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Biochar and Tillage Systems Influenced on Soil Physical Properties

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Abstract- Biochar is known as huge carbon storage in the soil. In the soil, biochar absorbs CO₂ from air and keep them for hundred years. In addition to prevention, reducing emission and green house effects, Biochar also contributes to soil productivity such as physical and chemical property improvement of the soil. How biochar amends soil physical properties combined with some tillage systems are imperative to find out. This study aimed to determine the influence of biochar and tillage systems on some soil physical properties. Treatment arranged in a factorial randomized block design with three replications. The treatment of biochar effect consist of four levels; 0, 10, 15, and 20 t ha⁻¹ Biochar. The tillage systems were three levels; no, minimum, and conventional tillage. The results showed that we found an interaction effect on the biochar application with tillage systems on dried bulk density, soil porosity, and soil permeability. No interaction was found on aggregate stability indexes and soil water holding capacity at water content at -0.3 and -15 bar of water potential (pF 2.54 and 4.2, accordingly). Biochar amounting of 10 t ha⁻¹ combined with minimum tillage gave significant benefits on soil productivity in terms of dried bulk density, porosity and soil permeability.

Keywords: Soil Physical Properties, Biochar and Tillage Systems

Introduction

Biochar is known as huge carbon storage in the soil and remains there for up to hundred years. (Kuzakov *et al.*, 2009). It plays a key role in helping degraded land and in sequestering atmospheric carbon dioxide (Barrow, 2012). Therefore, black carbon (C) or more popularly called biochar (biomass charcoal) may overcome some limitations in carbon management and thus good soil amendments for improving soil quality (Sohi *et al.* 2010). Soil amendments meant the increasing of carbon content in the soil through manure and compost often successfully rehabilitate soil degradation, but many farmers experience difficulties obtaining them and may even cause serious groundwater contamination. Some farmers, therefore, in the countryside prefer to use Biochar traditionally to avoid ground water contamination. Various studies show, biochar has the potential to improve soil fertility and productivity. Herath *et al.* (2013) reported that agronomic benefits of applying biochar into the soil are mainly derived from the fertilizer value of biochar and its effect on the improvement of soil physical condition. Experts are attracted to study more biochar because it has general high porosity and large inner surface area, thus physical-chemical processes might be important for crop production.

Biochar is not an organic fertilizer, because it cannot add nutrients but it has a high affinity for nutrients and persistent in the soil as well as increase cation exchange capacity (Barrow 2012). He *et al.* (2016) found biochar amendment increased soil nitrification activity in soils. Biochar may greatly improve soil structure and aeration due to its high porosity and low bulk density (Joseph *et al.*, 2010), thereby providing favorable condition for nitrification.

Influence of biochar on soil aggregation has been reported by Fungo et al (2017). They found that biochar is stored predominantly as free particulate organic carbon in the silt and clay fraction and promote a movement of native soil organic carbon from larger-size aggregates to the smaller fraction in the short-term (2 years). They did not find entirely that biochar would consistently increase soil aggregation and did not observe a significant change in macro-aggregate C content. Busscher et al. (2010) found Biochar combined with swiftgrass affected aggregation, infiltration, and water holding capacity. Biochar applications increased volumetric water content at each matric potential tested although the effect was not always significant, however biochar may facilitate drainage in poorly drained soil (Herath et al. 2013). Influence of biochar combined with kinds of tillage system on soil quality or productivity has not been understood yet. Farmers, in practices, broadcast the biochar evenly top of the soil surface, and let them one-week prior planting.

Busari et al. (2015) found that conservation tillage involving zero tillage and minimum tillage aiming reducing the potential soil breakdowns led to better soil environments and crop yield with the minimum impact on the environments. However Arthur *et al.* (2012) previously reported that physical practices of soils only slowly changed in response to cultivation practices like crop rotation and fertilisation; therefore they suggested that long-term field experiments are essential for assessments of the impact agriculture management. The more frequent tillage of agriculture field operation, the more potential soil structure is degraded if soil water content unnoticed (Darusman, 1991). Excessive of granules destruction may cause of soil granules becomes very smooth resulting the porosity becomes smaller, reduce soil aeration and drainage matters. These problems of soil caused by tillage operations could be prevented by applying biochar in suitable amount that the increase of soil bulk density could be avoided. The other benefit of biochar is reported by Barrow (2012) that biochar may reduce the need for fertilizer/ manure /compost and improve moisture retention thus reduce demand for irrigation and make cropping more secure.

The objective of this study was to find whether the provision of biochar and tillage systems might influence the soil physical properties. Our hypothesis was application of biochar and tillage system at field condition could affect soil physical properties such as bulk density, permeability, aggregate stability and water content at -0.33 bars and -15 bar of water potential.

Material and Methods

Field study was conducted at during Nov. 2014 till March 2015 on Ultisol soil in a community land of Jantho Baru village, Kota Jantho Sub district, Aceh Besar District of Aceh Province. The altitude of \pm 250-300 m above sea level. A factorial Randomized Block Design consisting of two factors was used. The first factor is the tillage system (OT) consisting of three levels: no tillage, minimum tillage, and conventional tillage and the second factor is the provision of biochar (B) consist of four levels: 0, 10, 15, and 20 t ha⁻¹ of biochar.

Table 1. Composition of the combination of tillage systems and provision of biochar.

No	Codes	Tillage System	(t. ha ⁻¹)
1	OT ₀ B ₀	No Tillage	0
2	OT ₀ B ₁	No Tillage	10
3	OT ₀ B ₂	No Tillage	15
4	OT ₀ B ₃	No Tillage	20
5	OT ₀ B ₀	Minimum Tillage	0
6	OT ₀ B ₁	Minimum Tillage	10
7	OT ₀ B ₂	Minimum Tillage	15
8	OT ₀ B ₃	Minimum Tillage	20
9	OT ₀ B ₀	Conventional Tillage	0
10	OT ₀ B ₁	Conventional Tillage	10
11	OT ₀ B ₂	Conventional Tillage	15
12	OT ₀ B ₃	Conventional Tillage	20

Amounting of 500 kg rice husks were used to produce biochar. N, P, K Starter fertilizer were injected into the soil until depth of 60 mm with spacing from the plant was 50 mm as much as 300 kg ha⁻¹. Irrigation applied twice a day depending water used. Corn (var. Pertiwi 3) was planted as a crop indicator. Soil samples taken before planting and after harvest at soil depth of 0-20 cm were brought to soil physic laboratory for physical properties analysis. Some physical parameters observed were (a) the stability aggregates index, (b) soil water holding capacity at water content at -0.3 and -15 bar of water potential (pF 2.54 and 4.2, accordingly) (c) dried bulk density, (d) soil porosity, (e) soil permeability.

Disturbed soil samples were collected from each plot, air-dried, and then stored until used. Soil aggregate stability was reported as aggregate stability index and determined using wet and dry sieving methods (Kemper and Rosenau, 1986). Average diameter soil aggregates from wet and dry sieving (instability index) was calculated as:

$$\text{Aggregate stability index} = 1 / \text{instability index}$$

Soil water holding capacity at water content at -0.3 and -15 bar of water potential (pF 2.54 and 4.2, accordingly) was determined by using a cellulose acetate membrane system. Gravimetric analysis was undertaken to determine the moisture content (g g⁻¹). Dried soil bulk density was determined using undisturbed ring sample techniques. Soil cores with diameter 50 mm and height 54 mm were pushed into a soil depth 100 mm. Total porosity was measured as the volume equivalent calculated using a soil particle density of 2.65 g cm⁻³. Soil permeability was measured using a constant head permeameter and reported as cm hr^{-1.0}

The statistical difference between the treatments was determined by analysis of variance (ANOVA) using SPSS software v. 1.7. The least significant difference within treatment at $P = 0.05$ was employed.

Results and Discussions

Soil Aggregate Stability Index

Analyses of variance (ANOVA) for aggregate stability index showed both treatments of biochar and tillage system independently influenced aggregate stability at P - level 0.05. Combination treatment of Biochar and tillage did show any influence on the aggregate stability (no interaction found). Means soil aggregate stability influenced by applying biochar and tillage system is given in Table 2. In general, the result showed that provision of biochar and tillage system reduced soil aggregate stability index. Amount of biochar of 10 t ha⁻¹ has lowered aggregate stability even though not significantly. Apply conventional tillage lowered the stability of aggregate significantly. He *et al.* (2016) reported that biochar may greatly influence aggregate stability due to its low bulk density. Frequent land cultivation may cause soil particles dispersed and creation of soil aggregate that a function of biological activity and time is disturbed (Herath *et al.*, 2013).

Table 2. Means of soil aggregate stability index influenced by combination of tillage and of biochar

Tillages (OT)	Biochar Doses (t. ha ⁻¹)				Means LSD _{0.05} = 4,75
	B ₀ (0)	B ₁ (10)	B ₂ (15)	B ₃ (20)	
OT ₀	67,80	64,29	58,13	53,37	60,90 C
OT ₁	66,22	60,52	57,08	57,63	60,36 B
OT ₂	57,07	53,37	57,83	53,31	55,40 A
Means LSD _{0.05} = 5,48	63,70 b	59,39 b	57,68 ab	54,77 a	

Note: Number followed by the same letter was significantly different by LSD test at the $P = 0.05$ level. Small letters are read horizontally and capital ones read vertically

Soil Water Holding Capacity at Water Content at -0.3 and -15 bar of water potential

Analysis of variance for soil water holding capacity at water content at -0.3 and -15 bar of water potential (pF 2.54 and 4.2) showed that application of biochar was not affected. No combination interaction was found at P -level 0.05. Tillage implementation influenced significantly soil water holding capacity. Minimum tillage can lead to the decreased levels of field capacity water content (pF 2.54), but

the conventional tillage can cause a decreasing of soil water content at the point permanent wilting (pF 4.2).

Table 3. Means of soil water content at -0.3 bar (pF 2.54), and -0.15 bar (pF 4.2) of water potential influenced by Tillage

Tillages (OT)	pF 2,54		pF 4,2
	%
OT ₀	25,16 A		16,30 A
OT ₁	22,36 A		14,50 B
OT ₂	23,26 AB		13,67 B
LSD _{0.05}	2,24		1,49

Note: OT₀ (without tillage), OT₁ (minimum tillage) and OT₂ (conventional tillage). Number followed by the difference letter was not significantly different at LSD test. P

Table 3 shows the water content in lowest field capacity occurred in minimum tillage indicated by the water content at pF 2.54 amounted to 22.36% and the highest water content occurred on no tillage that is amounted to 25.16%. Tillage operation influenced the amount of water hold in the soil. Seems that this type of soil was rather structure less, thus once it is tilled, and the pores that hold water become disturbed and less. Lal and Shukla (2004) stated that soil water content at -0.3 bar of water potential or pF 2.54 is the upper limit of moisture content that a soil can hold. It is the moisture content when all macro pores or transmission pores have been drained and water in the macrospores has been replaced by air. There are numerous soil factors that affect water content at pF 2.54. Important among these are texture and especially the clay content, clay minerals, porosity and pore size distribution, and soil organic matter content.

Soil Water Content at -15 bar of water potential (pF 4.2) is also named as the lower limit of the moisture content of soil at which forces of cohesion and adhesion holding moisture in soil far exceed the pull that plant roots can exert to extract moisture from the soil (Hillel, 1982). This is the moisture content at which plant leaves wilt permanently and do not regain turgidity even when placed in an atmosphere with a relative humidity of 100%. Similar to water content at pF 2.54, the water content also differs widely among soils. In contrast to water content at pF 2.54, this water content is not significantly influenced by aggregation, structural porosity, and soil organic matter content (Lal and Shukla, 2004).

Dried-Bulk Density

The means of dried bulk density (Table 4) due to the influence of combination treatments of Tillage system and Biochar showed significantly different at *P*-level 0.05.

Table 4. Means of bulk density influenced by combination of tillage and of biochar

Tillages (OT)	Biochar Doses (t. ha ⁻¹)			
	B ₀ (0)	B ₁ (10)	B ₂ (15)	B ₃ (20)
g cm ⁻³				
OT ₀	1,31 a A	1,31 a A	1,28 ab A	1,27 b A
OT ₁	1,24 a B	1,21 a B	1,21 ab B	1,20 b B
OT ₂	1,18 a C	1,15 a C	1,16 ab C	1,09 c C
LSD (OTxB) _{0.05}	0,03			

Note OT₀ (without tillage), OT₁ (minimum tillage) and OT₂ (conventional tillage). Number followed by the difference letter was not significantly different at 0,05 LSD test.

Table 4 shows that we found a very significant interaction between tillage systems with provision of biochar on soil bulk density. The highest bulk density found on no-tillage and no biochar (0 t ha⁻¹) is 1.31 g cm⁻³ while the lowest bulk density found on interaction between conventional tillage and 20 t ha⁻¹ of biochar is equal to 1.09 g cm⁻³. Busari *et al* (2015) stated that no tillage involves land cultivation with little or no soil surface disturbance, the only disturbance being during planting. While minimum tillage means reduced level of soil manipulation involving ploughing using primary tillage implements. In accordance with Hakim *et al.* (1986) tillage can reduce the bulk density and particle density in a certain type of land. So that the roots plant can penetrate the soil so well and the plants can thrive, either on the annual land and production land. Moreover applying biochar may greatly improve soil structure and aeration due to its high porosity and low bulk density (Joseph *et al.* 2010). However, lower bulk density is not appropriate for crop development because roots needs matrix to stand. Therefore, applying 10 t ha⁻¹ of biochar and combined with minimum tillage is economically effective to reduce bulk density for crop productivity.

Soil Porosity

Lal and Shukla (2004) define porosity is a general term used to designate all voids in the soil. Total porosity (f_t) is usually determined from the bulk density and particle density relationship ($f_t = 1 - \rho_b / \rho_s$). But, total porosity can also be determined from the saturation moisture content (Θ_s), provided that there is no entrapped air. These relationships hold for non-swelling soils. Soil porosity or pore space is the portion of soil bulk volume occupied by soil pores. The pores are filled with air/ and or water (Kirkham, 2014). Thus, porosity is affected by the bulk density and particle density of the soil. Lower bulk density, the higher porosity of the soil. In our research, soil porosity was calculated from the saturation moisture content (0 bar of water potential). Means of soil porosity affected by tillage and application of biochar is shown in Table 4.

Table 5 shows that we found significant influence of applying biochar combined tillage system (Interaction) on soil porosity. We found similar as the result of bulk density namely applying 10 ha⁻¹ combined with minimum tillage economically and significantly result good in soil pores. Applying biochar, which has lower bulk density, surely decreases soil porosity. Minimum tillage reduces the breakdown soil aggregate too much by tillage operations.

Table 5. Means of soil porosity influenced by combination of tillage and of biochar

Tillages (OT)	Biochar Doses (t. ha ⁻¹)			
	B ₀ (0)	B ₁ (10)	B ₂ (15)	B ₃ (20)
%				
OT ₀	34,78 a A	35,79 ab A	37,38 b A	37,31 b A
OT ₁	39,69 a B	40,62 a B	40,64 ab B	41,96 b B
OT ₂	41,60 a C	43,03 a C	43,37 ab C	47,38 c C
LSD (OTxB) 0.05	2,04			

Note.: Number followed by the difference letter was not significantly different at 0,05 LSD test.

Soil Permeability

Analysis of variance showed significant different of Means of soil permeability affected by soil tillage and biochar application.

Table 6 shows that interactions combination treatments between tillage systems and biochar provision on soil permeability. We found conventional tillage gave much higher values at any given biochar application. However at any tillage system, then applying 10 t ha⁻¹ results the increase soil permeability. In the light soil productivity we conclude that treatment combination of applying 10 t ha⁻¹ and minimum tillage economically better.

Table 6. Means of soil permeability influenced by tillage and of biochar

Tillages (OT)	Biochar Doses (t. ha ⁻¹)			
	B ₀ (0)	B ₁ (10)	B ₂ (15)	B ₃ (20)
OT ₀	5,62 a A	5,90 a A	6,25 a A	5,67 a A
OT ₁	7,93 a AB	6,98 a AB	7,73 a AB	8,77 a AB
OT ₂	11,32 a C	14,17 ab C	17,45 c C	18,21 c C
LSD (OTxB) 0.05	2,74			

Note.: OT₀ (without tillage), OT₁ (minimum tillage) and OT₂ (conventional tillage). Number followed by the difference letter was not significantly different at 0,05 LSD test.

Darusman (1991) stated that there is correlation with bulk density decreasing and the increasing in total of soil porosity, where due to the severe decline in bulk density and an increasing in total of soil porosity causes the increasing of the soil permeability. This is presumably due to decreasing of bulk density and increasing total of soil porosity. According to Hillel (1982) that soil physic properties that effected soil permeability such as soil water content, bulk density, total porosity, fast pore drainage, slow pore drainage, coarse sand content, fine sand content, silt content and clay content. However Busari *et al* (2015) said that effects of conservation tillage on soil properties vary, and these variations depend on the particular system chosen. Anikwe and Ubochi (2007) in Busari *et al* (2015) stated that no-till (NT) systems, which maintain high surface soil coverage, have resulted in significant change in soil properties, especially in the upper few centimeters. Furthermore Lal (1997) said that No tillage of conservation partices are generally more favourable in compare to tillage-based systems.

Conclusions

Tillage implementation and biochar aplication infulenced independently the aggregate stability index. However Soil water holding capacity at 2.54 pF and 4.2 pF was affected by minimum and conventional tillage. Treatment combination interaction significantly influenced dry bulk density, porosity, and permeability of the soil. Biochar amounting 10 t ha⁻¹ combined with minimum tillage gave significant benefits on soil productivity.

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