Utilizing rice husk biochar and selected phosphate fertilizer to increase phosphate status of ultisol and shallots (*Allium ascalonicum* L.) production

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Abstract. Low soil phosphorus (P) availability is an important impediment to successful shallot cultivation in ultisols, a type of soil distinguished by its low fertility. A field experiment was conducted to investigate the effects of rice husk biochar in combination with various types of phosphate fertilizers on ultisol P status, growth performance and production of shallot. The experiment followed a completely randomized design with three replications and involved the two fixed factors: the application of three different levels of rice husk biochar (0, 5, and 10 t ha^{-1}) and addition of three distinct phosphate fertilizer sources (90 kg ha^{-1}) that included triple superphosphate (TRP), rock phosphate (RP) and guano. Our experiment revealed that using rice husk biochar in conjunction with various sources of P fertilizer had a propensity to raise the pH, enhance the availability and total P content in the observed soil. Furthermore, the application of 5 t ha-^{1} of rice husk biochar, along with the use of TSP resulted in the highest P availability in the soil. The use of biochar and P fertilizers has the potential to be an effective strategy for improving soil phosphorus status and increasing shallot production, as evidenced by the weight of storable bulbs.

1 Introduction

Shallots (Allium ascalonicum L.) are one of the most valued and promising horticultural plants in Indonesia. Shallots are in high demand as a condiment to enhance the flavor and enjoyment of foods. According to Badan Pusat Statistik [1], the yield of shallots in the province of Riau has changed throughout the past four years (2018-2021), with the harvest area, production, and productivity per hectare shifting. Over the course of a span of four years, specifically from 2018 to 2021, there was a fluctuation observed in the area designated for cultivation of land. Nevertheless, it is noteworthy that the overall yield displayed a consistent upward trajectory, eventually reaching its peak at 507 tons in 2019. Moreover, the productivity achieved in 2021 was indeed remarkable, with a remarkable output of 4.91 tons per hectare [1]. However, shallot production in Indonesia is often constrained by soil acidity, especially in ultisols. Despite its low productivity, ultisols soil is commonly utilized in

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agricultural and plantation settings. The cultivation of ultisols poses several challenges, including acidity with a low pH, low cation exchange capacity, insufficient levels of essential nutrients such as nitrogen, phosphorus, potassium, calcium and magnesium [2]. Additionally, ultisol soil exhibits very low base saturation, typically below 20%, and high concentrations of aluminum (Al) and iron (Fe). These factors, combined with the clay to sand clay texture and a high density ranging from 1.3 to 1.5 g.cm^{-3}, may negatively impact agricultural yield [3]. One possible strategy for overcoming the challenges of growing shallots in ultisols is to incorporate soil amendments into the cultivation process in addition to fertilizer applications. Biochar is one of the soil amendments that contains a high carbon content produced by biomass pyrolysis. Biochar application has been demonstrated to boost soil pH, nutrient availability, water retention [4] and reduced bulk density and increased total porosity [5]. Biochar can also minimize aluminum toxicity by interacting with aluminum ions in the soil [6]. Conversely, phosphorus is a fundamental macronutrient that plants require to enhance their yield. However, phosphorus is sparsely available in ultisol and plays a critical role in the formation of roots and bulbs in plants. Therefore, the addition of phosphorus fertilizers is essential for the growth of shallot plant roots and bulbs [7]. Therefore, to ensure an adequate supply of the necessary P for plants, it can be provided through the application of phosphate fertilizers such as TSP, RP, and guano. Study on the combination of biochar and P fertilizer for shallot cultivation in ultisols is still limited. However, some preliminary studies have shown promising results, for instance, a study by Setyorini [8], Marwiansah and Warnita [9] demonstrated that the application of biochar and P fertilizer increased the growth and yield of shallots in Ultisols and improved the relative growth rate of edamame. Further research is needed to comprehensively understand how biochar and P fertilizer interact and maximize their benefits for shallot cultivation in ultisols. Therefore, the objective of this study was to examine the effect of rice husk biochar and phosphate fertilizer sources on shallot growth and yield along with phosphate status in tropical ultisol.

2 Material and method

The experiment was conducted at the experimental garden and soil science Laboratory of the Faculty of Agriculture, University of Riau, Pekanbaru. The study spanned four months, commencing in May and ending in August 2022. The research was designed with a completely randomized design (CRD) with three replications using two fixed factors: three different level of rice husk biochar i.e., nil, 5 and 10 t ha^{-1} and three different types of the phosphate fertilizer sources (90 kg ha^{-1}) i.e., TSP, RP, and guano. These two fixed factors were combined to create 9 treatment combinations, with each combination repeated three times, resulting in a total of 27 experimental units. The observed parameters included soil pH, available phosphorus, total phosphorus content, number of leaves, leaf length, harvest age, number of bulbs, bulb diameter, fresh bulb weight, and storable bulb weight. The data obtained were statistically analysed using analysis of variance (ANOVA) and further subjected to Duncan's multiple range test at a 5% significance level using SAS software version 9.4.

3 Result and discussion

3.1 Soil pH

The utilization of rice husk biochar and various sources of phosphate fertilizer appears to result in an elevation of the pH level in ultisol soil. Initially, the untreated soil possessed a pH value of 5.30, indicating its acidic nature. However, following the application of the treatment, the pH level was able to rise to 5.69, indicating only a slightly acidic state. When phosphate fertilizer derived from rock phosphate (RP) was employed, it demonstrated the most significant increase in pH as compared to other sources of phosphorus. This can be attributed to the substantial presence of calcium (Ca) in RP ($Ca(PO_4)_2$), which has the capacity to elevate soil pH. These findings are consistent with the research conducted by Hong-qing [10], who argued that the application of rock phosphate fertilizer leads to an increase in soil pH due to the calcium content, which exhibits a liming effect and subsequently raises the pH level of the soil. Additionally, according to El Zrelli [11], direct application of phosphate rock to red soil improves soil properties, including crop yield and the availability of phosphorus and exchangeable Ca and Mg.

Table 1. Soil pH, available phosphorus and total phosphorus content of ultisol after the application of rice husk biochar and selected phosphate fertilizer sources

Treatment	Soil pH (H_2O)	Available P (ppm)	Total P (mg $100g^{-1}$)
Biochar (0 t. ha^{-1}) + TSP	5.34	15.21	26.47
Biochar (5 t. ha^{-1}) + TSP	5.50	51.69	51.93
Biochar (10 t. ha^{-1}) + TSP	5.40	38.27	39.93
Biochar (0 t. ha^{-1}) + RP	5.61	12.42	32.10
Biochar (5 t. ha^{-1}) + RP	5.62	13.37	40.63
Biochar (10 t. ha^{-1}) + RP	5.69	13.40	45.06
Biochar (0 t. ha^{-1}) + Guano	5.57	11.53	33.09
Biochar (5 t. ha^{-1}) + Guano	5.58	10.30	56.37
Biochar (10 t. ha^{-1}) + Guano	5.52	20.13	42.21

3.2 Total phosphorus

The addition of rice husk biochar and phosphate fertilizer sources appears to enhance the overall concentration of P-total in the soil. The initial P-total concentration in the soil was recorded as 15.29 mg $100g^{-1}$, indicating a relatively low value. However, following the application of these treatments, the P-total concentration significantly rose to 56.37 mg $100g^{-1}$, signifying a considerable increase. The combination of rice husk biochar, administered at a rate of 5 tons per hectare, along with guano-derived phosphate fertilizer, yielded the highest P-total concentration within the soil. This outcome is predominantly attributed to the fact that guano fertilizer is an organic fertilizer known for its comparably elevated phosphorus content, thereby contributing to the phosphorus element within the soil due to its slow-release properties. Consequently, the chemical properties of the soil undergo noticeable transformations, as ascertained through soil analysis conducted subsequent to the harvest. Conversely, phosphate fertilizer obtained from TSP, classified as a fast-release fertilizer, demonstrated lower outcomes, albeit still falling within the range of moderate to high concentrations. This disparity is likely due to the occurrence of leaching prior to the analysis. Krishnamurti [12] lend support to this notion, stating that inorganic fertilizers are readily accessible to plants but are susceptible to leaching. In contrast, guano organic fertilizer contains various essential nutrients for plants, including 6.01% N, 10% P, 2.18% K, and 21.6% organic carbon (C-organic). The rise in P-total concentration in the soil can be attributed to the relatively high phosphorus content applied to the soil and the subsequent increase in soil pH.

3.3 Available phosphorus

The P status that was available in the ultisol soil reached 19.51 ppm after the application of both rice husk biochar and phosphate fertilizer sources. This value is considered moderate and leads to a classification of very high for the criteria of available P in the soil. The analysis of available P after treatment showed that the treatment with 5 tons per hectare of rice husk biochar and phosphate fertilizer from TSP had the highest value, which was 51.39 ppm, classified as very high. The initial available P content in the ultisol soil was lower compared to the soil treated with biochar. This difference can be attributed to the occurrence of phosphorus fixation by aluminum (Al) and iron (Fe) at low pH levels. The limited availability of phosphorus in the treatment using 5 tons per hectare of rice husk biochar and guano-based phosphate fertilizer can be attributed to the fact that the soil samples were analysed after the harvest. By that time, the P had already been absorbed by the roots of the shallot plant during its growth and development. The application of rice husk biochar promotes the release of P from Al-P and Fe-P via chelation processes by organic acid, this conclusion is consistent with Mayer [13] who indicate that biochar amendment can lead to additional phosphate release into the soil. Furthermore, an increase in soil pH increases the availability of P in the soil. According to Yao [14], increasing the pH of acidic soil and decreasing the concentration of Al-dd (dissolved organic aluminium) can boost soil microbial activity. This modification increases the availability of P in the soil. In addition, Singh [15] found that rice husk biochar application improves P status, and paddy productivity in nutrient-poor agriculture soils.

Table 2. Shallot growth and production parameters affected by application of biochar and selected phosphorus fertilizer.

Parameters	B0			B1			B2		
	TSP	RP	G	TSP	RP	G	TSP	RP	G
Number of leaves	9.32d	11.57bc	11.35bc	10.40cd	12.09b	14.48a	12.44b	10.39cd	11.66bc
Length of leaf (mm)	11.67c	12.83bc	12.33bc	15.67abc	14.00bc	20.67a	18.67ab	18.83ab	15.67abc
Diameter of bulbs (mm)	7.38a	6.39a	6.74a	9.32a	7.83a	9.92a	9.23a	9.04a	9.14a
Number of bulbs per clump	4.33c	5.33bc	5.67bc	4.67c	6.00abc	7.33a	6.67ab	4.67c	5.67bc
Fresh weight of bulbs (g)	4.98bc	4.32bc	9.54a	4.98bc	4.32bc	9.54a	7.1ab	4.4bc	6.1abc
Weight of storable bulbs (g)	2.44b	1.69b	1.38b	3.05b	2.84b	7.69a	4.98b	2.73b	3.50b

Biochar Application Rate: B0=nil; B1=5 t ha^{-1}; B2=1 t ha^{-1}
Phosphorus Fertilizer: TSP= Triple Super Phosphate; RP= Rock Phosphate; G=Guano
Mean value following the same letters within the rows are not significant

3.4 Number of leaves

Table 2 demonstrates that the utilization of rice husk charcoal and phosphate fertilizer influences the quantity of shallot leaves. Compared to alternative treatments, the application of 5 tons per hectare of rice husk charcoal and guano-based phosphate fertilizer significantly increased the number of shallot leaves. The application of rice husk biochar at doses of 5 tons per hectare and 10 tons per hectare resulted in a significantly different leaf count compared to the absence of rice husk biochar application. The utilization of guano-based phosphate fertilizer resulted in a significantly distinct number of leaves when compared to TSP and RP phosphate fertilizer. In addition, the application of 5 tons per hectare of rice husk biochar and guano-based phosphate fertilizer significantly increased the number of shallot leaves compared to other treatments. The application of rice husk biochar at dosages of 5 tons per hectare and 10 tons per hectare resulted in a significantly different number of leaves compared to no application of rice husk biochar. The use of guano-based phosphate fertilizer also led to a significantly different number of leaves compared to phosphate fertilizer from TSP and RP. The use of guano fertilizer not only enhances soil fertility but also promotes the growth of shallot plant vegetative components. Guano fertilizer, according to Marsono [16], is a rich source of organic nutrients for plants since it includes 8-13% N, 5-12% P, 1.5-2% K, 7.5-11% Mg, and 2-3.5% S, all of which encourage plant growth.

3.5 Length of shallot leaves

The application of 5 tons per hectare of rice husk biochar and guano-based phosphate fertilizer resulted in a significant increase in the length of shallot leaves compared to the application of 5 tons per hectare of rice husk biochar and phosphate fertilizer from RP, as well as the application of 0 tons per hectare of rice husk biochar and phosphate fertilizer from TSP, RP, and guano (Table 2). The application of rice husk biochar at dosages of 5 tons per hectare and 10 tons per hectare resulted in increased leaf length compared to the absence of rice husk biochar application. However, it exhibited no significant difference when compared to the application of 5 tons per hectare of rice husk biochar and phosphate fertilizer from TSP, as well as the application of 10 tons per hectare of rice husk biochar and phosphate fertilizer from TSP, RP, and guano. The application of rice husk biochar at dosages of 5 tons per hectare and 10 tons per hectare resulted in increased leaf height compared to the absence of rice husk biochar application. The application of phosphate fertilizer from TSP, RP, and guano did not have a notable impact on leaf length. The integration of rice husk biochar into ultisol soil is hypothesized to possess the capacity to enhance soil aggregates. The improvement of soil aggregation is often accompanied by advancements in soil chemical and biological properties. In accordance with the findings of Semita [17], the integration of biochar into soil exhibits the potential to significantly enrich various soil chemical properties such as soil pH, cation exchange capacity (CEC), and different compounds such as organic carbon (C-organic), total nitrogen (N-total), while also potentially reducing the activities of compounds like iron (Fe) and aluminum (Al), which may lead to an increase in available phosphorus (P) in the soil. According to [18], the addition of rice husk charcoal to the growth medium can enhance fertilization efficiency and effectively retain nutrients when they are in excess, subsequently releasing them gradually in accordance with the requirements of the plant.

3.6 Number of shallot bulbs per clump

The application of 5 tons per hectare of rice husk biochar in combination with guano-based phosphate fertilizer demonstrated a significant increase in the number of shallot bulbs per clump compared to the other treatments (Table 2). Interestingly, this increase was not significantly different from the application of 5 tons per hectare of rice husk biochar along with phosphate fertilizer from RP, or from the application of 10 tons per hectare of rice husk biochar and phosphate fertilizer from TSP. The utilization of various dosages of rice husk biochar and different sources of phosphate fertilizer (TSP, RP, and guano) did not yield any statistically significant differences in terms of the number of bulbs per clump. The highest number of bulbs was observed in the case of applying 5 tons per hectare of rice husk biochar and guano-based phosphate fertilizer. This can be attributed to the ability of biochar and phosphate fertilizer to provide the necessary availability of phosphorus (P) and potassium (K) nutrients for shallot plants. Our finding aligns to Wijaya [19], that utilization of rice husk biochar has combined with *Trichoderma asperellum* (4 t ha^{-1}) improved chlorophyll index and bulb height in shallot bulbs.

3.7 Diameter of shallot bulbs

Table 2 illustrates the absence of any observable interaction between the application of rice husk biochar and various sources of phosphate fertilizer in relation to the diameter of shallot bulbs. The study involved investigating different doses of rice husk biochar and utilizing different sources of phosphate fertilizer, specifically TSP, RP, and guano. Surprisingly, the results obtained did not exhibit any significant differences in terms of bulb diameter. This lack of impact on the diameter of shallot bulbs can be attributed to factors that extend beyond environmental influences. It is reasonable to suggest that the genetic characteristics of the shallot plant itself play a crucial role in determining bulb size, thus overshadowing any potential effects resulting from the application of rice husk biochar and phosphate fertilizer sources. Previous research findings Putrasamedja [20] have posited that, in addition to environmental factors, genetic characteristics also exert a certain level of influence on the size of bulbs. Furthermore, previous research Sutono [21] has argued that larger seed bulbs tend to undergo enhanced growth, leading to the development of longer leaves and a larger leaf area. Ultimately, this phenomenon contributes to a greater overall yield in terms of the number of bulbs per plant.

3.8 Fresh weight of shallot bulbs

The fresh weight of shallot bulbs was significantly increased with the application of 5 tons per hectare of rice husk biochar and guano-based phosphate fertilizer compared to the application of 0 tons per hectare of rice husk biochar and phosphate fertilizer from TSP, RP, and guano, as well as 5 tons per hectare of rice husk biochar and phosphate fertilizer from TSP and RP (Table 2). However, no significant difference was observed when compared to the use of 10 tons per hectare of rice husk charcoal and phosphate fertilizer from TSP, RP, and guano. The application of rice husk biochar at rates of 5 and 10 tons per hectare resulted in significantly larger fresh bulb weights compared to when no rice husk biochar was applied. This indicates that shallots can utilize the available P_2O_5 in the soil for bulb formation. This finding aligns with the suggestion made by Saragih [22], which proposes that biochar, as a soil conditioner, enhances the soil's water-holding capacity, thereby promoting plant growth by ensuring a sufficient supply of nutrients through the presence of water during plant development. The heaviest fresh bulb weight was produced by guano-based phosphate fertilizer due to its substantial content of macro- and micronutrients, as well as high levels of N and P nutrients, which are essential for shallot growth and development. This result is in line with Lingga [23], which demonstrates that the addition of an adequate amount of phosphorus supports generative plant development, particularly bulb formation.

3.9 Storable weight of shallot bulbs

When comparing different combinations, the application of 5 tons per hectare of rice husk biochar and guano-based phosphate fertilizer greatly increased the weight of storable shallot bulbs. The weight of storable bulbs was significantly higher when rice husk biochar was applied at rates of 5 and 10 tons per hectare compared to when no biochar was applied. The use of phosphate fertilizer from TSP, RP, and guano had similar effects. The treatment that included 5 tons per hectare of rice husk charcoal and guano-based phosphate fertilizer resulted in the highest weight of storable bulbs. This is because biochar has the ability to modify the chemical and physical properties of the soil, allowing shallot plants to grow and produce more effectively. Additionally, guano-based phosphate fertilizer is believed to fulfil the nutrient requirements of shallot plants for bulb formation due to sufficient nutrient availability in the soil. The increase in weight of storable bulbs is similar to the weight of fresh bulbs from shallot plants. The improvement in weight of storable bulbs is influenced by the average of plant leaves and nutrient availability. According to Kusuma [24], rice husk biochar and chicken manure enhanced shallot production up to 10.88 tons, while Adebajo [25] mentioned that rice husk biochar enhanced the growth and yield of tomato plants, resulting in higher plant heights, stem girths, leaf areas, and fruit weights.

4 Conclusion

The addition of rice husk biochar (ranging in quantity from 0 to 5 t ha^{-1}) and phosphate fertilizer supplies obtained from RP and guano resulted in a significant increase in soil pH, accessible phosphorus, and total soil phosphorus. Furthermore, this interaction boosted shallot growth and production by increasing the number of leaves and bulbs per clump. Rice husk biochar applied at rates of 5 and 10 tons per hectare improved leaf length, fresh bulb weight, and storable bulb weight. Furthermore, the use of guano-based phosphate fertilizer enhanced the number of leaves and bulbs per clump.

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