JOURNAL OF DEGRADED AND MINING LANDS MANAGEMENT
Volume 10, Number 2 (January 2023):4297-4304, doi:10.15243/jdmlm.2023.102.4297
ISSN: 2339-076X (p); 2502-2458 (e), www.jdmlm.ub.ac.id

Research Article

Utilization of organic soil amendments and phosphorus fertilizer to improve chemical properties of degraded dry land Vertisol and maize yield

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Article history:
Received 19 September 2022
Accepted 10 December 2022
Published 1 January 2023

Keywords:
maize yield
organic soil amendments
phosphorus fertilizer
soil chemical characteristics
Vertisols

Abstract

This study aimed to evaluate the effects of soil amendment and phosphorus fertilizer application techniques on the chemical properties of dry land Vertisols, P absorption efficiency by maize and maize yield. The study was conducted on farmer's land located in Noelbaki Village, Central Kupang District, Kupang Regency, East Nusa Tenggara, Indonesia. The study was conducted during two planting seasons, namely the rainy season 2020/2021 (PS-1) and the dry season 2021 (PS-2). The soil used in this experiment was included in the degraded Vertisols. This study used a split-plot design with three replications. The main plot was the type of organic soil-amendment material, and the subplot was the technique (dose and stage) of applying phosphorus fertilizer sourced from SP-36. The results showed that organic soil amendment and phosphorus fertilizer application techniques could improve soil chemical properties, P uptake, P absorption efficiency and maize yield in Vertisols until the second planting season. In the long term, the combination of maize stover biochar and the technique of applying phosphorus fertilizer (P3-T2) significantly increased the P uptake by 32.31 kg ha^{-1} (PS-1) and 31.23 kg ha^{-1} (PS-2), the P absorption efficiency by 28.65% (PS-1) and 27.75% (PS-2). The P3-T2 treatment gave maize yields of 6.92 t ha^{-1} (PS-1) and 6.92 t ha^{-1} (PS-2), which were higher than those of other treatments.

To cite this article: Matheus, R., Kantur, D. and Salli, M.K. 2023. Utilization of organic soil amendments and phosphorus fertilizer to improve chemical properties of degraded dry land Vertisol and maize yield. Journal of Degraded and Mining Lands Management 10(2):4297-4304, doi:10.15243/jdmlm.2023.102.4297.

Introduction

The potential of dry land for agricultural development in Indonesia is still very big. In East Nusa Tenggara, the potential for dry land reaches 3,230,649 ha (87.51%) of the total potential agricultural land, which reaches 3.69 million ha and the remaining 12.48% is wetlands (Matheus, 2019). The development of dryland agriculture in Indonesia is faced with soil quality problems characterized by nutrient health, low soil organic carbon, soil acidity and soil physical properties that are less supportive (Daria et al., 2010). Vertisols are the potential soil for agricultural development in East Nusa Tenggara as the distribution of Vertisols in East Nusa Tenggara reaches 0.189 million ha. Vertisols are sedimentary soils that are widely used for agricultural businesses in Indonesia (Prasetyo, 2007).

The main problem with developing maize farming on Vertisols is that the soils physically have hard properties because Vertisols have a clay content of >60%, so they are relatively difficult to cultivate. Soil clay content plays an important role in controlling the availability of P (Prasetyo, 2007). The second obstacle to developing maize farming on Vertisols is that Vertisols have low organic C and available P contents. P is an essential nutrient for plants; however, P is immobile in the soil because most soil P is absorbed into an unavailable form for plants. In neutral and alkaline soils such as Vertisols, P is absorbed by Al, Fe, clay, and Ca (Than and Egashira, 2008; Kasno, 2019).

The physical and chemical problems of the Vertisols significantly affect the growth and yield of maize on dry land. For this reason, efforts are needed to improve the quality of Vertisols. One of the easy and cheap practical efforts is to provide organic soil amendments to Vertisols. The use of organic soil amendments is a way that can be taken to accelerate the process of restoring and improving soil quality. Applying inorganic P fertilizer to Vertisols will increase available P and the plant's response to P if it is accompanied by soil amendments (Mutammimah et al., 2020).

In addition to being able to function as a source of nutrients, organic matter can also function as a fertilizer for organic soils, which have been widely proven to play a role in improving the quality of degraded soils (Hoffland et al., 2020). Various research results demonstrated that the use of organic matter as a soil amendment significantly improves the physical and chemical properties of the soil (Daria et al., 2010). Soil amendments in the form of organic fertilizers can function as a buffer and retain soil moisture. Zulkarnain et al. (2013), who studied the effect of organic soil amendment on sugarcane yields, reported that applying organic matter would increase sugarcane yields and improve soil quality. The effect best occurred on the application of cow manure, increasing sugarcane yield from 60 to 100 t ha^{-1}, lowering the weight of the soil contents, increasing the soil pH, organic matter content, exchangeable K, exchangeable Mg and CEC.

In addition to organic matter, biochar is an organic soil amendment that can improve soil properties such as soil structure, aeration, water and nutrient availability and reduce soil acidification (Dariah et al., 2010). Biochar can also help the conservation of carbon in the soil because it is difficult to decompose in nature, so it can last longer in the soil. The addition of biochar to the agricultural soil layer will provide considerable benefits, including improving soil structure, holding water and soil from erosion because the surface area is larger, enriching organic carbon in the soil, increasing soil pH so as to indirectly increase crop production (Chan et al., 2008). This is supported by the results of research by Dariah et al. (2010) that the application of biochar can increase soil organic C, soil pH, soil structure, soil CEC and groundwater storage capacity. Therefore, innovation is needed through the provision of organic soil amendment to increase productivity and improve soil quality and P fertilization efficiency in Vertisols.

This study aimed to evaluate the effects of soil amendments and P fertilizer on the chemical properties of degraded dry land Vertisol, P uptake by the plant, P absorption efficiency and maize yield.

Materials and Methods

The study was conducted on farmers' land in Noelbaki Village, Central Kupang District, Kupang Regency, East Nusa Tenggara, Indonesia, for two planting seasons, namely in the 2020/2021 rainy season (PS1) and the 2021 dry season (PS2). The soil used in this experiment belongs to degraded Vertisols, characterized by a low organic C content. Carbon (organic C) has long been recognized as a determinant indicator of soil quality. Other soil properties considered to be inhibitors of productivity in Vertisols are a slightly alkaline pH, very low CEC, high bulk density of >1.26 g cm^{-3}, low total pore space and a loamy clay texture, with a clay content of >72%. The soil used for this study has the following characteristics: texture = clay loam (72.74% clay, 18.45% silt, and 8.91% sand), bulk density = 1.26 g cm^{-3}, total pore space = 53%, pH H_2O = 7.66, organic C =1.56%, total N = 0.16%, available P = 5.26 ppm, exchangeable K = 0.40 me 100 g^{-1} soil, and cation exchange capacity (CEC) = 19.90 me 100 g^{-1} soil.

This study used a two-factorial split-plot design. The first factor, as the main plot, was the type of soil amendment sourced from agricultural wastes (P), which consisted of P0 = no organic soil amendment; P1 = cow manure; P2 = rice straw compost; P3 = maize stover biochar. The second factor, as a subplot, was the technique (dose and stage) of applying phosphorus fertilizer sourced from SP-36 in each planting season, PS (T), namely: T1 = PS1 0 kg P_2O_5 ha^{-1} and PS2: 90 kg P_2O_5 ha^{-1}; T2 = PS1 45 kg P_2O_5 ha^{-1} and PS2: 45 kg P_2O_5 ha^{-1}; T3 = PS1 90 kg P_2O_5 ha^{-1} and PS2: 0 kg P_2O_5 ha^{-1}. The characteristics of the organic soil amendment materials used in this experiment are presented in Table 1.

Table 1. Chemical compositions of soil amendments used for the study.

Analyzed parameters	Types of organic soil amendment		
	P1	**P2**	**P3**
pH H_2O	8.23	8.15	9.22
Organic C (%)	24.06	16.87	13.65
C/N ratio	12.15	13.08	14.22
Total N (%)	2.02	1.29	0.96
Total P (%)	0.76	0.31	0.24
Total K (%)	1.42	0.94	0.24

Remarks: P1 = cow manure; P2= rice straw compost; P3= maize stover biochar.

The experimental land size was 26 x 15 m^2. The land was completely cultivated and divided into four main plots, with the size of each main plot being 8 x 3 m^2. Each main plot was divided according to the number of subplot treatments. The size of the subplot was 2 x 3 m^2. The distance between blocks was 1 m. The treatment application of soil amendments was given at once in the first planting season (PS-1) at a dose of

5 t ha^{-1}. Soil amendments were applied 20 days before planting. The technique (dose and stage) of applying phosphorus fertilizer (SP-36) was applied according to each treatment, and the fertilizer was applied simultaneously with the planting of maize. Seeds of maize of the Lamuru variety were planted with a spacing of 80 x 40 cm^2. At harvest (95 days), composite soil samples were taken from all experimental plots of each planting season (PS-1 and PS-2), at a depth of 10-20 cm, for analysis of soil chemical properties. Soil acidity was measured using a pH meter at a 1:1 ratio of soil and distilled water. Soil organic C was determined using the Walkley and Black method. Total N was measured using the Micro Kjeldahl method. Available was determined using the Bray-2 method. Exchangeable K and CEC were measured using the extraction method with 1N NH_4 OAc. All methods used followed the soil analysis guidelines developed by the Soil Research Institute of Indonesia (2009). Observations on maize plants carried out on PS-1, and PS-2 included plant dry weight, total P (spectrophotometer method), P uptake, P absorption efficiency and dry maize yields. For the analysis of total P in the plants, plant samples were taken during the maximum vegetative phase at 56 days after planting (DAP). The sampling was carried out destructively. The efficiency of P absorption P was calculated by the formula of Yuwono (2004) as follows:

$$\text{PAE (\%)} = \frac{\text{A} - \text{B}}{\text{C}} \text{ x } 100\%$$

where:

PAE	=	P absorption efficiency
A	=	P uptake by plants grown in the fertilized soil (g)
B	=	P uptake by plants grown in unfertilized (control) soil (g)
C	=	The initial amount of P applied in the form of agricultural wastes (g)

The data obtained were subjected to the analysis of variance followed by a Duncan Multiple Range Test (DMRT) at a 5% level. The software used for statistical tests was Microsoft Excel and SPSS 21.0.

Results and Discussion

Soil chemical properties

The effect of organic soil amendments and the technique (dose and stage) of P fertilizer application during the two planting seasons (PS), indicated by the chemical properties of the soil at the end of the second planting season (PS-2), is presented in Table 2. In general, the application of organic soil amendments exerted a significant influence on the chemical properties of the soil until the second planting season (PS-2). The effect of the techniques of applying P fertilizer (applied simultaneously or gradually) did not differ markedly from the effect of applying soil amendment, instead exerting different influences on the pH, N content, P content, K content and CEC of the soil.

Soil pH

Soil pH is one of the important indicators of soil chemical fertility, as it reflects the availability of nutrients in the soil. Results of DMRT presented in Table 2 show that the treatments of organic soil amendment (P1, P2 and P3) noticeably lowered the soil pH of the soil from a pH of 7.60 (slightly alkaline) to a neutral pH at the end of PS-2, compared to no soil amendment (P0). This is because the organic soil amendments used had a high pH (8.15-9.22). According to Solaiman and Anwar (2015), the level of alkalinity in soil amendment is one of the factors contributing to its potential to improve soil pH. Changing the pH towards neutral facilitates the exchangeable ions in the soil to provide nutrients for plant growth.

Table 2. Effect of soil amendment and technique (dose and stage) of P fertilizer application on the chemical properties of the soil at a depth of 10-20 cm at the end of the second planting season (PS-2).

Treatment	pH	Organic C (%)	Total N (%)	Available P (ppm)	Exchangeable K (me 100 g^{-1})	CEC (me 100 g^{-1})
Types of organic soil amendment (P):						
P0	7.60 b	1.52 c	0.17 c	5.98 c	0.23 b	9.77 c
P1	7.40 a	2.27 b	0.27 a	7.62 b	0.42 a	24.78 b
P2	7.40 a	2.23 b	0.26 a	7.39 b	0.46 a	25.43 b
P3	7.06 a	2.49 a	0.23 a	8.39 a	0.51 a	31.08 a
Techniques of applying P fertilizer (T):						
T1	7.45 b	2.06 a	0.19 a	5.32 b	0.31 b	18.66 b
T2	7.35 a	2.19 a	0.26 a	9.17 a	0.50 a	26.58 a
T3	7.47 b	2.09 a	0.23 a	7.55 b	0.40 b	23.06 b

Description: Numbers followed by the same letters in the same column are not significantly different on the 5% DMRT. P0 = no organic soil amendment; P1 = cow manure; P2 = rice straw compost; P3 = maize stover biochar, T1 = PS1 0 kg P_2O_5 ha^{-1} and PS2: 90 kg P_2O_5 ha^{-1}; T2 = PS1 45 kg P_2O_5 ha^{-1} to PS2: 45 kg P_2O_5 ha^{-1}; T3 = PS1 90 kg P_2O_5 ha^{-1} and PS2: 0 kg P_2O_5 ha^{-1}.

According to Moreira et al. (2015), adding organic matter can increase or decrease the pH of the soil depending on the degree of maturity of the organic matter added and the type of soil. Treatments of the P fertilization technique in the subplot gave a marked difference in the soil pH at the end of the experiment (PS-2). The treatment of applying P fertilizer gradually (T2) noticeably decreased the pH of the soil to 7.35, lower than the treatment of P-at-a-time application (T1 and T2). Although it is still in the neutral pH category, the decrease in soil pH in this gradual P fertilization technique (T2) is because the inorganic P given was in small and gradual amounts, so there was no accumulation residue of organic acids sourced from P. This is different from the other treatments, where the accumulation of organic acids was high enough to affect the soil reaction.

Soil organic C

Soil organic carbon (organic C) is the key to soil fertility because it can increase the ability of soil to bind and absorb nutrients and water for plants, reduce nutrient leaching, increase soil granulation and act as a source of energy for soil biota (Hoffland et al., 2020). The treatment of organic soil amendments significantly affected ($p<0.01$) the organic C content of the soil at the end of the experiment (PS-2). Meanwhile, the treatment of subplots, the technique of applying P fertilizer (simultaneous or gradual application), did not significantly affect ($p>0.05$) the organic C content at the end of the experiment (PS-2). The application of maize biochar (P3) increased the organic C content of the soil until the end of PS-2 by 2.49% higher than other treatments. The high content of organic C in this treatment is because biochar has characteristics that are resistant to weathering into simple compounds. This is in line with the results of the research of Hammond et al. (2007), Matheus et al. (2017), and Putri et al. (2017) that biochar contains aromatic compounds that are recalcitrant in nature and able to maintain C stability in soil. In addition, biochar can also bind organic C in the soil so that it remains stable and not easily decomposed by microorganisms. Hammes and Schmidt (2009) stated that functional groups on the surface of biochar could absorb organic C in the soil.

Soil total N

Based on the soil analysis results of the PS-2 experiment (Table 2), the N content in the soil differed markedly between the treatments of organic soil amendments and the technique (dose and stage) of P fertilizer application. Organic soil amendments (P1, P2 and P3) increased the total N in the soil by 0.27%, 0.26% and 0.23%, respectively. They differed significantly from the control (without soil amendments), which featured a low soil total N of 0.17%. This is in line with Mutammimah et al. (2020), who argued that the increase in N nutrient levels in the soil was not only determined by the presence of input from fertilization but also by the contribution of added soil amendments. Soil amendments, sourced from organic fertilizers and biochar agricultural waste, generally contain N, even in small quantities. Syukur and Harsono (2008) reported that the application of cow manure dose significantly increased the total N level from 376.67 ppm to 474.00 ppm and soil available N from 10.65 ppm to 11.14 ppm. This is also in line with the research of Riyanti et al. (2015) that organic matter in the soil can increase the activity of organisms in decomposing and releasing soil N, as well as enhance the development of populations of N-fixing bacteria.

Available P

Available P is the form of P nutrient that can be absorbed by plants. P is a nutrient that is needed in large quantities for plant growth and development. Data presented in Table 2 show that the application of soil amendment and P fertilizer affected P availability in the soil. The amount of available P in the soil treated with biochar was 8.39 ppm at the end of the study (PS-2). This value was higher than and significantly different from the other treatments. The increase in the available P in the Vertisols treated with biochar was probably due to the stable and resistant nature of biochar to weathering so that it could be stored in the soil for a long time. The presence of biochar in the soil layer can have a positive influence in increasing the soil's copulation power against P nutrient leaching so that it will be easily available in the soil (Solaiman and Anawar, 2015; Matheus et al., 2017). According to Dariah et al. (2010), in addition to containing stable organic C, biochar also contains many organic compounds in the form of organic acids that play roles in the release of nutrients, especially P, which are generally absorbed in soil micelles.

The same role was also shown by soil amendments in the forms of manure (P1) and compost (P2), which also markedly increased the available P content in the soil by 7.62% and 7.37%, respectively, and the values were markedly different from the control treatment (5.98%). The role of soil amendments is to release or free P from micelle bonds absorbed by metals such as Al and Fe (Mutammimah et al., 2020). The application of the organic amendments eventually released plant nutrients into the soil. This study showed that the amendments increased P-availability in Vertisols until the end of PS-2. Organic matter is presumably decomposed in the presence of a phosphatase enzyme, which has a significant role in destroying organic P (Bhat et al., 2017). Melero et al. (2008) reported that phosphatase activities were much higher in organically fertilized soil than in control. Also, the phosphorus released from organic-P through biochemical mineralization is highly dependent on the released element. The increase in available P content after being given soil amendments treatment (P1, P2 and P3) is thought to be due to an increase in organic acids in the soil conditioner, which can help release P from the soil micelle bonds so that the concentration of available P increases. The increase in available P content after applying soil amendments (P1, P2 and P3) is thought to be due to an increase in organic acids in the soil amendments, which can help release P from the soil micelle bonds so that the concentration of available-P increases. The decomposition of organic matter produces humic and fulvic acids so that the bound P can be released and become available in the soil (Dotaniya et al., 2014)

A similar pattern is also seen in the treatments of subplots, i.e. the technique of applying P fertilizer at once or gradually. The results presented in Table 2 show that the gradual application of P fertilizer (T2) markedly increased the soil's available P by 9.17% higher than and was significantly different from other treatments (Table 2). The increase in the available P content up to PS-2 because P fertilizer, which was gradually applied in small stages, could properly minimize the loss of P to increase P availability in the soil. The increase in soil available P is due to the direct influence of phosphorus fertilization, where the properties of SP-36 are easily soluble. According to Cahyono and Minardi (2022), the increase in soil P-available content is due to the direct influence of P fertilizer because P fertilization increases P-available levels in the soil or through the mechanism of P release from the adsorption complex. Nursyamsi and Setyorini (2009) also stated that the application of P fertilizer also increases the availability of P element because phosphates saturate the place of adsorption.

Exchangeable K

Results of DMRT presented in Table 2 show that the provision of organic soil amendments has a significant effect on exchangeable K and is significantly different from the control treatment (without soil amendments). The provision of organic soil amendments (P1, P2 and P3) increased the exchangeable K of PS-2 by 0.51, 0.46 and 0.42 me 100 g^{-1} higher, respectively and differed markedly from the control treatment (0.23 me 100 g^{-1}). This proves that organic soil amendments sourced from agricultural waste are potential sources of organic C and can play a role in increasing the availability of macronutrients such as K in the soil that are useful for plants. This is in line with the findings of Abdillah and Widiyastuti (2022) that the application of rice straw compost and agro-industrial waste can improve the quality of soil chemistry, namely, exchangeable K and K absorption of rice plants. The technique treatment of applying P fertilizer (T2) noticeably decreased the pH of the soil to 7.35, lower than the treatment of applying P at once (T1 and T2). However, it is still in the neutral pH category. The decrease in soil pH in the gradual application of P fertilization (T2) was probably because the inorganic P was given in small and gradual amounts so that there was no accumulation/residue of organic acids sourced from P. This is different from the treatment of giving at once, where the accumulation of organic acids is high enough to affect the reaction of the soil.

Cation exchange capacity

Soil cation exchange capacity (CEC) is one of the important chemical properties of the soil because it affects the ease and availability of nutrients for plant roots. The treatment of organic soil amendments had a very noticeable effect ($p<0.01$) on the CEC value of the soil at the end of the PS-2 experiment. The maize biochar treatment (P3) increased the soil CEC to PS-2 by 31.08 me 100 g $soil^{-1}$ higher and differed markedly from the P1 and P2 treatments with soil CEC of 24.78 and 25.43 me 100 g of $soil^{-1}$, respectively. The increase in the CEC value of the PS-2 soils in biochar treatment is due to the nature of biochar which is resistant to weathering so that it can last longer in the soil, which ultimately affects the soil properties.

Hoffland et al. (2020) stated that the application of decomposed organic matter significantly contributes to soil CEC because organic matter can increase the adsorption power and exchangeable cations. This can happen because the decomposition of organic matter produces humus (organic colloids), a source of negative soil charge, so it has a surface that can retain nutrients and water. This differs from soil amendment sourced from manure (P1) and compost (P2) which reduced the CEC values at the end of PS-2. This is probably due to a decrease in humus content in the soil.

P uptake, P absorption efficiency and maize yield

The results of the analysis of variance showed that the application of organic soil amendment materials and the technique (dose and stage) of phosphorus fertilizer application (P_2O_5) had a noticeable influence on plant P uptake, P absorption efficiency and maize yield during the two planting seasons (Table 3). Duncan's analysis showed that applying soil amendment materials and techniques (dose and stages) of applying P fertilizer showed a significant effect of differences on plant P uptake, P absorption efficiency and maize yields during the two planting seasons. Duncan's analysis showed that applying organic soil amendments and techniques (dose and stage) of applying P fertilizer showed a significant effect of differences on plant P uptake, P absorption efficiency and maize yields during the two planting seasons.

P uptake by maize

The amount of P in maize plants can be known from the measurement of P uptake. Generally, plants absorb P in inorganic form. Based on the results of the analysis of the application of organic soil amendments and the techniques of applying P fertilizer (Table 3), a combination treatment of biochar soil amendments with gradual P application (P3-T2) markedly increased the P uptake by maize during the two planting seasons, by 32.31 kg ha^{-1} (PS-1) and 31.23 kg ha^{-1} (PS-2), respectively. These values were higher and significantly different from other treatment combinations. Followed by manure treatment with a gradual of applying P fertilizer (P2-T2) and rice straw compost treatment with a gradual of applying P fertilizer (P1-T2). The technique of applying P fertilizer at once (T1 and T2) combined with manure and compost as a soil amendment reduced P uptake by maize. This proves that biochar as a soil amendment provides a better response, as seen from the higher uptake of P by maize plants compared to manure and rice straw compost.

Table 3. The effects of soil amendments and techniques (dose and stage) of applying P fertilizer on plant P uptake, P absorption efficiency, and maize yield in two planting seasons (PS-1 and PS-2).

Treatments	P uptake by maize (kg ha^{-1})		P absorption efficiency (%)		Maize yield (t dry weight ha^{-1})	
	PS-1	PS-2	PS-1	PS-2	PS-1	PS-2
P0-T1	15.39 d	14.73 e	9.75 e	8.76 e	3.53 e	3.56 d
P0-T2	17.62 c	16.62 e	13.99 d	12.65 e	4.15 d	3.82 d
P0-T3	14.44 d	15.11 e	9.90 e	10.19 e	3.42 d	3.40 d
P1-T1	18.77 c	17.44 d	19.65 b	17.99 d	5.43 cd	5.29 c
P1-T2	25.03 b	24.69 b	25.65 b	24.65 b	6.22 b	5.73 b
P1-T3	17.12 c	18.12 d	21.25 c	19.59 c	4.87 cd	5.43 c
P2-T1	22.56 c	18.13 d	20.10 c	17.77 d	5.56 c	5.03 c
P2-T2	26.52 b	25.35 b	26.44 b	24.11 b	6.37 b	6.84 b
P2-T3	19.82 c	20.82 c	21.99 c	20.65 c	5.29 c	5.26 c
P3-T1	20.19 c	21.49 c	22.99 c	21.32 c	5.12 c	5.14 c
P3-T2	32.31 a	31.23 a	28.65 a	27.75 a	6.91 a	6.62 a
P3-T3	23.82 c	22.01 c	22.32 c	21.02 c	5.60 c	5.46 c

Description: Numbers followed by the same letters in the same column are not significantly different on the 5% DMRT. P0 = no organic soil amendment; P1 = cow manure; P2 = rice straw compost; P3 = maize stover biochar, T1 = PS1 0 kg P_2O_5 ha^{-1} and PS2: 90 kg P_2O_5 ha^{-1}; T2 = PS1 45 kg P_2O_5 ha^{-1} to PS2: 45 kg P_2O_5 ha^{-1}; T3 = PS1 90 kg P_2O_5 ha^{-1} and PS2: 0 kg P_2O_5 ha^{-1}.

The results of this study are in line with those of Kasno and Rostaman (2013), who reported that P uptake by maize plants could reach 51 kg P ha^{-1}. The provision of maize stover biochar helps the soil provide P so that it is available to plants. The increase in the amount of P uptake was due to the nature of biochar which is difficult to decompose, so it can last longer in the soil layer than decomposed manure and compost. Another property of biochar is its smooth structure with a large surface area. With a wider surface area, biochar has a higher capacity to hold water and nutrients (Putri et al., 2017). Yeboah et al. (2016) reported that biochar could reduce nutrient leaching so that nutrients absorbed by biochar can be utilized by the root of maize plants optimally.

In addition, biochar has more functional groups that function in nutrient exchange compared to the decomposition of organic fertilizers (Solaiman and Anawar, 2015). Such functional groups have a role in the supply of P through chelation reactions by over-carrying metal cations such as Al and Fe, which usually bind P in the soil. Satriawan and Handayanto (2015) reported that the P nutrient absorbed by plant roots depended on the amount and availability of P elements in the soil. The technique of gradually applying P fertilizer (T2) was also very appropriate to increase the absorption of P compared to the technique of giving it at once. This is because Vertisols generally have high P reserves but are in an unavailable form, so if given at once with high doses, it will be useless because many accumulate in the soil.

P absorption efficiency

Nutrient absorption efficiency was tested to see the effect of organic soil amendments and the techniques of applying P fertilizer on the amount of P taken up by maize plants. The results presented in Table 3 show that the combined treatment of maize biochar with phosphorus gradual (P3-T2) feeding techniques markedly increased the efficiency of maize P absorption until the second planting season by 28.65% (PS-1) and 27.75% (PS-2), respectively higher than other treatments. This shows that the application of biochar can minimize P loss in the soil, as evidenced by the higher P absorption efficiency in P3-T2 than in other treatments. Akasah et al. (2018) showed that the average efficiency of fertilizing P maize plants on land fed with organic fertilizers reached 27.8% compared to without organic matter, which only reached 16.6%.

The application of SP-36 fertilizer as a source of P directly affects the availability of P in the soil and the absorption by the plant. According to Muktamar et al. (2020), the uptake of P is highly dependent on the contact of the roots with P in the soil solution. The available P in the soil solubility comes from potential P, which is detached from metals due to the activity of organic matter. This is supported by the role of humic acids in increasing the availability of nutrients in the soil. Khaled and Fawi (2011) argued that humic acids could increase fertilization efficiency through changes in soil particles that are negatively charged organic matter so that they will bind to positively charged nutrients. This will increase the availability of phosphorus, nitrogen and other micronutrients in the soil. The addition of organic matter in the form of humic acids is one of the factors that support the increase in plant P.

Maize yield

The effect of organic soil amendments and the techniques of applying P fertilizer on maize yields on Vertisol soils for two planting seasons is presented in Table 3. Maize stover biochar with applying P fertilizer gradual (P3-T2) feeding technique gave maize yields, respectively, of 6.92 t ha^{-1} (PS-1) and 6.92 t ha^{-1} (PS-2), higher than other soil reformers. The increase in maize yields is quite stable during the two planting seasons because biochar soil amendment materials have a high water-holding capacity so they can keep macro and micronutrients from being easily washed away and make them more available to plants. According to Nguyen et al. (2017), the application of biochar can increase soil moisture and pH, thereby stimulating the nutrient mineralization process, which causes plant uptake to increase. Biochar increases the inorganic compounds needed for plant assimilation by increasing retention and reducing the impact of nutrient leaching. In addition, the provision of rice straw biochar also noticeably increased the exchangeable K of the soil. This increase was due to the biochar used having a relatively high K content (1.88-5.76%). In line with Widiowati et al. (2012), biochar can meet the needs of potassium for the vegetative growth of maize plants, so it has the potential to replace the use of KCl fertilizer.

Conclusion

The utilization of organic soil amendments and the techniques of applying P fertilizer could improve soil chemical properties, P uptake, P absorption efficiency, and maize yields during the two planting seasons. Organic soil amendment materials noticeably increased pH, organic C, total N, available P, exchangeable K and CEC in Vertisols until the second planting season. Maize stover biochar with the gradual application of P fertilizer (P3-T2), markedly increased the P uptake by 32.31 kg ha^{-1} (PS-1) and 31.23 kg ha^{-1} (PS-2), P absorption efficiency by 28.65% (PS-1) and 27.75% (PS-2) and gave maize yields of 6.92 t ha^{-1} (PS-1) and 6.92 t ha^{-1} (PS-2), during the two planting seasons higher than other treatments. In the long run, soil amendments from biochar are more effective than those from manure and rice straw compost.

Acknowledgements

The authors thank the Center for Research and Community Service of the Kupang State Agricultural Polytechnic for funding this research through the Leading Applied Research Program of 2020.

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