JOURNAL OF DEGRADED AND MINING LANDS MANAGEMENT
Volume 11, Number 2 (January 2024):5319-5327, doi:10.15243/jdmlm.2024.112.5319
ISSN: 2339-076X (p); 2502-2458 (e), www.jdmlm.ub.ac.id

Research Article

Improvement of N, P, and K availability of post-brick mining soil to increase maize yield by applying different types of biochar

Widowati[1*], Retno Wilujeng[1], Nurhidayati[2], E.R. Indrayatie[3]

[1] Department of Agrotechnology, Faculty of Agriculture, Tribhuwana Tunggadewi University, Jl. Telaga Warna, Malang, Indonesia
[2] Department of Agrotechnology, Faculty of Agriculture, Islamic University of Malang, Jl. Mayjen Haryono, Malang, Indonesia
[3] Department of Forestry, Faculty of Forestry, Lambung Mangkurat University, Jl. A. Yani Km. 35, Banjabaru, Indonesia

[*]corresponding author: widwidowati@gmail.com

Article history:
Received 15 June 2023
Revised 17 August 2023
Accepted 13 September 2023

Keywords:
biochar
biomass
nutrient availability
post-brick mining soil

Abstract

The low fertility of post-brick mining soil may be improved by applying biochar to the soil because biochar is an excellent soil amendment, although its quality varies depending on the raw materials used. Therefore, soil fertility, nutrient availability, and crop yields are affected by the type and amount of biochar added to soils. This study examined the effect of types and dosages of biochar on nitrogen, phosphorus, and potassium availability of post-brick mining soil to increase maize yield. The treatment combinations of biochar dosages (0 t ha^{-1}, 15 t ha^{-1}, 30 t ha^{-1}, and 45 t ha^{-1}) and biochar types (coconut shell, wood, and rice husk biochars) were arranged in randomized block design with three replications. Each treatment plot measuring 4 m x 4.5 m was planted with maize seeds with a planting space of 80 cm x 25 cm. Urea (135 kg N ha^{-1}), SP36 (36 kg P_2O_5 ha^{-1}), and KCl (110 kg K_2O ha^{-1}) were applied as basal fertilizers. The results showed that at eight weeks after biochar application, the amount and type of biochar positively affected maize yield. The application of rice-husk biochar at 30 t ha^{-1} resulted in the highest maize yield. The application of each type of biochar at 45 t ha^{-1} yielded the highest increase in the availability of nitrogen, phosphorus, and potassium in the soil.

To cite this article: Widowati, Wilujeng, R., Nurhidayati, and Indrayatie, E.R. 2024. Improvement of N, P, and K availability of post-brick mining soil to increase maize yield by applying different types of biochar. Journal of Degraded and Mining Lands Management 11(2):5319-5327, doi:10.15243/jdmlm.2024.112.5319.

Introduction

The practice of red brick making is commonly found at Jatikerto Village, of Malang Regency, Indonesia, due to the need for residential development. Brick production impacts agricultural production by utilizing fertile topsoil from agricultural lands (Brunel et al. 2011; Kathuria and Balasubramanian 2013) and releasing toxins, including heavy metals, that influence agricultural productivity (Skinder et al., 2014), threaten food security (Lal 2013) and agricultural sustainability (Srinivasarao et al., 2021). The red brick industry causes a decrease in the function of the topsoil, which is rich in nutrients (Kumar et al., 2015; Parera, 2021), which can reduce crop production by 40-80% (Biswas et al., 2018). Like soil erosion, topsoil mining results in eminent loss of soil and soil nutrients. Erosion is a gradual process causing the loss of topsoil over time, while topsoil mining causes abrupt soil loss with immediate adverse effects on soil quality (Singh et al., 2014). Kathuria and Balasubramanian (2013) reported that following topsoil removal for brick production in Tamil Nadu, soil manganese was reduced by 35% and zinc by 63%, and on average, topsoil removal resulted in a loss of about 28 kg of nitrogen, 3 kg of phosphorous and 34 kg of potash per hectare of land. This removal of topsoil was associated with a 124 kg per hectare (3%) reduction in rice yields and 62 kg per hectare (4%) reduction in groundnut yields. According to Lal (2013), the loss of topsoil results in the loss of 28 kg of nitrogen, 3 kg of phosphorus, and 34 kg of potassium per hectare of land.

The common problem that arises from red brick making in Jatikerto Village, of Malang Regency is neglecting the land after removing topsoil without reclamation and rehabilitation. Given the importance of crop production for long-term food and nutrient security, approaches to restoring degraded soils should be a priority. Efforts that can be made to restore the functions of post-red brick mining soil are the application of biochar to increase organic content in the post-red brick mining soils. Biochar is produced through a pyrolysis process of biomass without oxygen (Ahmad et al., 2014; Varma et al., 2018). The beneficial use of biochar as a soil amendment in tropical regions has been widely documented. As a soil amendment, biochar rests in its ability to enhance physical, chemical, and biological properties of agricultural soils (Zwieten et al., 2012). As a porous material of size and multifunction, biochar has a high surface area, high adsorption capacity and contains a high amount of carbon (Khalili et al., 2020; Obia et al., 2020; Hale et al., 2021; Tian et al., 2021).

Biochar has been shown in numerous studies have shown biochar increases both soil pH and CEC (Lehmann et al., 2011). The ability of biochar to improve soil pH and quality through its ash and organic matter content means that more of the available soil nutrients will be used (Jindo et al., 2020). Moreover, biochar has nitrogen, while the ash component has potassium and phosphorus (Jindo et al., 2020). Hence, soil nutrient contents can be raised by using biochar, an organic reservoir of nitrogen, phosphate, and potassium (Khan et al., 2021). Jindo et al. (2020) reported that adding biochar can reduce NH_3 volatilization and N_2 emissions and increase available P due to increased solubilization, reduced P fixation, and K extraction in the soil. In terms of soil physical properties, biochar increases water availability by 4-130%, increases porosity by 14-64%, decreases soil density by 3-31%, boosts wet aggregate stability by 3-22%, improves soil consistency by the same amount, and decreases saturated hydraulic conductivity in coarse-textured soils while increasing it in fine-textured soils (Blanco-Canqui, 2017).

Plants need nitrogen, phosphorus, and potassium, while the interaction of biochar with soil components can increase the availability of these nutrients. The effectiveness of biochar in the N, P, and K cycles is influenced by the quantity of biochar and the type of raw materials used for producing biochar (Oni et al., 2019; Jindo et al., 2020). According to Ouyang et al. (2014), the beneficial effect of biochar added to the soil depends on the nature of the biochar. The quality of biochar, including the availability of certain nutrients, can be affected by the raw material used to create it. Biochar made from hardwood and coconut shells leaches about the same amount of nitrate, according to a study by Widowati et al. (2014). Jaiswal et al. (2015) reported that the high dose harms the development of plants in pots, but yield increases are significant at high application rates in the field (Joseph et al., 2013).

The study aimed to examine the effects of types and dosages of biochar on nitrogen, phosphorus, and potassium availability of post-brick mining soil to increase maize yield.

Materials and Methods

A field experiment was conducted at a post-brick mining site at Jatikerto Village, Malang, Indonesia (8.13046°S 112.48785°E). The soil of the study site has a clay loam texture with low calcium content, low magnesium content, low cation exchange capacity, moderate acidity, low organic soil carbon content, low potassium, low phosphorus, and low nitrogen contents (Table 1).

The treatments tested in this experiment were the combinations of two factors. The first factor was biochar types comprising rice husk biochar, wood biochar, and coconut shell biochar. The second factor was the amount of biochar applied, including 0, 15, 30, and 45 t ha^{-1}. Biochar from each source material was prepared by pyrolyzing the material in a 56 cm x 23 cm drum. Wood and coconut shells were milled into a fine powder using a 2 mm filter to create biochar. Auto thermal heating and a restricted oxygen supply were applied for combustion. Before being heated, all source materials of biochar were dried, with moisture levels between 10 and 20%. The heating system maintained temperatures between 250 and 300 ºC. The length of time needed to heat anything changes with the ingredients. Coconut shells required 2-4 hours of heating time, whereas rice husks needed 9-12 hours. Traditional Indonesian mounds were used in commercial wood biochar production. The chemical properties of biochar and soil used for this study were analyzed in the Laboratory of Soil Chemistry, Brawijaya University, and the results are presented in Table 2.

Each treatment combination was applied to a field experimental plot measuring 4 m x 4.5 m and mixed with the soil evenly to a depth of 30 cm. After 7 days the biochar-amended plot was planted with maize plant with a planting space of 80 cm x 25 cm. Urea (135 kg N ha^{-1}), SP36 (36 kg P_2O_5 ha^{-1}), and KCl (110 kg K_2O ha^{-1}) were applied as basal fertilizers. Three seeds of the Pioneer 2 maize variety were planted in each hole and thinned to one plant after 7 days. The twelve treatments were arranged in a two-way factorial randomized block design with three replications. The maize plants were periodically watered during the experiment, and the weeds were removed to ensure maximum crop growth. The parameters measured were the contents of N, P, and K in the soil, leaf area, dry biomass, yield per thousand grains, ear length, ear diameter, and weight without the maize husk.

Table 1. Physical and chemical characteristics of the soil used for the experiment.

Soil physical and chemical characteristics*	Value
pH H_2O (1:1)	5.50
Organic C (%)	0.39
Total N (%)	0.08
C/N ratio	4
P (mg kg^{-1})	6.35
K (mg 100 g^{-1})	0.43
Na (mg 100 g^{-1})	0.54
Ca (mg 100 g^{-1})	4.36
Mg (mg 100 g^{-1})	1.85
Base saturation (%)	51
CEC (me 100 g^{-1})	14
Bulk density (g cm^{-3})	1.06
Particle density (g cm^{-3})	2.33
Total pore space (%)	54.50
Aggregate stability (mm)	1.12
pF 0 (cm^{-3})	0.55
pF 2.5 (cm^{-3})	43
pF 4.2 (cm^{-3})	0.18
Macro pores (%)	11.40
Medium pores (%)	25
Micro pores (%)	18
Soil texture	clay loam
Sand (%)	21
Loam (%)	47
Clay (%)	32

*Widowati et al. (2017).

Table 2. Characteristics of biochars from different raw materials.

Characteristics	Biochar type*		
	Rice husk	Wood	Coconut shell
pH H_2O (1:2.5)	7.90	9.30	9.40
Organic C (%)	20.93	71.47	60.07
Total N (%)	0.71	0.81	0.95
P (%)	0.06	0.01	0.10
K (%)	0.14	0.36	0.71
Na (%)	2.24	0.43	3.82
Ca (%)	1.37	1.20	
0.06	2.16		
Mg (%)	0.06		0.10
CEC ($cmol_{(+)}$ kg^{-1})	17.47	14.98	16.41

*Widowati et al. (2017).

Soil samples were taken at the time of maximum vegetative growth of 8 WAP (weeks after planting) at about 10 cm depth. Leaf areas of two plants per plot were measured at 4 and 8 WAP using a Leaf Area Meter (model LI-3100C). The plant biomass was measured at 8 WAP when the plants reached the maximum vegetative growth. The maize plants were harvested at 16 WAP when the plants had reached physiological maturity. The maize stalks were lopped off at ground level to harvest ground stovers. Plant dry weight was measured by drying in an oven at 80 °C until a constant weight. Soil samples were taken around the roots of the plants to measure the N, P, and K contents. Total N content was measured by the Kjeldahl method, P with the Bray method, and K with AAS spectrophotometry. The data obtained were subjected to analysis of variance (ANOVA) followed by an LSD test at the 0.05 level.

Results and Discussion

Status of N, P, and K in the soil

Nitrogen

The amount and types of biochar applied to the soil significantly increased the N, P, and K contents of the soil (Figure 1). An interaction between the type and the amount of biochar was found in examining the effect of biochar on soil N availability (Figure 1). The highest total N content was found in the soil applied with rice husk biochar at 45 t ha^{-1}. Figure 3 shows that the application of 15, 30, and 45 t biochar ha^{-1} increased the N content by 23%, 50%, and 70%, respectively (rice husk biochar); 27%, 30%, and 50% (coconut shell biochar); and 23%, 43%, 53% (wood biochar). Adekiya et al. (2020) reported increased nitrogen, phosphorus, potassium, sulfur, calcium, and magnesium in biochar-amended soil. The soil N availability increases because biochar application mediates microbes under field conditions to accelerate the N cycle process (Zhang et al., 2021).

Phosphorus

The amount and types of biochar had interaction effects on available P in the soil (Figure 1). The highest increase of available P was achieved by applying wood biochar at 45 t ha^{-1}, followed by rice husk biochar application of 45 t ha^{-1}. The application of biochar can enhance available P in the soil by raising soil pH and increasing the amount of P available to plants. Soil pH increases with biochar application, but the changes depend on the material and the pH value of the biochar itself (DeLuca et al., 2015). Gao and DeLuca (2016) reported that biochar alters phosphorus solubility by influencing soil pH. Satriawan and Handayanto (2015) found that applying 80 t ha^{-1} of sugarcane litter and 40 t ha^{-1} of maize litter biochars increased P availability and uptake. The application of 30 and 45 t ha^{-1} of coconut shell biochar resulted in the same amount of available P. Using more wood biochar resulted in a higher level of P. Available P content increased at doses of 15, 30, and 45 t ha^{-1}, respectively 167%, 226%, and 238% (rice husk); 75%, 107%, 119% (shell); and 137%, 169%, 451% (wood). According to Zhang et al. (2012), biochar can be utilized to raise phosphorus availability in acid soil.

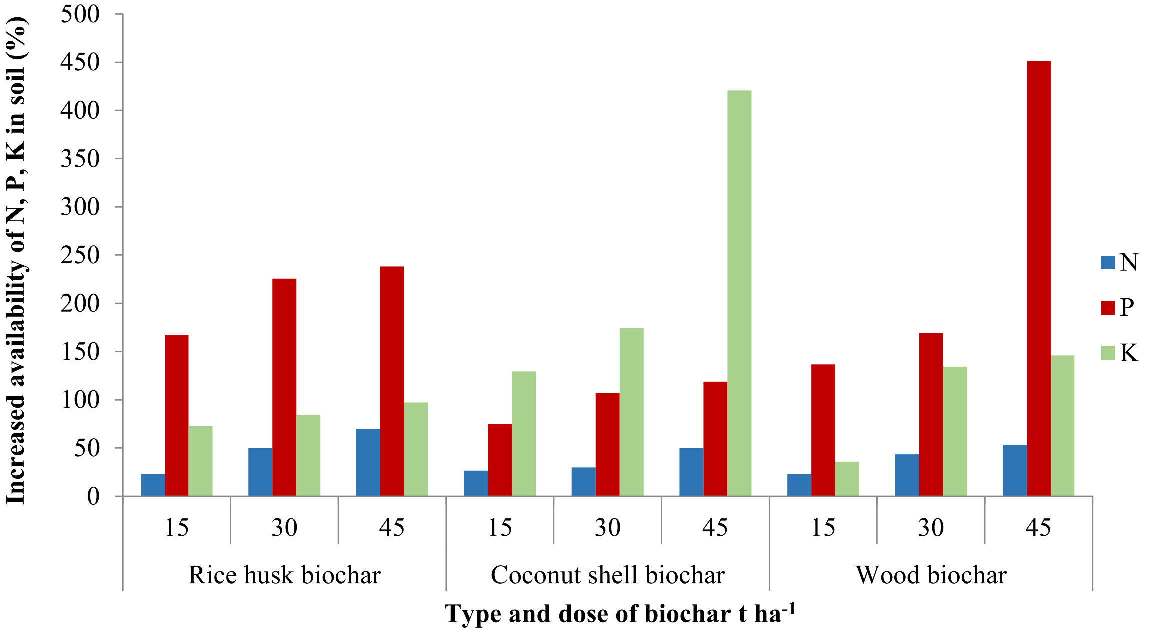

Figure 1. Effect of type and amount of biochar on increased availability of N, P, K in soil (Widowati et al., 2017).

Potassium

Available potassium increased by 73%, 84%, and 97%, respectively (rice husk biochar); 129%, 175%, 421% (shell); and 36%, 135%, and 146% (wood) at doses of 15, 30, 45 t ha^{-1} (Figure 3). Potassium availability is affected by the soil mineral composition and concentration. The amount of N lost through leaching affects the available nitrogen. The addition of biochar reduced the quantity of nitrate leached in greenhouse studies (Widowati et al., 2014), with the lowest leaching of nitrate occurring at 45 t ha^{-1}, between 1 and 30 days after planting. Despite a rise in soil N and K levels due to biochar application, neither N nor K leaching has risen. Except for rice husk biochar, nitrogen and potassium leaching from biochar made from other sources was uniform between 30 and 60 DAP. Beesley et al. (2011) confirmed that biochar boosted nutrient retention in high-rainfall tropical regions, particularly N.

Maize growth and yield

Leaf area

At 4 and 8 weeks after planting, there was no significant change in leaf area between the biochar treatments. The results showed that applying 15 t biochar ha^{-1} resulted in a 39% increase in leaf area at 8 WAP (Table 3). Biochar improves the physicochemical properties of the soil and the availability of nutrients needed to support plant growth. Soil physicochemical qualities (Shahzad et al., 2019; Zhang et al., 2020), plant growth and yield (Agegnehu et al., 2017), and nutrient availability are all improved by biochar treatments. However, there was no significant change in leaf area with an increase in biochar amount from 30 to 45 t ha^{-1}. At 4 WAP, the amount of biochar did not influence the leaf area, while at 8 WAP, it did (Table 3).

Table 3. The effect of type and amounts of biochar on plant leaf area of maize at 4 and 8 WAP on clay loam soil.

Treatments	**Leaf area (cm^2)***	
	4 WAP	**8 WAP**
Biochar type		
Rice husk	167.69 a	4623.83 a
Coconut shell	156.64 a	4548.65 a
Wood	148.38 a	4329.02 a
LSD 5%	ns	ns
Doses of Biochar (t ha^{-1})		
0	126.47 a	3440.36 a
15	158.16 a	4798.43 b
30	169.88 a	4838.67 b
45	175.77 a	4924.56 b
LSD 5%	ns	393.40

Remarks: Means followed by the same letter in the same column did not significantly differ (LSD<0.05), ns = not significant * Widowati et al. (2017).

In contrast to the results of Rahayu et al. (2022), the type of biochar and the dose of biochar separately had no significant effect on the leaf area of maize plants at 7 WAP. Leaf area, which increases with biochar application, is essential for photosynthesis. The photosynthesis rate is higher with the application of biochar because there is an increase in the conductance of maize stomata (Qian et al., 2019). The rate of photosynthesis is determined by chlorophyll, which requires nutrients and water to form carbohydrates.

Absorption of nutrients and water by plant roots is essential for plant growth, including plant biomass production. Sufficient and balanced nutrient absorption determines plant biomass production (Evans, 2013; Reich, 2017). Plants need leaves and roots to capture light, water, and nutrients (Evans, 2013). Similar results showed that the biomass of maize was influenced by the absorption of water, nutrients, carbon dioxide, and sunlight (Overman et al., 2011). Interactions between materials and biochar dosage in plant biomass. The application of rice husk biochar at 45 t ha^{-1}, coconut shell biochar at a dose of 30 t ha^{-1}, and wood biochar at 15 t ha^{-1} produced relatively the same dry biomass of 7.80-8.30 t ha^{-1} (Figure 1). The treatment without biochar application produced the lowest dry biomass of 5.47 t ha^{-1}.

Plant biomass

This study demonstrated that the quantity and type of biochar used on crop biomass had a reciprocal effect (Figure 2). In contrast to the findings of Rahayu et al. (2022), this study showed no significant difference in the 7 WAP dry weight of hybrid maize based on the dose or type of biochar applied. The application of 45 trice husk biochar ha^{-1}, 30 t coconut shell biochar ha^{-1}, and 15 t wood biochar ha^{-1} resulted in dry biomass yields of 6.88 t ha^{-1}, 6.89 t ha^{-1}, and 7.16 t ha^{-1}, respectively, at 8WAP (Figure 1).

Dry biomass is an indication of the photosynthetic process that takes place in the plant body, which will further affect plant growth. Because the nutrients and water absorbed by plants are used for plant metabolism. Plant growth during the vegetative phase will absorb many nutrients that are translocated throughout the plant. The proper dosage and type of biochar are necessary to maximize plant growth and development because biochar can increase soil organic matter and microbial activity, which helps provide nutrients.

The smallest amount of dry biomass, about 5.47 t ha^{-1}, was produced when no biochar was applied. These numbers are related to the properties of the biochar (Table 2) and the amount of biochar that affected plant biomass. The biochars contain 0.71-0.95% nitrogen, 0.01-0.10% phosphorus, 0.14-0.715% potassium, 0.43-3.83% sodium, 1.2-2.16% calcium, and to magnesium 0.06-0.1% magnesium. Table 2 indicates that biochar contains elements to support plant growth. Plant growth and biomass of various plant species increased significantly with biochar amendments (Seleiman et al., 2019; Solaiman et al., 2020).

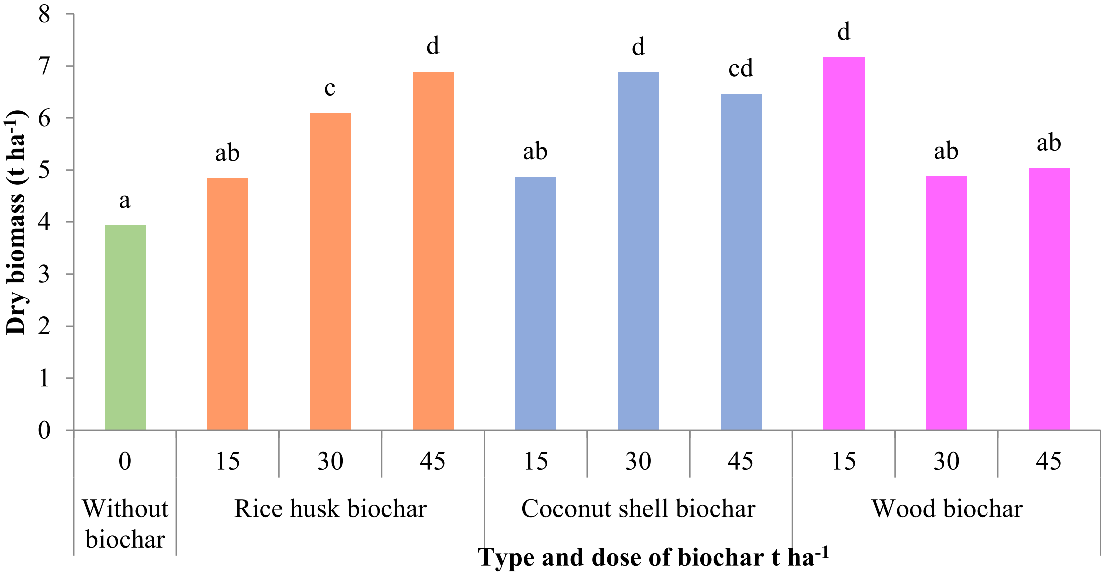

Figure 2. Effect of type and amount of biochar on dry biomass (Widowati et al., 2017).

Maize yield components

The application of biochar increased maize yield (Table 4). The types of biochar did not affect the maize yield component, but the amounts of biochar applied at 15, 30, and 45 t ha^{-1} increased maize yields. Biochar type and amount affected maize grains at harvest (Figure 3). The increase of available N, P, and K in the soils due to biochar application was likely responsible for this yield increase. The increasing amount of biochar applied caused a rise in the dry weight of maize of 14.67 t ha^{-1} or an average of 17.86% (Table 4). Maize yield significantly responded to the type and amount of biochar applied to the soil (Figure 3). Increasing the amount of biochar from 30 to 45 t ha^{-1} decreased maize yields by 4% for rice husk biochar and 9% for coconut shell biochar. The application of 45 t ha^{-1} of rice husk and coconut shell biochar yielded higher soil nutrient contents than other biochar doses. As shown in Table 2, the biochars used in this study contained 0.91% N, 1.75% P, and 1.18% K for rice husk, coconut shell, and wood biochars, respectively.

Table 4. The effect of type and amounts of biochar on maize yield components on clay loam soil.

Treatments	1000 grain weight (g)*	Ear length (cm)*	Ear diameter (mm)*	Weight without maize husk (t ha^{-1})*
Biochar type				
Rice husk	387.67 a	20.07 a	6.38 a	18.04 a
Coconut shell	393.25 a	19.82 a	6.30 a	17.88 a
Wood	385.00 a	19.84 a	6.35 a	17.67 a
LSD 5%	ns	ns	ns	ns
Doses biochar (t ha^{-1})				
0	358.67 a	18.70 a	6.05 a	14.67 a
15	401.33 b	20.34 b	6.43 b	18.83 b
30	391.44 b	20.38 b	6.46 b	19.06 b
45	403.11 b	20.21 b	6.43 b	18.89 b
LSD 5%	25.790	0.53	0.12	0.85

Remarks: Means followed by the same letter in the same column did not significantly differ ($p<0.05$), ns = not significant, *Widowati et al. (2017).

Widowati et al. (2014) found that maize plants absorbed more phosphorus (P) from rice husk biochar than young coconut shell biochar. The application of 5 and 15 t biochar ha^{-1} to acid soils resulted in a 37% and 71% decrease in soybean yields (Bedane et al., 2015). This was due to the lack of micronutrients and the high pH of the biochar. Agegnehu et al. (2016) observed that biochar can increase soil porosity and moisture capacity, leading to healthier root development in plants. Biochar, which is porous, can improve the porosity of the subsoil (Widowati et al., 2017). The soil structure in the subsoil is more compressed than the top, so biochar can reduce soil density. Furthermore, the soil is more aggregating, so the soil air system is better for plant roots. According to Blanco-Canqui (2017), water transport, nutrient retention, and aeration in the soil are all influenced by porosity. The ability of biochar to lessen soil compaction and bulk density while raising soil aggregation also helps to improve soil permeability (Blanco-Canqui, 2017). Basso et al. (2013) found an improvement in crop yields after adding biochar.

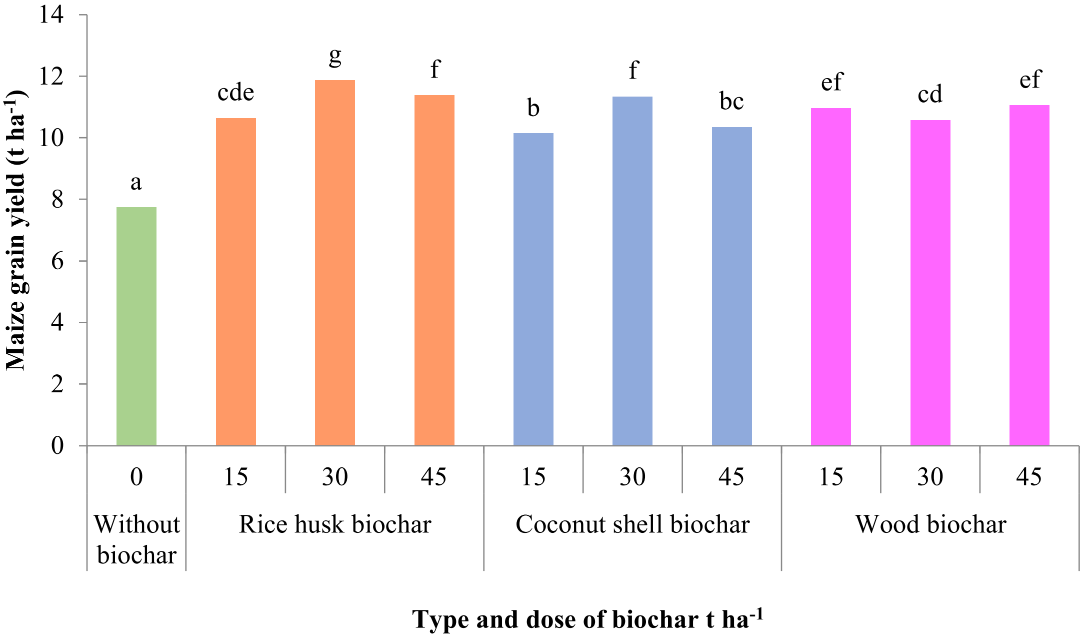

Figure 3. Effect of type and amount of biochar on maize grain yield (Widowati et al., 2017).

Crop output increased when acid soils in the tropics were treated with biochar and NPK fertilizers, according to studies conducted with rice (*Oryza sativa*) and sorghum (*Sorghum bicolor*) (Lehmann and Joseph, 2015). Similarly, radish (*Raphanus sativus*) yields increased linearly by adding biochar up to 50 t ha^{-1} with a basal N fertilizer (Biederman et al., 2013). The influence of biochar on crop yields is because it improves soil water holding capacity and cation exchange capacity, making it easier for plants to absorb nutrients and giving soil microbes a more favorable environment in which to multiply (Uzoma et al., 2011). The highest maize grain yield (11.88 t ha^{-1}) was obtained by the application of rice husk biochar at 30 t ha^{-1}, whereas the lowest maize grain yield added (7.77 t ha^{-1}) was observed on the treatments without biochar application. The varied doses of biochar application increased maize yield by 29% compared to control plots without biochar. Rafique et al. (2020) reported that biochar increased the fresh and dry weight of maize plants by 50-55%.

Conclusion

This study confirmed that biochars help prevent nitrate and potassium leaching from soils. They also improved the availability of potassium, phosphorus, and nitrogen for maize and possibly other crops. The application of biochar at 45 t ha^{-1} for all types of biochar tested yielded the highest increase in the availability of nitrogen, phosphorus, and potassium in the soil. The weight of the maize kernels harvested also increased, indicating a rise in grain yields. The application of 30 t rice husk biochar ha^{-1} resulted in the highest maize yield. The high alkalinity of rice husk, wood, and coconut shell biochar can be used to increase soil pH.

Acknowledgment

This research was made possible partly due to the support of the National Strategic Research grant from the Directorate General of Higher Education of the Ministry of Education, Culture, Research, and Technology of Indonesia.

References

Adekiya, A.O., Agbede, T.M., Olayanju, A., Ejue, W.S., Adekanye, T.A., Adenusi, T.T. and Ayeni, J.F. 2020. Effect of biochar on soil properties, soil loss, and cocoyam yield on a tropical sandy loam alfisol. *Science World Journal* Volume 2020 | Article ID 9391630 |, doi:10.1155/2020/9391630.

Agegnehu, G., Nelson, P.N. and Bird, M.I. 2016. Crop yield, plant nutrient uptake, and soil physicochemical properties under organic soil amendments and nitrogen fertilization on Nitisols. *Soil and Tillage Research* 160:1-13, doi:10.1016/j.still .2016.02.003.

Agegnehu, G., Srivastava, A.K. and Bird, M.I. 2017. The role of biochar and biochar-compost in improving soil quality and crop performance: A review. *Applied Soil Ecology* 119:156-170, doi:10.1016/j.apsoil.2017.06.008.

Ahmad, M., Rajapaksha, A.U., Lim, J.E., Zhang, M., Bolan, N. and Mohan, D. 2014. A review: Biochar as a sorbent for contaminant management in soil and water. *Chemosphere* 99:19-33, doi:10.1016/ j.chemosphere.2013.10.071.

Basso, A.S., Miguez, F.E., Laird, D.A., Horton, R. and Westgate, M. 2013. Assessing the potential of biochar for increasing the water-holding capacity of sandy soils. *Gcb Bioenergy* 5(2):132-143:doi:10.1111/Gcbb.12026.

Bedane, G.M., Saukuru, A.M., George, D.L. and Gupta, M.L. 2015. Evaluation of teff (Eragrostistef [Zucc.] Trotter) lines for agronomic traits in Australia. *Australian Journal of Crop Science* 9(3):242-253, doi:10.3316/informit.075411765097666.

Beesley, L., Moreno-Jiménez, E., Gomez-Eyles, J.L., Harris, E., Robinson, B. and Sizmur, T. 2011. A review of biochars' potential role in the remediation, revegetation, and restoration of contaminated soils. *Environmental Pollution* 159(12):3269-3282, doi:10.1016/ j.envpol.2011.07.023.

Biederman, L.A. and Harpole, W.S. 2013. Biochar and its effects on plant productivity and nutrient cycling: a meta-analysis. *GCB Bioenergy* 5(2):202-214, doi:10.1111/gcbb.12037.

Biswas, D., Emily, S.G., Shannon, R. and Stephen, P.L. 2018. The drivers and impacts of selling soil for brick making in Bangladesh. *Environmental Management* 62(4):792-802, doi:10.1007/s00267-018-1072-z.

Blanco-Canqui, H. 2017. Biochar and soil physical properties. *Soil Science Society of American Journal* 81:687-711, doi:10.2136/sssaj2017.01.0017.

Brunel, N., Meza, F., Ros, R. and Santibáñez, F. 2011. Effects of topsoil loss on wheat productivity in dryland zones of Chile. *Journal of Soil Science and Plant Nutrition* 11(4):129-137, doi:10.4067/ S071895162011000400010.

DeLuca, T.H., Gundale, M.J., MacKenzie, M.D. and Jones, D.L. 2015. Biochar effects on soil nutrient transformations. *Biochar for Environmental Management Science Technology Implement* 2:421-454.

Evans, J.R. 2013. Improving Photosynthesis. *Plant Physiology* 162:1780-1793, doi:10.1104/pp.113.219006.

Gao, S. and DeLuca, T.H. 2016. Influence of biochar on soil nutrient transformations, nutrient leaching, and crop yield. *Advances in Plants and Agriculture Research* 4:348-362.

Hale, L., Curtis, D., Azeem, M., Montgomery, J., Crowley, D.E. and McGiffen, Jr., M.E. 2021. Influence of compost and biochar on soil biological properties under turfgrass supplied deficit irrigation. *Applied Soil Ecology* 168:104134, doi:10.1016/j.apsoil.2021.104134.

Jaiswal, A.K., Frenkel, O., Elad, Y., Lew, B. and Graber, E.R. 2015. Non-monotonic influence of biochar dose on bean seedling growth and susceptibility to *Rhizoctonia solani*: the shifted max-effect. *Plant and Soil* 395(1-2):125-140, doi:10.1007/s11104-014-23312.

Jindo, K., Giovanni, M., Yuki, A, Fábio, S.H., Carlos, A.S., Kinya, A., Miguel, A.S.M. and Claudio, M. 2020. Role of biochar in promoting circular economy in the agriculture sector. Part 1: A review of the biochar roles in soil N, P, and K cycles. *Chemical and Biological in Technologies in Agricultural* 7(15):2-12, doi:10.1186/s40538-020-00182-8.

Joseph, S., Graber, E.R., Chia, C., Munroe, P., Donne, S., Thomas, T., Nielsen, S., Marjo, C., Rutlidge, H., Pan, G.X., Li, L., Taylor, P., Rawal, A. and Hook, J. 2013. Shifting paradigms: development of high-efficiency biochar fertilizers based on nano-structures and soluble components. *Carbon Management* 4(3):323-343, doi:10.4155/cmt.13.23.

Kathuria, V. and Balasubramanian, R. 2013. The environmental cost of using topsoil for brick-making: a case study from Tamil Nadu, India. *Review of Market Integration* 5(2):171-201, doi:10.1177/0974929214521892.

Khalili, F., Aghayari, F. and Ardakani, M.R. 2020. Effect of alternate furrow irrigation on maize productivity in interaction with different irrigation regimes and biochar amendment. *Communication in Soil Science Plant Analysis* 51:757-768, doi:10.1080/00103624.2020.1733001.

Khan Z., Nauman, K.M., Luo T., Zhang K., Zhu K. and Rana, M.S. 2021. Compensation for high nitrogen toxicity and nitrogen deficiency with biochar amendment through enhancement of soil fertility and nitrogen use efficiency promoted rice growth and yield. *GCB Bioenergy* 13:1765-1784, doi:10.1111/gcbb.12884.

Kumar, S.K, Satheesh, C.J., Santhoshi, B.C., Karishma, K.. and Kumar, V.G. 2015. Role of Soil Brick Industry in the Degradation of Land and Environment-A Case Study of Mallaram in Nizamabad, Telangana State. *International Journal of Civil and Structural Engineering Research* 3(1):222-227.

Lal R. 2013. Food security in a changing climate. *Ecohydrology & Hydrobiology* 13(1):8-21, doi:10.1016/j.ecohyd.2013.03.006.

Lehmann, J. and Joseph, S. 2015. *Biochar for Environmental Management: Science, Technology, and Implementation*. Routledge, London, 976 pages, eBook ISBN 9780203762264, doi:10.4324/9780203762264.

Lehmann, J., Rillig, M.C., Thies, J., Masiello, C.A., Hockaday, W.C. and Crowley, D. 2011. Biochar effects on soil biota–a review. *Soil Biology and Biochemistry* 43(9):1812-1836, doi:10.1016/j.soilbio.2011.04.022.

Obia, A., Cornelissen, G., Martinsen, V., Smebye, A.B. and Mulder, J. 2020. Conservation tillage and biochar improve soil water content and moderate soil temperature in tropical acrisol. *Soil and Tillage Research* 197:104521, doi:10.1016/j.still.2019.104521.

Oni, B.A., Oziegbe, O. and Olawole, O.O. 2019. Significance of biochar application to the environment and economy. *Annals of Agricultural Sciences* 64(2):222-236, doi.10.1016/j.aoas.2019.12.006.

Ouyang L., Tang Q., Yu L. and Zhang R. 2014. Effects of amendment of different biochars on soil enzyme activities related to carbon mineralization. *Soil Research* 52:706-716, doi:10.1071/SR14075.

Overman, A.R. and Scholtz III, R.V. 2011. Accumulation of biomass and mineral elements with calendar time by corn: Application of the expanded growth model. *PloS One* 6(12):28515, doi:10.1371/journal.pone.0028515.

Parera, Z. 2021. Soil exploitation and environmental impacts of brick making in Wasur 2 Merauke Regency. *Law Journal Volkgeist* 6(1):6-14, doi:10.35326/volkgeist.v6i1.1537.

Qian, Z.H.U., Kong, L., Shan, Y., Yao, X., Zhang, H., Xie, F. and Xue, A.O. 2019. Effect of biochar on grain yield and leaf photosynthetic physiology of soybean cultivars with different phosphorus efficiencies. *Journal of. Integrated Agriculture* 18:2242-2254, doi:10.1016/S2095-3119(19)62563-3.

Rafique, M., Ortas, I., Rizwan, M., Chaudhary, H.J., Gurmani, A.R. and Munis, H.F.H. 2020. Residual effects of biochar and phosphorus on growth and nutrient accumulation by maize (*Zea mays* L.) amended with microbes in texturally different soils. *Chemosphere* 238:124710, doi:10.1016/j.chemosphere.2019.124710.

Rahayu, M., Nurmalasari, A.I. and Aini, N.N. 2022. Effect of various types and doses of biochar on hybrid maize growth. *IOP Conference Series: Earth and Environmental Science* 1016:012053, doi:10.1088/1755-1315/1016/1/012053.

Reich, M. 2017. The significance of nutrient interactions for crop yield and nutrient use efficiency. *Plant Macronutrient Use Efficiency: Molecular, and Genomic Perspectives in Crop Plants* 65-82, doi:10.1016/B978-0-12-811308-0.00004-1.

Satriawan, B.D. and Handayanto, E. 2015. Effects of biochar and crop residue application on chemical properties of a degraded soil of South Malang, and P uptake by maize. *Journal of Degraded and Mining Lands Management* 2(2):271-280, doi:10.15243/jdmlm.2014.022.271.

Seleiman, M.F., Refay, Y., Al-Suhaibani, N., Al-Ashkar, I., El-Hendawy, S. and Hafez, E.M. 2019. Integrative effects of rice-straw biochar and silicon on oil and seed quality, yield and physiological traits of *Helianthus annuus* L. grown under water deficit stress. *Agronomy* 9:637, doi:10.3390/agronomy9100637.

Shahzad, K., Abid, M., Sintim, H.Y., Hussain, S. and Nasim, W. 2019. Tillage and biochar effects on wheat productivity under arid conditions. *Crop Science* 59:1191-1199, doi:10.2135/cropsci2018.08.0485.

Singh, P., Devi, R., Hooda, R. S., & Grewal, M. S. (2014). Soil desurfacing: A potential threat to soil health, productivity and fertility. Research on Crops, 15(3), 722–729. https://doi.org/10.5958/2348-7542.2014.01403.X

Skinder, B. M., Sheikh, A. Q., Pandit, A. K., & Ganai, B. A. (2014). Brick kiln emissions and its environmental impact: A review. Journal of Ecology and the Natural Environment., 6(1), 1–11. https://doi.org/10.5897/JENE2013.0423

Solaiman, Z.M., Shafi, M.I., Beamont, E. and Anawar, H.M. 2020. Poultry litter biochar increases mycorrhizal colonization, soil fertility, and cucumber yield in a fertigation system on sandy soil. *Agriculture* 10:480, doi:10.3390/agriculture10100480.

Srinivasarao, C.S., Rakesh, G., Ranjith, Kumar, R. Manasa, G. Somashekar, C., Subha, L. and Sumanta, K. 2021. Soil degradation challenges for sustainable agriculture in tropical India. *Current Science* 120(3):492-500.

Tian, X., Li, Z., Liu, Z., Wang, Y., Li, B., Zhang, K., Qiwen, X. and Wang, L. 2021. The combined effect of biochar and nitrogen fertilizer reduction on rapeseed productivity and nitrogen use efficiency. *Archive of Agronomy and Soil Science* 7:1-16, doi:10.1080/03650340.2021.1872782.

Uzoma, K.C., Inoue, M., Andry, H., Fujimaki, H., Zahoor, A. and Nishihara, E. 2011. Effect of cow manure biochar on maize productivity under sandy soil condition. *Soil Use and Management* 27(2):205-212, doi:10.1111/j.1475-2743.2011.00340.x.

Varma, A.K., Shankar, R. and Mondal, P. 2018. A review on pyrolysis of biomass and the impacts of operating conditions on product yield, quality, and upgradation. In: Sarangi, P.K., Sonil, N. and Pravakar, M. (eds.), *Recent Advancements in Biofuels and Bioenergy Utilization*. Springer pp. 227-259, doi:10.1007/978-981-13-1307-3.10.

Widowati, Sutoyo, and Hidayati, K. 2017. *Remedy of Degraded Soil with Biochar in Corn Crops*. IRDH (Research & Publishing) 89p ISBN 978-602-60770-6-6 (*in Indonesian*).

Widowati, Utomo, W.H. and Asnah. 2014. The use of biochar to reduce nitrogen and potassium leaching from soil cultivated with maize. *Journal of Degraded and*

Mining Land Management 2(1):211-218, doi:10.15243/jdmlm.2014.021.211.

Zhang, A., Liu, Y., Pan, G., Hussain, Q., Lianging, L., Zheng, J. and Xhang, X. 2012. Effect of biochar amendment on maize yield and greenhouse gas emissions from a soil organic carbon poor calcareous loamy soil from Central China plain. *Plant and Soil* 351:263-275, doi:10.1007/s11104-011-0957-x.

Zhang, C., Li, X., Yan, H., Ullah, I., Zuo, Z., Li, L. and Yu. J. 2020. Effects of irrigation quantity and biochar on soil physical properties, growth characteristics, yield, and quality of greenhouse tomato. *Agricultural Water Management* 241:106263, doi:10.1016/j.agwat.2020.106263.

Zhang, Y., Yiming, J., Chengrong, C., Yangzhou, X., Mehran, R.R., Yantao, L., Qi, D. and Renduo, Z. 2021. Effects of biochar application on soil nitrogen transformation, microbial functional genes, enzyme activity, and plant nitrogen uptake: A meta-analysis of field studies. *GCB Bioenergy* 13:1859-1873, doi:10.1111/gcbb.12898.

Zwieten, L.V., Singh, B.P. and Cox, J. 2012. Chapter Four: biochar effects on soil properties. Biochar in horticulture: prospects for the use of biochar in Australian horticulture. Horticulture Australia, NSW Department of Primary Industries.