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Improvement of phosphorus fertilization of cayenne pepper (*Capsicum frutescens* L.) in Alfisols

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Abstract The results showed that the application of fast soluble P fertilizer and dolomite was able to increase growth, ripen fruit yield, and P uptake efficiency in cayenne pepper plants. To increase the growth of cayenne pepper, this study recommended the use of fast soluble P fertilizer at a dose of 150 kg ha^{1} which is applied in a 3 times split application, given at planting time, at the 15 days after planting, and 30 days after planting plus dolomite applied at 2 weeks before planting. Meanwhile, to obtain fruit yields and P uptake efficiency, this study recommended to use a fast soluble P fertilizer at a dose of 100 kg ha^{-1} plus dolomite with the same method, which was 3 times of split application.

Keywords: Efficiency, Fast soluble P, Cayenne pepper

Introduction

Recently, the intensive utilization of fertilizers which leads to environmental pollution has become a global concern. There are many studies conducted on the efficient fertilization methods to reduce the use of artificial fertilizers, while still maintaining crop yields, reducing fertilizer loss, and increasing fertilizer use efficiency (Oosterhuis and Howard, 2008).

The use of synthetic fertilizers, including phosphorus (P) fertilizer, in crop cultivation practices is unavoidable. Most of the farmers use synthetic fertilizers. As a result, the consumption of synthetic phosphorus fertilizer for agricultural land is increasing globally. Consumption of P fertilizer, which in total 4.6 million tons in 1961, increased to 21 million tons in 2015 and has contributed to the success of global food security. Moreover, the need for P fertilizer in 2050 is estimated to reach 26 – 39 million tons/year for agricultural land and grasslands (Mogollón *et al.*, 2018). This will also have an impact on

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increasing demand for P fertilizer in Indonesia. The use of P fertilizer in 2014 was 798,816 tons/year and increased to 819,195 tons/year in 2019 (Asosiasi Produsen Pupuk Indonesia, 2019). This was due to an increase in the average dose per cultivated area.

However, P fertilizer generally has low efficiency, which ranges from 10% – 30% (Veneklaas *et al.*, 2012). Only a little fertilizer is absorbed by plants. Most fertilizer is bound to the soil, forming residual P-pools, or is lost through erosion and leaching to reach water bodies (Conijn *et al*., 2018).

Increasing the efficiency of P fertilization is an important strategy to prevent P accumulation in the soil. This method can be done by providing P fertilizer that does not leave much residue of P in the soil, by giving a fast soluble phosphate fertilizer. However, the phosphate in the soil will immediately form a reaction with other compounds. Therefore, the method of administration must be gradual (Cahyono and Hartati, 2013). The efficiency of P fertilization is increased by synchronizing the time of its application with the time of its absorption by plants. This tends to limit the physical contact between P ions and the P-binding soil component. The longer the soil colloid fixes or forms precipitate compounds, the more stable the bond (Barrow, 2015).

The application of fast soluble phosphate fertilizer in acidic soils needs to be balanced with the lime application. Dolomite lime is categorized as agricultural lime which is often used to reduce soil acidity. Liming of agricultural land is generally focused at improving soil conditions in relation to pH, neutralizing Al, to overcome calcium deficiency, and improving the soil P availability (Maulana *et al*., 2018).

The application of fast soluble P fertilizer using the split application method according to the plant growth phase with the use of dolomite lime can reduce the contact time between P ions and P-binding soil components. However, there has been no research on the effect of fast soluble fertilizer on cayenne pepper plants. This study aimed to assess the effect of the P application method on the growth, fruit yield, and uptake efficiency of cayenne pepper in Alfisols.

Materials and methods

The study was done in an Alfisols of Jumantono, Karanganyar, from July 2020 to March 2021. This research was carried out in two experiments, which are the pot experiment (in the greenhouse) and the field experiment.

The first experiment (pot experiment) was conducted from July until October 2021 by examining the treatment of phosphorus fertilization and dolomite application treatments. This pot experiment was conducted in a

completely randomized design using four replications. Meanwhile, the second experiment (field experiment) was conducted on Alfisols of Jumantono from November 2021 until March 2022 using a Completely Randomized Block Design. The treatments examined in this study included P fertilization treatment and dolomite application treatments. The P fertilization treatments consisted of P_0 = 0 kg ha^{-1} (without P fertilization), P_1 = 150 kg ha^{-1} SP36 applied at 0 day after planting (0 DAP), P_2 = 150 kg ha^{-1} of fast soluble P fertilizer, P_3 = 100 kg ha^{-1} of fast soluble P fertilizer, P_4 = 75 kg ha^{-1} of fast soluble P fertilizer. Fast soluble P fertilizer was applied at 0, 15, and 30 DAP of 1/3 dose each. The dolomite treatments consisted of K_0 = without dolomite and K_1 = application of dolomite to increase soil pH = 7. All plots were given manure of 10 t ha^{-1} which was applied at 2 weeks before planting. Moreover Urea and KCl were applied at the doses of 175 kg ha^{-1} and 200 kg ha^{-1} which each was given twice, 70% at 10 days after planting and the rest at 30 days after planting.

Cayenne pepper plants were grown and maintained until harvest. Parameters observed included plant height, fresh and dry weight of shoot, number of fruit, weight of fruit, P uptake, and P uptake efficiency. The recorded data were analyzed statistically using Analysis of Variance and 5% DMRT test. The P efficiency was calculated using the following formula (Mengel and Kirkby, 2001).

$$\text{P uptake efficiency} = \frac{(\text{P uptake } fertilized\ crops - \text{P uptake } control\ treatment)}{\text{P applied}} x\ 100\%.. (1)$$

Results

The initial soil characteristics of Alfisols used in this study are illustrated in table 1.

Table 1. Characteristics of early Alfisol soils

No.	Soil characteristics	Values
1.	pH (H_2O)	5 .50
2.	pH (KCl)	5. 13
3.	C - organic (%)	1.87
4.	N Total (%)	0.16
5.	P Total (ppm)	99.41
6.	P available (ppm)	3.12
7.	Retention P (%)	87
8.	Ca (me/100 g)	1.26
9.	Mg (me/100 g)	0.87
10.	K (me/100 g)	0.24
11.	Fe (ppm)	44.71
12.	CEC (me/100 g)	38.20
13	Texture	Clay

Growth of cayenne pepper in the treatment of fast soluble P fertilizer and dolomite

The study, both pot and field experiments, performed the increased growth of cayenne pepper under the treatment of P fertilizers.

Pot experiment

The results of observations and statistical analysis of plant height, fresh weight, and dry weight of shoot of the pot experiment are presented in Table 2. The data indicated that the P fertilizer and dolomite treatments affected significantly the growth of cayenne pepper. The highest plant height, 88.5 cm, was obtained by the addition of fast soluble P at a rate of 150 kg ha^{-1} + dolomite (K_1P_2). The plant height at this treatment was higher than that of the addition of 150 kg ha^{-1} of SP36, we called farmers' dosage because this is commonly applied by the farmers. The K_1P_2 treatment increased plant height as high as 24.25 cm compared to the farmers' dosage. Meanwhile, the lowest plant height, 62.25 cm, was in the treatment without P fertilizer and without dolomite (K_0P_0). The highest fresh weight of shoot, which was 65 grams, was obtained by the dosage of 150 kg ha^{-1} fast soluble P fertilizer + dolomite (K_1P_2). Conversely, the lowest one, 43.75 grams, was found in the control treatment (K_0P_0). While the farmers' dosage, K_0P_1, produced fresh weight of shoot as high as 50 grams The data also indicates that the highest dry weight of the shoot, which was 37 grams, was obtained by the addition of 150 kg ha^{-1} fast soluble P fertilizer + dolomite (K_1P_2). The farmers' dosage (K_0P_1) produced 24.25 grams and the lowest one, 20 g, was obtained by the treatment of no application of P fertilizer and dolomite (K_0P_0).

Table 2. Effect of P and dolomite fertilization on plant height, fresh and dry weight of shoot in the pot experiment

Treatments	Mean		
	Plant height (cm)	Fresh weight of shoot (g)	Dry weight of shoot (g)
K_0P_0 = 0 dolomite + 0 P	62.25a[3]	43.75a	20a
K_0P_1 = 0 dolomite + 150 kg/ha SP36 [1]	68bc	50b	24.25b
K_0P_2 = 0 dolomite + 150 kg/ha FSP [2]	73.5d	60.75c	29.25cd
K_0P_3 = 0 dolomite + 100 kg/ha FSP [2]	69.5bc	52.5b	26.25b
K_0P_4 = 0 dolomite + 75 kg/ha FSP [2]	67.5b	53.75b	24.5b
K_1P_0 = dolomite + 0 P	68bc	56.75bc	25.25b
K_1P_1 = dolomite + 150 kg/ha SP36 [1]	75.5de	60.5c	27.25bc
K_1P_2 = dolomite + 150 kg/ha FSP [2]	88.5f	65d	37e
K_1P_3 = dolomite + 100 kg/ha FSP [2]	76e	57.75bc	31.5c
K_1P_4 = dolomite + 75 kg/ha FSP [2]	70.25cd	54b	28.5c

[1] /SP36 given once on planting day, [2] /FSP given three times on days 0, 15, and 30 after planting
[3] /Mean values in one column followed by the same letter were not significantly different at $p < 0.05$ according to DMRT 5%.

Field experiment

The statistical analysis of effect of the treatments on plant growth (plant height, fresh and dry weight of shoot) for field experiments are shown in Table 3.

Table 3. Effect of P and dolomite fertilization on plant height, fresh and dry weight of plants in field experiments

Treatment	Mean		
	Plant height (cm)	Fresh weight of shoot (g)	Dry weight of shoot (g)
K_0P_0 = 0 dolomite + 0 P	65.35a[\3]	70.25a	25.25a
K_0P_1 = 0 dolomite + 150 kg/ha SP36 [\1]	71.1b	78.05b	32.2b
K_0P_2 = 0 dolomite + 150 kg/ha FSP [\2]	71.35b	88.7c	42.65c
K_0P_3 = 0 dolomite + 100 kg /ha FSP [\2]	79.75cd	90.05cd	45cd
K_0P_4 = 0 dolomite + 75 kg/ha FSP [\2]	73b	75.4ab	28.65ab
K_1P_0 = dolomite + 0 P	70.25ab	80.45b	31.8b
K_1P_1 = dolomite + 150 kg/ha SP36 [\1]	84.25d	107.7e	43.5c
K_1P_2 = dolomite + 150 kg/ha FSP [\2]	91.3f	129.2f	50.95d
K_1P_3 = dolomite + 100 kg/ha FSP [\2]	89.1ef	132.05f	50.8d
K_1P_4 = dolomite + 75 kg/ha FSP [\2]	82.8d	104.35e	40.65c

[1] /SP36 given once on planting day, [2] /FSP given three times on days 0, 15, and 30 after planting
[3] /Mean values in one column followed by the same letter were not significantly different at $p < 0.05$ according to DMRT 5%.

Consistent to the result of pot experiment, the result of field experiment showed that the highest plant, 91.3 cm, was obtained by the use of 150 kg ha^{-1} fast soluble P fertilizer + dolomite (K_1P_2) (Table 3). This treatment produced higher plant compared to the farmers' dosage, K_0P_1, that resulted plant height of 71.10 cm. Conversely, the lowest plant height, 65.35 cm, was found in the treatment of without P + no dolomite (K_0P_0). The data showed that the maximum fresh weight of shoot, as high as 132.05 g was obtained by the addition of fast soluble P fertilizer at a rate of 100 kg ha^{-1} + dolomite (K_1P_3), and this was significantly higher than the fresh shoot weight of P application of the farmers' dosage, that only as high as 78.05 grams. Meanwhile the minimum fresh weight of shoot, 70.25 g, was found in the treatment without P + without dolomite (K_0P_0). Moreover, the highest dry weight of shoot, which was 50.95 g, was found in the use of 150 kg ha^{-1} fast soluble P fertilizer + dolomite (K_1P_2), and the lowest was 25.25 g in no P + treatment without dolomite (K_0P_0). Meanwhile the application of P fertilizer at the farmers' dosage produced dry weight of shoot as high as 32.2 grams.

The yield cayenne pepper in the treatment of fast soluble P fertilizer and dolomite

The study, both pot and field experiment, found that the P fertilization along with dolomite application significantly improved the number of fruit and weight of fruit of cayenne pepper.

Pot experiment

The results of observations and statistical analysis regarding the fruit number per plant and the fruit weight per plant in the pot experiment are presented in Table 4.

Table 4. Effect of P and dolomite fertilization on the fruit number per plant and fruit weight per plant in the pot experiment

Treatment	Mean	
	Fruit number per plant	Fruit weight per plant(g)
K_0P_0 = 0 dolomite + 0 P	15.75a[3]	18.75a
K_0P_1 = 0 dolomite + 150 kg/ha SP36 [1]	18.75a	21.25ab
K_0P_2 = 0 dolomite + 150 kg/ha FSP [2]	25.25bc	28.25d
K_0P_3 = 0 dolomite + 100 kg/ha FSP [2]	20.25ab	23.25bc
K_0P_4 = 0 dolomite + 75 kg/ha FSP [2]	17.5a	20.5a
K_1P_0 = dolomite + 0 P	23.25b	26.25c
K_1P_1 = dolomite + 150 kg/ha SP36 [1]	26.75cd	30.25de
K_1P_2 = dolomite + 150 kg/ha FSP [2]	39.5e	43.25f
K_1P_3 = dolomite + 100 kg/ha FSP [2]	30.5d	33.75e
K_1P_4 = dolomite + 75 kg/ha FSP [2]	23.25ab	26.5cd

[1]/SP36 given once on planting day, [2]/FSP given three times on days 0, 15, and 30 after planting
[3]/Mean values in one column followed by the same letter were not significantly different at $p < 0.05$ according to DMRT 5%.

The data showed that the highest number of fruit per plant was obtained by the use of 150 kg ha^{-1} of fast soluble P fertilizer plus dolomite (K_1P_2). It produced as high as 39.5 fruits per plant. Meanwhile the lowest number of fruit, 15.75 fruits, was found in the control treatment (K_0P_0); and the farmers' dosage (K_0P_1) produced only as many as 18.75 fruits per plant. The addition of fast soluble fertilizer at the rate of 150 kg ha^{-1} plus dolomite also produced the highest weight of fruit per plant that was 43.25 grams. Meanwhile the lowest weight of fruit per plant,18.75 grams, was found in the control treatment (K_0P_0).

Field experiment

The results of observations and statistical analysis regarding the fruit number per plant and the fruit weight per plant in the field experiment are presented in Table 5.

Table 5. Effect of P and dolomite fertilization on the fruit number per plant and fruit weight per plant in the field experiment

Treatment	Mean	
	Fruit number per plant	Fruit weight per plant (g)
K_0P_0 = 0 dolomite + 0 P	26.35a[\3]	46.65a
K_0P_1 = 0 dolomite + 150 kg/ha SP36 [\1]	30.9a	64.5b
K_0P_2 = 0 dolomite + 150 kg/ha FSP [\2]	39.15c	81.6c
K_0P_3 = 0 dolomite + 100 kg/ha FSP [\2]	40.65c	79.95c
K_0P_4 = 0 dolomite + 75 kg/ha FSP [\2]	28.4a	57.75b
K_1P_0 = dolomite + 0 P	34.05b	69.5b
K_1P_1 = dolomite + 150 kg/ha SP36 [\1]	42.05b	85,1c
K_1P_2 = dolomite + 150 kg/ha FSP [\2]	58.05d	117.8d
K_1P_3 = dolomite + 100 kg/ha FSP [\2]	56.55d	121.1d
K_1P_4 = dolomite + 75 kg /ha FSP [\2]	36.4bc	72.6bc

[1] /SP36 given once on planting day, [2] /FSP given three times on days 0, 15, and 30 after planting
[3] /The average value in one column followed by the same letter was not significantly different at $p < 0.05$ according to DMRT 5%

The data showed that application of fast soluble P fertilizer at 150 kg ha^{-1} + dolomite (K_1P_2) resulted the highest fruit number per plant, 58.05 fruits, while the lowest fruit number per plant, 26.35 fruits, was obtained by the treatment of with no P fertilizer and with no dolomite (K_0P_0). However, the highest fruit weight per plant was obtained by the treatment of 100 kg ha^{-1} fast soluble P fertilizer + dolomite (K_1P_3), that was as high as121.1 grams per plant, while the lowest weight of fruits was found in the treatment without P + without dolomite fertilizer (K_0P_0) which was equal to 46.65 grams of plant. The farmers' dosage, 150 kg ha^{-1} of SP36 without dolomite just yielded 64.5 grams of fruits per plant.

P uptake and P uptake efficiency of cayenne pepper in the treatment of fast soluble P fertilizer and dolomite

The study in pot experiments and field experiments performed that the use of phosphorus fertilizer and dolomite affected significantly the P uptake and P uptake efficiency.

Pot experiments

The pot experiment showed that the application of P fertilizer and dolomite increased the P uptake of cayenne pepper. The highest P uptake, 44.48 mg per plant, was found in the treatment of 150 kg ha^{-1} of fast soluble P fertilizer plus dolomite (Table 6). This treatment yielded higher P uptake compared to the P uptake of the farmers' dosage, which was only 20.49 mg per

plant. Meanwhile the lowest P uptake was achieved by the control treatment (K_0P_0) which was only of 15.80 mg per plant. The P uptake efficiency of cayenne pepper was also increased by application of P fertilizers and dolomite. The data showed that the application of 100 kg ha^{-1} fast soluble P fertilizer plus dolomite (K_1P_3) resulted in the highest P uptake efficiency, which was as high as 25.94% and was higher than that in the farmers' dosage. Conversely the use of SP36 at farmers' dosage (K_0P_1) yielded the lowest P uptake efficiency, which was only 4.17%.

Table 6. Effect of P and dolomite fertilization on P uptake of cayenne pepper in the pot experiment

Treatment	Mean	
	P Uptake (mg per plant)	P Uptake Efficiency (%)
K_0P_0 = 0 dolomite + 0 P	15.80a [\3]	-
K_0P_1 = 0 dolomite + 150 kg/ha SP36 [\1]	20.49ab	4.17a
K_0P_2 = 0 dolomite + 150 kg/ha FSP [\2]	31.00c	13.51b
K_0P_3 = 0 dolomite + 100 kg/ha FSP [\2]	25.47bc	12.90b
K_0P_4 = 0 dolomite + 75 kg/ha FSP [\2]	19.77ab	7.06a
K_1P_0 = dolomite + 0 P	23.57b	-
K_1P_1 = dolomite + 150 kg/ha SP36 [\1]	32.07cd	14.47b
K_1P_2 = dolomite + 150 kg/ha FSP [\2]	44.48e	25.50c
K_1P_3 = dolomite + 100 kg/ha FSP [\2]	35.25de	25.94c
K_1P_4 = dolomite + 75 kg/ha FSP [\2]	22.66b	12.20b

[1] /SP36 given once on planting day,[2] /FSP given three times on days 0, 15, and 30 after planting
[3] /The average value in one column followed by the same letter was not significantly different at $p < 0.05$ according to DMRT 5%

Field experiment

The data of P uptake and P uptake efficiency of cayenne pepper in field experiments are presented in Table 7. The data showed that the addition of fast soluble P fertilizer plus dolomite could increase P uptake in cayenne pepper. The application of fast soluble P fertilizer at the rate of 150 kg ha^{-1} plus dolomite (K_1P_2) was able to increase P uptake from 10.05 mg per plant, at the farmers' dosage, to 36.70 mg per plant. Furthermore, the treatment of 100 kg ha^{-1} of fast soluble P fertilizer plus dolomite (K_1P_3) yielded the highest P uptake efficiency of 25.15%; while the lowest P uptake efficiency which was equal to 2.89% was found in the addition of 75 kg ha^{-1} fast soluble P fertilizer without dolomite application (K_0P_4).

Table 7. Effect of P and dolomite fertilization on P uptake and P uptake effocoency of cayenne pepper in field experiments

Treatment	Mean	
	P uptake (mg plant^{-1})	P uptake efficiency (%)
K_0P_0 = 0 dolomite + 0 P	3.56 a [3]	-
K_0P_1 = 0 dolomite + 150 kg/ha SP36 [1]	10.05 bc	3.45a
K_0P_2 = 0 dolomite + 150 kg/ha FSP [2]	25.70 e	11.77bc
K_0P_3 = 0 dolomite + 100 kg/ha FSP [2]	25.32 e	17.37d
K_0P_4 = 0 dolomite + 75 kg/ha FSP [2]	6.29 ab	2.89a
K_1P_0 = dolomite + 0 P	10.72 bc	-
K_1P_1 = dolomite + 150 kg/ha SP36 [1]	21.05 de	9.30b
K_1P_2 = dolomite + 150 kg/ha FSP [2]	36.70 f	17.63d
K_1P_3 = dolomite + 100 kg/ha FSP [2]	35.08 f	25.15e
K_1P_4 = dolomite + 75 kg/ha FSP [2]	16.33 cd	13.58c

[1] /SP36 given once on planting day, [2] /FSP given three times on days 0, 15, and 30 after planting
[3] /The average value in one column followed by the same letter was not significantly different at $p < 0.05$ according to DMRT 5%

Discussion

Growth and fruit yield of cayenne pepper under fast soluble P fertilizer and dolomite treatments

The P fertilization, using SP36 or fast soluble P fertilizers, improved growth and yield of cayenne pepper. However P fertilizer increased better the growth of the plants when it was applied in the form of fast soluble P fertilizer than as SP36. The observed growth components increased significantly when the plants were fertilized with P fertilizer plus dolomite in both experiments, pot and field experiments.

In the pot experiment, it was found that the use of 150 kg ha^{-1} fast soluble P fertilizer plus dolomite given in a 3 times split application increased plant height from 62.25 cm, in the control treatment, to 88.5 cm or increased by 42.17%. While the use of SP36 at the farmer's dosage only yielded in a plant height of 68 cm. The field experiment showed similar result to the pot experiment. The application of 150 kg ha^{-1} fast soluble P fertilizer plus dolomite in the field experiment also found that cayenne pepper plants were significantly higher than plants in the control treatment and in the farmer's dose treatment, which increased 44.12% compared to the plant height in control treatment and increased by 28.41% compared to plant height in farmers' dosage treatment.

The same results were also obtained for the variable fresh weight and dry weight of shoots. The pot experiment found that the addition of 150 kg ha^{-1} fast

soluble P fertilizer plus dolomite increased shoot fresh weight as much as 48.57% and 30% compared to the control and farmers' dosage treatments, respectively. The same results were found in the field experiment. The treatment of fast soluble P fertilizer at a rate of 100 kg ha^{-1} plus dolomite resulted in a shoot fresh weight of 87.97% higher than the control treatment and 89.18% higher than the farmer's dosage treatment.

The addition of fast soluble P fertilizer plus dolomite was also proven to increase shoot dry weight, fruits number and fruit weight per plant. However, the use of fast soluble P fertilizes without the application of dolomite did not improved significantly plant growth and yield. This indicates that dolomite is needed in Alfisols to increase soil pH. Alfisol soil used in this study was 5.13 which was suspected to be the cause of the low growth of cayenne pepper plants. Dolomite is a lime material which is not only able to increase soil pH but also to be able to increase exchangeable calcium, exchangeable magnesium and reduced exchangeable aluminum (Anis *et al*., 2020). Previous research also found that the dolomite applied with fast soluble P fertilizer was able to improve soybean growth and yield on Alfisols (Cahyono *et al.*, 2022), in tidal land (Wijanarko and Taufik, 2016). Other researchers stated that dolomite is a good soil ameliorant to reduce the level of Al saturation in the soil (Chimdi *et al*., 2012; Nora *et al*., 2014; Sadiq and Babagana, 2012). Soil that is treated with dolomite will increase its pH until it reaches a stable condition on day 17 (Shaaban *et al*., 2015).

P fertilization increased the growth and yield of cayenne pepper, because the Alfisols used in this study had a very low available P content of 3.12 ppm. P is an important element for plants that plays a role in energy transfer processes and various biochemical reactions in living cells (Devi *et al*, 2012). Therefore, low available P content will inhibit the photosynthesis process and consequently the plant biomass formed will be limited.

This study found that the use of fast soluble P fertilizer resulted in higher fruit number and fruit weight of cayenne pepper than the use of SP36 fertilizer. The application of 150 kg ha^{-1} fast soluble P fertilizer plus dolomite was able to double the number of fruits per plant and fruit weight per plant compared to the SP36 fertilizer treatment at farmers' dosage. In the pot experiment, the use of 150 kg ha^{-1} fast soluble P fertilizer plus dolomite produced 39.5 fruits per plant with the total weight of 43.25 grams. This result was much higher than the P fertilization treatment with farmers' dosage (150 kg ha^{-1} SP36 without dolomite) which only produced 18.75 fruits weighing of 21.25 grams. Similar results were also obtained from field experiments. The application of 150 kg ha^{-1} fast soluble P fertilizer plus dolomite produced 58.05 fruits per plant with the total weight of 117.8 grams. While the P fertilization using farmers' dosage

(150 kg ha^{-1} SP36 without dolomite) which only produced 30.9 fruits with a total weight of 64.5 grams.

The increase in fruit yield was caused by better plant growth due to the provision of more effective P elements. We also obtained the similar result in our previous research that soybean plants that performed better vegetative growth produced better seed products (Cahyono *et al*., 2022). The growth and yield improvement of various crops due to the use of P fertilizer was also reported by previous researchers (Amanullah and Khan, 2015; Kabir *et al*., 2013; Kaya, 2018; Lamptey *et al*., 2014; Rafiullah *et al*., 2020).

The study found that the use of fast soluble P fertilizer on cayenne pepper was better in increasing plant growth and yield than the use of SP36 fertilizer. This is caused by at least two reasons, the nature of its solubility and the method of application. In this study, the fast soluble P fertilizer used was mashed SP36 fertilizer to the finer size. The previous research reported that the finer the particle size, the more surface area and the faster it dissolved (David Jones and David, 2016; Wu *et al*., 2021), so that the fertilizer will be faster available to the plants (Cahyono, 2009). By giving it gradually through the split application method, the supply of P nutrients will be more in sync with the time of absorption by plant roots, so that the uptake efficiency will increase (Cahyono and Minardi, 2022).

P uptake and P uptake efficiency of cayenne pepper under fast soluble P fertilizer and dolomite treatments

The low available P content of the Alfisol soil used in this study caused the cayenne pepper plants were responsive to P fertilization. This was proven in this study, both pot and field experiments. The study showed that the addition of P fertilizer was able to improve P uptake by cayenne pepper plant. In these two experiments, P fertilization either plus dolomite or with no dolomite, resulted in higher P uptake by the plants when P fertilizer was applied in the form of fast soluble P fertilizer than in the form of SP36. In the pot experiment, the application of fast soluble P fertilizer at a dose of only 100 kg ha^{-1} without dolomite resulted in higher P uptake than the application of 150 kg ha^{-1} SP36, which was 25.47 mg per plant compared to 20.49 mg per plant. Similar results were found in the treatment with dolomite, the treatment of fast soluble P fertilizer at dose of 100 kg ha^{-1} produced P uptake of 35.25 mg per plant, while using 150 kg ha^{-1} SP36 fertilizer resulted in P uptake only 32.07 mg per plant. The results of this study were consistent with the results of previous studies, namely P uptake in soybean plants (Cahyono and Minardi, 2022; Cahyono *et al.*, 2022).

In addition, fast soluble P fertilizer in this study was applied using the 3 times split application method, namely at planting, 15 days after planting and 30 days after planting. This split aplication can reduce the fixation of dissolved P from the fertilizer. This method can also cause dissolved P from fertilizers to be readily absorbed when plants need nutrients. Yan *et al.*, (2016) stated that the solubility of P fertilizer is high in a few days after application, and will gradually decrease. A rapid decline occurred at 30 days after application. The time of giving P fertilizer in 3 split applications resulted in better growth and yields than given once as a basic fertilizer for rice plants (Cahyono and Hartati, 2013) and soybean plants (Cahyono and Minardi, 2022). Therefore, to increase the efficiency of fertilization, the timing of fertilizer application is very important to consider in addition to the dose, type of fertilizer, and method of placing fertilizer (Johnston and Bruulsema, 2014).

Fast soluble P fertilizer affects P uptake efficiency of cayenne pepper plants. The results indicated that the use of SP36 in farmers' dosage resulted in low P uptake efficiency, 4.17% in the pot experiment and 3.45% in the field experiment. P uptake efficiency, according to Mengel and Kirkby (2001), is the amount of P absorbed by the plant from the amount of P fertilizer added. The low P uptake efficiency in this study indicated that most of the added P fertilizer was not absorbed by plants but formed various forms of bonds with P ion-binding compounds.

The use of fast soluble P fertilizer plus dolomite increased P uptake efficiency. The pot experiment performed that the application of 100 kg ha^{-1} fast soluble P fertilizer plus dolomite resulted in the highest P uptake efficiency, which was 25.94%; and this was significantly higher than to P uptake efficiency at the farmers' dosage, which was only 4.17%. The similar result was obtained from the field experiment, which increased from 3.45% at farmers' dosage to 25.15% at a dose of 100 kg ha^{-1} fast soluble fertilizer plus dolomite. Although the use of fast-dissolving P fertilizer can increase the efficiency of P uptake compared to the use of SP36, the results of this study indicated that the efficiency of P did not increase compared to the results of previous studies, which ranged from 10 – 30% (Veneklaas *et al*., 2012); 23.57% in soybeans (Cahyono *et al*., 2022).

Low P uptake efficiency causes more P residue accumulate in the soil, This fertilizer residue will form insoluble compounds with various P-binding cations such as Fe, Al and Ca (Charana Walpola, 2012; Shen *et al.,* 2011; Shah *et al.,* 2013). The residue of P fertilizer left in the soil is estimated at 30-70% every time farmers fertilize (Jin *et al.*, 2011) and this continues every time we fertilize (Miller *et al*., 2011). The longer the P residue in the soil can induce formation of stable insoluble P bonds, occluded-P, a bonded-P that is enveloped

by hardened compound. So that these compounds have core and envelope compounds. The core can be Fe-P, Al-P, Ca-P or a mixture of the three which is then covered by hardened Fe2O3 or Mn2O3 (Hesse, 1972). De Datta *et al.*, (1990) reported that the occluded-P was the most dominant form of P-bond found in paddy fields. They reported that the bound P forms in Ultisol soils included Ca-P (11.7%), Fe-P (27.4%), Al-P (8%), occluded Fe-P (47%) and occluded Al-P (3.8%). Meanwhile, Egashira *et al.* (1996) found that the average occluded-P in soils around the Mekong River in Laos was more than 60% of inorganic P. The results of the study reported by Ruiz *et al.* (1997) showed that the high content of occluded-P in 12 soil types in Europe was caused by intensive fertilization. Meanwhile, the results of Bowman *et al.* (1998) showed that Molokai soil (Oxisols from Hawaii) contained the highest levels of occluded-P reaching 573 mg kg^{-1}, Duroc (Mollisols rich in organic matter) contained 114 mg kg^{-1}, Redfeathers (Alfisol from Rocky Mountain) contains 61 mg kg^{-1}, and Ascalon (Mollisol from semi-arid region) which is rich in Ca still contains occluded-P of 20 mg kg^{-1}.

Oppositely, a high P uptake efficiency means that the P absorbed by plants from the added P fertilizer is also high. Accordingly, to get a high P uptake efficiency, the solubility of P ions must be synchronous with the time of P uptake by plants. To achieve these conditions can be done by means of gradual P provision through a split application. The results of previous studies showed that the use of fast soluble P fertilizer plus dolomite which was given in a 3 times split application, 0, 15 and 30 days after planting, was able to increase P uptake efficiency (Cahyono and Minardi, 2022; Cahyono *et al.*, 2022) . Flatian *et al*. (2018) stated that the effect of P fertilization on sorghum plants reached a maximum, 54%, if 40 ppm of SP36 fertilizer was added. Meanwhile, the contribution of P fertilizer did not significantly increase P uptake and shoot dry weight. Research by Suyono and Citraresmini (2010) found that P of SP36 fertilizer and organic P fertilizer did not improve the dry weight of rice biomass planted on soil with moderate P status. From the results of their study Fageria *et al*. (2013) sequenced P uptake efficiency on shoots and seeds of several annual crops from lowest to highest, as follows: maize, upland rice, soybeans, and beans.

P fertilizer residues left in the soil and have formed insoluble compounds can cause waste, because they cannot be consumed by plant. In addition it can also reduce soil productivity and cause serious environmental problems (Cahyono *et al*., 2022; Azeem *et al*., 2014; Eghbali Babadi *et al*., 2015; Kuscu *et al.*, 2014; Rashidzadeh and Olad, 2014; Zhang *et al.,* 2011). The intensive use of P fertilizer also triggers an increase in residual Cadmium (Cd) which can be absorbed by plants (Meng *et al.*, 2019).

The recent study concluded that application of fast soluble P fertilizer plus dolomite was able to improve growth, fruit product, and P uptake efficiency of cayenne pepper in Alfisol. In order to get higher growth of the plants, this study recommended the use of fast soluble P fertilizer at a dose of 150 kg ha^{-1} applied in a 3 split application method, given at planting, at 15 days after planting, and at 30 days after planting plus dolomite which was applied at 2 weeks before planting. Moreover to obtain fruit yields and P uptake efficiency, the study recommended to use fast soluble P fertilizer at a dose of 100 kg ha^{-1} plus dolomite applied in a method of 3 split application, given at planting, at 15 days after planting, and at 30 days after planting plus dolomite that was applied at 2 weeks before planting.

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