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Selection of the Best Method of Soil Phosphorus Test for Tomato (*Solanum lycopersicum* L.) on Andisols

Seleksi Metode Ekstraksi Fosfor Terbaik untuk Tanaman Tomat (Solanum lycopersicum L.) pada Tanah Andisol

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ABSTRAK

Kajian penentuan rekomendasi pupuk fosfor (P) untuk tanaman tomat berdasarkan uji tanah pada tanah Andisol belum banyak dilakukan di Indonesi. Penelitian dimulai dengan pembuatan status hara P di kebun Percobaan IPB Pasirsarongge Ciputri Cianjur dilanjutkan dengan uji korelasi di rumah kaca kebun Percobaan PKHT IPB Tajur Bogor Jawa Barat, pada bulan November 2015 sampai April 2016. Tujuan penelitian adalah menetapkan metode ektraksi P terbaik bagi tanaman tomat di tanah Andisol. Status P tanah dibuat dengan larutan asam fosfat (H_3PO_4) dengan lima taraf P (0, ¼,X, ½X, ¾X, and X), X adalah 2240 kg P ha^{-1} sebagai dosis P maksimum yang ditambahkan untuk mencapai kadar P maksimum yang ditambahkan untuk mencapai kadar P maksimum dalam larutan tanah. Larutan H_3PO_4 disiramkan merata pada bedengan tanah dan diinkubasi selama 4 bulan. Ekstraksi P tanah menggunakan 5 metode yaitu: Bray 1 (HCl 5N), HCl 25%, Morgan Wolf ($NaC_2H_3O_{2.3}H_2O$), Mechlich (HCl 0.05N + H_2SO_4 0.025N) dan NH_4OAc (NH_4OAc, pH 7). Hasil penelitian menunjukkan adanya perbedaan respon tinggi tanaman, dan bobot kering biomas, pada berbagai status hara P tanah Andisol. Pola respon kuadratik ditunjukkan pada tinggi tanaman umur 7 minggu setelah tanam dan bobot kering total. Metode ekstraksi P Andisols terbaik untuk tomat adalah Morgan Wolf dengan nilai koefisien korelasi (r): 0.79.

Kata kunci: biomas, metode ekstaksi, rumah kaca, H_3PO_4, Morgan Wolf

ABSTRACT

Determination of recommendations for phosphorus (P) based on soil tests for tomato in Andisol has not been done in Indonesia. Beginning with the making of P soil status in IPB Research Station Pasirsarongge Cianjur and followed by a correlation test in PKHT IPB greenhouse Tajur Bogor West Java, from November 2015 to April 2016. The objective was to select the best extraction method of P Andisols for tomato. This research used a single-location approach; with a randomized block design. The treatments were soil P status by application of phosphoric acid solution (H_3PO_4) with five rates of P : 0, ¼,X, ½X, ¾X, and X. X was the P rate of 2240 kg P ha^{-1} was applied to achieve maximum P concentration in the soil. H_3PO_4 solution was applied to the bed surface and incubated for 4 months to obtain different P nutrient statuses. A study of the Correlation test conducted in the greenhouse used the 4 month incubated soil. Analysis of soil P using five extraction methods: Bray 1 (HCl 5N), HCl 25%, Morgan Wolf ($NaC_2H_3O_{2.3}H_2O$), Mechlich (HCl 0.05N + H_2SO_4 0.025N) dan NH_4OAc (NH_4OAc, pH 7). The results showed differences in response of plant height and biomass dry weight on nutrient status of Andisols P. Quandratic response pattern was shown in tomato plant height at 7 weeks after planting and biomass dry weight. The best Andisols P extraction method for tomato is Morgan Wolf, with a correlation coefficient (r) was 0.79.

Keywords: biomass, extraction method, greenhouse, H_3PO_4, Morgan Wolf

INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is the most widely grown vegetable in the world (Rubatzky and Yamaguchi, 2012) including Indonesia (FAO, 2018). Besides, cabbage and potatoes, tomatoes are cultivated by mostly Indonesian farmers on Andisols. Andisols are one of the potential and productive agricultural soils that are rich in organic matter (Dahlgren et al., 2004), such as organo-Al/Fe complex and/or short-range order Al/Fe minerals developed from volcanic matterial deposition (Imaya et al., 2010*)*. Low and very low levels of availability of phosphorus (P) nutrient can be a problem in Andisol (Saleque et al., 1998; Sukarman and Dariah, 2014). This is estimated as the cause of the low productivity of tomato in Indonesia, around 15-17 t ha^{-1} (FAO, 2018), below its potential which is around 40-60 t ha^{-1} (Purwati, 2009). Phosphorus often limits tomato plant growth (Schachtman et al., 1998) and essential nutrient for tomato production (Adebooye et al., 2006).

Previous efforts have been conducted on P fertilization on Andisol soils to increase production, yet the results were not satisfactory. One of the reasons is the incorrect determination of the P nutrient dosage. Therefore, the dosage of P applied by farmers varied in a large gap, which is 71-600 P_2O_5 kg ha^{-1}. Despite the ineffective result, inaccurate application of P fertilizer can also increase environmental pollution. Ideally, the determination of recommended dosage is based on the soil analysis and the previous cultivated crop, before the tomato. However, this determination method is expensive and can increase the production cost. Therefore, an excellent extraction method to determine the general recommended dosage for Andisol Soil is essentially needed as guidance for agricultural practitioners.

Currently, there are numerous P extraction methods to discover the value of available P in the soil. Each soil type and crop has it's unique extraction method to determine the available P for the crop; for instance Trough and Olsen method for soybean in Inceptisols (Nursyamsi and Fajri, 2005), the Truogh, Colwell, dan Bray 1 for maize in Inceptisols (Syafruddin, 2008), Mechlich I for tomato in Inceptisols (Izhar et al., 2012) and Bray1, Olsen and Mechlich for chilli pepper in Inceptisols (Amisnaipa et al., 2014). We have developed a hypothesis that there is a specific method to determine the available P for tomato on Andisols.

Generally, the determination of the best extraction method is based on a correlation test of P nutrient with tomato, and the correlation coefficient of the extraction method, which is significant against the productivity (Nursyamsi and Fajri, 2005; Izhar et al., 2012; Amisnaipa et al., 2014). Therefore, this research is aimed (a) to determine the various statuses of P nutrient in Andisols soil; (b) to examine several extraction method of P from soil, and (c) to determine the best P extraction methods for tomato in Andisol soils.

MATERIALS AND METHODS

Determination of P nutrient status was conducted in the experimental farm of IPB at Pasirsarongge Pacet-Cianjur (-6.765810, 107.051241; 1,200 m asl.) from November 2015 to April 2016. It was conducted on fallow soils from the past 10 years. Andisols were determined based on the characteristics of dark brown color, unique consistency, low bulk density, and high water holding capacity (Nanzyo et al., 1993).

Land clearing was conducted through pulling out the existing plant, then followed by two rounds of manual tillage within 25-30 cm in between 2 weeks. Then, the beds were made with a size of 1.5 m × 25 m × 0.4 m (width×length×height) as one experimental unit.

Saturation of P was conducted to determine the status of P in soil from the lowest to the highest. The saturation of P in soil was conducted using a suspension of phosphoric acid 85% (H_3PO_4), with 5 dosages, i.e., very low (0X), low (1/4), moderate (1/2X), high (3/4X), and very high (X). Value of X is the value of the highest P nutrient sorption in the form of number of P which is supposed to be added into the soil to reach 0,2 µg P L^{-1} in soil. The determination of P sorption value was based on the Fox and Kamprath method. The value of X, which was used to obtain the maximum P content, is 2240 kg P ha^{-1}, equal to 4893 L H_3PO_4 ha^{-1} or 3.67 L H_3PO_4 per plot.

This dosage is equal a solution of H_3PO_4: 0, 4.59, 9.18, 13.76, or 18.35 L H_3PO_4 per plot. To simplify the application, each H_3PO_4 dosage was diluted in water until 100 liters, and applied equally across the plot surface. Furthermore, the land was incubated for 4 months. Every 2 weeks, the tillage was conducted within 25-30 cm. Each dosage is applied within one experimental plot.

After the incubation period, the status of P nutriens was observed. The observation was conducted by collection of soil sample from each plot, then analyzed using five extraction method, i.e. Bray 1 (HCl 5*N*), HCl 25% (HCl 25%), Morgan Wolf ($NaC_2H_3O_2.3H_2O$), Mechlich (HCl 0.05*N* + H_2SO_4 0.025*N*) and NH_4OAc (NH_4OAc; pH 7) with Hitachi *U-2001 UV/Vis* Spectrophotometer. Soil fertility analysis, prior to and after, the research was conducted at The Laboratory of Soil

Research Center, Bogor.

Soil correlation test was conducted in May-June 2016 at the Screen House of PKHT IPB Experimental Field in Tajur, Bogor (-6.6371795,106.8234344; 363 m asl.). The incubated soil from Experimental I was collected 100 kg from each plot using zigzag pattern (W pattern), then cleaned of plant roots and other materials, stirred evenly, and dried for 1 week. After drying, then shifted and weighed as much as 10 kg for each soil and gathered into a polybag.

The research was conducted using a randomized group design with one factor, which is five levels of P nutrient status. Each level is repeated five times, resulting in 25 experimental units. Each repetition consists of five 20 cm × 35 cm polybags.

The tomato crop was within 21 days after planting of the Marta F1 EWSI variety. One tomato seedling was planted in one polybag. The basic fertilizer was given, i.e., urea (46% N) and K_2SO_4 (60% K_2O). The dosage of the fertilizer was 46 kg N ha^{-1} and 60 kg K ha^{-1} (Amisnaipa et al., 2009). 1/3 of the N and K fertilizer was applied during the planting, and the 2/3 of N and K fertilizer was applied 3 weeks after planting (3 WAP). Other maintenance treatments, such as irrigation, pest and disease control, as well as weed control were conducted accordingly.

The observed factors are crop height (cm), dry weight of shoot, roots and total, as well as P content in the crop. The height of the crop was observed on 2, 3, 4, 5, 6, and 7 WAP. The dry weight was observed by dividing the shoot and roots, then dried and stored in an oven at 70 ^oC within 2-4 days. P content in shoot and soil was then analyzed at the Laboratory of Soil Fertility and Chemistry of the Department of Soil Science and Land Resource, Faculty of Agriculture, Bogor Agricultural University.

The effect of P soil status treatment on the responses of the crop was determined through ANOVA analysis. If the treatments were significantly different, then followed by a polynomial orthogonal test was followed to find the curve of response pattern. The best extraction method was determinde based on the correlation coefficient value (r) significant between extracted P (X) and relative plant dry weight (Y). The higher value showed the better ability (Sulaeman 2002).

RESULTS AND DISCUSSION

Soil status and responses to P application

Generally, the availability of P nutrient in Andisols soil at the experimental field has a lower status compared to the potential P content (Table 1). This condition is ideal to determine the gradual status of P content from lower to higher (Al Jabri, 2007).

Table 1. Physiscochemical analysis of Andisols at Pasirsarongge Ciputri, Cianjur, West Java 2016

Characteristics	Measurment Index	Method
Texture		
sand (%)	37	pippeline
dust (%)	34	pippeline
clay (%)	29	pippeline
pH		
H_2O	5.1 (acid)	pH meter
KCl	4.8 (acid)	pH meter
Organic Matters		
C-org (%)	4.48 (high)	Walkley and Black
N-org (%)	0.35 (moderate)	Kjeldahl
C/N	13 (moderate)	-
Available P (ppm)	15 (low)	Bray-1
Potential P (mg $100g^{-1}$)	310 (very high)	HCl 25%
K_2O Potential (ppm)	17 (low)	HCl 25%
Cation exchange capacity		
Ca (cmol kg^{-1})	13.54 (high)	CH_3COONH_4 1M pH 7
Mg (cmol kg^{-1})	1.28 (moderate)	CH_3COONH_4 1M pH 7
K (cmol kg^{-1})	0.07 (very low)	CH_3COONH_4 1M pH 7
Na (cmol kg^{-1})	0.33 (low)	CH_3COONH_4 1M pH 7
Cation exchange capacity	22.26 (moderate)	CH_3COONH_4 1M pH 7
Base saturation (%)	43.58 (moderate)	-
Al (cmol kg^{-1})	0.06	KCl 1M
H (cmol kg^{-1})	0.14	KCl 1M

P fertilizer addition was positively correlated with an increase in the value of extracted P nutrient on five extraction solutions (Figure 1). This fact shows that the four month incubation period was sufficient to determine the status of P nutrient in soil. Figure 1 shows that each extraction solution showed a different P nutrient status. Morgan Wolf extract showed the highest correlation value to analyze the content of P nutrient on Andisols soil at Pasirsarongge. This showed that the determination of the extraction method can show the level of sufficient P in Andisols soil. P fertilizer addition is positively correlated with an increase in the value of extracted P nutrient on five extraction solution (Figure 1). This fact shows that the four month incubation period is sufficient to determine the status of P nutrient in soil. Figure 1 shows that each extraction solution showed a different P nutrient status. Morgan Wolf extract showed the highest correlation value to analyze the content of P nutrient on Andisols soil at Pasirsarongge. This showed that the determination of the extraction method can show the level of sufficient P on Andisols.

Crop responses to P soil status

ANOVA test has shown that the treatments of P soil status significantly affected the height of crop on 2 WAP and very significantly during 3-6 WAP (Table 2). The growth of tomato during 2-6 WAP showed a linear response pattern towards the increase of P nutrient status in soil. However, on 7 WAP, the height of the crop showed a quadratic response pattern towards the increase of soil P status. On soil with very low P status, the tomato crop had a height of 57.33 cm, while the highest growth was found at the crop in high soil P status, which is 98.41 cm. According to Subhan et al., (2009), the absorption of P by tomato increases along with the increase of crop growth, especially distributed to the vegetative organ.

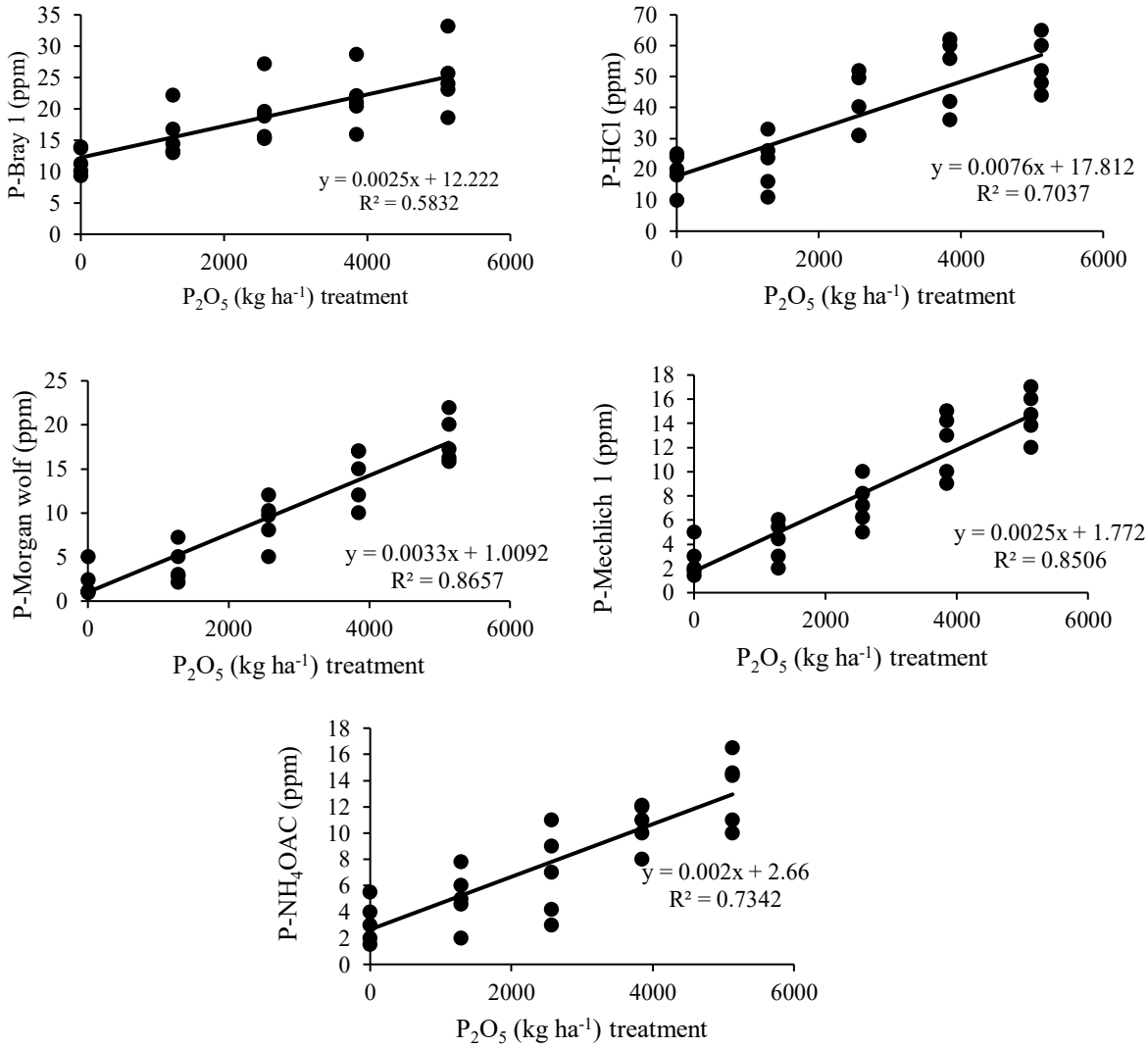

Figure 1. The relationship between P extraction methods, such as Bray 1, HCl 25%, Morgan Wolf, Mechlich 1 and NH_4OAc with phosphorus fertilizer treatments on Andisols

Table 2. Mean and responses of tomato crop height on 1, 2, 3, 4, 5, 6, and 7 weeks after planting (WAP) at Tajur, Bogor, on various P status treatments on Andisols from Pasirsarongge, Cianjur

Status of P in soil with additions of H_3PO_4 (kg P ha^{-1})	Plant height (cm)						
	1	2	3	4	5	6	7
	---------- W.A.P ----------						
0	5.60	10.96	19.62	27.60	36.98	47.62	57.33
560 (1/4x)	6.17	11.18	23.48	31.68	41.26	51.88	71.80
1120 (1/2x)	6.01	11.32	27.13	35.53	44.45	56.13	83.73
1680 (3/4x)	6.16	11.31	30.56	39.16	49.30	60.16	91.09
2240 (X)	6.41	11.46	36.15	44.95	55.83	66.35	98.41
Responses	NS	L*	L**	L**	L**	L**	L**Q**

Notes: NS-not significantly different, * significantly different at 5%, ** significantly different at 1%; L-liner, Q-quadratic.

The dry weight of biomass is an indicator of crop growth, showing that the status of P in soil significantly affected the weight of shoots, and was very significant towards the dry weight of roots and total dry weight of tomato (Table 3). The status of P in soil is positively correlated with the high total dry weight of the crop. However, the response of dry weight against the status of P has a quadratic response curve with high P status (3/4X), resulting in the highest total weight of 23.14 g. On the other hand, very low P status (0X) produces the lowest crop weight, which is 12.59 g. This showed that the various responses toward the dry weight of the crop are highly correlated with the ability of the soil to provide the P nutrient, as shown by the significant correlation in statistics.

P soil status was positively correlated with the absorption of P nutrient by the crop (Table 3). This fact indicates that the increase of P nutrient status up to a certain degree can increase the availability of P inside the tissue of the crop, as indicated by increased number of absorbed P nutrients (Figure 2). The result of the analysis also showed that the increase in P content in crop tissue was in line with the increase in biomass dry weight.

The additions of H_3PO_4 to the soil result in a quadratic response towards the content of P, as well as the biomass dry weight (Figure 2). The addition of H_3PO_4 until 3670 kg ha^{-1} can increase the biomass dry weight but decreases after the addition of more than 4000 kg ha^{-1} H_3PO_4. The quadratic relation is shown to be consistent with the content of P in the shoot. The content of P reaches the maximum with the addition of 3670 kg ha^{-1} H_3PO_4. It showed that the tomato crop normally absorbs P nutrients until 40 days after planting, or according to the crops's needs.

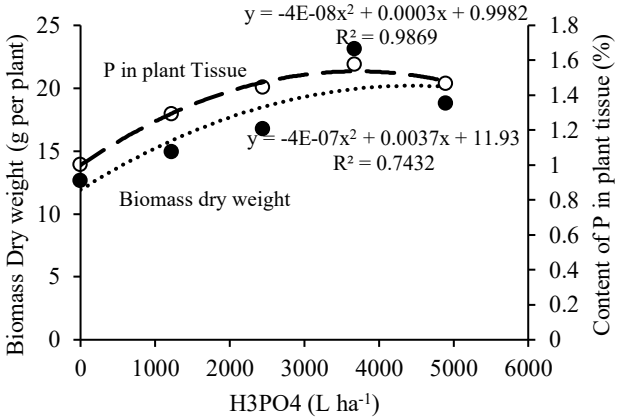

Figure 2. The relationship between the addition of P soil (H_3PO_4) and with content of P in plant tissue and the canopy dry weight of tomato plants

Correlation of P Soil Value and Relative Dry Weight of Plant

Generally, the value of extracted P from soil using five extraction methods increases with the higher status of P (Figure 3). It showed that the treatment of H_3PO_4 sollution can produce a linear response of the extracted P value. Between those five methods, the correlation of extracted P value is around 0.75 – 0.94 (Table 4). This fact showed that the correlation of extracted soil P and the treatment of P status was highly associated, according to Sulaeman (2002). The highest value was from Morgan Wolf, followed by the Mechlich 1, NH_4OAc, HCl 25% and Bray I extraction methods, respectively. Inside the soil, there are two forms of P, which are organic P and inorganic P. Both are bound by other materials with different strengths, affected by various factors, for instance, soil pH.

Table 3. Mean and responses of biomass dry weight of tomato crop at Tajur, Bogor, towards various soil P and Andisols status from Pasirsarongge

Status of P in soil with additions of H_3PO_4 (kg P ha^{-1})	Dry weight (g)		
	Shoot	Root	Total biomass
0	9.69	2.89	12.59
560 (1/4x)	11.52	3.42	14.94
1120 (1/2x)	13.94	3.89	17.84
1680 (3/4x)	18.73	4.40	23.14
2240 (X)	15.39	3.81	19.20
Responses	Q*	Q**	Q**

Notes: * significantly different at 5%, ** significantly different at 1%; Q-quadratic.

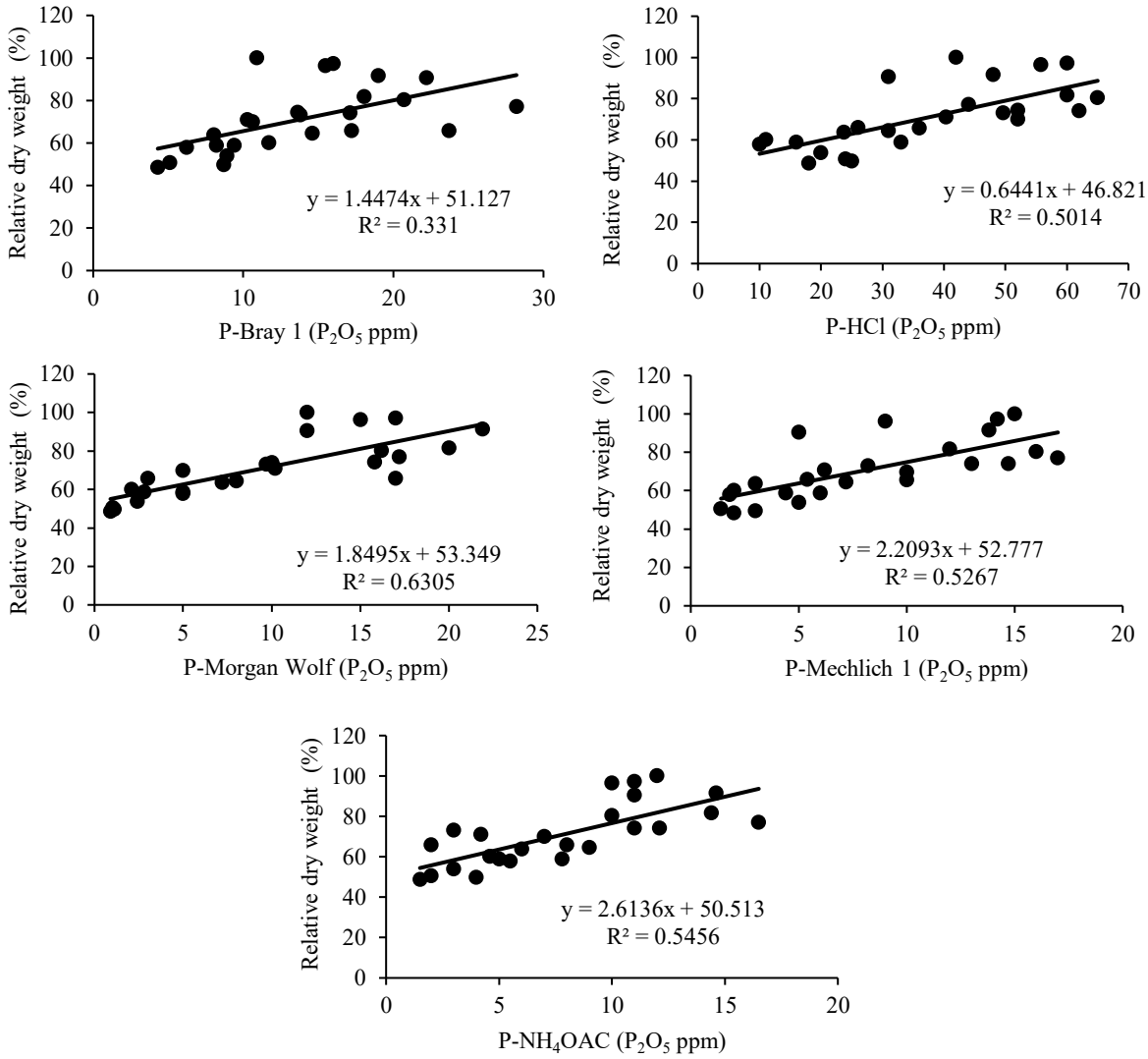

Figure 3. The relationship between the extraction of P (using Bray 1, HCl 25%, Morgan Wolf, Mechlich 1 and NH_4OAc) methods with relative plant dry weight of tomato on Andisols

The different values of extracted P showed the degree of ability of each extraction method to dissolve the various P forms inside the soil (Nursyamsi and Fajri, 2005; Haden, et al., 2007). In other words, each extraction method has a different ability to neutralize the pH.

The highest value of extracted P does not mean that it is available for the crop. Generally, the crop absorbs P in the form of phosphate ion, which are $H_2PO_4^-$, HPO_4^2 or in the form of organic phosphate; especially within a acidic condition crop will absorb more of the $H_2PO_4^-$ (Shen et al., 2011).

Table 4. Value of extracted P based on Bray 1, HCl 25%, Morgan Wolf, Mechlich 1, and NH_4OAc on several P status of Andisols soils from Pasirsarongge, Cianjur

Soil P status	Repetition	Extracted P value (ppm)				
		Bray 1	HCl 25%	Morgan Wolf	Mechlich 1	NH_4OAc
Very low (0)	1	13.90	20.00	2.40	5.00	3.00
Very low (0)	2	9.40	10.00	5.00	1.80	5.50
Very low (0)	3	13.70	25.00	1.10	3.00	4.00
Very low (0)	4	11.20	18.00	0.90	2.00	1.50
Very low (0)	5	10.10	24.00	1.01	1.40	2.00
Low (1/4X)	1	13.20	16.00	2.80	6.00	7.80
Low (1/4X)	2	14.20	26.00	3.00	5.40	2.00
Low (1/4X)	3	16.70	11.00	2.10	2.00	4.60
Low (1/4X)	4	22.20	33.00	5.00	4.40	5.00
Low (1/4X)	5	13.02	23.70	7.20	3.00	6.00
Moderate (1/2X)	1	19.60	31.00	8.00	7.20	9.00
Moderate (1/2X)	2	15.60	31.00	12.00	5.00	11.00
Moderate (1/2X)	3	18.80	49.60	9.70	8.20	3.00
Moderate (1/2X)	4	27.20	52.00	5.00	10.00	7.00
Moderate (1/2X)	5	15.25	40.30	10.20	6.20	4.20
High (3/4X)	1	22.10	62.00	10.00	13.00	12.10
High (3/4X)	2	28.70	36.00	17.00	10.00	8.00
High (3/4X)	3	21.00	60.00	17.00	14.20	11.00
High (3/4X)	4	15.90	42.00	12.00	15.00	12.00
High (3/4X)	5	20.45	55.80	15.00	9.00	10.00
Very high (X)	1	24.00	48.00	21.90	13.80	14.60
Very high (X)	2	33.20	44.00	17.20	17.00	16.50
Very high (X)	3	25.70	65.00	16.20	16.00	10.00
Very high (X)	4	18.60	52.00	15.80	14.70	11.00
Very high (X)	5	23.04	60.00	20.00	12.00	14.40
Correlation Coefficient (dry weight)		0.58*	0.71**	0.79**	0.73**	0.74**

Notes: N=25; $r_{0.05(23)}$=0.396; $r_{0.01(23)}$ =0.505; *) = significantly at P< 0.05; **) = significantly at P< 0.01; ns = not significantly.

Previously, it was known that the test value of P in soil can be used as the standard to determine the recommendation of fertilization if it has a high relation with the crop response (Al Jabri, 2007). The ability of the extractants varied based on the types of crop and soils (Nursyamsi and Fajri, 2005; Horta and Torrent, 2007). Therefore, the correlation test is important to determine the best extraction method. Based on the test of correlation between the value of P in soil at several extraction methods with the responses of crop, the four extractors, i.e., Morgan Wolf, NH_4OAc, Mechlich 1 and HCl 25% have a high assiciated value of correlation coefficient with the relative dry weight of tomato crop, i.e., 0.79, 0.74, 0.73 and 0.71, respectivelly (Table 4). Extractor Bray I has a substantial correlation value of 0.58. Therefore, the four extraction methods which are Morgan Wolf, NH_4OAc, Mechlich 1, and HCl 25% can be used to estimate the content and required P fertilizer for the tomato crop cultivated at Andisols in the high land. Between the four methods, the Morgan Wolf method has the highest correlation coefficient, thus, it is recommended as the specific P extractor for Andisols for high land tomato. However, due to the quality of the Andisols, which can be diverse according to the time, location, vegetation and parental materials (Prasetya et al., 2012; Wibisono, et al., 2016), further research on varion of Andisols soil is essentially needed.

CONCLUSIONS

Application of phosphate solution (H_3PO_4) can increase the P Andisols status at the experimental field. The increase of soil P status affected the response of vegetative growth and dry weight of the tomato crop, which quadratically increases where the higher P status produces the best response. There is a correlation between the high association of P soil value and the dry weight using Morgan Wolf, NH_4OAC, Mechlich 1 and HCl 25% extraction methods, with coefficient values of 0.79, 0.74, 0.73, and 0.71, respectively. Morgan Wolf is the best extraction methods of soil phosphorus test for tomato in Andisols, Pasirsarongge, Cianjur.

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