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Calibration of Soil P Test and Phosphorus Fertilizer Requirement for Pepper (*Capsicum annuum* L.) in Inceptisols Soil

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Abstract: Calibration of soil P test is a stage in determining P fertilizer rate that appropriate to plant requirement and soil nutrient availability. Research on soil test calibration conducted by field trials on pepper response to P fertilization on various nutrient status in Inceptisols soil from the lowest to highest. This research has been conducted from August 2012 to April 2013 in district of Prafi, Manokwari, West Papua. The research was conducted in order to determine the class of P nutrient availability and calculates the recommended P fertilizer for pepper on Inceptisols soil. Treatment placement use split-plot design with three replications. Treatment in the main plot is constructing P soil nutrient status, namely: Very low (0X), low (1/4X), medium (1/2X), high (3/4X) and very high (1X), where X = 1730.16 L H_3PO_4 ha^{-1} or 5.69 H_3PO_4 $plot^{-1}$. Subplot treatment is rate of P fertilizer, namely: 0, 40, 80, 160 and 320 kg P_2O_5 ha^{-1}. The results showed that P fertilization on Inceptisols with P status very low to moderate significantly effect on the growth and yield of pepper, while at high and very high status, the effect is not significant. Class of soil P nutrient availability with three extractors each for very low, low, medium, high and very high are: Bray I (<185, 185-<472, 472 -<1027, = 1027, >1027 ppm P_2O_5), Olsen (<107, 107-<338, 338-<837 ppm, = 837, >837 ppm P_2O_5), dan Mechlich (<533, 533-< 982, 982-<1811, = 1811, >1811 ppm P_2O_5). The needs of optimum P fertilizer for pepper cultivation on inceptisols with class of nutrient availability very low, low and moderate are: 148.24, 111.56, dan 85.75 kg P_2O_5 ha^{-1}, respectively. Inceptisols with high and very high nutrient availability does not require P fertilizer but for maintanance purposes of as much as 3.75 kg P_2O_5 ha^{-1} is needed.

Key words: Calibration, phosphorus, fertilization, inceptisols, pepper

INTRODUCTION

Pepper planting area is still great potential to be expanded, because dry land in Indonesia reached 148 million ha (Abdurachman *et al*., 2008). Of the area, 102.8 million ha are acid soils dominated by inceptisols, ultisols and oxisols (Mulyani *et al*., 2004), Inceptisols area reached 40.9 million ha and mostly found in Sumatra, Kalimantan and Papua. Generally, acid soils have low natural fertility, so that fertilization is needed to increase the fertility. Fertilization is intended to supplement the nutrients that are not able to be provided by the soil so the plant needs fulfilled.

Commonly, growth limiting factor in acid soils, including inceptisols, are low P availability. Pepper is a vegetable that require relatively high P nutrients. The farmers often use high rate of fertilizer to meet the nutrient needs. Every planting season, farmers use TSP as much as 300-600 kg ha^{-1} (Hafif and Wardani, 2005; Nurlenawati *et al*., 2010). The use of high rate chemical fertilizers continuously cause a decline in productivity, land resources quality and environmental pollution. Excess nutrients that not utilized by plants can change to pollutant and cause nutrient imbalances, in turn declining plant response (Santoso and Sofyan, 2005).

P fertilizer at appropriate rate according to the plants needs and soil nutrient availability is key factor to improve the productivity of agricultural lands. Calibration of soil P test is a stage to determine the class of nutrient availability and the recommended fertilizer rate (Al-Jabri, 2007). Soil test calibration conducted by field trials on plant response to P fertilization on various nutrient status from the lowest to highest. Thus, P fertilizer can be given in appropriate amount and specific to each class of P soil nutrient availability in Inceptisols for pepper cultivation.

The research was conducted in order to: (1) Determine the class of P nutrient availability and (2)

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Calculates the recommended P fertilizer for pepper on Inceptisols soil, in Manokwari, West Papua.

MATERIALS AND METHODS

This research has been conducted from August 2012 to April 2013 in district of Prafi, Manokwari, West Papua. Soil chemical properties of Inceptisols as research field are as follow: pH 4.68, the C/N ratio 8.26, P available 3.02 ppm, K-exchangable 0.13 cmol kg^{-1} and CEC 11.25 cmol kg^{-1}. The materials needed are: Pepper seed of Horizon varieties, phosphoric acid solution 85% (H_3PO_4), urea (46% N), SP-36 (36% P_2O_5), KCl (60% K_2O) and organic fertilizer of chicken manure.

This research use single location approach, that is create an artificial nutrient status from very low to very high, using H_3PO_4 solution with concentration, namely: 0X, 1/4X, 1/2X, 3/4X and X. X is the amount of P added to achieve 0.02 mg PL^{-1} in the soil solution (Nursyamsi and Fajri, 2005; Syafruddin, 2008), which is equivalent to 1730.16 L H_3PO_4 ha^{-1} or 5.69 H_3PO_4 plot^{-1}. Subplot treatment is rate of P fertilizer, namely: 0, 40, 80, 160 and 320 kg P_2O_5 ha^{-1}.

Land cleared then cultivated twice using hand tractor. After the second cultivation, beds constructed as the main plot, the size is 1.5 m wide, 25 m long and 0.4 m high. Furthermore, soil P nutrient status created, namely very low to very high, using phosphoric acid solution (H_3PO_4) with concentrations of 0, 1.42, 2.85, 4.27 and 5.69 L H_3PO_4 plot^{-1}, respectivelly. Each concentration is dissolved in water to reach a volume of 20 liters and watered evenly throughout the plot surface and then incubated for 4 months. During the incubation period, the soil stirring every 2 weeks to make H_3PO_4 solution mixed.

After incubation, main plot divided into subplot, that is 1.5 m wide, a 5 m length and 0.4 m high. Application of P fertilizer rate to subplot conducted a week before seedling, by sowing to the bed surface and evenly stiring.

Healthy pepper seedlings planted as many as 1 plant per planting hole. To support the growth, N and K fertilizer applied with a rate of 200 kg N ha^{-1} and 150 kg K_2O_5 ha^{-1}. Fertilizer application is conducted two times, namely 50% urea +100% KCl was given a day before planting and the remaining 50% of urea is applied at 4 weeks after planting. Watering and controlling (maintenance) performed during the growth.

Before fertilization treatment carried out, a composite soil sample from each main plot was taken for P soil analysis in the laboratory. Analysis of P soil content using the best extraction method for pepper in Inceptisols (the results of previous studies,) namely: Bray-1, Olsen and Mechlich. Measurements of plant height carried out at 4 and 8 weeks after planting (MST). Biomass dry weight was observed at 8 MST by weighing the canopuy and root parts that have been dried using an oven at 70°C for 2-4 days. Harvesting conducted when 50% of the pepperes surface has changed in color to red, then the fruit is weighed and the amount calculated.

Effect of P fertilizer treatment on pepper response identified through analysis of variance. If significantly effect found then continued with orthogonal polynomial test to determine the response pattern. Determination of P soil nutrient availability class is refers to Kidder (1993), which classify into five on relative yield basis, i.e.,: Very low (<50%), low (50-75%), moderate (75-100%), high (100%) and very high (<100%). Critical limit to distinguise extracted p-value of each class is determined by the regression equation of the calibration curve between extracted p-values (X) with relative yield (Y). Calculation of P fertilizer needs is using regression analysis of response curve for each nutrient availability class. The regression equation is:

$$Y = a+bX+CX^2$$

where, a, b, c is regression coefficient, X is rate of P fertilizer (kg P_2O_5 ha^{-1}) and Y is relative yield (%). The optimum rate (P fertilizer requirements to achieve optimum yield) is calculated with the assumption that the optimal outcome is achieved when 90% of the yield is maximum.

RESULTS AND DISCUSSION

Plant response on P fertilization:

Plant high: Fertilization is nutrients addition to soil to meet plants nutrient requirement for their growth. P fertilization significantly affect pepper plant height at 4 and 8 MST on very low, low and medium soil P status. Meanwhile, the effect is not significant at high and very high soil P status. This suggests that the response of pepper plant high to P fertilization depends on soil P status. P fertilization up to 320 kg P_2O_5 ha^{-1} linearly increases pepper high with very low P status. However, the rate has passed the optimum point on low and medium P status, because plant height increases quadratically (Table 1).

Biomass dry weights: Pepper growth response to P fertilization was also seen on the biomass dry weight. P fertilization has significant effect on roots and canopy dry weight of pepper grown on soils with very low, low and medium P status. This indicates that very low to moderate soil P status still require the addition of P nutrients to

Table 1: High response of pepper to P fertilizer at various P soil status

Rate of P (kg P_2O_5 ha^{-1})	Soil P status Very low	Low	Medium	High	Very high
	Plant hight at 4 MST (cm)				
0	24.10	26.00	28.70	44.5	46.0
40	29.40	30.40	29.70	47.5	49.3
80	35.00	38.20	39.90	50.1	49.6
160	42.70	47.10	48.40	47.9	52.5
320	46.10	50.20	49.90	50.2	53.5
F value	4.50*	6.59*	6.81*	1.11ns	3.13ns
Response pattern‡	Q*	Q*	Q*	-	-
	Plant hight at 8 MST (cm)				
0	52.40	54.3	56.8	72.5	74.0
40	53.40	56.4	59.1	77.5	77.5
80	60.90	64.2	65.4	76.8	78.3
160	70.70	75.1	76.0	77.9	79.7
320	74.10	78.2	77.7	78.2	81.6
F value	34.52**	5.14*	4.73*	0.98ns	2.66ns
Response pattern‡	L**	Q*	Q*	-	-

‡Response pattern on P rate tested with orthogonal polynomials, L: Linear, Q: Quadratic, *Significant difference at $p<0.05$, **Significant difference at $p<0.01$, ns: Not significant difference, the same description also apply for Table 2 and 3

Table 2: Biomass dry weight response to P fertilizer of pepper at different soil P status

Rate of P (kg P_2O_5 ha^{-1})	Soil P status Very low	Low	Medium	High	Very high
	Root dry weight (g plant^{-1})				
0	4.65	4.94	5.48	8.65	8.96
40	5.68	5.84	5.72	9.32	9.61
80	6.84	7.39	7.74	9.76	9.33
160	8.29	9.13	9.48	9.33	10.25
320	8.97	9.78	9.75	9.79	10.53
F value	4.89*	6.87*	7.48**	1.09ns	3.96ns
Response pattern‡	Q*	Q*	Q**	-	-
	Canopy dry weight (g plant^{-1})				
0	19.57	20.83	22.99	35.57	36.77
40	23.52	24.32	23.73	38.29	39.41
80	28.00	30.56	31.95	40.11	39.04
160	34.19	37.65	38.75	38.35	42.03
320	36.91	40.16	39.95	40.16	43.09
F value	31.39**	6.83*	7.06*	1.08ns	3.73ns
Response pattern‡	L**	Q*	Q*	-	-

support plant growth. P fertilization up to 320 kg P_2O_5 ha^{-1} on very low P status showed a quadratic increase in root dry weight and a linear increase for canopy dry weight. P fertilizer with the same rate in soil with low-medium P status show quadratic increase on roots and canopy dry weight (Table 2).

In soil with high and very high P status, P fertilization has no effect on root and canopy dry weight. This means that P requirement for plant growth has been met from existing soil P nutrients, so that no longer respond to fertilization. P nutrient needs are already met to increase the biomass dry weight. This research show the highest biomass dry weight was found on soil with very high P nutrient status, namely 10:53 g plant^{-1} for root and 43.09 g plant^{-1} for canopy.

Table 3: Yield response to P fertilizer at various soil P status

Rate of P (kg P_2O_5 ha^{-1})	Soil P status Very low	Low	Medium	High	Very high
	No. of fruit (fruit plant^{-1})				
0	23.5	25.0	27.6	42.7	44.1
40	28.2	29.2	28.5	45.9	47.3
80	33.6	36.7	38.3	48.1	47.5
160	39.7	45.2	46.5	46.0	50.5
320	44.3	48.2	47.9	48.2	51.7
F value	33.45**	7.42**	7.66**	1.20ns	3.91ns
Response pattern‡	L*	Q**	Q**	-	-
	Weight per fruit (g)				
0	9.39	10.07	11.04	11.21	11.59
40	10.21	10.34	11.39	12.39	12.08
80	11.03	10.44	12.80	12.73	11.15
160	11.91	11.86	13.11	11.36	10.95
320	12.05	12.15	12.09	11.33	11.20
F value	12.45**	10.08**	7.09*	0.78ns	0.76ns
Response pattern‡	L**	L**	Q*	-	-
	Yield weight (g plant^{-1})				
0	254.38	270.55	298.87	464.31	480.17
40	306.64	316.68	309.23	499.94	514.78
80	365.82	398.48	416.75	523.64	507.96
160	415.97	491.26	506.38	500.61	549.01
320	481.67	524.41	521.85	524.44	556.38
F value	29.79**	6.87*	7.18*	1.08ns	3.17ns
Response pattern‡	L**	Q*	Q*	-	-

Yield: P fertilization on very low, low and medium P status is also affects yield of pepper. Fruits and weight per fruit increase as result of P fertilization. Increasing the amount of fruits and weight per fruit will be followed by an increase in weight of fruit at harvesting (Table 3). This suggests that the increased in yield weight is due to an increase in the amount of fruits and weight per fruit. In soil with very low P status, the response of fruit number, weight per fruit and yield weight increased linearly towards P fertilizer up to 320 kg P_2O_5 ha^{-1}. However, the rate of P fertilizer has passed the optimum point on low and medium soil P status due to the amount of fruits and fruit weight increased quadratically.

The highest number of fruit, namely 51.7 fruit plant^{-1}, found in the soil with very high P nutrient status. The number of fruits was followed by the highest yield weight, namely 556.38 g plant^{-1}. P nutrient requirements for fruit formation have been fulfilled in this nutrient status, because pepper have no further response to P fertilizer. Results of other studies also showed that P fertilization no longer increase the yield of corn in soil with high to very high P status (Syafruddin, 2008).

Class of soil P nutrient availability: The results of soil P test correlation showed that the best extraction method for pepper in Inceptisols is Bray I, Olsen and Mechlich with a correlation coefficient value (r) is 0631, 0571 and 0561, respectivelly. Extracted p-values from these three methods have no agronomic meaning before calibrated with plant response in the field. Soil test calibration

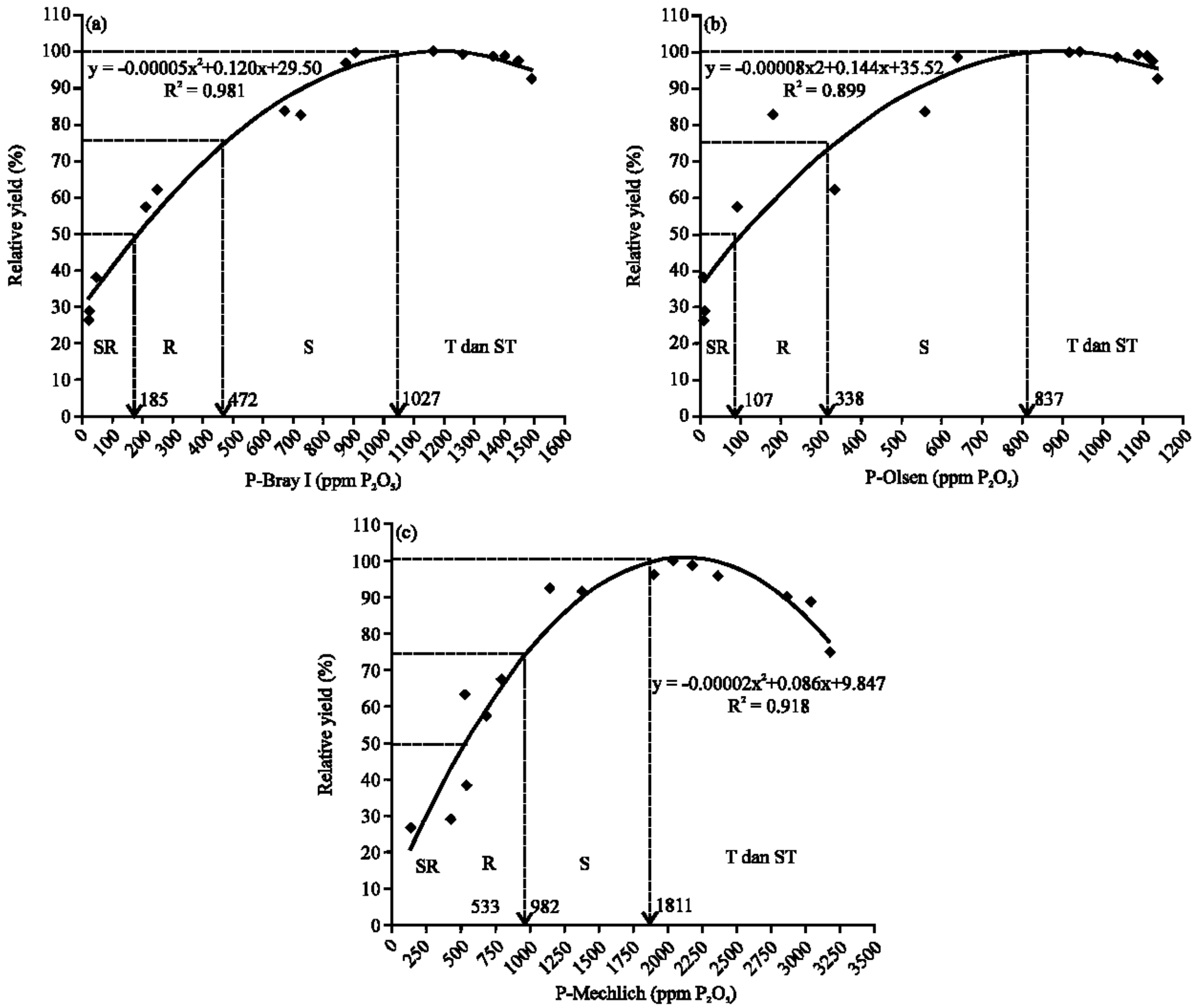

Fig. 1(a-c): Critical limit of extracted p-value on pepper relative yield, (a) Bray I extractor, (b) Olsen and (c) Mechlich

provides information on critical limits of each class of nutrient availability for plants in certain soil types (Guerin *et al*., 2007; Mendoza *et al*., 2009; Susila *et al*., 2010; Kidder, 1993) has divide nutrient availability to 5 categories on relative yield response basis, namely: (1) Very low, relative yield <50%, (2) Low, relative yield 50-75%, (3) Moderate, relative yield 75-100%, (4) High, relative yield = 100% and (5) Very high, relative yield <100%. Each class is limited by critical value determined by the calibration curve (Fig. 1).

Critical limit of P nutrient availability for the third best extractors for pepper are as follow: 185, 472 and 1027 ppm P_2O_5 (Bray I); 107, 338 and 887 ppm P_2O_5 (Olsen) and 553, 982 and 1811 ppm P_2O_5 (Mechlich). Mechlich extraction method has the highest critical limit, then followed by Bray I and Olsen. This sequence shows the level of extraction power in dissolving P forms in the soil (Nursyamsi and Fajri, 2005). Due to the critical limit value, there is five soil P nutrient availability classes for pepper, namely: Very low, low, medium, high and very high (Table 4).

Table 4: Class of P nutrient availability for pepper in Inceptisols soil

Class of P nutrient availability	Relative yield (%)	Range of extracted p-value (ppm P_2O_5) Bray I	Olsen	Mechlich
Very low (SR)	<50	<185	<107	<533
Low (R)	50-<75	185-<472	107-<338	533-<982
Medium (S)	75-<100	472-<1027	338-<837	982-<1811
High (T)	100	1027	837	1811
Very high (ST)	<100	>1027	>837	>1811

Class of soil P nutrient availability using Bray I extracting method are classified as follows: Extracted p-values less than 185 ppm P_2O_5 with relative yield less than 50% is classified as " very low ", extracted p-values between 185-<472 ppm P_2O_5 with relative yield between 50-<75% classified as "low", extracted p-values between 472-<1027 ppm P_2O_5 with relative yield between

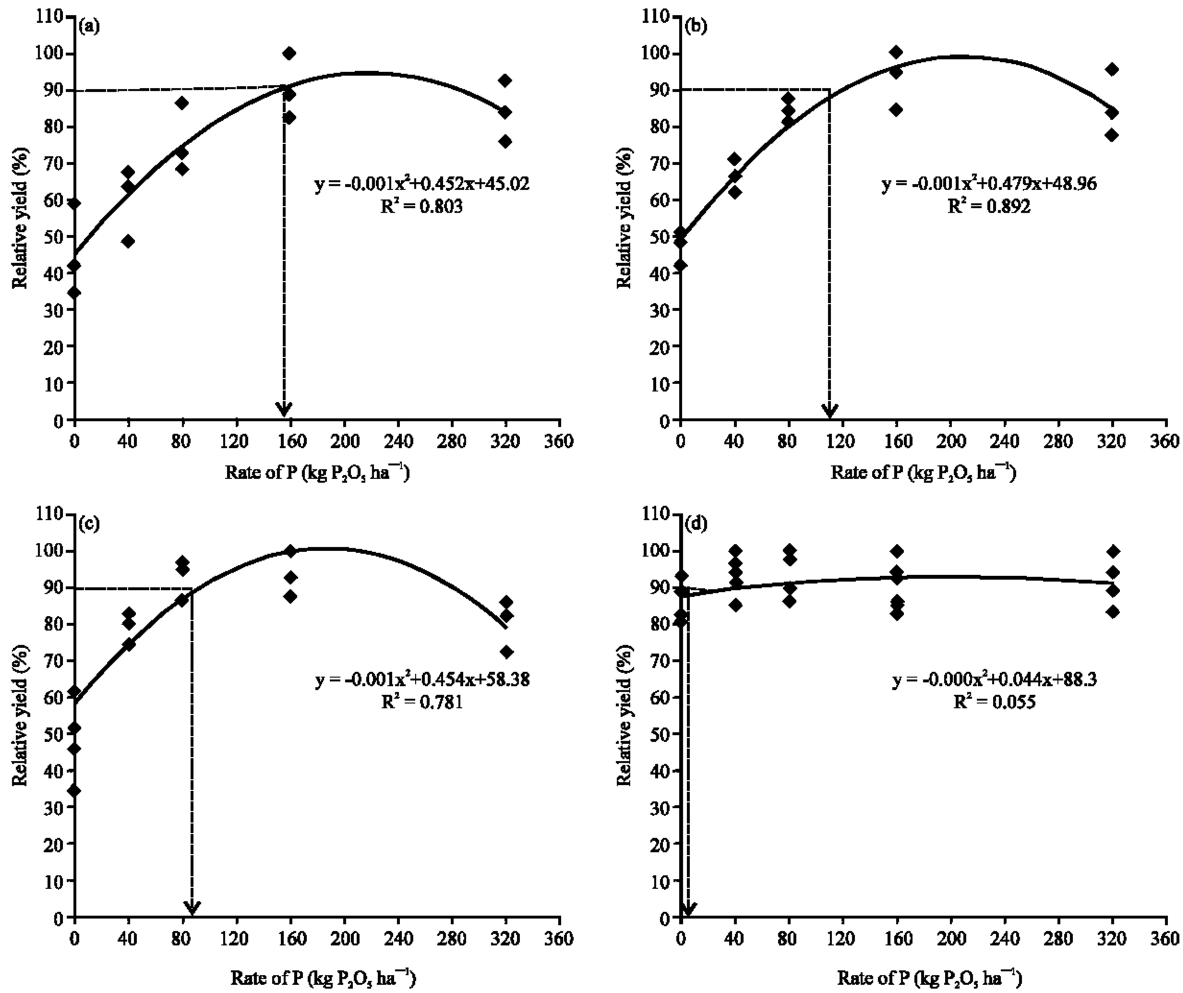

Fig. 2(a-d): Response of optimum yield to P fertilization on various classes of soil P availability in inceptisols for pepper, (a) Very low, (b) Low, (c) Medium and (d) High and very high

75-<100% is classified as "medium", extracted p-values 1027 ppm P_2O_5 with relative yield 100% is classified as "high" and extracted p-value 1027 ppm P_2O_5 with relative yield less than 100% is "very high". For Olsen and Mechlich extracting method, classification of extracted p-values are as follow: Very low (<107 ppm P_2O_5 and <533 ppm P_2O_5), low (107-<338 ppm P_2O_5 and 533-<982 ppm P_2O_5), medium (338-< 837 ppm P_2O_5 and 982-<1811 ppm P_2O_5), high (837 ppm P_2O_5 and 1811 ppm P_2O_5) and very high (>837 ppm P_2O_5 and >1811 ppm P_2O_5).

P fertilizer needs: The nutrients availability in the soil will determine plant response to a fertilization. Pepper yield response to P fertilization on each class of soil P availability in Inceptisols is decribed at Fig. 2. P fertilization on very low to moderate P availability show significant response on the yield. Instead, the plants did not show a significant response to P fertilization on soil with high-very high class availability. High availability of P causes P fertilization had no effect on the growth and yield (Syafruddin, 2008). Therefore, the calculation of P fertilizer needs performed for each class of soil P nutrient availability.

Yield response show quadratic pattern on P fertilizer. The addition of P fertilizer to the nutrient adequacy levels can increase yields, but if the rate exceeds the nutrient adequacy cause yields to decline. Indicators of nutrient adequacy can be seen from relative yield response that reached 90-100% (Ruhnayat, 2007; Suwandi, 2009).

P fertilizer required to achieve optimum yield (relative yield 90%) showed the highest for very low P availability in soil, then declined to the lowest in the class

Table 5: Optimum rate of P fertilizer for pepper on various classes of soil P availability in inceptisols

Class of soil P availability	Regression equation	R^2	Optimum rate (kg ha^{-1}) P_2O_5	SP36
Very low	$Y = 45.020+0.452P-0.001P^2$	0.803	148.24	411.78
Low	$Y = 48.960+0.479P-0.001P^2$	0.892	111.56	309.89
Medium	$Y = 58.380+0.454P-0.001P^2$	0.781	85.75	238.19
High and Very high	$Y = 88.300+0.044P-0.000P^2$	0.055	3.75	10.42

of high and very high. Regression models that describe response pattern between yield and rate of fertilizer used to calculate P fertilizer requirements in various classes of soil nutrient P availability (Table 5).

The optimum rate of P fertilizer recommended for pepper cultivation on Inceptisols soil contructed into 4 classes of soil P nutrient availability. At very low rate of P with the regression equation $Y = 45\ 020+0.452P-0.001P^2$ (R^2 = 0.803), the optimum rate is 148.24 kg P_2O_5 ha^{-1} or equivalent to kg SP36 ha^{-1}. Due to the regression equation $Y = 48.960+0.479P-0.001P^2$ (R^2 = 0892), the optimum rate for low P is 111.56 kg P_2O_5 ha^{-1}, equivalent to 309.89 kg ha^{-1} SP36. Meanwhile, for medium class of P with the regression equation $Y = 58\ 380+0.454P-0.001P^2$ (R^2 = 0.781), the optimum rate is 85.75 kg P_2O_5 ha^{-1}, equivalent to 238.19 kg SP36 ha^{-1}.

High and very high P nutrient availability does not require the addition of P fertilizer to increase the yields. This is consistent with the basic philosophy of fertilization namely Nutrient Suficiency Level, that is the addition of fertilizer is only performed when the soil is not able to supply nutrients to plants. However, for the purpose to maintenance soil P nutrient, P fertilizer required as much as 3.75 kg P_2O_5 ha^{-1}, equivalent to 10.42 kg SP36 ha^{-1}. Barus (2007) states that on soils with high P status, needs to be fertilized as much as P transported by plant to maintain high P availability.

CONCLUSION

P fertilization on inceptisols soil with very low to moderate P status significantly effect on the growth and yield of pepper, while for high and very high status, the effect is not significant.

Class of soil P nutrient availability in Inceptisols soils for pepper by three extractors are as follow: (a) Bray I: very low (<185 ppm P_2O_5), low (185-<472 ppm P_2O_5), medium (472-<1027 ppm P_2O_5), high (1027 ppm P_2O_5), very high (>1027 ppm P_2O_5), (b) Olsen: Very low (<107 ppm P_2O_5), low (107-<338 ppm P_2O_5), medium (338-<837 ppm P_2O_5), high (837 ppm P_2O_5), very high (>837 ppm P_2O_5) and (c) Mechlich: Very low (<533 ppm P_2O_5), low (533-<982 ppm P_2O_5), medium (982-<1811 ppm P_2O_5), high (1811 ppm P_2O_5) and very high (>1811 ppm P_2O_5).

Requirements of P fertilizer to achieve optimum yield on various classes of soil P availability in Inceptisols soil are as follow: (a) 148.24 kg P_2O_5 ha^{-1} or 411.78 kg SP36 ha^{-1} for very low, (b) 111.56 kg P_2O_5 ha^{-1} or 309.89 kg SP36 ha^{-1} for low and (c) 85.75 kg P_2O_5 ha^{-1} or 238.19 kg SP36 ha^{-1} for medium. Meanwhile, high and very high need as much as 3.75 kg P_2O_5 ha^{-1}, equivalent to 10.42 kg SP36 ha^{-1} only for maintanance purpose.

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