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Research Article

Utilization of crops residues as compost and biochar for improving soil physical properties and upland rice productivity

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Abstract: The abundance of crops waste in the agricultural field can be converted to organic fertilizer throughout the process of composting or pyrolysis to return back into the soil. The study aimed to elucidate the effect of compost and biochar application on the physical properties and productivity of upland rice at Village of Sukaraja Nuban, Batanghari Nuban Sub district, East Lampung Regency in 2015. The amendment treatments were A. control; B. 10 t rice husk biochar/ ha; C. 10 t maize cob biochar/ha; D. 10 t straw compost/ha; E. 10 t stover compost/ha, F. 10 t rice husk biochar/ha + 10 t straw compost/ha; F. 10 t maize cob biochar/ha + 10 t maize stover compost/ha. The treatments were arranged in randomized block design with four replicates. The plot size for each treatment was 10 x 20 m. After incubation for about one month, undisturbed soil samples were taken using copper ring at 10–20 cm depth for laboratory analyzes. Analyses of soil physical properties included bulk density, particle density, total porosity, drainage porosity, and soil water condition. Plant observations conducted at harvest were plant height, number of panicle, number of grain/panicle, and grain weight/plot. Results of the study showed that biochar and compost improved soil physical properties such as bulk density, total porosity, fast drainage pores, water content, and permeability of soil. The combination of rice husk biochar and straw compost gave better effect than single applications on rice production components (numbers of panicle and grains of rice), and gave the highest yield of 4.875 t/ha.

Keywords: *biochar, compost, plant waste, soil physical properties*

Introduction

The decline in soil fertility in tropical agricultural land is a major problem that causes a decrease in productivity of food crops, high mineral and organic matter weathering rate, soil erosion, and intensively nutrient leaching. Thus, under such circumstance, the efficiency of applied mineral fertilizers is low.

Soil organic matter is essential importance for maintaining soil quality by improving biological, physical and chemical soil conditions; it consists of a variety of simple and complex carbon compounds (Fisher and Glaser, 2012). The role of the organic materials in the soil is very important that as the primary granules soil into a binder in the formation of stable aggregates. To physical soil, organic matter affects the porosity, improved water retention or water content (Evanylo et al., 2008; Yatno, 2011). Drought problems often occur in agriculture in the tropics, especially in the dry season, which affect growth and yields of crops. Badiane et al. (2012) reported that the water stress significantly affects lower grain yields of maize. So, the soil organic matter can modified the soil water dynamic as well as increase water holding capacity (Milla et al., 2013).

Soils amended with organic fertilizers also have lower bulk density and higher aggregate stability than mineral-fertilized soils (Lal, 2009). Compost can effectively be used to improve soil quality, soil hydraulic, and soil pore characteristics (Eusufzai and Fujii, 2012). The abundance of rice straw as an organic waste in the rice field can be converted to fertilizer throughout the process of composting. It is widely known that organic amendments such as plant residues, manure or compost maturity should be used to improve soil quality. Compost contains significant amounts of valuable plant nutrients including N, P, K, Ca, Mg and S and a variety of essential trace elements (Smith and Collins, 2007; Quilty and Cattle, 2011; Fisher and Glaser, 2012). Thus, compost can be defined as an organic multi nutrient fertilizer (Smith and Collins, 2007; Amlinger et al., 2007). Agegnehu et al. (2015) reported that application of 40 g compost/pot as fertilizer significantly increased plant growth, soil nutrient status and plant nutrient content, with shoot biomass (as a ratio of control value).

Biochar is an organic material that is resistant to decomposition process (Hunt et al., 2010), that can be stabilized through chemical interactions and limiting its spatial accessibility to soil microorganisms and their enzymes (Lehmann et al., 2011). Biochar could be used as an alternative liming material in improving acid soil fertility and productivity (Nurhidayati and Mariati, 2014). Biochar application to soil influences various soil physico-chemical properties, due to the high specific surface area of biochar. Significant changes in soil aggregate stability, water retention, and pore size distribution were observed after addition of biochar to a clayey soil (Sun and Lu, 2014).

Application of biochar improves agricultural productivity by reducing soil acidity, pH and base saturation (Major et al., 2010; Masulili et al., 2010). Enhancing CEC and fertilizer-use efficiency (Steiner et al., 2008 ; Chan et al., 2007; Chan and Xu, 2009), and plant-available water content (Laird et al., 2010; Cornelissen et al., 2013; Tammeorg et al., 2014; Agegnehu et al., 2015). Increased available P (Nurhidayati and Mariati, 2014), and soil-water retention, as well as increase soil water-holding capacity (Laird et al., 2010; Novak et al., 2012; Yu et al., 2013; Mila et al., 2013). The optimum application rate for biochar depends on the specific soil type and crop management (Hunt et al., 2010). Dariah et al. (2010) suggested that application of biochar as starting dose 10 t/ha and further continuously dose of 5 t/ha each planting season effectively could be used to improve acid soil quality.

Biochar can be combined with compost to promote positive and synergistic effects for an efficient and optimized management of natural resources including ‘organic wastes’ to create humus and nutrient-rich substrates with beneficial effects for soil amelioration, carbon sequestration for sustainable land use systems and a sustainable material flow management (Fischer and Glaser, 2012). Biochar addition to soil in combination with organic fertilizers has synergistic effect to C sequestration and plant growth (Schulz and Glaser, 2012). This study aimed to elucidate the effect of compost and biochar application singly and the combination on the physical properties of tropical acid soil and productivity of upland rice in East Lampung.

Material and Methods

Study Site and Soil Characteristics

The experiment that was conducted at upland East Lampung included two crops per year in 2015 (soybean and rice). The soil characteristics were as follows: pH (H_20) 5.25, Organic- C by Walkley and Black method 1.23 %; total N- Kjeldahl 0.15 %; P_2O_5 (Bray 1) 22 mg/100g; K_2O 12 mg/100g, cation exchange capacity 8.94 cmol/kg; sand 10 %; silt 54 %; and clay 36 %.

Biochar and Compost Preparation

Husks and maize cobs biochar were produced through low temperature by pyrolysis process (burning without oxygen) at 200 – 300 ˚C using drum oil which on the bottom has been fitted with cavities. Fresh rice straw and maize stover were chopped and composted with effective microorganism (EM) for one month. The characteristics of biochars and composts are presented in the Table 1.

Application of biochar and compost

Soil amendments, two biochars (rice husk and maize cob biochar) and straw compost applied first at April 2015 and second at November 2015 before planting in dry season (soybean) and wet season (rice). The treatments were A. control; B. 10 t rice husk biochar/ ha; C. 10 t maize cob biochar/ha; D. 10 t straw compost/ha; E. 10 t stover compost/ha; F. 10 t rice husk biochar/ha + 10 t straw compost/ha; F. 10 t maize cob biochar/ha + 10 t maize stover compost/ha. The treatments were arranged in randomized block design with four replicates. The plot size for each treatment was 10 x 20 m. After incubation about one month, undisturbed soil samples were taken after compost and biochar application (before planting) using copper ring at 10–20 cm depth for analyses of soil physical properties, bulk density, particle density, total porosity, drainage porosity, and soil water condition. Plant observations conducted at harvest were plant height, number of panicle, number of grain/panicle, and grain weight/plot.

Table 1. Chemical composition of biochar (rice husk and maize cobs) and straw compost (Barus et al., 2015)

Types of	Analysis	Husk biochar[1]	Maize cobs biochar[2]	Straw compost[3]	Maize stover compost
pH	(H_2O)	7.24	7.89	8.65	8.05
Organic-C	(%)	2.40	8.65	1.78	3.,09
N-total	(%)	1.46	0.64	0.79	1.02
Na	(%)	0.02	0.01	0.03	0,04
Ca	(%)	0.22	0.25	0.38	0.47
Mg	(%)	0.15	0.16	0.19	0.14
S	(%)	0.22	0.18	0.18	0.16
Fe	ppm	1491	-	-	-
Mn	ppm	553	-	-	-
Cu	ppm	0.0	-	-	-
Zn	ppm	195	-	-	-
CEC	(cmol(+)/kg)	9.83	11.72	15.45	
P_2O_5	(%)	0.24	0.37	0.56	0.67
K_2O	(%)	0.70	0.57	0.87	0.93

[1,,2, 3] Barus et al. (2015).

Statistical Analysis

The collected data was statistically analyzed using analysis of variance (F-Test) at level ($P \leq 0.05$); Duncan post-hoc test at 5% level was used to compare all treatments with control using SPSS/PASW Statistic 18.

Results and Discussion

Applications of biochar and compost were able to reduce soil bulk density (BD) and particle density (PD) (Table 2). Application compost has potentially given greater impact to soil BD than biochar. The lowest bulk density was observed in straw compost treatment (decrease of 7.5% compared to control). Soil bulk density is affected by soil organic matter content as reported Busscher et al. (2011), that increasing total organic carbon by the addition of organic amendments in soils can significantly decrease BD.

The study micromorphological observations of the amended soils indicated the flocculation of soil microaggregates after the addition of biochar (Jien and Wang, 2013). Compost application generally influences soil structure by lowering soil density due to low density OM than the mineral of soil fraction. This positive effect has been detected in most cases and it is typically associated with an increase in porosity beca.use of the interactions between organic and inorganic fractions (Amlinger et al., 2007). Biochar and compost application improve total porosity and increase fast drainage pores (FDP) of soil (Table 2). Macroaggregate formation was an important factor in maintaining soil porosity as a result of the increase in microbial activity. Sun and Lu (2014) reported that application of straw biochar (SB) and water-sludge biochar (WSB) significantly enhanced the formation of 5–2 and 0.25–0.5 mm macroaggregates in the clayey soil relative to the control treatment, while the < 0.25-cm microaggregate decreased with biochar additions.

Biochar and compost application increase water content at pF 2.54 (field capacity), pF 4.2 (permanent wilting point), and available water for plant (the value among pF 2.54 and pF 4.2) compared to control (Table 3). Compost application increase field capacity, secondary pore structures and improved water retention (Fisher and Glaser, 2012). The same results reported by Bass et al. (2016) showed that application of 10 t biochar/ha and 25 t compost/ha significantly increased soil water content compared to control at trial mid-point.

Application of biochar and compost have synergistic benefits to soil organic matter (SOM) and water holding capacity (WHC) (Liu et al., 2012), and have positively correlation with R^2 = 0,7824 (Blazka and Fischer, 2014). Chan et al. (2007) concluded that biochar application improved some physical soil properties, such as: increased soil aggregation, water holding capacity and decreased soil strength.

Stover compost (E) and combination of husk biochar and straw compost (F) significantly increase plant high compared to control (A).

Table 2. Soil physical characteristic (average and standard deviation) affect of biochar (rice husk and maize cobs) and straw compost after second application at 2015

	Treatments	Bulk Density (BD) (g/cm^3)	Particle Density (PD) (g/ cm^3)	Total Porosity (% Volume)	Fast drainage pores (FDP)	Low drainage pores (LDP)
A	Control	1.18 ± 0.03	2.17 ± 0.11	43.23 ± 3.81	13.82 ± 4.15	5.13 ± 1.41
B	10 t husk biochar /ha	1.12 ± 0.11	2.12 ± 0.09	46.20 ± 3.77	16.65 ± 3.13	4.95 ± 0.52
C	10 t maize cob biochar/ha	1.13 ± 0.09	2.14 ± 0.10	46.35 ± 3.21	16.46 ± 2.23	4.68 ± 0.64
D	10 t straw compost /ha	1.07 ± 0.04	2.10 ± 0.14	47.87 ± 1.45	20.38 ± 2.83	5.68 ± 0.38
E	10 t stover compost /ha	1.09 ± 0.03	2.13 ± 0.13	49.05 ± 3.13	18.88 ± 1.62	5.03 ± 0.91
F	B + D	1.08 ± 0.03	2.13 ± 0.10	48.35 ± 2.14	20.38 ± 3.38	5.40 ± 0.45
G	C + E	1.10 ± 0.04	2.13 ± 0.13	47.63 ± 3.55	19.58 ± 4.35	5.24 ± 0.35

Table 3. Soil water condition (average and standard deviation) after application of biochar (rice husk and maize cobs) and straw compost at the second planting

	Treatments	Soil Water (% volume)				Permeability (cm/hour)
		pF 2	pF 2.54	pF 4.2	Available water	
A	Control	25.8 ± 3.72	20.63 ± 2.69	11.42 ± 1.93	9.21 ± 1.64	7.35 ± 4.57
B	10 t husk biochar /ha	28.5 ± 0.27	23.60 ± 0.41	12.75 ± 0.66	10.85 ± 0.63	12.54 ± 2.55
C	10 t maize cob biochar/ha	27.4 ± 1.76	23.01 ± 1.14	12.88 ± 1,31	10.13 ± 0.28	14.67 ± 3.71
D	10 t straw compost /ha	29.98 ± 3.69	24.92 ± 3.44	13.43 ± 3,35	11.49 ± 2.26	10.99 ± 2.35
E	10 t stover compost /ha	27.35 ± 2.47	22.45 ± 2.11	11.48 ± 0,89	10.93 ± 1.29	13.78 ± 3.66
F	B + D	28.24 ± 1.17	23.72 ± 1.27	13.36 ± 1,28	11.36 ± 1.31	12.23 ± 2.24
G	C + E	27.75 ± 1.86	22.70 ± 1.94	11.60 ± 1,15	10.53 ± 1.64	9.51 ± 1.52

Compost treatments (D and E) and combination of rice husk biochar and straw compost (F) significantly increase numbers of panicle and grains compared to control, but combination of maize cob biochar and stover compost (G) did not significantly increase numbers of panicle and grains compared to control (Table 4). Application biochar or compost did not significantly effect on grain yield, but the treatment combination of husk biochar and straw compost (F) significantly increase grain yield compared to control (Figure 1).

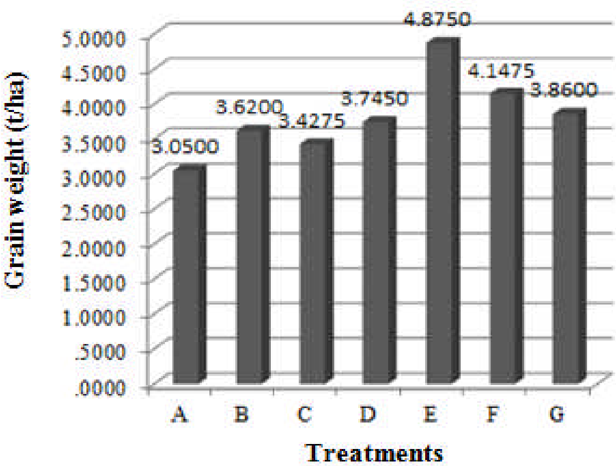

Figure 1. Effect of biochar (rice husk and maize cobs) and straw compost on grain yield

Major et al. (2010) reported that maize grain yield did not increase significantly in the first year following addition of 20 t /ha of biochar, but its effect was significant after the 3 years of application. Addition of manure biochar increased maize yield by 98–150% and water use efficiency by 91–139% (Uzoma et al., 2011). Due to its multiple positive effects on the physical, chemical and biological soil properties, compost and/or biochar contribute to the stabilization and increase of crop productivity and quality (Amlinger et al., 2007; Chan et al., 2007). Soil bulk density values had negative correlation with grain yield (r = -0.0197), but water available for plant had positive correlation (r = 0.422) (Figure 2). Yu et al. (2013) reported their result study, that the biochar increases water holding capacity of a loamy sand soil 1.7% by mass for each 1% of added biochar, the value of water holding capacity of soil, 16%, is doubled by the addition of 9% by mass of biochar. Another study reported that after incubation of 105 days in a soil classified as a Typic Paleudults, the bulk density of the biochar-amended soil significantly decreased from 1.42 g/cm^3 to 1.15 g/cm^3, and rate of decrease was increased with the biochar application rate (Jien and Wang, 2013).

Table 4. Effect of biochar (rice husk and maize cobs) and straw compost on rice production components

	Treatments	Plant Height (cm)		Numbers of panicle		Numbers of grain/ panicle	
A	Control	115.9	b	11.5	b	150.3	b
B	10 t husk biochar /ha	120.5	ab	13.1	ab	172.3	ab
C	10 t maize cob biochar/ha	120.1	ab	14.6	ab	176.2	ab
D	10 t straw compost /ha	120.7	ab	15.6	a	204.8	a
E	10 t stover compost /ha	123.4	a	15.8	a	207.9	a
F	B + D	123.9	a	15.2	a	211.8	a
G	C + E	116.15	b	14.2	ab	174.8	ab
	St.Dev.	3.54		1.92		11.66	

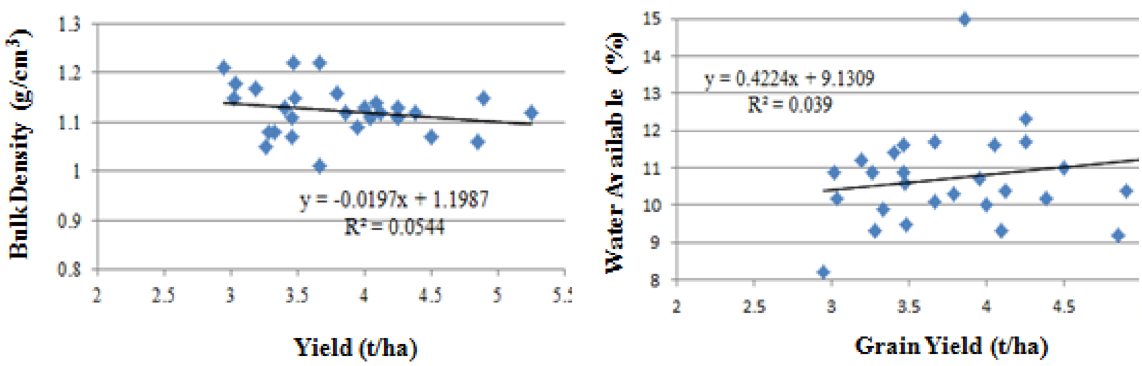

Figure 2. Correlation soil bulk density and water available for plant with grain yield

Conclusion

Biochar and compost application improved soil physical properties such as bulk density, total porosity, fast drainage pores, water content, and permeability. The combination of rice husk biochar and straw compost gave better effect than single applications on rice production components (numbers of panicle and grains of rice), and gave the highest yield 4.875 t/ha.

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