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Research Article

Evaluation of phosphorus fertilizer rate based on Upland Soil Test Kit analysis for tomato fertigation

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ABSTRACT

Upland Soil Test Kit (PUTK) is a rapid soil analysis kit that estimates the nutrient availability in soil. From previous studies, tomato plant production showed a good correlation with available phosphorus (P) and potassium (K) analysis using the PUTK. This study aimed to find the optimal P fertilizer rate based on PUTK analysis for tomato fertigation. This experiment was carried out using a randomized complete block design, four replications with a single factor, namely P fertilizer rate comprising 0% X, 50% X, 100% X, 150% X, and 200% X, with X the recommended P fertilizer of PUTK on moderate P availability (175 kg ha^{-1}). The ANOVA showed that P fertilizer did not significantly affect the vegetative growth, production, and fruit quality of tomatoes. It means that PUTK analysis had low accuracy as a basis for determining the optimum P fertilizer rate for tomato fertigation. The low accuracy could be due to PUTK underestimating the status of soil P availability. Mechlich-1 analysis showed that the experimental field had high P availability (44.6 ppm), while PUTK analysis still indicates moderate P availability. This shows that PUTK needs to be developed further, especially quantifying the result to help make informed and accurate decisions.

Keywords: precision farming; precision fertilization; Upland Soil Test Kit; FERADS; sustainable agriculture

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INTRODUCTION

Global climate change has been a serious issue that has affected various aspects of human life, including the agricultural sector as the main source of food. Changes in rainfall patterns and rising air temperatures will cause agricultural production to go down (Surmaini et al., 2011). One of the adaptation actions of the agricultural sector to deal with the effects of climate change is the application of a precision farming system (Bappenas, 2021).

Precision agriculture itself can be defined as an agricultural management strategy that uses information technology to collect and analyze various spatial and temporal data to increase productivity, efficiency, and sustainability of agricultural production processes (Lowenberg-Deboer & Erickson, 2019). With the help of modern technologies, farmers can apply various agronomic inputs according to plant needs, so that they can provide benefits both directly and indirectly to the production process.

In precision farming systems, fertilizer recommendation is no longer based on one general dose for a certain plant, but according to the nutrient supply and demand balance for a specific crop, season, and field. By implementing a local specific fertilization system, nutrient applications can be carried out according to specific plant nutrient needs at certain locations and climates, so that it is expected to be able to maximize farmers' income through increasing production yields and reducing production costs (Gorai et al., 2021). In addition, to increase fertilizer efficiency, the fertigation method can be applied along with the most popular method of fertigation drip irrigation.

Brewer et al. (2018) stated that the fertigation method using drip irrigation can maintain the balance of nutrients in the effective root area of plants thereby optimizing nutrient absorption by plants. Wang et al. (2018) also showed that subsurface drip irrigation could promote tomato growth. A fertigation system does provide many benefits, but good irrigation and fertilization management is also necessary. To achieve this, several things need to be considered, namely: 1) plant nutrient needs, 2) available nutrients in the soil, and 3) fertilizer application according to plant development (Incrocci et al., 2017).

As mentioned before, fertigation methods also benefit from precision fertilizing, which is fertilizing plants according to their needs. According to research done by Chathurika et al. (2015) on maize, Aksani et al. (2018) on rice, Chuan et al. (2019) on cabbage plants, Filho et al. (2020) on tomato plants, and Mesfin et al. (2021) on barley shows that fertilizer given at the optimum dose will produce maximum plant production, in addition, it could also reduce fertilizer use and maintain environmental quality. Excessive fertilization not only has the potential to reduce production yields but also damages soil quality and health as a result of fertilizer residues not being utilized by plants (Krasilnikov et al., 2022; Loks et al., 2014; Ozlu & Kumar, 2018). To achieve optimum production and preserve the environment, it is necessary to fertilize at the right dose.

Hochmuth et al. (2018b) stated that the use of the term soil analysis refers to an important technique for estimating how many nutrients the soil can provide for plants which can then be used to determine the amount of nutrients in the form of fertilizer that need to be added to the soil so that the cultivation process runs well. According to Hochmuth et al. (2018a), there are three basic philosophies of fertilizer recommendations based on soil testing, namely 1) sufficient level of available nutrients philosophy (SLAN), 2) building up and maintaining nutrients philosophy (build-up and maintenance), and 3) basic cation saturation ratio. Between 1973-1980, Olson et al. (1982) conducted a 7-year-long study in Nebraska to compare those three fertilizer recommendation philosophies, and the most suitable fertilizer recommendation philosophy to apply is the SLAN philosophy, which recommends fertilizer use based on the sufficient level of nutrients available in the soil (sufficiency level). In his research, there was no real difference in the productivity of each philosophy, however, the cost for the build-up maintenance philosophy was higher, because fertilization was still carried out even though the nutrient content conditions in the soil were high.

It is important to know the nutrient content available to plants before making fertilizer recommendations (Chuan et al., 2019). To date, estimating the values of available nutrients is done through chemical testing in integrated laboratories, and usually, these tests take quite a long time (AISAC, 2024). Frequently, testing laboratories are not easily accessible near agricultural areas, leading to farmers being disinclined to conduct soil testing. To overcome this problem, the Soil Study Center has developed the Upland Soil Test Kit (PUTK) which can be used to estimate available nutrients in the soil. However, the PUTK recommendation was still intended for agronomic crops such as corn and soybeans (Widowati et al., 2018). PUTK also lacks precision when describing soil nutrient availability, requiring further testing and development.

Fertilization recommendations based on a particular soil analysis method can only be developed after conducting field tests on that particular soil analysis method. The testing process involves conducting calibration and correlation tests before establishing fertilizer recommendations based on soil nutrient analysis (Susila, 2023). Correlation tests are carried out to obtain the best soil nutrient extraction method for certain plants because not all soil nutrient extraction methods are suitable for all plants (Aprianto et al., 2020; Dermawan et al., 2024; Dermawan et al., 2022). Plants use organic acids to extract nutrients from soil absorption and each plant uses different organic acids (Keuskamp et al., 2015). In an integrated laboratory, the estimation of available nutrients for plants is carried out using a weak acid solution to imitate the organic acid, so it is necessary to carry out a correlation test to determine the best extraction method (Dimkpa et al., 2017). From a previous study (Adji, 2022), correlation and calibration testing of available P and K analysis using PUTK on tomato plants has been carried out. This study aimed to find the optimal P fertilizer rate based on PUTK analysis for tomato fertigation.

MATERIALS AND METHODS

This study was conducted from July to November 2023 at Cikarawang Teaching Farm, Bogor (250 m above sea level), with inceptisols soil. The tomato used in this study was the Servo F1 variety, a high-yielding determinate tomato variety with good adaptation in low to midland and resistance to bacterial wilt and Geminivirus.

Composite soil samples were collected using the 'X' methods with a total of 24 samples and then analyzed with PUTK (exp. February 2024) to identify the P nutrient status and also analyzed by Soil Analysis Laboratory to identify the pH, Mechlich-1-extracted P, Mechlich-1-extracted K, and C-Organics. The initial extracted P level was moderate according to PUTK (Figure 1), while pH, Mechlich-1-extracted P, Mechlich-1-extracted K, and C-Organics were 5.42, 44.6 ppm, 141.5 ppm, and 2.09% respectively. Based on Mechlich-1-extracted K, the initial level of extracted K was classified as very high (141.5 ppm), so no additional K was added through fertilizer.

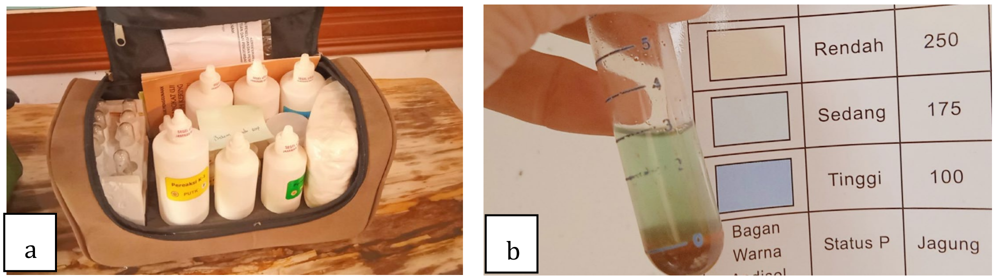

Figure 1 . Upland Soil Test Kit (PUTK), (a) Set of chemicals, (b) Extracted P level based on PUTK analysis showed moderate ('Sedang').

This study was prepared using a randomized complete block design (RCBD), four replications with a single factor, namely P fertilizer comprising 0% X, 50% X, 100% X, 150% X, and 200% X, with X as the recommended SP-36 fertilizer of PUTK for moderate P availability, 175 kg ha^{-1}. Each plot was a 6 m long and 1 m wide bed. The N fertilizer dose was based on FERADS recommendation, 487 kg ha^{-1} urea.

Preplant fertilizer was applied +/- 10 days before planting, consisting of 100% P fertilizer according to each treatment respectively and 40% N. The remaining 60% of N was applied weekly through drip irrigation for 10 weeks (Table 1) with NUTRIGADS, an automatic irrigation and fertigation machine. In addition, 4.2 tons ha^{-1} dolomite and 14 tons ha^{-1} manure were applied before planting to adjust the pH and Organic-C level in the experimental field. The beds were also sprayed with biofertilizer (Bio-Extrim) containing *Rhizobium* sp., *Azospirillum* sp., *Azotobacter* sp., *Pseudomonas* sp., *Bacillus* sp., phosphate solubilizing bacteria, N, P, K, auxin, and cytokinin. The beds also broadcasted with *Trichoderma* (Trico-Wish). One line of drip tape with flow rates of 40mL/min was placed in the middle of each bed, and then the bed was covered with polyethylene mulch. Healthy tomato seedlings with at least 4 true leaves were transplanted 4 weeks after sowing in a double row with 50 cm x 30 cm spacing, planted alternately, so each plot consisted of 24 plants.

Table 1. Preplant and follow-up fertilizer rate for tomato plant fertigation.

Application	Urea	SP-36	KCl	Organic matter	Dolomite
Rate	8.77 kg	Treatment	0 kg	584 kg	122.5 kg
Preplant	3.5 kg (40%)	100% Treatment	0 kg (40%)	584 kg (100%)	122.5 kg (100%)
1 to 10 WAT, weekly	525 g	-	0 g	-	-

Note: WAT = week(s) after transplanting.

Observations were done on randomly selected 5 sample plants within each experimental unit, excluding 4 plants bordering other treatments. Observation included vegetative growth, namely plant height, number of leaves, and number of branches; generative growth, namely time of 50% flowering and time of 50% fruiting; production, namely marketable and unmarketable fruit weight, number of marketable and unmarketable fruit, and fruit size; dry weight of fruit, branch, and root of tomato plants; and nutrient uptake, namely nitrogen, phosphorus, and potassium uptake of tomato plants. Plant nutrient uptake was done by analyzing an 11-week-old tomato plant (1 week after the last fertilizing) in AGH IPB Testing Laboratory.

Observation on post-harvest characteristics of tomatoes was done on 15 randomly selected ripe tomato fruits including total soluble solid, total titrable acid, and vitamin C content. Total soluble solid and total titrable acid were measured using Atago BX/ACID 9 (ATAGO, Japan). Since Atago BX/ACID 9 can only measure 0-3.5% acidity, samples were diluted by 50 times (1 g sample was diluted with 49 g of water). Vitamin C was measured by the following methods by Fitriana & Fitri (2020).

Data obtained was then subjected to Levene's homogeneity test before being subjected to analysis of variance (ANOVA) at α=5% with the help of SAS Studio software. Then if the ANOVA results show significant differences, an orthogonal polynomial test was carried out to determine the pattern of the plant response curve to P fertilization with SAS Studio and Excel 2013 software.

RESULTS AND DISCUSSION

General condition

This study was conducted in an open field between the dry and rainy season. Diseases that attack tomato plants are fusarium, bacterial wilt, and blossom end rot. Disease control was done chemically by spraying fungicides mancozeb and propineb alternatively on a weekly basis. No pests were observed during the vegetative phase, but there were caterpillar attacks on tomato fruit, although the numbers were not much.

Pest control was mainly done by using pheromone traps to control fruit flies (*Bractocera* spp.) and chemical spraying with insecticides fipronil and profenofos alternatively on a weekly basis. Fruit damage of splitting occurred due to dry conditions that immediately turned wet when the rainy season came in November 2023.

Vegetative and generative growth

Phosphorus is an important nutrient for plants in both the vegetative and generative phases, where the phosphorus element is part of Adenosine Tri Phosphate (ATP) which is a source of energy for plants that are used in various plant metabolisms (Uchida, 2000), therefore phosphorus deficiency will disrupt various physiological activities in plants. As a result, there will be a slowdown in the growth of both shoots and roots and even death at severe deficiency levels. Phosphorus is also an important component of DNA and RNA which are important components of genes in living things (Raven, 2013). In tomato plants, P deficiency will cause impaired growth and reduced yields (Tiziani et al., 2020; Zhu et al., 2017). On the other hand, an adequate supply of P elements will encourage tomato plant production (Filho et al., 2020; Higo et al., 2020). The general symptom of P deficiency in chrysanthemums is the appearance of a purplish color on old leaves, whereas in chilies chlorosis occurs on old leaves, resulting in leaf death and growth (Henry et al., 2018), but this was not observed in this study.

The observation results showed that the P fertilizer rate did not significantly affect the vegetative growth of tomato plants (Table 2). According to other studies on moderate P availability, a higher rate of P fertilizer will still promote tomato growth (Higo et al., 2020). Contrary to that, observation in this study showed that a higher P fertilizer rate did not significantly affect tomato plant vegetative growth. This is because the experimental field used in this study already has high P availability. Based on soil analysis using the Mechlich-1 method, it was found that the available P on the experimental field was 44.6 ppm and was classified as high P availability (Hanlon & Hochmuth, 1992; Maguire & Heckendorn, 2018). Other research on land with high P availability showed that tomato plants did not show a significant response to additional P fertilizer (Hochmuth et al., 1999).

Table 2. Effect of phosphorus fertilizing on tomato vegetative growth.

P fertilizer rate (%)	Plant height (cm)	Number of leaves	Number of branches
0	83.9 ± 11.6	18.9 ± 0.5	1.7 ± 1.7
50	82.0 ± 8.6	19.0 ± 0.8	1.5 ± 0.8
100	83.1 ± 11.6	17.8 ± 1.0	1.8 ± 1.2
150	83.2 ± 11.9	18.0 ± 0.6	2.5 ± 1.4
200	87.5 ± 8.5	21.9 ± 0.8	2.3 ± 1.5
Pr>F	0.5056	0.0668	0.0916 ^{T}
F-test	ns	ns	ns ^{T}
CV (%)	12.27	25.55	26.96 ^{T}

Note: * = significant at α=5%, ** = significant at α=1%, ns = not significant, CV = coefficient of variations, T = ANOVA was subjected to transformed data using square root transformation.

Phosphorus fertilization does not affect the age at which tomato plants first flower (Table 3). However, it significantly influences the age at which they first bear fruit, namely the higher the P fertilizer, the faster the tomato plants will form fruit. One of them is because phosphorus is an important substance in the process of seeds and fruit filling.

Table 3. Effect of SP-36 fertilizer rate on time of first flowering and fruiting of tomato.

P fertilizer rate (%)	Time to 50% flowering (Days after sowing)	Time to 50% fruiting (Days after sowing)
0	54.7 ± 4.8	65.8 ± 5.5
50	54.7 ± 4.5	65.2 ± 5.2
100	53.9 ± 4.4	64.4 ± 5.1
150	53.9 ± 4.8	64.3 ± 5.5
200	52.7 ± 5.4	63.2 ± 5.8
F-test	ns	*
CV (%)	8.849	8.320
Trend	ns	L**

Note: * = significant at α=5%, ** = significant at α=1%, ns = not significant, CV = coefficient of variations, L = polynomial orthogonal contrast detects linear trends on the data.

Production

In this study, harvesting is done when the tomato fruit is in the "turning red" stage, with 30% of the fruit turning red. Harvesting is done every 3-4 days. The harvest components observed include marketable harvest, unmarketable harvest, number of fruit, and fruit size. Unmarketable harvest is a fruit that is not suitable for marketing because it is damaged either mechanically or due to disease attacks and the fruit is too small (<14 g per fruit).

One of the most common causes of tomato fruit damage is blossom end rot and fruit cracking. Blossom end rot (BER) is a physiological disorder in which tomato fruit develops one or more tiny lesions slightly depressed below the surface at or near the blossom end of the fruit, and gradually shrinks or collapses, forming a depressed, leathery necrosis of the distal part of the placenta and the adjacent pericarp that gradually turns from brown to almost black. On the other hand, fruit cracking is damage to the fruit due to the physiological condition of the fruit. one of the causes of this damage is an imbalance in water conditions, high soil-moisture growing conditions will cause fruit to enlarge rapidly and cuts occur frequently on the fruit surface. In this study, a higher number of BER and fruit cracking were also harvested after a change in the weather in November 2023.

Table 4. Effect of different levels of SP-36 fertilizer on tomato production.

P fertilizer rate (%)	Marketable harvest (g)	Unmarketable harvest (g)	Total harvest (g)	Number of marketable fruit	Number of unmarketable fruit
0	201.7 ± 69.1	28.9±25.9	230.6±78.2	7.9± 2.4	1.8±1.6
50	224.4 ± 72.6	24.7±41.6	249.1±72.1	9.2±2.7	1.7±2.6
100	228.1 ± 82.0	14.5±19.4	242.6±88.1	9.4±3.3	0.9±1.0
150	230.6 ± 96.7	26.6±29.8	257.2±106.3	9.6±4.1	1.4±1.5
200	273.1 ± 109.2	26.1±31.9	299.2±116.6	11.3±3.7	2.1±2.1
F-test	ns	ns	ns	*	ns
Pr>F	0.131	0.775 T	0.175	0.032	0.567 T
CV (%)	37.00	76.32 T	35.93	34.01	45.51 T
Trend	ns	ns	ns	L*	ns

Note: * = significant at α=5%, ** = significant at α=1%, ns = not significant, CV = coefficient of variations, T = ANOVA was subjected to transformed data using square root transformation, L = polynomial orthogonal contrast detects linear trends on the data.

In this study, phosphorus fertilization did not significantly affect the production of tomato plants, either marketable fruit, unmarketable fruit, total harvest, or number of unmarketable fruit (Table 4). The phosphorus fertilizer rate only affects the number of marketable fruits, but the effect was still linear. Because of this, the optimum SP-36 fertilizer rate for tomato fertigation in moderate P availability cannot be determined. Phosphorus fertilization does not have a significant effect on tomato production because of the availability of soil phosphorus. Although according to PUTK the phosphorus availability on the land is moderate, based on soil analysis using the Mechlich-1 method it was found that the available phosphorus on the experimental field was 44.6 ppm and was classified as high (Hanlon & Hochmuth, 1992; Maguire & Heckendorn, 2018). Other studies also showed that excess phosphorus fertilization in tomato cultivation has no effect on production, and even has the potential to reduce production (Filho et al., 2020; Hochmuth et al., 1999; Nishat et al., 2021; Nowaki et al., 2017).

The same thing also happens to the post-harvest characteristics of tomatoes, namely total soluble solid and total titrable acid (Table 5). Phosphorus fertilizing didn't affect both of them. On the other hand, the vitamin C content of tomato fruit was affected by phosphorus fertilizer, but the response is still linear, so the optimum rate cannot be determined (Figure 2). Vitamin C is a lactone sugar and was mainly synthesized through the Smirnoff-Wheeler pathway from d-mannose and L-galactose (Smirnoff, 2018), and increased phosphorus will benefit carbohydrate synthesis and transport of photosynthetic sugar (Bernardi & Verruma-Bernardi, 2013).

Table 5. Effect of different levels of SP-36 fertilizer on tomato post-harvest characteristics.

P Fertilizer dose	Total soluble solids	Total titrable acid	Vitamin C
F-test	ns	ns	*
Pr>F	0.174	0.396	>0.0001
CV (%)	7.369	23.5	23.4
Trend	ns	ns	*L

Note: * = significant at α=5%, ** = significant at α=1%, ns = not significant, CV = coefficient of variations, L = polynomial orthogonal contrast detects linear trends on the data.

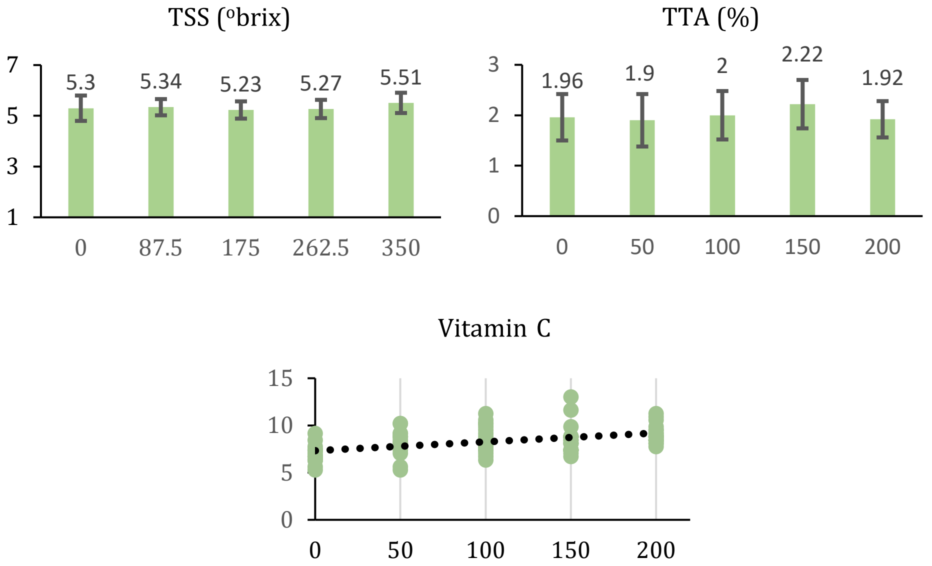

Figure 2. Effect of different levels of SP-36 fertilizer dose on tomato post-harvest characters. Bar ± S.E.

Low P availability will reduce plant growth, so plants may mobilize soil-bound P by altering root morphology, exuding root-derived compounds, or forming a symbiosis with microorganisms (Dixon et al., 2020). According to Marques et al. (2022), P-deficiency stress will cause a decrease in tomato plant dry weight, especially in severe P-deficiency. However, in this study, the fertilization treatment did not have a significant effect on the dry weight of tomato plants, either on the shoot, roots, or fruit (Table 6). As with production, this occurs because the available phosphorus is already high enough for tomato plants to grow optimally.

Table 6. Effect of SP-36 fertilizer dose on tomato plant biomass

P fertilizer rate (%)	Shoot dry weight (g)	Root dry weight (g)	Fruit dry weight (g)
0	18.1	1.9	5.5
50	22.6	2.5	8.1
100	22.0	2.7	7.6
150	22.3	2.6	7.7
200	24.6	2.5	7.7
F-test	ns	ns	ns
CV (%)	15.35	29.4	27.28

Note: ns = not significant, CV = coefficient of variations.

Phosphorus use efficiency

Nutrient uptake is the amount of nutrients that enter plant tissue. Nutrient uptake is calculated by multiplying the dry weight of the plant by the specific nutrient content in the plant tissue which comes from tissue analysis in an integrated laboratory. The N, P, and K nutrient uptake by tomato plants was not significantly different between P fertilization treatments (Figure 3). The nutrient uptake of each treatment can be seen in Figure 3. Tomato plants mostly absorb K, followed by N, Ca, S, Mg, P, Mn, Fe, Cu, Zn, and B (Purquerio et al., 2016; de Moraes et al., 2018). Nitrogen, phosphorus, and potassium were mostly accumulated in fruits, while Ca, Mg, and S were mostly accumulated in vegetative organs (de Moraes et al., 2018). Different P fertilizer rates did not affect N, P, and K uptake of tomato plants cultivated in a high P availability according to Mechlich-1 (Figure 3), especially total phosphorus uptake. The same result was reported by Zhu et al. (2018), where different P fertilizer rates did not affect total phosphorus uptake in calcareous soil with 37 to 51 ppm Mechlich-3 extractable P.

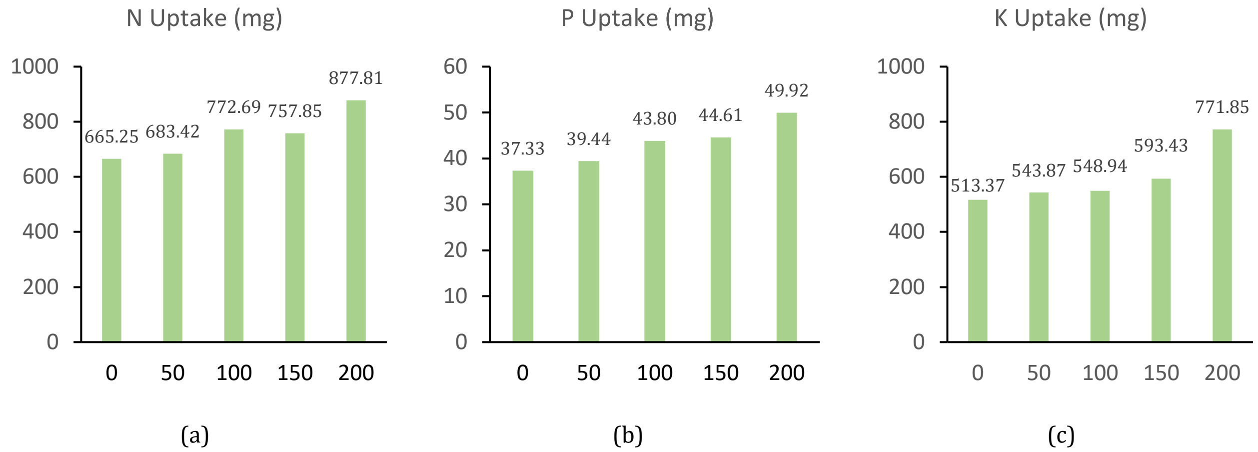

Figure 3. Nitrogen (a), Phosphorus (b), and Potassium (c) uptake by tomato plants with different P fertilizer rates.

Phosphorus acquisition by plants mostly happens by uptaking soluble inorganic P from the soil solution (Lambers et al., 2008). However, because the solubility of P compounds in the soil is very low and the tendency of the equilibrium P in the form of a solid phase, the number of P in soil solutions at a certain time becomes very low (Holford, 1997). The availability of P for plants also depends on the P acquisition strategy method for each type of plant (Lambers, 2022). Several plants have symbiosis with arbuscular mycorrhiza to help obtain P even in areas where plant roots cannot reach it (Lambers et al., 2015). Phosphate solubilizing microorganisms is an option to optimize P uptake by crops, allowing the exploration of less available fractions of the nutrient in soils and reducing the demand for P fertilizers (da Silva et al., 2023). Most phosphate-solubilizing bacteria can mineralize the insoluble P in the soil by secreting acids and enzymes and chelate cations (Ca^{2+}, Fe^{2+}, Al^{3+}) in the soil to release P (Pan & Cai, 2023). The biofertilizer used in this study contains phosphate-solubilizing bacteria, which should help increase P availability (Lovitna et al., 2021; Silawibawa et al., 2018). Biofertilizer application has been an SOP in the best practices for commercial vegetable production (Susila, 2023).

PRE or Phosphorus Recovery Efficiency is the proportion of nutrients absorbed by a plant that comes from applied fertilizer (Cassman & Dobermann, 2022), and in the case of this study is Phosphorus RE. PRE is calculated using the formula:

$$\mathrm{RE} = \frac{(\mathrm{P\ Uptake}_{123} - \mathrm{P\ Uptake}_{0}\ )}{\mathrm{Total\ applied\ P\ fertilizer}}$$

Table 7. Effect of phosphorus fertilizing on nutrient efficiencies of tomato.

P Fertilizer rate (%)	PRE (%)	PPE (%)	PAE (%)	PPFP (kg kg^{-1})
0	-	-	-	-
50	1.1	133248.1	1466.0	70.5
100	0.5	121354.1	646.3	39.7
150	0.8	56010.9	449.4	28.8
200	0.4	103583.9	443.3	22.5

Note: PRE = Phosphorus Recovery Efficiency, PPE = Phosphorus Physiological Efficiency, PAE = Phosphorus Agronomic Efficiency, PPFP = Phosphorus Partial Factor Productivity.

PRE or Phosphorus Recovery Efficiency is the proportion of nutrients absorbed by a plant that comes from applied fertilizer (Cassman & Dobermann, 2022), and in the case of this study is Phosphorus RE. PRE is calculated using the formula:

$$\mathrm{RE} = \frac{(\mathrm{P\ Uptake}_{123} - \mathrm{P\ Uptake}_{0})}{\mathrm{Total\ applied\ P\ fertilizer}}\ x\ 100\%$$

PRE is calculated by comparing the amount of phosphorus absorbed by plants in each phosphorus fertilizer treatment with the amount of phosphorus absorbed by plants in the treatment without phosphorus fertilizer and then compared with the amount of phosphorus fertilizer applied. This shows the percentage of fertilizer absorbed from the applied phosphorus fertilizer. In this case, the PRE value is very small because the soil already has a high phosphorus availability according to the Mechlich-1 test results, so most of the phosphorus absorbed by plants is phosphorus that is naturally available from the soil. The Recovery Efficiency value of phosphorus is usually around 10-15% and a small PRE value indicates that the phosphorus fertilizer applied is not being utilized efficiently (Roberts & Johnston, 2015). Phosphorus Recovery Efficiency tends to start low around 10% to as high as 30%, but since phosphorus is a relatively immobile nutrient, it has higher Recovery Efficiency in subsequent planting (Ghosh et al., 2015). In this study, the PRE of all treatments was very low (Table 7), which is under 1 % and this result indicates that adding more P fertilizer when planting tomato fertigation in soil with high phosphorus availability is not efficient.

Phosphorus Physiological Efficiency or PPE shows the ability of plants to convert nutrients absorbed from applied fertilizer into biomass and in the case of this study is PPE. PPE is calculated by the formula:

$$\mathrm{PPE} = \frac{(\mathrm{Dry\ Matter\ Yield\ P}_{123} - \mathrm{Dry\ Matter\ Yield\ P}_{0})}{(\mathrm{P\ Uptake}_{123} - \mathrm{P\ Uptake}_{0})}\ x\ 100\%$$

PPE is calculated by comparing the increase in plant biomass yield with the amount of nutrient uptake from the applied fertilizer. It can be seen in Table 7 that the higher the fertilizer dose, the smaller the PE value. This means that the efficiency of biomass production per unit of fertilizer applied is getting smaller. Of course, this is also related to the high phosphorus nutrient status of the land used, so it can be said that fertilization on land with high phosphorus nutrient status according to Mechlich-1 is not efficient.

Phosphorus Agronomic Efficiency or PAE shows the efficiency of plants in using the fertilizer applied. PAE is calculated using the formula:

$$\mathrm{PAE} = \frac{(\mathrm{Dry\ Matter\ Yield\ P}_{123} - \mathrm{Dry\ Matter\ Yield\ P}_{0})}{\mathrm{Total\ applied\ P\ fertilizer}}\ \mathrm{x}\ 100\%$$

PAE is calculated by comparing the increase in biomass resulting from fertilizer treatment with the amount of fertilizer applied. The higher PAE value shows that each weight unit of fertilizer applied contributes more to increasing plant biomass. In Table 7, it can be seen that the higher the dose of fertilizer applied, the lower the PAE value. This shows that additional fertilizer application was not able to increase biomass production in this study. This is related to the high phosphorus nutrient status according to Mechlich-1 on the land used and shows that fertilization is inefficient on land with high P status based on the Mechlich 1 test.

Phosphorus Partial Factor Productivity or PPFP of applied nutrients shows the efficiency of plants in using the applied fertilizer to produce harvestable yield. PPFP is calculated using the formula:

$$\text{PPFP} = \frac{\text{Yield P}_{123}}{\text{Applied P Fertilizer}_{123}}$$

PPFP is calculated by comparing the change of yield from fertilizer treatment. This will show how much yield could be produced from applied P fertilizer. In Table 7 it can be seen that the higher the applied fertilizer, the lower the number of PPFP, it means that the yield produced from higher fertilizer treatment is less efficient than the lower fertilizer dose. Other studies on tomatoes (Du et al., 2021; Ozores-Hampton et al., 2015) also showed that a lower fertilizer dose tends to have a higher PFP value. In this study, this is due to the soil used having high P availability, so most P nutrients taken by plants were P already available in the soil not from applied fertilizer, as shown by a very low PRE value.

The differences in soil analysis results using PUTK and the Mechlich-1 method in this study indicate that PUTK needs to be developed further to support precision agriculture. Until now, the PUTK test results are still in qualitative form, so the determination of medium-high and medium-low nutrient availability cannot be differentiated. As in this study, the experimental field used was detected to have moderate phosphorus availability, but analysis using the Mechlich-1 method showed that the land used was classified as having quite high phosphorus availability.

Excessive fertilization not only has the potential to reduce production yields, but also damages the environment as a result of fertilizer residues not being utilized by plants, so when cultivating plants it is necessary to fertilize at the right dose so that optimum production can be achieved and is also environmentally friendly. Based on the results of this experiment, the addition of SP-36 fertilizer did not affect the growth, yield, or post-harvest characteristics of the Servo F1 tomato variety. This could happen because the PUTK test results show that the experimental land has moderate P availability, whereas the results of the Mechlich-1 analysis in the lab show that the experimental plot has high P availability. This shows that the test results using PUTK, which are still qualitative, cannot differentiate between medium-low and medium-high, so it can be said that PUTK still needs to be developed further to support the development of precision agriculture and agriculture 4.0.

CONCLUSIONS

In this study, additional phosphorus fertilizer didn't affect the growth and production of Servo F1 tomato on medium phosphorus availability. Since PUTK shows medium phosphorus availability, while the Mechlich 1 test shows high phosphorus availability, the optimum dosage for medium phosphorus availability based on PUTK cannot be determined. The results of this study show that PUTK still needs to be improved further to support precision agriculture, especially precision fertilization.

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