Improvement of Soybean Yields under Acid Soil Conditions in Indonesia

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ABSTRACT

Acid soils usually are deficient in major nutrients such as phosphorous, potassium, calcium, and magnesium, toxic to exchangeable aluminum and low cation exchange capacity. Soybean cultivars grown in this soil usually produced low yields. The soybean yield can be improved by growing soybean varieties tolerant to the acid soil, soil management, and nutrient management. Results of several experiments indicated that some varieties were more tolerant to acid soil than others. Some improved varieties were developed to obtained varieties tolerant to acid soil. Application of manure in acid soils increased organic matter content and increased soybean yields. Artificial soil conditioners did not affect the soybean yield, because they only affected soil physics but not the soil chemical properties. Plant inoculation with Rhizobium in an areas where soybean had not previously been grown increased nodule weight, percentage of nitrogen content, and seed yield. In some experiments, plant inoculation with Rhizobium in an areas where soybean had been grown increased soybean yield, but in other experiments did not affect the yield. Results of nitrogen fixation experiments using ^{15}N showed that total nitrogen fixed by soybean plants was 63.2 kg/ha or 45.4% from the total plant requirement of nitrogen. Liming at the rate of 1.0 to 1.5 x exchangeable aluminum was enough to obtain a good soybean yield. Anorganic fertilizers (P and K) were needed in the acid soils. The rate of P fertilizer was between 46 to 92 kg P_2O_5/ha, while and K fertilizer was 60 kg K_2O/ha.

Key words: *Glycine max*, improvement, acid soil, management, yield

INTRODUCTION

In Indonesia, soybean was mostly grown (65%) on lowland area after rice and only 35% was grown on upland areas. In the upland areas, Drissen and Soepraptohardjo (1974) estimated that about 48.3 million hectares or <30% of the total land area of Indonesia consisted of acid soils. Acid soil is one of the potential areas for soybean production, and the crop is primarily grown on the Oxisols. These soils are strongly weathered soils with low cation exchange capacity. They exhibit major mineral element deficiencies (phosphorous, potassium, calcium, and magnesium), high content of toxic exchangeable Al, and extensive P fixation by soil particles. A high percentage of Al saturation in the soils damages plant growth. High Al saturation effects limit soybean yield because soybean is sensitive to aluminum toxicity. Generally, soybean grown in acid soils produced low yield (<1.0 t/ha), because of many constraints are present. Improvement of soybean yield in these soils can be achieved by an integrated approaches, such as growing soybean cultivars tolerant to acid soil, management of soil properties, and cultural management practices, and combinations of those practices. In an effort to increase soybean productivity, considerations need to be done was not only on factors that provide more nutrients, but also on a comprehensive inter-disciplinary review of the entire system to identify constraints and opportunities. In the past decade, strong research emphasis has been placed on elimination of the production constraints of low soil fertility through nutrient management including soil tillage, liming, plant inoculation with Rhizobium, and anorganic fertilizers applications. A combination of good crop and soil management on acid soils is expected to improved soybean productivity the same as or even higher that on lowland areas at approximately 2.0 t/ha.

VARIETAL IMPROVEMENT AND ADAPTATION

The search for soybean cultivars for Al tolerance has been started in the 1980's through evaluation of soybean inbreed lines from germplasm collections and introduction. Marzuki *et al.* (1989) reported that responses soybean varieties and inbreed lines to different Al saturation in the soil varied, and generally soybean crops produced high yields when grown on soil with Al saturation less than 30% (Table 1). In Lampung, growing soybean variety Wilis with good management, with good crop management, farmers produced soybean yield of approximately 2.0 t/ha. Results from a field experiment showed that soybean line AGS 129 from AVRDC, Taiwan, could produced yield of up to 2.5 t/ha (Table 2). In contrast, soybean yield from a field experiment in Jambi was generally low, except one variety that produced yield higher

Table 1. Grouping of 18 soybean varieties and inbred lines based on yield potential and tolerance soil with different Al saturation, Bogor, rainy season of 1987/88

Yield potential	Tolerance of cultivars and inbred lines		
	Low (20%)	Medium (30%)	High (>40%)
Low	-	Tidar	Galunggung, Merbabu, Lokon, No.1298, No.1354, No.1355, No.1466
Medium	-	Orba	-
High	Dempo, No. 2340, No. 29, No. 986, No. 2129, No. 1567, No. 3060	Kerinci, No.16	-

Source: Marzuki *et al.*, 1989

Table 2. Yields and days to maturity of four soybean varieties and lines in Lampung, during the rainy season of 1988/89

Variety/line	Yield (t/ha)	Days to maturity
AGS129	2.46	87
B3344	2.28	89
B3362 C	2.27	88
Wilis	2.22	88

Source: Sunarlim, 1990

than other cultivars including variety Wilis (Table 3). A field trial conducted in Central Lampung, during rainy season of 1993/94, showed no significant differences among seed yields of 10 soybean varieties. When these varieties were evaluated in the greenhouse using the same soils as that on the field trials, it was shown that varieties Tambora and Tampomas produced the highest seed yields than other varieties (Table 4).

Subakti *et al*. (1992) reported that in Sitiung with soil pH 4.12 and exchangeable Al 3.25 me/100 g, screening from 405 inbreed lines + 5 varieties resulted in 27 selected lines with good performance (0.68-1.14 t/ha). Other evaluation in the field trial showed that the highest yield was obtained from local variety namely Kipas Merah (2.07 t/ha) but succeptible to pod suckers.

The latest research progress on soybean improvement was reported by Sunarto. From breeding of varieties Wilis x Dempo, he released two national improved varieties, Sindoro and Slamet, that were tolerant to acid soils.

Table 3. Yield of six soybean varieties grown on acid Oxysol in Kuamang Kuning, Jambi

Variety	Grain yield (t/ha)
Orba	0.27
Wilis	0.46
Lokon	0.26
Kerinci	0.72
Galunggung	0.49
B3343	0.61

Source: Rochayati *et al.*, 1992

Table 4. Adaptation of several soybean varieties on acid soils in the greenhouse of RIFCB, Bogor and in the field of Central Lampung during the rainy season of 1993/94

Varieties	Seed yield[1]	
	Greenhouse (g/plant)	Field (t/ha)
Wilis	7.82[b]	1.25[a]
Rinjani	6.36[c]	1.28[a]
Malabar	7.03[c]	1.26[a]
Orba	6.49[c]	1.06[a]
Raung	7.69[b]	1.26[a]
Petek	7.48[b]	1.29[a]
Lumajang Bewok	7.33[b]	1.24[a]
Tambora	8.79[a]	1.23[a]
Merbabu	7.60[b]	1.28[a]
Tampomas	8.76[a]	1.37[a]

Notes: [1]Values in each column followed by the same letter are not significantly different at 5% different (HSD)

Source: Sunarlim *et al.*, 1997a

SOIL MANAGEMENT

Soil Preparation

In upland soil, soil tillage is done to control weeds and farmers usually do the tillage several days before planting. While waiting for the rain to come, farmers till the soil several times until ready for sowing. Some farmers, however, grew soybean without practice soil tillage. Results of a field trial in Central Lampung indicated that minimum tillage or no tillage combined with herbicide application was enough to support growth and development of soybean to produce high yield. Reduced the numbers of soil tillage could decreased the chance of soil erosion (Table 5). It was also reported that soil hilling up at 14 and 21 days after planting did not affect the grain yield. Minimum soil tillage still enable the production of soybean seed ranging from 1.48 to 1.57 t/ha during the early rainy season and from 1.61 to 1.69 t/ha in the rainy season of 1992/93 (Hutami *et al.*, 1994).

Soil Conditioner

Application of natural or artificial soil conditioner could increase yield of soybean seeds. Results of a field trial in Central Lampung and a greenhouse trial at RIFCB, Bogor, on the same soil type showed that increasing the rate of application of cow manure increased soybean yield. The maximum soybean yield from both experiments was obtained at the rate of 16 t/ha of cow manure (Figure 1). Results of a greenhouse trial on use of artificial soil conditioners (Agri-Sc, OST, and ELKO) and cow manure in acid soils showed an interaction between soybean varieties and the soil conditioners, while no interaction was found in the field trial. Application of cow manure increased seed yield significantly by 21.1% in the field and 45.4% in the greenhouse. OST was the best soil conditioners among the three soil conditioners used in the trial. In the greenhouse trial soil conditioners ELKO and OST increased seed yields of variety Kerinci by 30.5 and 28.4%, respectively (Figure 2). Makarim and Ningrum (1991) using lime and organic matter in combination of 4 t/ha lime + cow manure increased soybean yield significantly from 1.60 to 2.23 t/ha.

Table 5. Seed yields of soybeans as affected by the soil tillage in Central Lampung, early and late rainy season of 1992/93

Soil tillage	Seed yield (t/ha)	
	RS I	RS II
Maximum soil tillage[1]	1.58ª	1.73ª
Minimum soil tillage[2]	1.54ª	1.51ª
No tillage + herbicide[3]	1.44ª	1.65ª

Notes: RS = rainy season, [1] plowing 2 x + rotary 1 x, [2] weeding from soil surface, [3] herbicide of gliposate applied one week before planting with concentration 4 liter/ha

Source: Hutami *et al.*, 1994

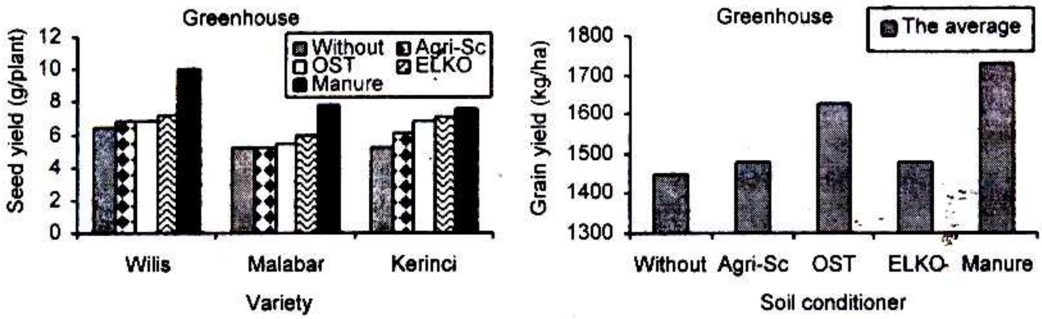

Figure 1. Soybean yields as affected by the rate of cow manure applications in the field and in the greenhouse experiments

Source: Supriati and Sunarlim, 1994

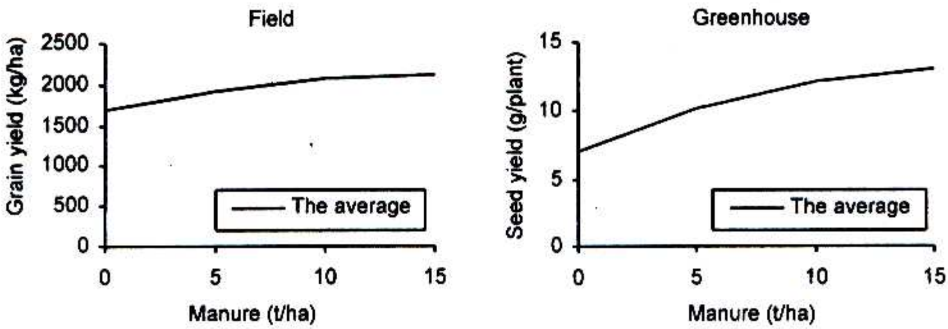

Figure 2. Seed yields of three soybean improved varieties as affected by the soil conditioners in the field and in the greenhouse trials

Source: Mastur and Sunarlim, 1994

Prayoto and Herudjito (1990) conducted an experiment using fresh latex, city refuse, and aquasyms as soil conditioners on soybean production in Podzolic soil of West Java. They found that soil conditioners affected soil physics but not the soybean seed yields. They suggested that soil conditioners must have two effects (physically and chemically) to make the induce high soybean yields. Fresh latex and aquasyms affecting only on soil physics, but they did not affect soil chemicals, therefore the soybean yield was not affected

NUTRIENT MANAGEMENT

Nitrogen Fixation

Keyser and Li (1992) reported that the nitrogen requirement of soybean is the highest among legume crops. One ton of soybean seeds is required by the crop to assimilate approximately 100 kg nitrogen. The proportion of nitrogen derived from fixation varies substantially from zero to as high as 97%, most estimates fall between 25 to 75%. The nitrogen requirement of soybean can be met by both either application of mineral nitrogen nor symbiotic N-fixation. Availability of soil nitrogen has a large influence on potential rate of biological nitrogen fixation. Responses of soybean genotypes grown in the acid soil that was treated with Rhizobium varied among localities, depend on the soil conditions and how many times soybean has been grown previously.

Field trials on inoculation of soybean crops with Rhizobium inoculants were conducted on two locations in Central Lampung. The results showed that in an area where soybean had not been grown previously, inoculation with Rhizobium increased nodule weight, nitrogen content and seed yield. Rhizobium infestation in an area where soybean had been grown previously did not affect nodule weight, nitrogen content and seed yield (Table 6). A similar result was found from another experiment in Central Lampung indicating that Rhizobium application increased seed yield from 1.24 to 1.60 t/ha (Sunarlim *et al.*, 1990). In Sitiung, West Sumatera, application of three different inoculants (Legin, Rhizogen, and Trizobium) to soybean crops resulted in the same seed yields ranging from 1,25 to 1,28 t/ha (Jalid and Salin, 1994). Another experiment in an area where soybean had not been grown previously showed that Rhizobium application increased soybean seed yield significantly from 1.15 to 1.82 t/ha (Ridwan and Basri, 1987).

An experiment on application of two Rhizobium inoculants, Legin and Rhizogen, on several soybean varieties was conducted to compare with N fertilizer application (50 kg N/ha). The results showed that seed yield of soybean plants inoculated with Legin was the same as that from Rhizogen, but higher 14-18% than the seed yield of plants fertilized with synthetic N fertilizer. The range of seed yields of soybean plants inoculated with Legin were from 1.41 to 2.10 t/ha that was higher than the range of seed yields from plants inoculated with Rhizogen (1.17-1.77 t/ha) (Table 7).

Supriati *et al.* (1990) reported that increasing level of application of Rhizobium inoculant at planting time did not increase soybean yield. Use of Arabic gum in plant inoculation together with Rhizobium inoculant at planting time also did not affect the seed yield (Table 8).

Among legume plants, soybeans had the total nitrogen content higher than the others. The highest percentage of nitrogen in soybeans was in the seed that was taken

Table 6. Seed yields, nodule weights, and the percentages of N content on acid soils that had not been grown and previously been grown with soybean as affected by application of Rhizobium inoculant, Central Lampung, the rainy season of 1988/89

Parameter	Soybean had not been grown		Soybean had been grown before	
	No inoculant	With inoculant	No inoculant	With inoculant
Nitrogen content (%)	2.48	2.89	2.94	2.78
Nodule weight (mg/plant)	65	292	224	200
Seed yield (kg/ha)	1567	2137	1927	1864

Source: Sunarlim, 1992

Table 7. Effects of plant inoculation with Rhizobium inoculants and N fertilizer application on yields of 10 soybean varieties and lines grown on an acid soil in Central Lampung

Variety	Seed yield (t/ha)			
	Legin	Rhizogen	50 kg N/ha	Average
Wilis	1.88	1.74	1.25	1.62
Rinjani	2.10	1.71	1.46	1.76
Lompobatang	1.58	1.52	1.38	1.49
IAC-11	1.61	1.53	1.33	1.49
B 3357	1.53	1.67	1.60	1.60
B 3344	1.44	1.17	1.18	1.26
630/1343-1	1.41	1.43	1.30	1.38
B 3343	1.45	1.44	1.53	1.47
Tambora	1.53	1.77	1.26	1.52
Kerinci	1.52	1.56	1.26	1.45
Average	1.60[a]	1.55[a]	1.36[b]	1.50

Notes: Legin and Rhizogen are two product of Rhizobium inoculants

Source: Sumarno *et al.*, 1990

Table 8. Soybean yields as affected by the level of Rhizobium inoculant and Arabic gum on an acid soil in Central Lampung

Treatment	Seed yield (t/ha)
Gum arabic	
Without	1.47
With	1.55
Inoculant (g/kg of seed)	
0	1.51
5	1.51
10	1.45
15	1.68
20	1.45
25	1.46

Source: Supriati *et al.*, 1990

out at harvest. Therefore the residue of nitrogen left in the soil was not be enough for the following crops. Nevertheless, the nitrogen residue left from nitrogen fixation by the previous soybean plants was still enough to maintain availability of the nitrogen in the soil for the next crops, without addition of nitrogen to the soil (Sunarlim *et al.*, 1994). Results of an experiment using ^{15}N on residual effect of nitrogen from soybeans to the following crops (maize) showed that the treatment of soybean crops with lime (2 t/ha) + PK fertilizers (69 kg P_2O_5/ha and 50 kg K_2O/ha, respectively) provided nitrogen equal to the amount of 45 kg N/ha applied to the maize crops (Table 9). It was also indicated that the total fixed nitrogen was 63.2 kg/ha or 45.4% from the total nitrogen requirement of the plant (Sunarlim *et al.*, 1993).

Another alternative to increase nitrogen fixation by the plants is to develop Rhizobium inoculant tolerant to acid soil. Simanungkalit *et al.* (1995) had tested 12 strains of *Bradyrhizobium japonicum* and found two most promising strains that were tolerant to acid soil i.e. strains FCB 251/3 and FCB 15/2 (Table 10).

Liming and PK Fertilizers

The main problem in acid soils is the low soil pH and high aluminum saturation. Application of lime to the soil is one way to solve the problem. However, the response of soybean plant to liming very much dependent on soil pH and Al saturation in the soil. Liming decreases the Al toxicity and increases availability of phosphorous (P) and molibdenum (Mo) that are needed by soybean plants. Results of a greenhouse

Table 9. Grain yield and total N production of corn grown after soybean, Central Lampung, rainy season of 1992/93

Treatment	Grain yield (t/ha)[1]	Total N production (kg/ha)[1]
Residue of soybean	1.58^{bc}	40.6^{ab}
Residue of soybean + lime[2]	1.97^{ab}	53.6^{ab}
Residue of soybean + PK[3]	1.63^{bc}	44.2^{ab}
Residue of soybean + lime + PK	2.23^{a}	60.2^{a}
Residue of corn	1.36^{c}	36.9^{b}
Fallow	1.63^{bc}	38.1^{b}
45 kg N/ha	2.11^{ab}	61.7^{a}
90 kg N/ha	1.57^{bc}	49.3^{ab}

Notes: [1] Values followed by the same letter are not significantly different at 5% different (HSD), lime[2] = 2 t/ha, PK[3] fertilizers = 69 kg P_2O_5 + 50 kg K_2O/ha

Source: Sunarlim *et al.*, 1993

Table 10. The effects of 12 strains of *Bradyrhizobium japonicum* tolerant to acid soil on nodule score, nodule dry weight, and seed yield of Wilis variety in Toto Projo, Lampung

Strain	Nodule score	Nodule dry weight (mg/plant)	Seed yield (t/ha)
FCB 178/1	1.9	48	1.43
FCB 215/3	0.9	31	1.12
FCB 249/3	2.4	51	1.44
FCB 211/2	2.3	58	1.21
FCB 229/3	2.3	39	1.48
FCB 230/3	2.2	48	1.54
FCB 44/2	2.6	50	1.38
FCB 187/3	2.2	57	1.33
FCB 31/1	2.5	45	1.32
FCB 246/3	2.6	49	1.30
FCB 251/3	2.2	67	1.63
FCB 15/2	2.4	77	1.64
Control	0.4	10	0.94
LSD 0.05	0.4	25	0.34
0.01	0.5	33	0.46

Source: Simanungkalit *et al.*, 1995

experiment showed that lime application on soybean crops at the rate of 1.0-1.5 x Exchangeable-Al (Exch-Al) was enough to obtain a good yield (Figure 3). Results from a field experiment showed that increasing the rate of lime application up to 2.0 t/ha increased soybean yield significantly following a linear regression line (Figure 4).

Further studies indicated that application of 2.0 t lime/ha in Lampung increased soybean seed yield from 1.28 to 1.77 t/ha (Sunarlim *et al.*, 1990). Another result from field experiment in Onembutu, Sulawesi, showed that lime application at the rate of 2.35 x Exch-Al (5.9 t/ha) improved soybean yields to a range from 1.47-1.56 t/ha (Gunarto, 1985). In Lubuk Minturun, West Sumatera, liming at the rate of 1.5 x Exch-Al was enough to obtain good soybean at around 1.20 t/ha (Rusman, 1990). In Sitiung IV, West Sumatera, grain yields of soybean ranging from 1.50 to 1.90 t/ha were obtained from application of lime at the rate of 1 x Al_{dd} (3 t $CaCO_3$/ha) (Hakim, 1990). In an acid soil with pH 3.81 and Exch-Al 20.59 me/100 g, application of lime (4 t/ha) increased soybean yield from 1.79 to 3.89 t/ha (Makarim and Ningrum, 1991).

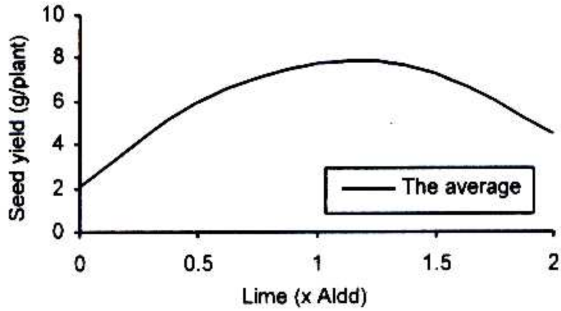

Figure 3. Seed yields of soybean as affected by the rate of lime application in the greenhouse 1987/88

Source: Achlan and Sunarlim, 1989

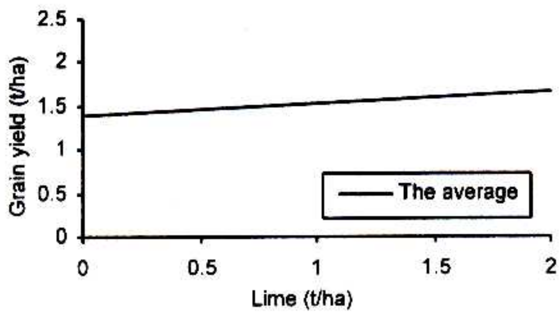

Figure 4. Soybean yields as affected by different rate of lime application in South Lampung 1990

Source: Ginting, 1993

Results of the P fertilizer experiment in the greenhouse using acid soils from West Java showed that the maximum rate of P fertilizer application for soybean was 106 kg P_2O_5/ha (Figure 5). In another greenhouse experiment using acid soils from West Java, the results were different from the previous trial. The seed yield increase was significant and in a linear regression of Y = 3.124 + 0.026 X with rates of P fertilizer applied (Murtado, 1989). Djafar and Zen (1991) reported that in a P deficient soil, applications of P fertilizer at the rate ranging from 90 to 135 kg P_2O_5/ha were sufficient to produce high soybean yield (1.5-1.64 t/ha). Results of a field trial in Central Lampung and a greenhouse trial using soils from Central Lampung showed that P fertilizer increased seed yield significantly. Seed yield was still increased although the rate of P fertilizer was already 92 kg P_2O_5/ha (Table 10).

Pulung (1991) reported that residual effect of P fertilizers still affected soybean yields for two subsequent seasons. When P fertilizer was applied to winged bean crops and soybean was planted in the same field after the winged bean crops, the soybean yields of the first and second cropping seasons were higher as affected by the residual P fertilizers. In the third season, however, the residual P fertilizer did not affect the soybean yield (Table 11).

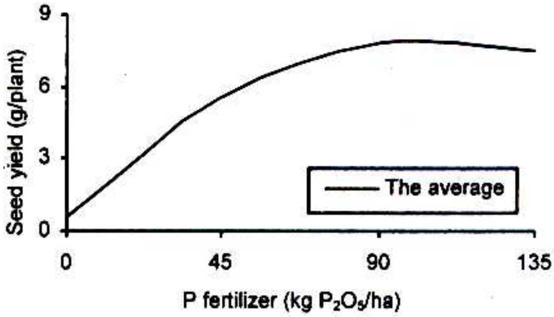

Figure 5. Seed yield of soybean as affected by different rate of P fertilizer application in greenhouse 1987/88

Source: Achlan and Sunarlim, 1989

Table 11. Soybean seed yields as affected by P fertilizers in Central Lampung and in the greenhouse 1993/94

P fertilizer (Kg P_2O_5/ha)	Seed yield	
	Greenhouse (g/plant)	Field (t/ha)
0	6.75^{c}	1.11^{c}
23	7.46^{b}	1.23^{b}
92	8.40^{a}	1.41^{a}

Notes: [1] Values in each column followed by the same letter are not significantly different at 5% different (HSD)

Source: Dewi and Sunarlim, 1994

Experiments on effect of P and K fertilizers on soybean yields were conducted in Central Lampung for 3 seasons from 1987-1988 and one season in the greenhouse using the same soils from the field. Results of the experiments showed that combined application of P and K fertilizers increased the soybean yields. Fertilizer application at the rate of 46 kg P_2O_5 + 60 kg K_2O/ha gave the results (Table 12).

CONCLUSION

There were many ways to improve soybean productivity in acid soils. Several biotic and abiotic stresses and unfavorable post-harvest conditions were serious problems to the crop production. Growing soybean cultivars tolerant to acid soils with higher yield potential and yield stability as well as good crop-soil management practices are important in efforts to increase soybean productivity.

Table 12. Effects of residual P fertilizer on soybean yield in three seasons, Tanjungan, Southern Lampung 1987-1988

Residual P fertilizer (kg P_2O_5/ha)	Seed yield (t/ha)		
	Season I	Season II	Season III
0	0.74^{a}	0.98^{a}	1.08^{a}
50	0.73^{a}	1.23^{ab}	1.15^{a}
100	0.97^{b}	1.37^{bc}	1.15^{a}
150	1.07^{ab}	1.61^{c}	1.18^{y}
200	1.17^{c}	1.78^{d}	1.42^{y}

Notes: Values in each column followed by the same letter are not significantly different at 5% different (HSD)

Source: Pulung, 1991

Table 13. Yields of soybean seeds as affected by P and K fertilizers in Central Lampung and in the greenhouse during the period of 1993/94 – 1994/95

P fertilizer + K fertilizer (kg P_2O_5/ha + kg K_2O/ha)	Yield of seeds			
	Central Lampung (t/ha)			Greenhouse (g/plant)
	WS I 1993/94	WS II 1993/94	WS I 1994/95	
0	0.98^{c}	1.37^{b}	0.84^{c}	5.76^{b}
23 + 30	1.30^{b}	1.38^{b}	1.23^{b}	6.85^{b}
46 + 60	1.37^{b}	1.51^{a}	1.32^{ab}	8.44^{a}
92 + 120	1.61^{a}	1.57^{a}	1.39^{a}	8.67^{a}

Notes: [1] Values in each column followed by the same letter are not significantly different at 5% different (HSD)

Source: Sunarlim *et al.*, 1997b

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