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Research Article

Changes in chemical properties of three soil types after application of biochars and organic fertilizers for two years

Frengky Umbu Kolambani, Widowati*

Department of Agrotechnology, Faculty of Agriculture, Tribhuwana Tunggadewi University, Jl. Telaga Warna, Tlogomas, 65144 Malang, Indonesia

*corresponding author: widwidowati@gmail.com

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Abstract

This study assessed organic matter, N, P, and K contents in three soil types after the application of biochars and organic fertilizers for two years. The experiment was arranged in a nested design with two factors. Three types of biochar and two types of organic fertilizer were used singly or in combination on three soil types. Among the treatments, the application of tobacco processing waste biochar on Inceptisol and rice husk biochar plus manure on Entisol resulted in the highest soil organic matter and total nitrogen contents. The highest phosphorus content was observed from rice husk biochar treatment on Inceptisol and from rice husk biochar+manure treatment on Entisol and Litosol. The highest K content in Inceptisol and Litosol occurred with each biochar treated rice husk biochar+manure treatment. The highest K content in Inceptisol and Litosol was observed in each tobacco waste biochar+compost treatment and in compost treatment only, respectively.

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Introduction

The high content of organic matter in soils is the key to the success of sustainable agriculture. It is known that soil organic matter contains nutrients needed for plant growth. Benefits of soil organic matter include improvement of soil quality through increased retention of water and nutrients (Ontl and Schulte, 2012), as well as reducing environmental pollution to maintain soil quality and plant production (Fageria, 2012). However, soil organic matter content rapidly decreases in humid tropics due to the rapid decomposition process. Therefore, the addition of organic matter, such as manure, compost, crop residues, sewage sludge, and municipal solid waste (Rehman et al., 2017), is necessary to maintain and improve the soil quality of dry land with low soil fertility. Yet, adding organic matter routinely in every growing season is not easy because large quantities of organic matter input require high labour, transport, and application costs. In addition, organic matter often contains hazardous components and weed seeds (Assefa and Tadesse, 2019). One of the efforts to overcome the problems above is the application of biochar into the soil.

Biochar is formed when biomass is thermally converted to charcoal in oxygen-limited circumstances, which yields a high-carbon composition and excellent absorbency (Medyńska-Juraszek, 2016). Wang et al. (2015) found that biochar can persist in soils for 100 years and that it can promote the dynamics of soil organic matter. The stability and the possibility of long-term carbon sequestration of biochar in soil are due to the presence of stable aromatic organic carbon compounds (Kuzyakov et al., 2014; Sandhu et al., 2017). The decomposition rate of biochar in soils depends on raw materials, pyrolysis temperatures, duration, soil clay content (Wang et al., 2015), and groundwater status in the soil (Ghezzehei et al., 2019). The characteristics of biochar depend on the thermochemical conversion conditions and its raw materials (Tomczyk et al., 2020). The temperature for the production process duration determines the carbon content, pH, and cation change capability (Zhao et al., 2017; Tomczyk et al., 2020).

Several research results indicate that water holding capacity and soil moisture depend significantly on each type of biochar and applied dosage as well as characteristics of soil (Duong et al., 2017). In soils with low organic matter content, adding biochar mixed with compost and manure can improve the soil ability to hold water (Seyedsadr et al., 2022). It is known that soil water retention is influenced by the distribution and connectivity of pores within the soil, which is governed by the size of soil particles, structural traits (aggregation) and soil organic matter content (Malik and Lu, 2015). Improvement of soil physical properties after the addition of biochar depends on the characteristics of the biochar (Agegnehu et al., 2016; Widowati et al., 2020).

In addition to improving the physical properties of the soil, the addition of biochar also increases the chemical reactivity of the inorganic and organic compounds in the soil, which makes beneficial surroundings for improving degraded soil (Cross and Sohi, 2011; Macdonald et al., 2013). The increase in the activity of organo-mineral complexes in the soil due to the addition of biochar occurs due to the reaction of minerals and organic compounds in the soil (Zhang et al., 2015) and changes in soil pH (Yuan et al., 2011). Because biochar is continual within the soil and persistent (Lehmann et al., 2015), it has an excessive affinity for nutrients (Hossain et al., 2020), and it might reduce residues for the following planting seasons (Widowati and Asnah, 2014). The heterogeneous nature of biochar in numerous forms influences soil organic and nutrient availability (Streubel et al., 2011; Hossain et al., 2020).

The effect of biochar on soil properties also depends on the type of soil. Wang et al. (2015) reported that the addition of biochar to sandy soil strongly enhanced the mineralization of soil organic matter by 20.8%. After biochar application, the increase of soil carbon became higher in fine to medium textured soils than in coarse soils (Gross et al., 2021).

As described above, the effect of biochar on the physical and chemical properties of the soil is determined by the types of biochar and soil properties. This study reports the effect of adding three types of biochar on changes in soil organic matter, N, P, and K contents after three types of soil for two years. Wastes of raw organic materials that are difficult to decompose, such as corn cob or rice husk, are abundant in Indonesia (Sarwani et al., 2013). These agricultural residues are about 3.1 million tons per year (Nurida et al., 2015), including 1.77 million tons per year of rice husk, with a biomass potential of 6.8 million tons per year. Another organic waste that can be converted into biochar is cigarette manufacturing processes in Kediri, Indonesia produces more than 20 tons of organic industrial waste per year.

Materials and Methods

Materials

A pot experiment in a glasshouse was conducted in 2017. The materials used in this study were three types of biochar (corn cob biochar, rice husk biochar, and tobacco processing waste biochar) and two types of organic fertilizer (chicken manure and municipal waste compost). The above materials were applied to a 10 kg pot containing soil. Biochars generated from rice husk and corn cob were produced by pyrolysis for four hours at 350-500 ºC at the Bioenergy Laboratory, Tribhuwana Tunggadewi University Malang.

Tobacco processing waste was obtained from PT. Gudang Garam Tbk, Kediri, Indonesia. The tobacco processing waste biochar was produced by pyrolysis for 15 minutes at 700 ºC. Before application to soil, corn cob biochar was ground to a size of <2 mm, while rice husk and tobacco processing waste biochar were used applied because of their small size. Chicken manure was obtained from PT. Charoen Pokhpand farm in Malang, and municipal waste compost was obtained from Waste Management in Dau Malang.

The three types of soil used in this study were taken from dry land in Malang, namely an Inceptisol from Kalipare District, a Litosol from Donomulyo District, and an Inceptisoll from Poncokusumo Subdistrict. The Entisol from Kalipare has the following characteristics: organic C = 0.49%, N = 0.07%, P =10.53 mg kg^{-1}, K = 0.36 me 100 g^{-1}, and loamy sand texture (86% sand, 3% silt, 11% clay). The Litosol from Donomulyo has the following characteristics: organic C = 0.77%, N = 0.17%, P = 45.66 mg kg^{-1}, K = 0.36 me 00 g^{-1}, and clay texture (11% sand, 24% silt, 65% clay). The Inceptisol from Poncokusumo has the following characteristics: organic C = 1.37%, N = 0.11%, P = 45.66 mg kg^{-1}, K = 0.35 me 100 g^{-1}, and clay texture (9% sand, 15% silt, 76% clay). 10 kg of oven-dried soil that passed through a 2 mm sieve was placed into a plastic pot and then added with biochar and organic fertilizer according to the treatment.

Treatments

Biochars and organic fertilizers were applied separately, each type of material at a dose of 300 g pot^{-1}. According to treatment, the dose for a mixture of biochar and organic fertilizer was 150 g pot^{-1}. The experiment used a nested design and was repeated three times. The level of one factor was nested in another factor. The first factor was the types of soil (Entisol from Kalipare, Litosol from Donomulyo, and Inceptisol from Poncokusumo) nested in the second factor, namely the types of biochar and organic fertilizer. The second factor consisted of 12 treatments as follows: 1. Control (C), 2. Corn cob biochar (BC), 3. Rice husk biochar (BR), 4. Tobacco processing waste biochar (BJ), 5. Municipal waste compost (Ct) , 6. Chicken manure (M), 7. Corn cob biochar+municipal waste compost (BC+Ct), 8. Corn cob biochar+chicken manure (BC+M), 9. Rice husk biochar+municipal waste compost (BR+Ct), 10. Rice husk biochar+chicken manure (BR+M), 11. Tobacco processing waste biochar+compost (BJ+Ct), and 12. Tobacco processing waste biochar + chicken manure (BJ+M). The application of biochars and organic fertilizers was carried out on 7 May 2017. Corn was planted twice in a row, and the pots were left after the second harvest on 21 January 2018.

Soil sampling was carried out on 23 April 2019 from three composite pots to measure organic C, N, P, and K contents. Organic C content was determined by the Walkley and Black method (Walkley and Black, 1934). The total N content was determined by the Kjeldahl method (Bremner, 1965). Available P content was determined using the Bray method (Bray dan Kurtz, 1945) for Kalipare Entisol and the Olsen method (Olsen et al., 1954) for Poncokusumo Inceptisol and Donomulyo Entisol. The K content was determined with 1N NH_4OAC at pH 7 (Page et al., 1982).

Statistical analysis

Data obtained were subjected to analysis of variance (ANOVA) followed by a Duncan Multiple Hypothesis Test at α= 5%. All statistical analyses were carried out using the SPSS software version 13.0.

Results and Discussion

Soil organic matter content

The organic matter content of the soils used in this study was strongly influenced by the application of biochars and organic fertilizers. After two years of application, the combination of biochars and organic fertilizer did not affect the organic matter content of the Donomulyo Litosol. There was a difference in soil organic matter content between soil with and without biochars and organic fertilizers. It is important to note that the three soil types used in this study had different clay and organic C contents. Before the study, the clay and organic C contents were 76% and 1.36%, respectively, in Poncokusumo Inceptisol, 65% and 0.76%, respectively in Donomulto Litosol, and 11% and 0.48%, respectively, in Kalipare Entisol. It has been known that soil aggregation is affected by soil organic matter content. Widowati et al. (2020) found that the type of soil amendments determines the composition of sand, silt, and clay fractions in the soil, which determines the soil physical properties. Nath (2014) reported that organic matter and clay contents were significantly correlated with water holding capacity, while sand content was negatively correlated. Furthermore, Nath (2014) stated that organic matter and soil texture significantly affect soil water holding capacity. The organic matter content in Kalipare Entisol ranged from 1.63 to 3.13%, while organic matter content in Donomulyo Litosol ranged from 1.54 to 2.31%. Organic matter content in Poncokusomo Inceptisol fluctuated from 1.03 to 5.01%.

Table 1. Effect of biochars and organic fertilizers on soil organic matter content in Kalipare Entisol, Donomulyo Litosol and Poncokusuma Inceptisol.

Treatments	**Soil Organic Matter (%)**		
	Entisol from Kalipare	**Litosol from Donomulyo**	**Inceptisol from Poncokusumo**
Control (Cl)	1.63 a	1.54 ns	1.03 a
Corn cob biochar (BC)	2.47 cdef	1.90 ns	4.19 e
Rice husk biochar (BR)	2.41 cde	2.12 ns	3.77 e
Tobacco processing waste biochar (BJ)	2.84 fg	1.70 ns	5.01 f
Municipal waste compost (Ct)	1.99 ab	2.05 ns	2.16 bc
Chicken manure (M)	2.37 bcde	2.08 ns	2.85 d
Corn cob biochar+municipal waste compost (BC+Ct)	2.69 def	1.97 ns	2.90 d
Corn cob biochar+chicken manure (BC+M)	2.31 bcd	2.18 ns	3.81 e
Rice husk biohar+municipal waste compost (BR+Ct)	2.14 bc	2.01 ns	2.10 bc
Rice husk biohar+chicken manure (BR+M)	3.13 g	2.02 ns	2.59 cd
Tobacco waste biochar+municipal waste compost (BJ+Ct)	2.44 cdef	1.99 ns	1.97 b
Tobacco waste biochar+chicken manure (BJ+M)	2.75 ef	2.31 ns	2.36 bcd

Note: Numbers followed by the same letters in the same column are not significantly different based on the Duncan Multiple Hypothesis Test at = 5%, ns = not significant.

Pandian et al. (2016) reported that the application of biochar to acidic red soil favoured good soil physical, chemical and biological environment. In Kalipare Entisol, the lowest organic matter content (1.63%) was observed in the control treatment, which was not different from the treatment with compost (Table 1). This proves that the compost decomposed completely after two years so that the amount of organic matter was the same as the control. Soil with corn cob biochar treatment had an organic matter content of 2.47%, whereas when combined with compost application, the soil had an organic matter content of 2.69%. A synergy of corn cob biochar with compost effectively increased soil organic matter content by 9% after two years, while soil with chicken manure had a low organic matter content decreasing from 2.47% to 2.31%. The addition of compost and chicken manure could not maintain the organic matter content of the soils after two years. The soil that was given rice husk biochar combined with compost had a soil organic matter of 2.41%, higher than the soil that was only applied with rice husk biochar (2.14%).

The application of chicken manure could increase the organic matter content of the soil by 3.13%. Compared to compost, manure and rice husk biochar have higher organic C contents (25.02% for compost and 29.80% for rice husk biochar) (Widowati et al., 2017). The application of tobacco waste biochar and manure increased the organic matter content of the soil to 2.84%, while the application of biochars or biochars+organic fertilizers did not affect the organic matter content of the Donomulyo Litosol. In Poncokusumo Inceptisol, the organic matter content in the control treatment was the lowest (1.03%). Puncokusumo Inceptisol had the lowest soil organic matter content (Table 1). The application of the three types of biochar without organic fertilizer to the three soil types studied resulted in higher organic matter content of the soils than those applied with biochars+organic fertilizers. According to Sadowska et al. (2020), biochar, in doses of 15 and 45 t ha^{-1}, increased the NH_4-N concentration in the soil in the second and third year of the study.

Biochar is relatively inert, remaining in the soil for a long time and improving soil health and yields for a longer period when applied to the soil rather than other organic amendments (Filiberto and Gaunt, 2013). After two years of biochar application in this study, tobacco waste biochar treatments yielded the highest organic matter content of 5.01%, followed by corn cob biochar and biochar rice husk treatments, respectively 4.19% and 3.76%, in the soils studied. This is related to the total C of the tobacco waste biochar, corn cob biochar, and rice husk biochar, i.e.45.6%; 40,0%; and 29.8%, respectively (Widowati et al., 2017). Gross et al. (2021) reported that more soil organic carbon accumulated in pots, in the field, and over 6-10 years in the field during the long duration of the experiment.

Pyrolysis increases aromatization and the stability of biochar (Zhang et al., 2022) so that soil organic carbon is more durable in two years in this study. This condition will be advantageous in providing nutrients for plants because the loss of nutrients will be lower. The application of tobacco waste biochar and organic fertilizers, both compost and manure, produced lower soil organic matter content, namely 1.97% and 2.36%, than that applied with tobacco waste biochar alone.

Soil that received corn cob biochar and chicken manure had the same organic matter content as the soil that received corn cob biochar alone, which was 3.81%. In contrast, the soil that was treated with corn cob biochar and compost had a low organic matter content of 2.90%. The application of rice husk biochar also resulted in higher organic matter content than that of soil that was applied with rice husk biochar and organic fertilizers (compost and chicken manure). According to Jílková and Gerrit (2022), microbial activity and nutrient release in soils increased with the addition of biochar and compost, but the effect of biochar was relatively long (>6 months), and the effect of compost was relatively short-term (<2 months). Ding et al. (2016) reported that biochar has a huge surface area, well-developed pore structure, amounts of exchangeable cations and nutrient elements, and plenty of liming. Because of these properties, soil properties could be improved after biochar treatment (Ding et al., 2016). Akça and Namli (2015) reported that soil organic matter content increased significantly after adding biochar than control and chemical fertilizers. The activity of alkaline phosphatase, β-glucosidase, urease and arylsulphatase enzymes in the soil increased significantly with the application of biochar, which accelerated the decomposition of organic matter. Soil enzyme activity is related to the physiochemical characteristics of the soil (Kussainova et al., 2013).

Total N content

Significant changes in total N content were seen in Kalipare Entisol and Poncokusumo Inceptisol after two years of application of biochars and organic fertilizers. The application of biochars and organic fertilizers did not affect the total N content of the Donomulyo Litosol. Kalipare Entisol had a total N content of 0.12-0.22%. Donomulto Entisol had a total N content ranging from 0.13 to 0.17%, while Poncokusumo Inceptisol had a total N content ranging from 0.07 to 0.30%. However, the control on Kalipare Entisol had the lowest total N content of 0.11%. Soil treated with corn cob biochar, rice husk biochar, and tobacco waste biochar had higher total N content than the control of 0.17%, 0.16%, and 0.17%, respectively (Table 2). The N content of tobacco waste biochar (1.83%) was higher than that of corn cob biochar (0.84%) and rice husk biochar (0.57%). The results of this study are in line with the results of Mensah and Kwame (2018) that biochar and compost applied alone or in combination significantly increased soil pH, total organic carbon, available phosphorus, mineral nitrogen, reduced exchangeable acidity, and increased effective cation exchange capacity in both soils. However, biochar added with organic fertilizers (compost from municipal waste and chicken manure) showed higher total N content than those without organic fertilizers. The addition of rice husk biochar and chicken manure resulted in the highest increase in N (0.22%). It can be concluded that the use of biochars together with organic fertilizers contributed to a greater increase in total soil N in Kalipare Entisol than the use of biochar alone. Organic matter in fertilizers will contribute nutrients, especially nitrogen after it is decomposed and mineralized. Tripura et al. (2021) found that adding biochar to soil increased cation exchange capacity and nutrient availability. Nutrient retention and availability increased after adding biochar to the soil due to increased soil surface area, exchange capacity, and direct nutrient release.

In Poncokusumo Inceptisol, the control treatment had the lowest total N content of 0.08%. The application of corn cob, rice husk, and tobacco waste biochars alone or organic fertilizers alone increased the total N four times compared to the control. However, when biochar was added with organic fertilizers, the total N content was lower than the application of biochar alone. The application of corn cob biochar and compost yielded a total N of 0.29%, while the addition of compost or manure produced a total N of 0.23% and 0.21%, respectively (almost three times that of the control). Application of rice husk biochar contributed 0.28% of total N, while the application of compost and manure contributed 0.24% and 0.19%, respectively. When combined with compost and manure, tobacco waste biochar yielded 0.30% total N content when combined with compost (Table 2). Based on the results of this study, the application of biochar alone was better than the application of biochar with organic fertilizers to increase the total N content of Poncokusumo Inceptisol. Only when biochar was applied to the soil did the N content of Poncokusumo Inceptisol increase according to the increase in organic matter. Pocokusumo Inceptisol applied with rice husk biochar+chicken manure had the highest total N content after two years, while that was applied with tobacco waste biochar alone had the highest total nitrogen content after two years. Kalipare Entisol has a coarse texture, and Poncokusumo Inceptisol has a fine texture.

Table 2. Effect of biochar and organic fertilizers on N content in Kalipare Entisol, Donomulyo Litosol and Poncokusuma Inceptisol after two years.

Treatments	**N total (%)**		
	Entisol from Kalipare	**Litosol from Donomulyo**	**Inceptisol from Poncokusumo**
Control (Cl)	0.12 a	0.13^{ns}	0.08 a
Corn cob biochar (BC)	0.17 bcde	0.13^{ns}	0.29 de
Rice husk biochar (BR)	0.16 abc	0.15^{ns}	0.28 cde
Tobacco processing waste biochar (BJ)	0.17 bcd	0.14^{ns}	0.30 e
Municipal waste compost (Ct)	0.13 ab	0.17^{ns}	0.29 de
Chicken manure (M)	0.17 bcd	0.17^{ns}	0.25 bcde
Corn cob biochar+municipal waste compost (BC+Ct)	0.20 def	0.14^{ns}	0.23 bcde
Corn cob biochar+chicken manure (BC+M)	0.20 def	0.15^{ns}	0.21 bc
Rice husk biohar+municipal waste compost (BR+Ct)	0.21 ef	0.14^{ns}	0.24 bcde
Rice husk biohar+chicken manure (BR+M)	0.22 f	0.14^{ns}	0.19 b
Tobacco waste biochar+municipal waste compost (BJ+Ct)	0.19 cdef	0.16^{ns}	0.22 bcd
Tobacco waste biochar+chicken manure (BJ+M)	0.19 cdef	0.16^{ns}	0.20 b

Note: Numbers followed by the same letters in the same column are not significantly different based on the Duncan Multiple Hypothesis Test at = 5%, ns = not significant.

The N content in the soils studied was influenced by the interaction between biochar types and soil types. Compared to application with biochar only, the addition of manure to coarse-textured soils increased the N content of the soil. In Kalipare Entisol, the synergistic use of rice husk biochar and manure increased the total N content. In a two-year field trial, Sharma et al. (2021) found that combining organic fertilizers with biochar could improve soil functions (infiltration rate, aggregate stability, maximum water holding capacity and hydraulic conductivity). Biochar application can improve soil moisture and pH to increase N mineralization, thereby increasing the efficiency of nitrogen fertilizers (Widowati et al., 2011; Nguyen et al., 2017). By increasing the efficiency of nitrogen fertilizers, yields increase with biochar application (Widowati et al., 2012).

Available P content

Phosphorus (P) is essential for plants, and its availability is governed by pH. Widowati et al. (2020) reported changes in the pH of Kalipare Entisol and Poncokusumo Inceptisol to 6.5 and 7.0, respectively, after being given biochar and/or organic fertilizers for

56 days. Research on Ultisols with the addition of vermicompost, chicken manure, and cow manure resulted in a slow increase in P in the first three weeks, then continued to increase dramatically in the fourth week after incubation (Muktamar et al., 2020). Considering that biochar can serve as short, medium and long-term P fertilizer, Glaser and Lehr (2019) reported that biochar increased phosphorus availability for at least five years when added to agricultural soils. According to Asomaning (2020), pH, soil organic matter, time, iron oxides, and soil aluminium affect P absorption. Soil pH range of 4-8 affects phosphate adsorption. Organic matter can affect P adsorption by inhibiting iron oxide crystallization (indirectly) and competing for adsorption sites (directly) (Asomaning, 2020).

The P contents of Kalipare Entisol, Donomulyo Litosol, and Poncokusumo Inceptisol were 30.96-71.78 mg kg^{-1}, 14.31-43.94 mg kg^{-1}, and 25.35-58.82 mg kg^{-1}, respectively. Donomulyo Litosol had lower available P content (14.31 mg kg^{-1}) than Kalipare Entisol and Pncokusumo Inceptisol in control. Application of corn cob and rice husk biochars did not affect P availability in Kalipare Entisol compared to control. Applications of tobacco waste biochar resulted in the highest soil available P content of 63.73 mg kg^{-1}. This is thought to be related to the higher P content in tobacco waste biochar (0.47 mg kg^{-1}) than that in corn cob biochar (0.45 mg kg^{-1}) and rice husk biochar (0.15 mg kg^{-1}). The application of compost and manure without biochars increased available P content higher than the control, namely 59.85 mg kg^{-1} and 64.29 mg kg^{-1}. The application of corn cob biochar+compost and the application of corn cob biochar+manure on Kalipare Entisol resulted in similar available P contents to that of tobacco waste biochar+compost and tobacco waste biochar+manure treatments by 55.57 mg P kg^{-1} and 43.48 mg P kg, respectively (Table 3). However, the application of rice husk biochar + compost and rice husk biochar+manure resulted in low available P content. According to Akande et al. (2010), the decomposition of organic matter produces organic acids that will cover the clay surface, which reduces the adsorption of P. The application of poultry manure compost or organic fertilizer increases the available phosphorus (P) and organic matter content in all soils; however, the quantity of P and organic matter decreased with an increase in incubation time (Yu et al., 2013). Salawati et al. (2016) reported that the application of rice husk biochar decreased the surface area of P adsorption, thereby increasing the availability of P. In Donomulyo Litosol, the P content in control was 14.31 mg kg^{-1}. After two years, the application of corn cob biochar or rice husk biochar did not increase the P content of the soil, but the application of tobacco waste biochar doubled the P content of the soil. The application of compost and manure also did not increase P content.

Table 3. Effect of biochar and organic fertilizers on available P content in Kalipare Entisol, Donomulyo Litosol and Poncokusuma Inceptisol after two years.

Treatments	**Available P (mg kg^{-1})**		
	Entisol from Kalipare	**Litosol from Donomulyo**	**Inceptisol from Poncokusumo**
Control (Cl)	40.17 abc	14.31 a	27.43 a
Corn cob biochar (BC)	47.42 abcd	25.47 abc	49.11 e
Rice husk biochar (BR)	34.79 ab	19.29 ab	58.82 f
Tobacco processing waste biochar (BJ)	63.73 de	30.83 cd	28.40 ab
Municipal waste compost (Ct)	59.85 cde	16.99 a	25.19 a
Chicken manure (M)	64.30 de	19.71 ab	47.64 e
Corn cob biochar+municipal waste compost (BC+Ct)	54.40 bcde	29.87 bc	27.22 a
Corn cob biochar+chicken manure (BC+M)	71.78 e	43.94 e	39.91 cde
Rice husk biohar+municipal waste compost (BR+Ct)	30.96 a	16.12 a	30.48 abc
Rice husk biohar+chicken manure (BR+M)	51.06 abcde	34.06 cde	43.86 de
Tobacco waste biochar+municipal waste compost (BJ+Ct)	55.57 bcde	41.15 de	25.35 a
Tobacco waste biochar+chicken manure (BJ+M)	43.48 abcd	16.04 a	33.27 abc

Note: Numbers followed by the same letters in the same column are not significantly different based on the Duncan Multiple Hypothesis Test at = 5%, ns = not significant.

The application of manure combined with biochar and compost affected the available P content in the soil. Corn cob biochar+compost or manure increased the available P content higher than the application of corn cob biochar alone, whereas the application of rice husk biochar+manure doubled the amount of P available in the soil. The highest P content in Poncokusumo Inceptisol was found in the rice husk biochar treatment, while the application of tobacco waste biochar resulted in a P content of less than half of the soil P content due to rice husk biochar application. After two years, the application of compost or compost mixed with biochar showed the same available P without biochar or organic fertilizer. The manure treatment increased the available P content from 27.43 mg kg^{-1} (control) to 47.64 mg kg^{-1}. Corn cob biochar and manure used separately increased the available P content in Poncokusumo Inceptisol. The available P content from the combination with manure was still much lower than the application of corn cob biochar or rice husk biochar alone.

Available K content

The application of biochars and organic fertilizers significantly increased the available K content in the three soil types studied. The available K content in Kalipare Entisol, Donomulyo Litosol, and Poncokusumo Inceptiso. ranged from 0.37 to 0.60 mg 100 g^{-1}, 0.52 to 1.02 me 100 g^{-1}, and 0.26 to 1.01 me 100 g^{-1}, respectively. The treatments indicated that the available K content was not different for coarse-textured soils but significantly different for fine-textured soil. Gholami et al. (2019) stated that significant relationships were found between different forms of K and some soil properties like clay, CEC, sand, pH and organic carbon.

In Kalipare Entisol, the available K content after being amended with biochar and organic fertilizer did not change significantly. While on Donomulyo Litosols, a significant improvement after biochar gave singly or combined with organic fertilizer. The content of K is available in the control treatment in Donomulyo Litosols of 0.56 me 100 g^{-1} and K content of the lowest available (Table 4). In Kalipare Entisol, biochar and organic fertilizer application did not significantly change the available K content. However, the application of biochar, either alone or in combination with organic fertilizers, significantly increased the available K content. The available K content in control in the Donomulyo Litosol was 0.56 me 100 g^{-1}, which was the lowest available K content (Table 4). A 6-year field study in Alfisol of China with five treatments, including no fertilization, chemical fertilization, low biochar content, high biochar content, and biochar-based fertilizer, showed that biochar-based fertilizer significantly increased phosphorus and potassium availability in the soil. The effect was better than chemical fertilization (Liu et al., 2019). K concentrations ranged from 0.52 to 1.02 me 100 g^{-1} after applying biochar alone or in combination with organic fertilizer. The available K content is considered very high if the content is more than 1 me 100 g^{-1} (Hardjowigeno, 2007).

The single biochar treatment in this study did not increase the available K content. The application of compost and manure resulted in the highest K content of 1.02 me 100 g^{-1} and 0.85 me 100 g^{-1}, respectively, which was almost twice that of other organic fertilizers. Meanwhile, corn cob biochar and rice husk biochar combined with compost or manure did not increase the available K content in the soils studied. Provision of tobacco waste biochar mixed with compost or manure increased the available K content by 0.34-0.39 me 100 g^{-1} to 0.95 me 100 g^{-1} and 0.90 me 100 g^{-1}, respectively. The highest K content was observed in the tobacco waste biochar treatment (5.15 me 100 g^{-1}), followed by corn cob biochar treatment (3.96 me 100 g^{-1}) and rice husk biochar treatment (1.71 me 100 g^{-1}).

Table 4. Effect biochar and organic fertilizers on available K content in Kalipare Entisol, Donomulyo Litosol and Poncokusuma Inceptisol after two years.

Treatments	**Available K (me 100 g^{-1})**		
	Entisol from Kalipare	**Litosol from Donomulyo**	**Inceptisol from Poncokusumo**
Control (Cl)	0.47 ns	0.56 a	0.26 a
Corn cob biochar (BC)	0.60 ns	0.70 abc	0.74 bcd
Rice husk biochar (BR)	0.48 ns	0.69 abc	0.74 bcd
Tobacco processing waste biochar (BJ)	0.50 ns	0.52 a	0.73 bcd
Municipal waste compost (Ct)	0.37 ns	1.02 d	0.76 cd
Chicken manure (M)	0.48 ns	0.85 bcd	0.84 de
Corn cob biochar+municipal waste compost (BC+Ct)	0.57 ns	0.65 ab	0.57 b
Corn cob biochar+chicken manure (BC+M)	0.54 ns	0.70 abc	0.59 bc
Rice husk biohar+municipal waste compost (BR+Ct)	0.40 ns	0.72 abc	0.94 ef
Rice husk biohar+chicken manure (BR+M)	0.41 ns	0.75 abc	0.83 de
Tobacco waste biochar+municipal waste compost (BJ+Ct)	0.48 ns	0.95 cd	1.01 f
Tobacco waste biochar+chicken manure (BJ+M)	0.52 ns	0.90 bcd	0.94 ef

Note: Numbers followed by the same letters in the same column are not significantly different based on the Duncan Multiple Hypothesis Test at = 5%, ns = not significant.

In Poncokusumo Inceptisol, available K content in the control treatment was 0.26 me 100 g^{-1}. After giving biochar singly or in combination with organic manure, increased available K content by 0.57 to 1.01 me 100 g^{-1} (Table 4). Corn cob, rice husk and tobacco waste biochar could increase the content of K available to 3 times that of the original. Similarly, Khan et al. (2014) reported that total N, P, and K are much higher after biochar-treated soil than biomass. In addition, organic fertilizer alone tripled the availability of K. Corn cob, rice husk, and tobacco waste biochars in combination with organic fertilizer increased the content of available K by two times, three times, and four times, respectively. The addition of tobacco waste biochar and compost with manure increased the available K content to 1.01 me 100 g^{-1} and 0.94 me 100 g^{-1}, respectively.

In Poncokusumo Inceptisol, the available K content in control was 0.26 me 100 g^{-1}. Applying biochar alone or with organic fertilizers increased the available K content from 0.57 to 1.01 me 100 g^{-1} (Table 4). Corn cob, rice husk and tobacco waste biochars increased the available K content up to 3 times from the original. Khan et al. (2014) reported that the total N, P, and K contents in the soils they studied were much higher after biochar-treated soil than biomass-treated soils (Khan et al., 2014). Corn cob, rice husk, and tobacco waste biochars combined with organic fertilizers increased the available K content by twofold, threefold, and fourfold, respectively. The application of tobacco waste biochar and compost with manure increased the available K content to 1.01 me 100 g^{-1} and 0.94 me 100 g^{-1}, respectively.

Clay dominates the composition of Poncokusumo Inceptisol, which results in reduced K concentration in soil solution. In soil, pH and base saturation are closely correlated, so nutrients will be lost through leaching if pH and base saturation values are low. The effects of biochar on soil carbon content and pH differ by soil type (Abujabhah et al., 2016). Additionally, soil with a high cation exchange capacity can hold more K, reducing leaching potential. Elangovan and Sekaran (2014) reported that biochar addition to clay increased nitrate, phosphorus, and potassium availability in cotton soils after harvest.

Conclusion

Soil organic matter, total N, available P and available K contents in Entisols and an Inceptisol studied increased when biochars were applied in combinations with organic fertilizers. Total N content increased from the low (control) to moderate (biochars combined with organic fertilizers) on Entisol and Inceptisol (biochar only). However, there was no significant effect on Litosol. Available P content increased from moderate to very high in Entisol treated with biochars combined with organic fertilizers, from low to in Litosol treated with biochar and manure, and from moderate to high in Inceptisol treated with biochar only. A decrease in K content was observed in three soil types treated with biochars and organic fertilizers. The most influential treatments in improving the total N, soil organic matter, and available P contents in Entisol were corn cob biochar+compost, rice husk biochar+manure, and tobacco waste biochar. In Litosol, applying tobacco waste biochar+organic fertilizers (manure or compost) provided the best effect in increasing available P and K contents compared to control and other treatments. Comparing the application of rice husk biochar+compost, tobacco waste biochar+compost, and corn cob biochar only to control and other treatments, biochar+compost improved soil organic matter, nitrogen, available phosphorous, and available potassium contents in the soils studied.

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