3. Phosphorus Rate for Vegetables Grown in the Ultisols, Nanggung, Bogor, Indonesia

Anas D. Susila[1], Juang G. Kartika[1] and Manuel C. Palada[2]

Abstract

Amaranth (*Amaranthus* sp.), kangkung (*Ipomoea aquatica* L.), eggplant (*Solanum melongena* L.), chili (*Capsicum annuum* L.), tomato (*Lycopersicon esculentum* Mill), green bean (*Phaseolus vulgaris* L.), and yard-long bean (*Vigna unguiculata* L.) were grown on Ultisols soil of Nanggung with low pH (5.2), low organic C (1.70%), very low total N (0.21%), low K content (0.33 me/100 g), but high soil P_2O_5 concentration (10.8 ppm) to optimize P rate application. Treatments were P rate: 0, 45, 90, 135 and 180 kg P_2O_5/ha or equal to 0, 125, 250, 375 and 500 kg SP36 (36% P_2O_5)/ha. Treatments were arranged in Randomized Completely Block design with three replications. In the level of soil P concentration of 10.8 ppm (Bray-1) of Ultisols, application of P fertilizer up 180 kg P_2O_5/ha linearly increased plant height of kangkung, eggplant, chili, tomato, yard-long bean and green bean and linearly increased yield of amaranth, kangkung, eggplant, chili, tomato and green bean. To achieve optimum P fertilizer rate, the range of P rate application needs to be increased.

Keywords: vegetables, fertilization, P-rate, fruit yield, Ultisols

1. Introduction

Vegetables are the main source of vitamins and minerals in the human diet. Vegetable consumption per capita per year recommended by the Food and Agriculture Organization (FAO) is approximately 75 kg. However, Indonesian vegetable consumption per capita per year is 35.3 kg, which is still far below FAO recommendation, showing that vegetable production in Indonesia still needs to be improved. Increasing cropping area and building best management practices for vegetable production are thus critical issues to be addressed.

Proper crop fertilization depends on knowing the crop nutrient requirements to achieve maximum yield and derive the potential level of

[1]Plant Production Division, Department of Agronomy and Horticulture, Faculty of Agriculture, Bogor Agricultural University Jl. Meranti, Komplek IPB Darmaga Bogor 16680, Indonesia. anasdsusila@ipb.ac.id, Tel/Fax: 0251 629353

[2]Crop and Ecosystems Management Unit AVRDC, World Vegetable Center, P.O. Box 42, Shanhua, Tainan 74199, Taiwan. mpalada@gmail.com

nutrients available from the soil. In addition to yield, quality of the commodity is an important factor of profit and shelf-life for high-value crops (Hochmuth et al., 1993).

Nitrogen, phosphorus and potassium availability are the most limiting factors for maximum growth and yield (Tisdale et al., 1990). In mineral soils, phosphorus concentration and availabilty are low; therefore application of P fertilizer is needed. In acid soil, most of the P is not available for plants due to its having been fixed by Al and Fe, such that P availablitity normally becomes the most critical nutrient. Phosphorus is needed for the cell formation of apical root and shoot, flower and reproductive process, flower and initiation and fruit development (Thompson and Troeh, 1978; Nyakpa et al., 1988; Rosmarkam and Yuwono, 2002). Phosphorus deficiency will reduce plant growth, stunt root formation and fruit initiation and delay development (Embleton et al., 1973; Marschner, 1995).

Soil testing is employed to identify the level of plant available nutrients provided by the soil and predict needed fertilizer. For predictive soil testing to be succesful, the nutrient tested for must be immobile (Kidder, 1993; Melsted and Peck, 1977), and nutrients extracted must be related to crop response (Danke, 1993; Nelson and Anderson, 1977). For practical purposes, it is desirable to use an extraction reagent that is effective for many nutrients in one extraction proceure (Jones, 1990). However, in Indonesia, fertilizer recommendations based on soil analysis for vegetable crop have not been developed.

Application of phosphorus on tomatoes var. Intan was reported to increase plant height, biomass dry weight, and root and stem dry weight. It also influenced the days of flowering and maturity and the number of flowers per plant (Musa, 1991). Phosphorus application up to 11.5 ppm in the nutrient solution increased biomass dry weight of corn (Syafruddin, 2002). Syarif (2005) reported that P application on rice influenced root/stem ratio, root length and P efficiency.

This experiment was established as a preliminary database to build soil P status and as quick references to obtain P optimum rate in the acid soil (Ultisols-Nanggung) for seven vegetable crops. This experiment will be followed by correlation and calibration study to build P fertilization recommendation based on soil analysis.

2. Materials and Methods

Research was carried out at the SANREM Base Camp at Hambaro villlage, Nanggung subdistrict, Bogor, West Java, Indonesia Demo Farm, Tenjo area, Bogor Regency from December 2006 to April 2007. The soil type in the location was Ultisols, which typically has low pH and high P-fixation by Aluminum. Pre fertilizer-application soil samples were taken with a soil probe from the top 15 cm. Fertilizer was applied at 200-90 kg N-K_2O/ha from urea (45% N) and potassium sulfate (60% K_2O). The rate of phosphorus application was based on the treatments. All the P and 50% of N and K were applied prior to planting, and 50% of N and K were side-dressed twice each of 25% at 3 and 6 weeks after transplanting.

Treatments were P rate: 0, 45, 90, 135 and 180 kg P_2O_5/ha or equal to 0, 125, 250, 375 and 500 kg SP36 (36% P_2O_5)/ha. Treatments were arranged in Randomized Complete Block design with three replications.

Pre-plant applications were done by broadcasting fertilizer broadcast and rototilling this into raised beds approximately 0.9 m wide and 20 cm high. The plot sizes were 1.5 x 4 m, with 0.9 m for raised beds and 0.6 m for ditches. Seven vegetables used in this experiment were tomato (*Lycopersicon esculentum* L.) var Ratna, chili (*Capsicum anuum* L.) var. Prabu, eggplant (*Solanum melongena*) var. Ungu, kangkung (*Ipomoea reptans* L.) var Sutera, and yard-long bean (*Vigna unguiculata* L.) var. hijau panjang, amaranth (*Amaranthus* sp.) var. local, green bean (*Phaselous vulgaris* L.) var. low land. Chili, tomato and eggplants were spaced 0.4 m within rows and 0.6 m between rows (double rows). Yard-long bean and pole bean were spaced 0.25 m within rows and 0.6 m between rows (double rows). Kangkung and amaranth were spaced 0.1 m within rows and 0.25 m between rows (four rows).

Measurement of plant height was conducted for chili, tomato, eggplant at 2, 3, 4, 5, 6 and 7 weeks after transplanting, whereas that for kangkung, amaranth, yard-long bean and green been was conducted at 2, 3, 4 weeks after transplanting. Fruit weight per plant and per plot were measured for marketable and unmarketable fruit. Analysis of variance of data was calculated using SAS 6.12 (SAS Institute, N.C). Polynomial regression was used to analyze P-rate effect (linear or quadratic) and to find out the optimum rate for maximum yield..

3. Results and Discussion

3.1 Soil analysis

Pre-plant soil analysis showed that soil pH (water) at the experimental area was very low (pH 5.2). It was the common situation for Ultisols/Podzolic soil type. Organic C content was 1.70% (low), total N 0.21% (very low), with a C/N ratio of 6 (considered very low). Soil P_2O_5 concentration (Bray 1) was 10.8 ppm (high), but the P availability for the plant was low and K (NH4 Acetate 1N, pH 7) was 0.33 cmol/kg. The soil analysis is presented in Table 1.

Table 1. Pre-plant soil analyses for Ultisols at the experimental site

Soil Character	Soil Index	Methods
pH H2O	5.20	pH meter
pH KCl	4.10	pH meter
C-org (%)	1.70	Walkley and Black
N-org (%)	0.21	Kjeldahl
P Bray-1 (ppm)	10.8	Bray-1
K_2O Morgan (ppm)	167	Morgan
Ca (cmol/kg)	18.45	1 N NH_4Oac pH 7.0
Mg (cmol/kg)	4.63	1 N NH_4Oac pH 7.0
K (cmol/kg)	0.33	1 N NH_4Oac pH 7.0
Na (cmol/kg)	0.07	1 N NH_4Oac pH 7.0
KTK	27.98	1 N NH_4Oac pH 7.0
Al (me/100 g)	1.14	1 N KCl
H (me/100 g)	0.40	1 N KCl
Texture:		
Pasir (%)	10	Pipet
Debu (%)	30	Pipet
Liat (%)	60	Pipet

3.2 Amaranth (*Amaranthus* sp.)

The total weight of plants, shoots and roots of amaranth linearly increased with an increase in P rate from 0 to 180 kg/ha P_2O_5. With no P application, the total plant weight, shoot weight and root weight per plot were 247.0 g, 209.0 g and 38.0 g, respectively; and with 180 kg/ha P_2O_5 they were 2,804.31 g, 2,587.33 g and 384 g, respectively (Table 2). This data indicated that soil P concentration of 10.8 ppm (Bray-1) was still not enough to contribute available P for amaranth yield with application of P fertilizer up to 180 kg/ha P_2O_5. To achieve maximum yield, P rate can still be increased. However, in variable shoot/root ratio, an increase in P application from 135 to 180 kg/ha P_2O_5 tended to reduce the number.

Table 2. Effect of P rate on total plant, leaf, root weight per plot, and leaf/root ratio of amaranth (*Amaranthus* sp.)

P Rate (kg P_2O_5 ha^{-1})	Total Plant weight	Shoot weight	Root weight	Shoot/ Root
	-----gram-----			
0	247.00	209.00	38.00	3.37
45	1,304.83	1,143.83	201.00	5.54
90	1,999.33	1,944.67	291.33	6.68
135	2,179.67	2,080.33	332.67	7.31
180	2,804.31	2,587.33	384.00	6.60
Regression	L*	L*	L*	

Note: ns, *, ** Non significant or significant at P = 0.05 and 0.01, respectively; P rate effects were L = Linear, Q = Quadratic

Table 3. Effect of P rate on plant height of kangkung (*Ipomoea aquatica* L.)

P Rate	Plant Height (cm)		
(kg P_2O_5 ha^{-1})	2 WAT	3 WAT	4 WAT
0	12.13	16.62	23.19
45	11.53	13.97	19.19
90	12.33	18.08	25.69
135	12.91	17.79	27.70
180	13.92	19.42	28.61
Regression	L*	L**	L**

Note: ns, *, ** Non significant or significant at P = 0.05 and 0.01, respectively; P rate effects were L = Linear, Q = Quadratic

3.3 Kangkung (*Ipomoea aquatica* L.)

The plant height of kangkung at 2, 3 and 4 weeks after transplanting (WAT) linearly increased (Table 3). However, the total plant weight, shoot, and root weights per plot of kangkung was not influenced by P rate from 0 to 180 kg/ ha P_2O_5 (Table 4.) Leaf weight per plant linearly increased with P application. With no P application the weight of leafs per plant was 3.69 g; and with 180 kg/ha P_2O_5 it was 7.99 g (Table 5). This data indicated that soil P concentration of 10.8 ppm (Bray-1) was insufficient to contribute available P for amaranth yield with application of P fertilizer up to 180 kg/ha P_2O_5. To achieve maximum yield, P rate can still be increased. However, application of 180 kg/ha P_2O_5 is enough to increase plant height.

Table 4. Effect of P rate on total plant weight, leaf, root weight per plot, and leaf/root ratio of kangkung (*Ipomoea aquatica* L.).

P Rate (kg P_2O_5 ha^{-1})	Total P\plant weight	Shoot weight	Root weight	Shoot/Root Ratio
	---gram---			
0	490.60	403.93	86.67	4.63
45	562.73	458.70	104.03	4.53
90	437.63	361.77	75.83	4.58
135	667.03	559.40	107.63	5.09
180	642.28	520.63	121.63	4.61
Regression	ns	ns	ns	

Note: ns, *, ** Non significant or significant at P = 0.05 and 0.01, respectively; P rate effects were L = Linear, Q = Quadratic

Table 5. Effect of P rate on leaf weight per plant of amaranth (*Amaranthus* sp)

P Rate (kg P_2O_5 ha^{-1})	Shoot weight per plant (g)
0	3.69
45	2.60
90	5.14
135	6.67
180	7.99
Regression	L*

Note: ns, *, ** Non significant or significant at P = 0.05 and 0.01, respectively; P rate effects were L = Linear, Q = Quadratic

3.4 Eggplant (*Solanum melongena* L.)

The effect of P application was not significant for plant height of eggplant at 2 and 3 Weeks After Transplanting (WAT), but increased linearly the plant height at 4, 5, 6 and 7 WAT (Table 6). Fruit weight per plot was not influenced by P application, but fruit weight per plant linearly increased with P application to 180 kg/ha P_2O_5 (Table 7).

Table 6. Effect of P rate on plant height of eggplant (*Solanum melongena*).

P Rate (kg P_2O_5 ha^{-1})	Plant height (cm)					
	2 WAT	3 WAT	4 WAT	5 WAT	6 WAT	7 WAT
0	3.43	4.57	5.30	6.60	9.40	10.01
45	4.14	5.77	7.67	12.27	17.90	19.04
90	3.66	4.90	7.40	12.66	20.63	27.03
135	2.85	4.40	6.07	9.90	10.80	13.70
180	3.11	5.33	7.98	13.23	19.93	30.73
Regression	ns	ns	L*	L**	L**	L**

Note: ns, *, ** Non significant or significant at P = 0.05 and 0.01, respectively; P rate effects were L = Linear, Q = Quadratic

Table 7. Effect of P rate on fruit weight per plot and fruit weight per plant of eggplant (*Solanum melongena*)

P Rate (kg P_2O_5 ha^{-1})	Fruit Weight per Plot	Fruit Weight per Plant
	gram	
0	419.32	80.54
45	285.89	75.56
90	786.02	167.79
135	252.71	44.68
180	633.53	176.47
Regression	ns	L*

Note: ns, *, ** Non significant or significant at P = 0.05 and 0.01, respectively; P rate effects were L = Linear, Q = Quadratic

3.5 Chili (*Capsicum annuum* L.)

The trend of chili plant height at 2, 3 Weeks After Transplanting (WAT) was quadratic with the application of P rate from 0 to 180 kg/ha P_2O_5. However, application of P to 180 kg/ha P_2O_5 linearly increased plant height at 4, 5, 6 and 7 WAT (Table 8). Total fruit yield and total marketable yield also linearly increased with P application to 180 kg/ha P_2O_5 (Table 9). Similar with eggplant, application of P fertilizer up to 180 kg/ha P_2O_5 still linearly increased fruit yield of chili grown in the Ultisols with soil P concentration of 10.8 ppm (Bray-1). However, P application had no influence on unmarketable chili fruit.

3.6 Tomato (*Lycopersicon esculentum* L.)

Phosphorus application from 0 to 180 kg/ha P_2O_5 linearly increased the plant height of tomato from 1 to 7 WAT (Table 10). The linear trend also occurred in total fruit weight and marketable fruit weight, but not significant in unmarketable fruit weight (Table 11). With no P application the total fruit weight and marketable fruit weight were 96.67 g and 87.79 g, respectively, and with 180 kg/ha P_2O_5 the corresponding figures were 315.76 g and 304.45 g, respectively. Similar with eggplant and chili, application of P fertilizer up to 180 kg/ha P_2O_5 still linearly increased the fruit yield of tomato grown in the Ultisols with soil P concentration of 10.8 ppm (Bray-1). However, P application was not an influence on unmarketable tomato fruit.

Table 8. Effect of P rate on plant height of chili (*Capsicum annuum*)

P Rate	Plant Height (cm)					
(kg P_2O_5 ha^{-1})	2 WAT	3 WAT	4 WAT	5 WAT	6 WAT	7 WAT
0	15.40	19.87	23.31	27.40	32.30	33.90
45	17.27	19.90	24.77	29.93	35.43	36.63
90	18.24	23.43	26.27	33.23	36.93	39.60
135	15.49	220.83	26.03	31.93	38.53	41.27
180	15.53	21.13	28.47	34.47	41.40	41.97
Regression	Q**	Q*	L*	L**	L*	L*

Note: ns, *, ** Non significant or significant at P = 0.05 and 0.01, respectively; P rate effects were L = Linear, Q = Quadratic

Table 9. Effect of P rate on total, marketable, and un-marketable fruit weight per plant of chili (*Capsicum annuum*)

P Rate	Total Fruit Weight	Marketable Fruit Weight	Un-marketable Fruit Weight
(kg P_2O_5 ha^{-1})	---gram---		
0	66.64	61.56	5.08
45	102.70	101.31	1.40
90	86.58	84.30	2.28
135	144.17	141.83	2.33
180	140.49	138.50	1.99
Regression	L**	L**	ns

Note: ns, *, ** Non significant or significant at P = 0.05 and 0.01, respectively; P rate effects were L = Linear, Q = Quadratic

Table 10. Effect of P rate on plant height of tomato (*Lycopersicon esculentum*)

P Rate ($kg\ P_2O_5\ ha^{-1}$)	Plant Height (cm)					
	2 WAT	3 WAT	4 WAT	5 WAT	6 WAT	7 WAT
0	19.87	21.57	28.50	32.00	35.40	36.50
45	17.27	24.15	31.03	36.20	40.73	43.77
90	20.07	28.60	37.33	49.90	54.40	53.57
135	17.47	26.47	31.00	38.17	44.77	42.4
180	20.40	30.10	38.23	50.53	59.80	61.03
Res	L*	L**	L*	L**	L**	L**

Note: ns, *, ** Non significant or significant at P = 0.05 and 0.01, respectively; P rate effects were L = Linear, Q = Quadratic

Table 11. Effect of P rate on total, marketable, and un-marketable fruit weight per plant of tomato (*Lycopersicon esculentum*)

P Rate ($kg\ P_2O_5\ ha^{-1}$)	Total Fruit Weight	Marketable Frut Weight	Un-marketable Fruit Weight
	---gram---		
0	95.67	87.79	7.88
45	150.39	138.26	12.13
90	204.97	192.87	12.18
135	176.29	168.90	7.39
180	315.76	304.45	11.31
Regression	L**	L**	ns

Note: ns, *, ** Non significant or significant at P = 0.05 and 0.01, respectively; P rate effects were L = Linear, Q = Quadratic

3.6 Green bean (*Pahaseolus vulgaris* L.)

The effect of P application was not significant for plant height of green bean except at 2 WAT (Table 12). Fruit weight per plot was not influenced by P application, but fruit weight per plant linearly increased with P application to 180 kg/ha P_2O_5 (Table 13).

Table 12. Effect of P rate on plant height of green bean (*Phaseolus vulgaris*)

P Rate (kg P_2O_5 ha^{-1})	Plant Height (cm)		
	2 WAT	3 WAT	4 WAT
0	24.03	39.90	55.03
45	17.43	37.83	71.23
90	24.67	41.23	72.97
135	43.43	43.43	80.23
180	30.57	40.10	112.50
Regression	L**	ns	ns

Note: ns, *, ** Non significant or significant at P = 0.05 and 0.01, respectively; P rate effects were L = Linear, Q = Quadratic

Table 13. Effect of P rate on fruit weight per plot and fruit weight per plant of green bean (*Phaseolus vulgaris*)

P Rate (kg P_2O_5 ha^{-1})	Fruit Weight per Plot	Fruit Weight per Plant
	----------gram----------	
0	355.67	27.33
45	889.00	86.44
90	616.00	36.21
135	924.00	96.48
180	944.67	102.96
Regression	ns	L*

Note: ns, *, ** Non significant or significant at P = 0.05 and 0.01, respectively; P rate effects were L = Linear, Q = Quadratic

3.7 Yard-long bean (*Vigna unguiculata*)

The effect of P application was not significant for plant height of yard-long beans except at 25 WAT (Table 14). Fruit weight per plot was not influenced by P application, but fruit weight per plant linearly increased with P application to 180 kg/ha P_2O_5 (Table 13).

Table 14. Effect of P rate on plant height of yard-long bean (*Vigna unguiculata*)

P Rate (kg P_2O_5 ha^{-1})	Plant Height (cm)			
	2 WAT	3 WAT	4 WAT	5 WAT
0	13.23	16.57	40.73	84.16
45	12.70	20.43	36.83	62.83
90	12.13	19.20	51.13	89.43
135	12.90	23.76	52.30	81.57
180	11.83	18.92	42.87	97.87
Regression	ns	ns	ns	L*

Note: ns, *, ** Non significant or significant at P = 0.05 and 0.01, respectively; P rate effects were L = Linear, Q = Quadratic

Table 15. Effect of P rate on fruit weight per plot and fruit weight per plant of yard-long bean (*Vigna unguiculata*)

P Rate (kg P_2O_5 ha^{-1})	Fruit Weight per Plot	Fruit Weight per Plant
	------------------------gram	-----------------
0	192.89	62.51
45	233.11	101.96
90	144.50	85.96
135	100.33	39.63
180	31.67	84.91
Regression	ns	ns

Note: ns, *, ** Non significant or significant at P = 0.05 and 0.01, respectively; P rate effects were L = Linear, Q = Quadratic

Table 16. Analyses of variance for all measured variables of the P application on vegetable grown on Ultisols at Nanggung, Bogor, Indonesia

Variable	F value	p	Average	Response
Amaranth (*Amaranthus* sp.)				
Leaf weight per plots (4x1.5 m)	6.32	0.0135tn	402.6420	
Total biomass weight per plots	4.55	0.0328*	46.37291	L*
Root weight per plot	5.82	0.0170*	39.10681	L*
Root/leaf ratio	1.28	0.3550tn	64.94166	
Kangkung (*Ipomoea aquatica*)				
Plant height 1 WAT	2.77	0.0341*	16.7414	L*
Plant height 2 WAT	6.52	0.0002**	18.1197	L**
Plant height 3 WAT	6.99	0.0001**	22.3743	L**
Leaf weight per plots (4x1.5 m)	0.59	0.6769tn	39.5639	
Total biomass weight per plots	0.61	0.6652tn	38.5088	
Root weight per plot	0.73	0.5951tn	36.8056	
Root/Leaf ratio Bobot	0.29	0.8787tn	15.6481	
Leaf weight per plant	4.09	0.0429*	35.7447	L*
Eggplant (*Solanum melongena*)				
Plant height 1 WAT	1.83	0.1340tn	41.6674	
Plant height 2 WAT	1.69	0.1615tn	33.4012	
Plant height 3 WAT	2.79	0.0330*	38.6123	L*
Plant height 4 WAT	6.34	0.0002**	44.5600	L**
Plant height 5 WAT	5.59	0.0006**	54.7793	L**
Plant height 6 WAT	12.99	0.0001**	46.6756	L**
Fruit weight per plot	1.26	0.3593tn	74.2585	
Fruit weight per plant	3.99	0.0057*	105.4840	L*
Chili (*Capsicum annuum*)				
Plant height 1 WAT	5.15	0.0011**	13.4900	Q**
Plant height 2 WAT	2.94	0.0267*	15.6200	Q*
Plant height 3 WAT	3.02	0.0235*	16.5200	L*
Plant height 4 WAT	3.95	0.0061**	17.9900	L**
Plant height 5 WAT	3.26	0.0165*	19.6600	L*
Plant height 6 WAT	2.45	0.0540*	21.5300	L*
Total fruit weight per plot	0.74	0.5887tn	45.7100	
Marketable fruit weight per plot	0.75	0.58298tn	46.5000	
Unmarketable fruit weight per plot	0.60	0.6746tn	113.4980	
Total fruit weight per plant	4.94	0.0015**	54.4200	L**
Marketable fruit weight per plant	5.26	0.0009**	55.4800	L**
Unmarketable fruit weight per plant	0.74	0.5703tn	246.1820	

Table 16. (Cont.)

Variable	F value	p	Average	Response
Tomato (*Lycopersicon esculentum*)				
Plant height 1 WAT	2.45	0.0540*	21.5305	L*
Plant height 2 WAT	4.42	0.0031**	24.0482	L**
Plant height 3 WAT	3.06	0.0221*	28.6531	L*
Plant height 4 WAT	5.63	0.0006**	30.2450	L**
Plant height 5 WAT	7.79	0.0001**	29.4160	L**
Plant height 6 WAT	6.51	0.0002**	29.3266	L**
Total fruit weight per plot	5.39	0.0211*	32.3809	L*
Marketable fruit weight per plot	5.86	0.0167*	32.1767	L*
Unmarketable fruit weight per plot	0.17	0.9454tn	81.0680	
Total fruit weight per plant	5.47	0.0007**	71.7349	L**
Marketable fruit weight per plant	5.8	0.0004**	72.6542	L**
Unmarketable fruit weight per plant	0.22	0.9278tn	190.8840	
Green Bean (*Pahaseolus vulgaris*)				
Plant height 1 WAT	11.57	0.0001**	42.4100	L**
Plant height 2 WAT	0.45	0.7722tn	29.3200	
Plant height 3 WAT	1.97	0.1082tn	35.8300	
Plant height 4 WAT	6.49	0.0002**	35.5900	L**
Fruit weight per plot	1.33	0.3382tn	51.5000	
Fruit weight per plant	2.98	0.0251*	84.9200	L*
Yard-long bean (*Vigna unguiculata*)				
Plant height 1 WAT	1.06	0.3845tn	17.0880	
Plant height 2 WAT	1.1	0.3642tn	49.1750	
Plant height 3 WAT	1.47	0.2210tn	47.8700	
Plant height 4 WAT	2.79	0.0329*	36.1305	L*
Fruit weight per plot	1.93	0.1267tn	121.2260	
Fruit weight per plant	2.39	0.0594tn	80.8920	

4. Conclusions

The following conclusions may be drawn from the experiment:

1. At the level of soil P concentration of 10.8 ppm (Bray-1) of Ultisols, application of P fertilizer up 180 kg/ha P_2O_5 linearly increased plant height of kangkung, eggplant, chili, tomato, yard-long bean and green bean.

2. The same (point 1) application linearly increased the yield of amaranth, kangkung, eggplant, chili, tomato and green bean.

3. To achieve optimum P fertilizer rate, the range of P rate application has to be increased.

4. To accomplish correlation study in this Ultisols wider range of soil P status of higher than 180 kg/ha P_2O_5 should be applied.

5. Acknowledgments

This publication was made possible through support provided by the United States Agency for International Development and the generous support of the American People (USAID) for the Sustainable Agriculture and Natural Resources Management Collaborative Research Support Program (SANREM CRSP) under terms of Cooperative Agreement Award No. EPP-A-00-04-00013-00 to the Office of International Research and Development (OIRED) at Virginia Polytechnic Institute and State University (Virginia Tech).

References

Bahri, S. 2002. Pengaruh Pemupukan N dan P terhadap Pertumbuhan dan Produksi Soba (*Fagopyrum esculentum* Moench.). Skripsi. Jurusan Budidaya Pertanian, Fakultas Pertanian, IPB, Bogor. 40 hal.

Brady, N.C. 1990. *The Nature and Properties of Soils.* 10th ed. Macmillan Publ. Co., New York.

Dahnke, W.C. 1993. Soil test interpretation. *Commun. Soil Sci Plant Anal.,* 24: 11-27.

Embleton, T.W., W.W. Jones, C.K. Lebanaukas and W. Reuther. 1973. Leaf analysis as a diagnostic tool and guide to fertilization in W. Reather (ed.). The citrus industry. *Rev. ed. Univ. Calif. Agr. Sci. Barkely.,* Vol. 3183-3210.

Hochmuth, G., E. Hanlon, G. Kidder, D.Hensel, W. Tilton, J. Dilbeck and D. Scheader. 1993. Fertilizer demonstration for the tri-county potato production area of Northeast Florida. *Proc Fla State Hort Soc.,* 106: 190-198.

Jones, J.B. Jr. 1990. Universal soil extractants: Their composition and use. *Commun. Soil Sci Plant Anal.,* 21: 1091-1101.

Kidder, G. 1993. Methodology for calibrating soil tests. *Soil Crop Sci Soc Fla Proc.,* 52: 70-73

Marschner, H. 1995. *Mineral Nutrition in Higher Plants.* New York: Academic Press. 675 pp.

Musa, A. 1991. Tanggap Tanaman Tomat Varietas Intan terhadap Pemberian Pupuk Fosfat dan Pupuk Daun Mikrofid Zn 10. Tesis. Fakultas Pascasarjana, IPB, Bogor. 106 hal.

Melsted, S.W. and T.R. Peck. 1977. The itscherlich-bray growth fiction, pp. 1-18. In: T.R. Peck, J.T Cope, Jr. and D.A. Whitney (eds): *Soil Testing: Correlation and Interpreting the Analytical Results.* ASA Spec Pub No. 29. Amer Soc Agron, Crop Sci Soc of Amer, Soil Sci Soc of Amer, Madison,

Nelson, D.W. and R.L Anderson. 1977. Partitioning soil test-crop response propability, pp. 19-38. R. Peck, J.T Cope, Jr. and D.A. Whitney (eds): *Soil Testing: Correlation and Interpreting the Analytical Results.* ASA Spec Pub No. 29. Amer Soc Agron, Crop Sci Soc of Amer, Soil Sci Soc of America, Madison, Wisconsin.

Nyakpa, M.Y., Lubis, A.M., Pulung, M.A., Amrah, A.G., All Munawar, Go Ban H and Hakim N. 1988. Kesuburan Tanah. Universitas Lampung. 258 hal.

Rosmarkam, A. and N.W. Yuwono. 2002. Ilmu Kesuburan Tanah. Kanisius. Yogyakarta.

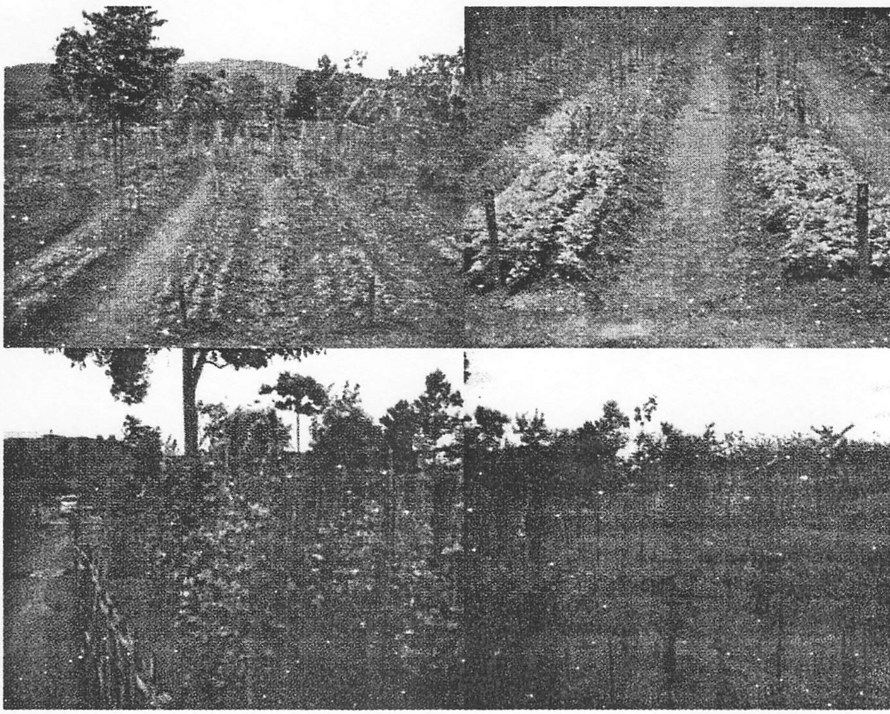
Syafruddin. 2002. Fisiologi Hara Fosfor pada Tanaman jagung (*Zea mays* L.) dalam Kondisi Cekaman Alumunium. Tesis. Program Pascasarjana, IPB, Bogor. 69 hal.

Syarif, A.A. 2005. Adaptasi dan Ketenggangan Genotipe Padi Terhadap Defisiensi Fosfor di Tanah Sawah. Disertasi. Sekolah Pascasarjana, IPB, Bogor. 131 hal.

Thompson, L.M. and F.R. Troeh. 1978. Soil and Fertility. McGraw-Hill Book Company, New York.

Tisdale, S.L., Nelson, W.L. and J.D. Beaton. 1990. Soil Fertility and Fertilizers. 4th edition. Macmillan Publ. Co. New York. 754 pp.

Appendix 1. Photos from the study of P rates. From upper left: Planting for P fertilizer recommendation study; P recommendation study for vegetables; Fertilization trial for yard-long bean; P fertilization trial for chili



4. Correlation Study of Soil-P Test for Vegetables Grown in the Ultisols at Nanggung, Bogor, Indonesia

Juang G. Kartika and Anas D. Susila[1]

Abstract

Phosphorus (P) correlation experiment has been done in Ultisols in Nanggung District, Bogor, Indonesia from 2006-2007 to find the best P extraction method suitable for vegetables i.e. amaranth (*Amaranthus* sp.), kangkung (*Ipomoea aquatica* L.), eggplant (*Solanum melongena* L.*)*, chili (C*apsicum annuum* L.), tomato (*Lycopersicon esculentum* Mill), green bean (*Pahaseolus vulgaris* L.) and yard-long bean (*Vigna unguiculata* L.). Treatments were P rate: 0, 45, 90, 135 and 180 kg/ha P_2O_5 equal to 0, 125, 250, 375 and 500 kg/ha SP36 (36% P_2O_5). Treatments were arranged in Randomized Complete Block design with three replications. Soil samples were taken from every plot and analyzed with five extraction methods (25% HCl, Morgan Vanema, Bray-1, Mehlich and Olsen). Soil analysis results were correlated with the relative yield of each vegetable. The best soil extraction method is that which showed highest correlation with vegetable relative yield. Olsen method showed highest correlation with amaranth, chili and tomato relative yield; 25% HCL with yard-long bean and eggplant; and Morgan Vanema kangkung relative yield and Bray-1 for green bean.

Keywords: Vegetables, P-correlation, relative yield, Ultisols.

1. Introduction

Phosphorus (P) is the macro nutrient for plants; and next to nitrogen, is the second highest needed by plants. P nutrients have a role in carbohydrate, fat and protein metabolism. Phosphorus acts as intermediary, to keep and supply energy for metabolism like respiration and fermentation (Soepardi, 1983). P also arranges enzymatic process, closely related to compilation of crop essentials like nucleic acid at cell core; increases resilience to disease and increases crop quality.

Sufficient amounts of available P can increase root development, assist in flower initiation and other reproductive organs and quickens ripening process of fruit (Nyakpa et al., 1988; Rosmarkam and Yuwono, 2002). Addition of P into the soil can increase production and dry matter of the plant. P nutrients in plant also helps reduce nitrogen stimulating fungus effect.

[1]Plant Production Division, Department of Agronomy and Horticulture, Faculty of Agriculture, Bogor Agricultural University, Jl. Meranti, Komplek IPB Darmaga, Bogor 16680, Indonesia. ika_juang@yahoo.com, anasdsusila@ipb.ac.id, Tel/Fax: 0251 629353

Phosphorus deficiencies also lead to growth degradation as plants are unable to absorb other elements. Phosphorus is immobile in the soil. Most of it is in unavailable forms for plants. P availability is critical compared to other kinds of nutrients. The presence of high amount of soluble Al in the soil also reduces P availability for plants, because Al can bond with P in soil. Adiningsih (1988) showed that only 10-20% of P fertilizer given to the soil is absorbed by plant; the rest stays in the soil and bonds with Fe, Al and Ca.

Indonesia has many soil types with varying levels of fertility. Soils in Ultisols order are the second largest soil type for agricultural use. They have an acidic soil reaction with pH level around 4.1-5.5 (Subagyo et al., 2000). Hakim et al. (1986) mentioned that acid mineral soils faced the constraints of low soil pH, unavailable N and P, lack of Ca, Mg, K and Mo, and excessive Mn and Fe, as with high amount of dissolved Al. These problems in acid mineral soil are major problems which will inhibit plant growth and production.

Rational and proportional P fertilizer can be reached by paying attention to nutrient status and dynamics in soil, and crop requirements to reach optimum production. Determination of fertilizer recommendations can be arrived at through soil testing, because this activity refers to soil condition and crop nutrition requirement. Soil testing can increase fertilizer use efficiency, soil productivity and farmers earnings. It will also reduce contamination level of the agricultural area.

Soil testing experiments can provide fertilizer recommendation for a crop at various soil nutrition status (low/medium/high). This recommendation can be applied in other soils in the same family (Nursyamsi et al., 2004). The soil test consists of three steps, the first phase of which is the correlation test, followed by calibration and optimization of fertilizer. The correlation test is part of the soil test to arrive at recommendations on a specific location, crop production and crop type.

Various methods of P soil at subtropical areas for specific commodities and crop production techniques have been developed, but in Indonesia soil-P method is done for paddy crop and some other field crops. Soil test method is seldom done for vegetable commodities. This experiment was conducted for seven kinds of vegetables (amaranth, kangkung, eggplant, chili, tomato, green bean and yard-long bean).

For good P soil management, it is important to know soil-P status and factors influencing it. One way to determine soil nutrient status is by soil extraction. Many extractants are applicable to specify soil ability to provide P for a crop, but the extractants are not always compatible with soil type, crop production technique and climate. Methods that are commonly used to extract P from soil are Bray-1, Bray-2, Mehlich, Morgan, Truog, 25% HCl and air.

Each method has a different ability to extract P from the soil. Hence experiments on soil correlation should be done to determine the most suitable soil extraction method for specific crops and soil types that can be used as references in developing P fertilizer recommendation. The best extraction method is the one that shows the highest correlation between P nutrient content and relative crop yield. Correlation is one of the important phases to determine the fertilizer recommendation. Correlation experiments choose the most suitable extraction method for specific nutrients, crops and soil type.

2. Materials and Methods

Research was carried out at the SANREM Base Camp at Hambaro village, Nanggung subdistrict, Bogor, West Java, Indonesia, from December 2006 to September 2007. The soil type in the location is Ultisols, which typically has low pH and high P-fixation by aluminum.

The experiment was a randomized complete block design with three replications. Blocking was based on the field slope. The treatments were five rates of P fertilizer: 0, 125, 250, 375, 500 kg SP36/ha (SP36 contains 36% P_2O_5) or equal to 0, 45, 90, 135 and 180 kg/ha P_2O_5.

Pre-treatment soil samples were taken with a soil probe from the top 15 cm. Fertilizers were applied at pre-planting, and 3 and 6 weeks after planting (WAP). Pre-plant fertilizer applications were 199 kg/ha urea (45% N) and 90 kg/ha KCl (60% K_2O), applied one week before planting. At 3 and 6 WAP, 100 kg/ha Urea and 45 kg/ha KCl were applied. Phosphorus rates were based on the treatments.

Pre-plant applications were applied by broadcasting fertilizer and rototilling the fertilizer into raised beds approximately 0.9 m wide and 20 cm high. The plot size was 1.5 x 4 m, with 1.0 m for raised bed and 0.5 m as a ditch. Seven vegetables used in this experiment were tomato (*Lycopersicon esculentum* L.) var. Ratna, chili (*Capsicum anuum* L.) var. Gada, eggplant (*Solanum melongena*) var. Mustang, kangkung (*Ipomoea reptans* L.) var. Grand, and yard-long bean (*Vigna unguiculata* L.) var. 777, amaranth (*Amaranthus* sp.) var. local, green bean (*Phaseolus vulgaris* L.) var. low land. Chili, tomato and eggplants were spaced 0.5 m within rows and 0.5 m between rows (double rows). Yard-long bean and green bean were spaced 0.25 m within rows and 0.5 m between rows (double rows). Kangkung was spaced 0.15 m within rows and 0.25 m between rows (four rows) and amaranth was spaced 0.25 m between rows without space within rows.

The observation parameter was divided into two, which are *yield of the vegetables* and *soil-P content* analyzed with five different extraction methods. The result of soil-P content will be correlated with vegetable yield to determine the best soil analysis method that shows the highest correlation. Vegetable yields for amaranth and kangkung were measured from total crop weight and yield from eggplant, chili, tomato, green bean and yard-long bean were measured from fruit weight per plant and per plot.

3. Results and Discussion

3.1 Soil analysis

Pre-plant soil analysis showed that soil pH was low (5.20), which meant that the soil reaction was acidic. Soil P_2O_5 concentration extracted from 25% HCl and Bray-1 methods showed high soil-P, but availability for the plant was low because Al bonds into the soil. The soil analysis is presented in Table 1.

Table 1. Pre-plant soil analyses for Ultisols at the experimental site

Soil Character	Soil Index	Methods
pH H_2O	5.20	pH meter
pH KCl	4.10	pH meter
C-org (%)	1.70	Walkley and Black
N-org (%)	0.21	Kjeldahl
P HCl (mg/100 g)	39	HCl 25%
P Bray-1 (ppm)	10.8	Bray-1
K_2O Morgan (ppm)	167	Morgan
Ca (cmol/kg)	18.45	1 N NH_4Oac pH 7.0
Mg (cmol/kg)	4.63	1 N NH_4Oac pH 7.0
K (cmol/kg)	0.33	1 N NH_4Oac pH 7.0
Na (cmol/kg)	0.07	1 N NH_4Oac pH 7.0
CEC	27.98	1 N NH_4Oac pH 7.0
Al (me/100 g)	1.14	1 N KCl
H (me/100 g)	0.40	1 N KCl
Texture:		
Pasir (%)	10	Pipet
Debu (%)	30	Pipet
Liat (%)	60	Pipet

Results of the experiment showed that amaranth, kangkung, eggplant, chili, tomato and green bean crop relative yield linearly increased with an increase in P rate from 0 to 180 kg/ha P_2O_5 (Table 2).

Table 2. Effect of P rate on plant and fruit weight per plant

P Rate (kg/ha P_2O_5)	Amaranth Plant Weight	Kangkung shoot weight	Total Fruit Wight per Plant (gram)				
			Eggplant	Chili	Tomato	Green Bean	Yardlong Bean
	-----------------g-----------------						
0	247.00	3.69	80.54	66.64	95.67	27.33	62.51
45	1,304.83	2.6	75.56	102.70	150.39	86.44	101.96
90	1,999.33	5.14	167.79	86.58	204.97	36.21	85.96
135	2,179.67	6.67	44.68	144.17	176.29	96.48	39.63
180	2,804.31	7.99	176.47	140.49	315.76	102.96	84.91
Regression	L*	L*	L*	L**	L**	L*	ns

3.2 Amaranth (*Amaranthus* sp.)

From five extraction methods used to extract soil-P content in amaranth-cultured soil, Olsen method showed the highest correlation value, which was 0.91. But Mehlich-1, 25% HCl, Bray-1 and Morgan Vanema also showed high correlation with amaranth relative yield, each showing more than 0.50 in correlation value. The closer the correlation value is to 1, the higher the correlation between two compared variables (Table 3).

Table 3. Correlation coefficient between extracted P value of 5 extraction methods with amaranth relative yield

Extraction Methods	Linear Equation	Coefficient Correlation
25% HCL	Y= -12.125 + 0.118 P	0.76416
Olsen	Y = 1.192 + 3.445 P	0.90706
Bray-1	Y = 14.508 + 1.044 P	0.76033
Mehlich	Y = 16.639 + 1.577 P	0.78158
Morgan Vanema	Y = 13.457 + 22.851 P	0.69082

3.3 Kangkung (*Ipomoea aquatica* L.)

Table 4 indicates that the Morgan Vanema method showed the highest correlation value compared to kangkung relative yield, followed by Olsen. The other methods showed small correlation value (under 0.50).

Table 4. Correlation coefficient between extracted P value of 5 extraction methods with kangkung relative yield

Extraction Methods	Linear Equation	Coefficient Correlation
HCL 25%	Y = 23.986 + 0.088 P	0.40556
Olsen	Y = 46.360 + 1.659 P	0.59191
Bray-1	Y = 54.621 + 0.323 P	0.37589
Mehlich	Y = 52.918 + 0.499 P	0.47877
Morgan Vanema	Y = 21.960 + 14.078 P	0.69361

3.4 Eggplant (*Solanum melongena* L.)

Eggplant relative yield showed the highest correlation value when compared with 25% HCl method. Olsen and Bray-1 methods showed relative higher values than Mehlich and Morgan Vanema that showed less than 0.50 in correlation value (Table 5).

Table 5. Correlation coefficient between extracted P value of 5 extraction methods with eggplant relative yield

Extraction Methods	Linear Equation	Coefficient Correlation
25% HCL	Y = 47.745 + 0.042 P	0.72355
Olsen	Y = 60.189 + 1.032 P	0.66928
Bray-1	Y = 63.510 + 0.311 P	0.56725
Mehlich	Y = 63.222 + 0.479 P	0.44726
Morgan Vanema	Y = 63.069 + 1.158 P	0.37536

3.5 Chili (*Capsicum annuum* L.)

Like in Amaranth, the Olsen method also showed the highest correlation with chili relative yield, with a correlation value of 0.90 (Table 6). The Olsen value was followed by Mehlich, Bray-1, 25% HCl and Morgan Vanema. All the extraction methods showed higher than 0.50 correlation value.

3.6 Tomato (*Lycopersicon esculentum* L.)

Phosphorus application from 0 to 180 kg/ha P_2O_5 linearly increased the fruit weight of tomato (Table 7). The best method to extract soil-P from tomato-cultured soil is Olsen, similar to amaranth and eggplant, followed by Bray-1 and Mehlich methods. However, 25% HCl method and Morgan Vanema showed very little correlation value.

Results of the experiment showed that amaranth, kangkung, eggplant, chili, tomato and green bean crop relative yield linearly increased with an increase in P rate from 0 to 180 kg/ha P_2O_5 (Table 2).

Table 2. Effect of P rate on plant and fruit weight per plant

P Rate (kg/ha P_2O_5)	Amaranth Plant Weight	Kangkung shoot weight	Total Fruit Wight per Plant (gram)				
			Egg-plant	Chili	To-mato	Green Bean	Yard-long Bean
	g						
0	247.00	3.69	80.54	66.64	95.67	27.33	62.51
45	1,304.83	2.6	75.56	102.70	150.39	86.44	101.96
90	1,999.33	5.14	167.79	86.58	204.97	36.21	85.96
135	2,179.67	6.67	44.68	144.17	176.29	96.48	39.63
180	2,804.31	7.99	176.47	140.49	315.76	102.96	84.91
Regression	L*	L*	L*	L**	L**	L*	ns

3.2 Amaranth (*Amaranthus* sp.)

From five extraction methods used to extract soil-P content in amaranth-cultured soil, Olsen method showed the highest correlation value, which was 0.91. But Mehlich-1, 25% HCl, Bray-1 and Morgan Vanema also showed high correlation with amaranth relative yield, each showing more than 0.50 in correlation value. The closer the correlation value is to 1, the higher the correlation between two compared variables (Table 3).

Table 3. Correlation coefficient between extracted P value of 5 extraction methods with amaranth relative yield

Extraction Methods	Linear Equation	Coefficient Correlation
25% HCL	Y= -12.125 + 0.118 P	0.76416
Olsen	Y = 1.192 + 3.445 P	0.90706
Bray-1	Y = 14.508 + 1.044 P	0.76033
Mehlich	Y = 16.639 + 1.577 P	0.78158
Morgan Vanema	Y = 13.457 + 22.851 P	0.69082

3.3 Kangkung (*Ipomoea aquatica* L.)

Table 4 indicates that the Morgan Vanema method showed the highest correlation value compared to kangkung relative yield, followed by Olsen. The other methods showed small correlation value (under 0.50).

Table 4. Correlation coefficient between extracted P value of 5 extraction methods with kangkung relative yield

Extraction Methods	Linear Equation	Coefficient Correlation
HCL 25%	Y = 23.986 + 0.088 P	0.40556
Olsen	Y = 46.360 + 1.659 P	0.59191
Bray-1	Y = 54.621 + 0.323 P	0.37589
Mehlich	Y = 52.918 + 0.499 P	0.47877
Morgan Vanema	Y = 21.960 + 14.078 P	0.69361

3.4 Eggplant (*Solanum melongena* L.)

Eggplant relative yield showed the highest correlation value when compared with 25% HCl method. Olsen and Bray-1 methods showed relative higher values than Mehlich and Morgan Vanema that showed less than 0.50 in correlation value (Table 5).

Table 5. Correlation coefficient between extracted P value of 5 extraction methods with eggplant relative yield

Extraction Methods	Linear Equation	Coefficient Correlation
25% HCL	Y = 47.745 + 0.042 P	0.72355
Olsen	Y = 60.189 + 1.032 P	0.66928
Bray-1	Y = 63.510 + 0.311 P	0.56725
Mehlich	Y = 63.222 + 0.479 P	0.44726
Morgan Vanema	Y = 63.069 + 1.158 P	0.37536

3.5 Chili (*Capsicum annuum* L.)

Like in Amaranth, the Olsen method also showed the highest correlation with chili relative yield, with a correlation value of 0.90 (Table 6). The Olsen value was followed by Mehlich, Bray-1, 25% HCl and Morgan Vanema. All the extraction methods showed higher than 0.50 correlation value.

3.6 Tomato (*Lycopersicon esculentum* L.)

Phosphorus application from 0 to 180 kg/ha P_2O_5 linearly increased the fruit weight of tomato (Table 7). The best method to extract soil-P from tomato-cultured soil is Olsen, similar to amaranth and eggplant, followed by Bray-1 and Mehlich methods. However, 25% HCl method and Morgan Vanema showed very little correlation value.

Table 6. Correlation coefficient between extracted P value of 5 extraction methods with chili relative yield

Extraction Methods	Linear Equation	Coefficient Correlation
25% HCL	Y = 2.417 + 0.082 P	0.78478
Olsen	Y = 25.991 + 1.923 P	0.90242
Bray-1	Y = 30.141 + 0.674 P	0.82256
Mehlich	Y = 28.213 + 1.113 P	0.87930
Morgan Vanema	Y = -15.970 + 10.881 P	0.71011

Table 7. Correlation coefficient between extracted P value of 5 extraction methods with tomato relative yield

Extraction Methods	Linear Equation	Coefficient Correlation
25% HCL	Y = 15.070 + 0.055 P	0.46952
Olsen	Y = 24.034 + 1.144 P	0.80757
Bray-1	Y = 33.579 + 0.378 P	0.59688
Mehlich	Y = 33.461 + 0.474 P	0.56113
Morgan Vanema	Y = 34.812 + 2.531 P	0.16587

3.7 Green bean (*Pahaseolus vulgaris* L.)

The effect of P application on green bean relative yield correlated with soil extraction methods showed that Bray-1 gave the best correlation value (Table 8). This was followed by Morgan Vanema, 25% HCl and Mehlich. The correlation value of Olsen had the smallest value comparing with all other methods.

Table 8. Correlation coefficient between extracted P value of 5 extraction methods with green bean relative yield

Extraction Methods	Linear Equation	Coefficient Correlation
25% HCL	Y = -20.334 + 0.110 P	0.74633
Olsen	Y = 15.476 + 0.551 P	0.49675
Bray-1	Y = 15.932 + 0.545 P	0.84214
Mehlich	Y = 20.162 + 0.757 P	0.59180
Morgan Vanema	Y = -10.165 + 7.936 P	0.64503

3.8 Yard-long bean (*Vigna unguiculata*)

HCl (25%) method showed the highest correlation value compared to the relative yield (0.86) of yard-long bean. This was followed by Mehlich, Olsen, Bray-1 and Morgan Vanema. All extraction methods showed higher than 0.50 correlation value (Table 9).

Table 9. Correlation coefficient between extracted P value of 5 extraction methods with yard-long bean relative yield

Extraction Methods	Linear Equation	Coefficient Correlation
25% HCL	Y = 10.853 + 0.082 P	0.85964
Olsen	Y = 34.689 + 0.549 P	0.77968
Bray-1	Y = 41.158 + 0.509 P	0.74870
Mehlich	Y = 41.875 + 0.739 P	0.79835
Morgan Vanema	Y = 36.941 + 4.618 P	0.64050

4. Conclusions

The conclusions of the experiment are as follows:

On the level of soil-P concentration of 10.8 ppm (Bray-1) of Ultisols, the application of P fertilizer up to 180 kg/ha P_2O_5 linearly increased plant weight of amaranth, kangkung, eggplant, chili, tomato and green bean.

The Olsen method showed the highest correlation with amaranth, chili and tomato relative yield, while 25% HCl showed the highest correlation with the yard-long bean and eggplant. Morgan Vanema demonstrated the highest correlation with kangkung and Bray-1 for green bean.

5. Acknowledgments

This publication was made possible through support provided by the United States Agency for International Development and the generous support of the American People (USAID) for the Sustainable Agriculture and Natural Resources Management Collaborative Research Support Program (SANREM CRSP) under terms of Cooperative Agreement Award No. EPP-A-00-04-00013-00 to the Office of International Research and Development (OIRED) at Virginia Polytechnic Institute and State University (Virginia Tech).

References

Adiningsih, J.S. and M. Soepartini. 2002. Pengelolaan pupuk pada sistem usaha tani lahan sawah. *Dalam* Pramono J dan Supadmo H. Kajian penggunaan pupuk majemuk Kalphos 20:10 pada lahan sawah berstatus P tinggi dan K rendah. Hal 151-

158. *Dalam* Zaini Z, Sofyan A dan Kartaatmadja S (*eds*). Pengelolaan Hara P dan K pada Padi Sawah. Pusat Penelitian dan Pengembangan Tanah dan Agroklimat. Bogor. 168 hal.

Hakim, N., M.Y. Nyakpa, A.M. Lubis, S.G. Nugroho, M.A. Diha, G.B. Hong, and H.H. Bailey, 1986. Dasar-Dasar Ilmu Tanah. Universitas Lampung.

Nursyamsi, D., M.T. Sutriadi and U. Kurnia. 2004. Metode ekstraksi dan kebutuhan pupuk tanaman kedelai pada Typic Kandiudox di Papanrejo, Lampung. Jurnal Tanah dan Iklim. 22, Desember 2004. Hal 15-25.

Nyakpa, M.Y., A.M. Lubis, M.A. Pulung, A.G. Amrah, All Munawar, Go Ban H and Hakim N. 1988. Kesuburan Tanah. Universitas Lampung. 258 hal.

Rosmarkam, A. and N.W. Yuwono. 2002. Ilmu Kesuburan Tanah. Kanisius. Yogyakarta.

Soepardi, G. 1983. Sifat dan Ciri Tanah. Jurusan Tanah. Fakultas PErtanian. IPB, Bogor. 429 hal.

Soebagyo, H., N. Suharta and A.B. Siswanto. 2000. Tanah-tanah pertanian di Indonesia. Hal 21-66. *Dalam* Sumber Daya Lahan Indonesia dan pengelolaannya. Usat Penelitian Tanah dan Agroklimat. Bogor.

Appendix 1. Photos from the phosphorus study. From top left: TMPEGS team in SANREM Base Camp Hambaro, Nanggung, Indonesia; Net house for vegetable nursery; Inside the vegetable nursery; Land preparation for field trials