower yield. With similar approach, the B/C ratios of other treatments and for crops 1 to 7 were calculated and the results are summarised in Table 2 and 3. The B/C ratios of the different treatments showed that in general only the SP-36 treatments gave beneficial returns.

Table 1. Total budgeting of selected treatments for the third corn crop in the rainy season 1998/1999 in Pauh Menang, Indonesia

Item	Amount (US$ ha^{-1})	
	Control	SP-36(2)
A. Labour cost		
Unrelated with P, OM, and lime treatment		
Land preparation	13,2	13,2
Application of basal fertilizer (Urea, KCl)	3,0	3,0
Planting	13,8	13,8
Related with P, OM, and lime treatment		
Application of inorganic P fertilizer	0	23
Application of lime	2.2	2.2
Application of FYM	0	0
Management of Stylo	0	0
Weeding 2X	5.5	18.1
Spraying pesticide	2.2	2.4
Harvesting and product processing	2.8	24.8
Transporting yield	0.5	1.7
Sub total labour cost	43.2	85.5
B. Material inputs		
Unrelated with P, OM, and lime treatment		
Corn seed	10.0	10.0
Urea	12.0	12.0
KCl	16.0	16.0
Kieserite	9.0	9.0
Related with P, and OM treatment		
SP-36	0	21.6
Rock phosphate	0	0
Lime	13.6	13.6
FYM	0	0
Pesticide	2.7	8.2
Sub total material inputs	63.3	90.4
C. Total production cost = (A + B)	106.5	175.9
D. Gross income	62.2	569.5
E. Benefit = (D – C)	-44.3	393.6
F. Benefit-cost ratio = (E/C)	-	2.2
Note: Corn grain yield (t ha^{-1})	0.39	3.56
Corn price = US$160 per t		
Exchange rate US$ 1 = Rp 6.700		

A field study in the Philippines showed that application of 27 kg P ha^{-1} combined with 80 kg N, 34 kg K and 3.6 t lime ha^{-1} on an acid mineral soil gave high net incomes from a peanut-corn cropping pattern by about US$ 357; 134; and 514 ha^{-1} for the second, third, and fourth crops, respectively (Duque *et al*., 1995). However, another study showed that application of 45 kg P ha^{-1} combined with 134 kg N and 45 kg K ha^{-1} only provided a net income of about US $ 59 ha^{-1} $season^{-1}$ from a corn crop on an upland acid mineral soil in Ohio (Tisdale *et al*., 1990).

Although many of the B/C ratios from the study in Jambi were less than 1.0, it should be noted that all labour costs were considered as cash costs in calculating B/C ratio. In reality, however, farmers in Pauh Menang village rarely have hired labour and almost all of farming activities is carried out using family labour or sharing labour with neighbouring farmers. In addition, although many of the B/C ratios were relatively small of less than 1.0, the amount of total benefits that could be earned by farmers were considerably high because the total production cost used in the calculation which included all labour costs.

CONCLUSION

The soil in the experimental site in Pauh Menang village was very P deficient. Application of soluble P fertilizer in the form of SP-36 at a rate of about 38 kg P ha^{-1} increased corn grain yields significantly from less than 1.0 to about 3.5 t ha^{-1} for the first four crops. The higher rates of P applied didn’t increase further corn grain yields.

The application of P fertilizer has important residual effect. Repeated applications of P fertilizer resulted in accumulation of residual P. Four times applications of SP-36 at 57 kg P ha^{-1} until the fourth crop has adequately built up P content of the soil, and resulted in a high corn grain yield of about 3.5 t ha^{-1}. Subsequent applications of SP-36 at 19 kg P ha^{-1} in the following seasons (for crops 5, 6 and 7) were sufficient as a maintenance rate. It should be noted, however, that the P fertilizer was banded locally along rows of corn. An even distribution of fertilizer to increase P status of the soil in the entire farmland would require much higher rate of P application.

Table 2. Benefit of applying different treatments to seven corn crop seasons in Pauh Menang, Indonesia

Treatment	Benefit (US $) of crop						
	1	2	3	4	5	6	7
Control	32.04	-63.76	-44.25	-61.00	-269.44	-286.96	-374.51
SP-36 (1)	101.82	-37.50	258.99	95.27	45.42	65.90	-63.31
SP-36 (2)	152.18	-2.11	393.62	146.94	107.35	158.42	-12.12
SP-36 (3)	179.41	14.74	451.47	154.31	107.50	226.59	1.97
SP-36 (4)	192.27	20.50	471.00	148.80	72.62	193.79	62.39
SP-36 (5)	196.18	19.61	473.60	139.53	86.06	175.36	130.49
SP-36 (2) – Lime	168.52	-7.24	211.08	5.41	-244.44	-365.93	-365.67
Stylo	27.75	-104.34	-12.90	-116.50	-427.3	-404.35	-418.36
FYM	68.75	-93.84	182.11	-89.99	-219.40	-342.33	-297.39
Rock P	52.83	-66.64	125.24	-47.69	-193.64	-240.42	-77.33
Rock P + Stylo	56.93	-102.91	115.90	-36.95	157.29	-275.35	-64.98
Rock P + FYM	104.30	-53.92	270.91	63.39	159.57	37.83	-9.99
SP-36 (2) + Stylo	132.90	-29.69	353.50	74.59	70.04	111.12	0.06
SP-36 (2) + FYM	200.27	71.19	514.73	241.71	80.23	319.02	5.91

Table 3. Benefit-cost ratio of applying different treatments to seven corn crop seasons in Pauh Menang, Indonesia

Treatment	Benefit – cost ratio of crop						
	1	2	3	4	5	6	7
Control	0.35	-0.82	-0.42	-0.67	-0.64	-0.72	-0.89
SP-36 (1)	0.85	-0.29	1.67	0.64	0.09	0.14	-0.13
SP-36 (2)	1.17	-0.02	2.24	0.92	0.21	0.32	-0.02
SP-36 (3)	1.27	0.10	2.42	0.90	0.20	0.44	0
SP-36 (4)	1.26	0.13	2.39	0.82	0.13	0.36	0.11
SP-36 (5)	1.20	0.11	2.27	0.73	0.15	0.31	0.22
SP-36 (2) – Lime	1.47	-0.51	1.32	0.03	-0.50	-0.79	-0.75
Stylo	0.24	-0.86	-0.08	-0.82	-0.92	-0.92	-0.90
FYM	0.60	-0.76	1.13	-0.62	-0.45	-0.71	-0.61
Rock P	0.44	-0.54	0.76	-0.32	-0.45	-0.56	-0.18
Rock P + Stylo	0.45	-0.77	0.68	-0.25	-0.36	-0.63	-0.15
Rock P + FYM	0.83	-0.40	1.58	0.41	-0.32	0.08	-0.02
SP-36 (2) + Stylo	0.98	-0.21	1.96	0.45	-0.14	0.22	0
SP-36 (2) + FYM	1.46	0.49	2.83	1.45	-0.14	0.59	0.01

Estimation of P balances--between the applied P in fertilizer and the total amount of P taken out from the system by harvesting corn grain plus cob and husk-- resulted in positive balances for all crops under all treatments, except for those under the control and the Stylo treatments. The data suggest that considerable amounts of P remained in the soil and this residual P measured as increasing Colwell P content of the soil.

The Zn content in plant tissue decreased with increasing rate of applied P. Although no apparent symptom of Zn deficiency was observed in the field, this phenomenon may indicate the present of other limiting factors that restricted crop growth beside phosphorus.

Analyses on benefit-cost ratio of the different treatments showed that in general only the SP-36 treatments gave beneficial returns. Although many of the B/C ratios were less than 1.0, it should be noted that the analyses were carried out by calculating all labour costs as cash costs. In reality, farmers in Pauh Menang village rarely have hired labour and almost all of farming activities is carried `out using family labour or sharing labour with neighbouring farmers. In addition, although many of the B/C ratios were relatively small of less than 1.0, the amount of total benefits that could be earned by farmers were considerably because the total production cost used in the calculation were high which include all labour cost.

Acknowledgment

This study was a part of the IBSRAM *ASIALAND* Acid Soils network funded by the Australian Center for International Agricultural Research (ACIAR). The authors are grateful for the financial support and for the collaboration within the network.

REFERENCES

Barrow, N.J., and N.A. Campbell. 1972. Methods of measuring residual value of fertilizers. Aust. J. of Expt. Agric. and Animal Husbandry. 12: 502-510.

Dev, G., A.K. Sarkar, P.K. Sharma, and S.K. Sahu. 1999. Studies on residual effect of rock phosphate in different crop sequences in acid soils in India. IMPHOS Phosphate News Letter. 8 and 9 Issues: 1 and 5.

Djaenudin, D. and M. Sudjadi. 1987. Land resources in four major islands available for agriculture in year 2000. J. Agric. Research and Development. Agency for Agricultural Research and Development. VI (3): 55-61 (in Indonesian).

Duque, C.M., R.B. Cagmat, N.P. Daquido, and A.R. Maglinao. 1995. Management of acid soils for sustainable food crop production the Philippines. *In* R. A. Date, N.J. Grundon, G.E. Rayment, and M.E. Probert (*Eds.*). Plant-Soil Interactions at Low pH: Principles and Management. Development in Plant and Soil Science. Kluwer Academic Publisher. New Delhi. p. 775-778.

Garrity, D.P., C.P. Mamaril, and G. Soepardi. 1990. Phosphorus requirement and management in upland rice-based cropping systems. Phosphorus Require-ment for Sustainable Agriculture in Asia and Oceania. Proc. of a Symps. International Rice Research Institute. Manila. p. 333-347.

Lefroy, R., S. Blair, and G. Blair. 1988. Phosphorus and Sulphur Deficiency in Tropical Cropping Systems. Final Report. ACIAR Project 8328.

Marschner, H., F.P. Rebafka, H. Hafner, and A. Buerkert. 1995. Crop residue management for increasing production of pearl millet on acid sandy soils in Niger, West Africa. *In* R. A. Date, N.J. Grundon, G.E. Rayment, and M.E. Probert (*Eds*.). Plant-Soil Interactions at Low pH: Principles and Management. Development in Plant and Soil Science. Kluwer Academic Publisher. New Delhi. p. 767-770.

Mulyani, A., M. Soepartini, Suwarto, and Mugiyanto (Eds.). 1994. Potency of the region and the implementation of agriculture development programs. Identification of Potency of the Region, Constraints, and Opportunity in Increasing Adoption of Technology in Jambi. Center for Soil and Agroclimate Research. p 3 – 38 (in Indonesian).

Santoso, D., J. Purnomo, I G.P. Wigena, Sukristiyonubowo, and R.D.B. Lefroy. 2001. Management of phosphorus and organic matter on an acid soil in Jambi, Indonesia. Indonesian Soil and Climate Journal. 18: 64 – 72.

Siem, N.T. and T. Phien. 1995. Acid upland soil in Vietnam and their management for agriculture. *In* R. A. Date, N. J. Grundon, G.E. Rayment, and M.E. Probert (*Eds*.). Plant-Soil Interactions at Low pH: Principles and Management. Development in Plant and Soil Science. Kluwer Academic Publisher. New Delhi. p. 771-774.

Tisdale, L.T., W.L. Nelson, and J.D. Beat. 1990. Soil Fertility and Fertilizer. Fourth edition. Macmillan Publishing Company. New York.

Utomo, M. and Sunyoto. 1995. Rock phosphate and minimum tillage for management of acid soil in Sumatra. *In* R. A. Date, N. J. Grundon, G.E. Rayment, and M.E. Probert (*Eds*.). Plant-Soil Interactions at Low pH: Principles and Management. Development in Plant and Soil Science. Kluwer Academic Publisher. New Delhi. p. 775-778.

Wigena, I G.P., J. Purnomo, Sukristyonubowo, and D. Santoso. 1997. Evaluation of soils nutrient balance and status of soil-crop management systems on an Epiaquic Kandihumult. Proc. of Discussion and Communication of Research Results on Soil and Agroclimate. Soil Chemistry and Biology Section. CSAR. Bogor. p. 177-189.

Yost, R.S., E.J. Kamprath, G.C. Naderman, and E. Lobato. 1981. Residual effects of phosphorus applications on a high phosphorus adsorbing Oxisol of Central Brazilia. Soil Sci. Soc. Am. J. 45:540-543.