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Effects of Incorporating Biochar into the Soil Using Power Tiller and Ox-Plough

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Abstract

Existing knowledge about biochar is derived from trials where biochar incorporation into the soil is done by hands, a practice too tedious to scale-up to commercial levels. To enhance scalability, biochar incorporation needs to be integrated into conventional mechanised tillage systems. This study aimed at assessing the effects of incorporating biochar by power tiller and ox-plough on soil water retention, maize growth and yield. A 2 x 3 factorial experiment was conducted in a split-plot design with biochar incorporating method as a main plot factor and biochar level as subplot factor, on ferralsols of central Uganda. Incorporation methods were by power tiller and ox-plough with hand mixing in planting basins as a control, while levels of biochar were 0 and 10 t ha^{-1} application rates. Data was analysed using two-way ANOVAs in Minitab for significant differences among incorporation methods. Results showed that incorporating biochar by power tiller significantly increased water retention effect of biochar by 27.5% ($p < 0.05$), while no significant effect was observed ($p \geq 0.05$) when incorporated by ox-plough, compared to hand mixing. No significant difference on growth and yield was observed ($p \geq 0.05$) as a result of incorporating biochar by power tiller and ox-plough instead of hands in planting basins. These findings suggest that biochar incorporation can be scaled-up, to commercial levels, through the use of power tiller and ox-plough, without negative effects on biochar performance. It is recommended that promotion of biochar technology encompasses the use of power tillers and ox-ploughs to enhance scalability.

Keywords: commercial level, ferralsols, incorporation methods, maize yield, scale up, Uganda

1. Introduction

Current knowledge on benefits of biochar suggests that biochar application to the soil is highly viable and appropriate for intensive commercial farming in countries with restricted land availability like Uganda (Barrow, 2012; Konz, Cohen & Merwe, 2015). However, farmers are yet to benefit from it (Vochozka, Maroušková, Váchal & Strakov á, 2016**)**. Most of this knowledge is derived from potted plants or small trial plots. Laufer and Tomlinson (2013) reported that out of 31 biochar field studies published, only three were set on a 0.1 ha or larger plot. According to The African Biodiversity Network (2010), all biochar projects were on small trial plots while large scale deployment was the explicit aim of the projects. However, farming methods used in the small trial plots do not match farming methods practiced at a commercial level. In particular, incorporation of biochar into the soil in most of these trials is done by hands in planting basins or pots, a practice too labour-intensive to be scaled up to commercial levels (Cornelissen et al., 2013; Deal, Brewer, Brown, Okure & Amoding, 2012; Konz et al., 2015).

Hunt, Duponte, Sato and Kawabata (2010) observed that biochar is commonly incorporated into the soil by mechanical tillage or hand tools. Blackwell, Riethmuller and Collins (2009) noted that biochar can be incorporated by hand hoe tillage, animal powered tillage or mechanical tillage. However, there are no empirical studies on how these methods affect biochar effect (Verheijen, Jeffery, Bastos, Van Der Velde & Diafas, 2010). Moreover, there is no consensus on effects of different biochar incorporation methods on biochar performance (Lehmann et al. 2011). Thus, how biochar is to be applied and mixed with the soil at a commercial level has not been recommended yet especially to farmers practicing intensive cultivation of 2 to 5 ha of land (Konz et al., 2015; Sitko & Jayne, 2012; World Bank, 2011).

To enhance scalability, there is a need to explore conventional mechanised tillage methods that can be recommended for integration into biochar technology. The objective of this study was to assess the effects of incorporating biochar into the soil using power tiller and ox-plough on the performance of biochar. It was hypothesised that both power tiller and ox-plough could effectively be used to incorporate biochar without negative effects on the performance of biochar.

2. Materials and Methods

2.1 Study Site

The experiment took place at Makerere University Agriculture Research Institute, Kabanyolo (MUARIK) on 00° 27′ 54.2″ N, 32° 36′ 46.8″ E in central Uganda. Deal *et al*. (2012) describes the soils at MUARIK as clay loam with 36% sand, 22% silt, and 42% clay. Central Uganda has two rain seasons a year, the first one peaking around April while the second one peaks around November, totaling 1500 mm on average. The temperature at the site ranges between 16.4^{o}C in August and 28.4^{o}C in January (Uganda Beureau of Statistics [UBOS], 2016).

2.2 Sources of Draught Power for Biochar Incorporation

At that time the institute had a pair of draught oxen consisting of well-built Boran and Zebu beasts capable of delivering a total of over 10 KN of draught force sustainably (Harrigan & Roosenberg 2002). Both beasts were well trained in pulling equipment such as the common mouldboard plough. At hand, in the workshop, was a Daedong R60 rotary tiller coupled to a 13 HP Italian-made Daedong two wheel tractor. This set of a two wheel tractor and rotary tiller together is commercially referred to as a Power Tiller (Kataoka & Sakai 2009).

2.3 Biochar

The biochar used was produced through slow pyrolysis of wilted banana leaves at temperatures of between 350^{o}C and 450^{o}C using a batch thermal bioreactor found at MUARIK. Alvum-Toll, Karlsson and Strom (2011) give elemental composition of resultant biochar when wilted banana leaves are pyrolysed at 450^{o}C.

2.4 Research Design

A 2 x 3 factorial experiment was conducted in a split-plot design with biochar incorporating method as a main plot factor and biochar level as subplot factor (K. Gomez & A. Gomez, 1983). The incorporation methods were by power tiller (PT) and animal-drawn plough (AD) with mixing by hands in planting basins (PH) as control. While the biochar level was 10 t ha^{-1} application rate (10) with unenhanced soils (0) as control. To achieve this, a rectangular area of 23 m x 8 m was demarcated and marked by wooden pegs. The area was then divided along its width into three stripes of 2 m wide separated by 1 m spaces. Each stripe was divided along its length into six 3 m long subdivisions separated by 1 m spaces. Eventually, this resulted in 18 experimental units.

2.5 Treatment Allocation

Two stripes were randomly selected on which three units from each stripe were applied with biochar at 10 t ha^{-1}. To achieve this, the content of a pre-weighed 6 kg bag of biochar was spread evenly on each of the selected units. One of the two stripes was tilled by power tiller and the other was tilled by ox-plough as a way of seedbed preparation operation. The tillage, which was done at 15 cm depth, also served as biochar incorporation operation. The power tiller and ox-plough tilled stripes were labeled PT and AD respectively.

Planting basins of approximately 20 cm long x 20 cm wide x 15 cm deep were dug on each and every unit in the third remaining stripe. The basins were arranged in 75 cm spaced rows and spaced 40 cm within a row (Asea, Serumaga, Mduruma, Kimenye, & Odeke, 2014). This resulted in four rows of basins with five basins per row, which eventually gave a total of 20 basins per unit. Out of the six units of this stripe, three were randomly selected and applied with 40 g of biochar per planting basin. Four grams of diammonium phosphate (DAP) fertilizer was added in each and every planting basin (Bayite-kasule, 2005). Then in basins with biochar, 2 kg of soil was added and thoroughly mixed with the biochar by hands. While in basins without biochar, 3 kg of soil were added and as well mixed with fertilizer. This biochar application rate was equivalent to 20 g kg^{-1} of soil as done by Deal *et al.* (2012) in potted plants using soil from the same site, and the 10 t ha^{-1} as in other stripes. This stripe was labeled PH.

Maize (*Zea mays L.*, Longe 5) was planted on all the units at a seed rate of 100,000 ha^{-1} which were later thinned to achieve a recommended plant density of 66000 ha^{-1}. In PH stripe three seeds were directly planted at 2.5 to 3 cm depth by hands (Komakech, Zurbrügg, Semakula, Kiggundu & Vinnerås, 2015) in all the basins. While on the other stripes, 10 cm long x 5 cm wide x 5 cm deep planting holes were dug by a hand hoe. The holes were arranged in 75 cm spaced rows and 40 cm within the row. Four grams of DAP fertilizer was applied on each and every such planting hole and covered by the soil of about 2 to 2.5 cm depth. Then 3 seeds were placed on top and covered by the soil of about 2.5 to 3 cm depth (Asea *et al*, 2014). In the second season, the same variety of maize was planted through small holes on same sites of the first season hills (Cornelissen, Shitumbanuma, & Mantinsen, 2014). During the growing period, all the units received similar conventional management practices.

2.6 Data Collection

2.6.1 Soil Moisture Content

Soil moisture content was measured by a Rapitest Digital Moisture Meter, (model 1825; Luster Leaf Products). A manufacturer's specified procedure as described by Luster Leaf (2012) was followed. The readings were taken at 10 cm depth every day when there was no rainfall event, or 24 hours after a rainfall event, the lapsed time was deemed enough to drain the excess water (Peters, Desta & Nelson, 2012; Zotarelli, Dukes & Morgan, 2010). According to Luster Leaf (2012), the readings from 1 to 9.9 signify increasing wetness of the soil and no plant can tolerate either extreme for a long time. A reading of 7 is considered to be ideal for maize while readings of less than 4 and above 8 are detrimental to the optimal growth of maize.

Rapitest Digital Moisture Meter readings are referred as 'relative moisture content or MC values' because a higher reading merely tells how wetter the soil is in comparison with that of a lower reading. In other words, a soil of lower reading is deemed to have less moisture than that of a higher reading and the difference in the readings is directly proportional to the difference in the amount of water in the two soils. Therefore, the MC values were used to compare the amount of moisture in the soil among locations (units) and points in time. Eventually, these differences in MC values among units at a given point in time were used to compare the soils' water holding capacities.

2.6.2 Soil pH

The soil pH values were obtained by a Rapitest 3-Way Soil Analyser (model 1835; Luster Leaf Products). A manufacturer's specified procedure as described by Luster Leaf (2014) was followed. The readings were taken before biochar application, immediately after first and second season harvests.

2.6.3 Crop Heights

Crop heights were obtained by measuring from the soil surface to growing tip (Komakech *et al*. 2015) during the vegetative growth stage. This stage was chosen because it is believed that during this time plant elongation (increase in height) is directly proportional to soil fertility and inversely proportional to water stress in maize (Cakir 2004; Asea *et al.* 2014). In the first season, the crop heights were measured weekly until tasselling. However, it was observed that the growth was faster than expected, thus in the second season, the measurements were taken every fourth day, until the crop tasseled. The measurements were done by a steel pocket tape due to its availability, easy to use, and reliability. One row from each unit could randomly be selected and the height of the taller crop of each hill, in that row, was measured and recorded in centimeters (Major 2009).

2.6.4 Grain and Residue

The grain from each unit was separately weighed after it was sun dried to about 15% moisture content as measured by salt-jar method (Food and Agriculture Organisation of United Nations [FAO] 2011). The residue was separated into stalk (stem and leaves), husks, and cobs before weighing it. The stalk and husk from each unit were cut into 10 cm long pieces, sun dried and packed in plastic bags before weighing. While the cobs were directly packed in plastic bags and weighed. All the weights were obtained by a digital kitchen scale and were recorded in kilograms.

2.7 Data Analysis

Data was analyzed in Minitab software package and Microsoft Excel. The descriptive statistical analysis was done on the raw data, whose results were presented in forms of line graphs (in the case of continuous data) and bar charts (in the case of distinct data). This graphical presentation of descriptive statistic results was used to check the general outlook of the data characteristics and identify outliers in the data. Inferential statistical analysis on the data was done using a two-way ANOVA in Minitab. Main effects were due to the different incorporation methods and biochar levels (0 and 10 t ha^{-1}). Significant differences between incorporation methods were investigated using Tukey's pairwise and multiple comparisons at $\alpha = 0.05$.

The effects of biochar incorporation methods on the performance of biochar were computed using magnitude differences in MC values, crop heights and grain yield from the control main plot. Statistically significant differences ($p < 0.05$) between the control main plot and each of the other two main plots were expressed as a percentage of the control main plot value to give the extent of the effect. While the statistically insignificant differences were deemed to mean zero effect.

3. Results and Discussion

3.1 Effects on Soil Water Retention

The graphs of the mean daily MC values revealed that from 26th day, the area did not receive any precipitation that could bring the soil moisture content to field capacity. This scenario caused a downwards trends of MC values until the 43rd day when the area received rainfall that raise soil moisture content to field capacity (Figure 1). In particular, during the period between 34th and 43rd day of the first season there was no any sort of precipitation, hence soil moisture was the major limiting factor of crop growth. Although the growth rate reduced in all the treatments, some treatments were less affected causing the variability in crop heights on the 40th day. This was due to differences in the amount of plant available water caused by different treatments.

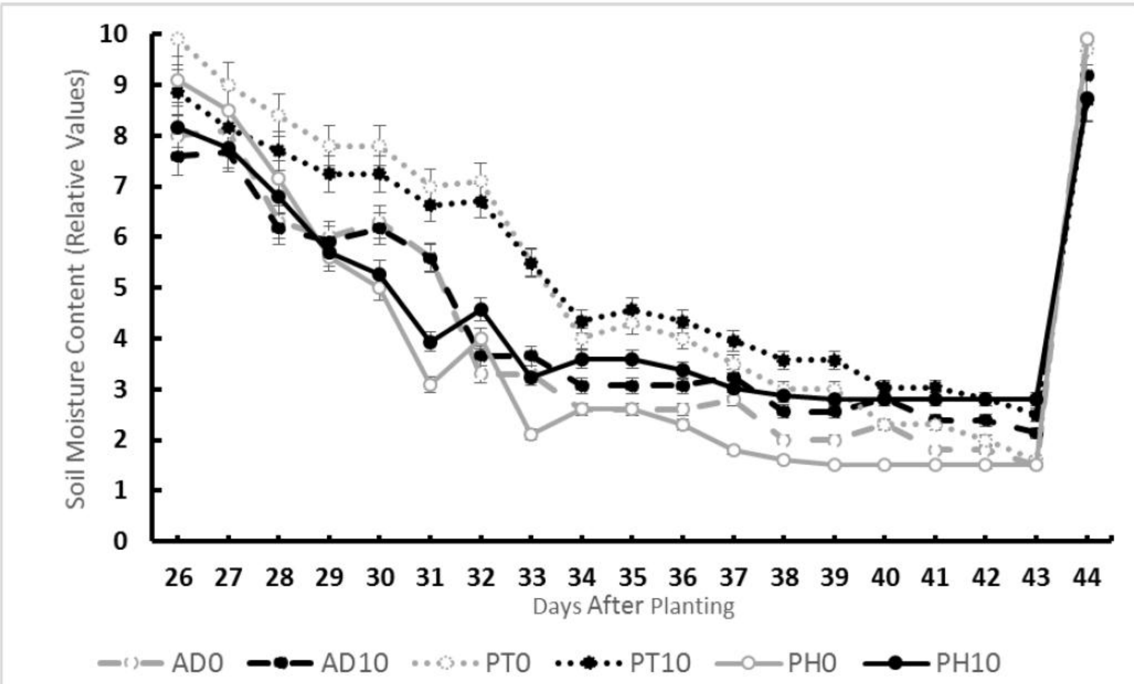

Figure 1. Soil Moisture Content Graphs for Various Treatment

NOTE: The bars stands for Percentage Error in the Values

AD10 and AD0 represent ox-plough tilled soils with and without biochar respectively

PT10 and PT0 represent power tiller tilled soils with and without biochar respectively

PH10 and PH0 represent soils with planting basins with and without biochar respectively

MC values observed on the 38th day of crop growth showed a highly significant difference ($p < 0.001$) between pot-holed and power tiller tilled soils. A multiple comparison analysis that followed grouped the treatments as depicted in Table 1. Thus to quantify the effects of using power tiller and ox-plough, to incorporate biochar into the soil, on moisture conservation, the mean MC values on the 38th day were used. Table 1 shows the mean MC values on the 38th day and calculated effects of using power tiller and ox-plough to incorporate biochar into the soil.

These results mean that when biochar was incorporated by power tiller, water retention effect of biochar increased by 27.5% compared to hand mixing in planting basins. One of the reasons for this increase was inconsistency in manual mixing as the operation became tedious. This is one of the problems agricultural mechanization programs in most of the national policies are aimed at solving (Hatibu, 2013; Wanyama et al., 2016). While incorporating biochar with ox-plough had no notable effect on soil water retention when compared with mixing biochar by hand in planting basins. Solaiman, Murphy & Abbott (2012) reported an increase in water holding capacity of the soil of 75 to 247% due to the application of various biochars. This study suggests that if power tiller was used to incorporate the biochar this effect would have improved further by 27.5%.

Table 1. Effects of Using Power Tiller and Ox-plough to Incorporate Biochar on Soil Water Content

Biochar Level (t ha^{-1})	Treatment[a](N)	MC Values[b]	Differences From Control	Effects(%)
0	PH0 s(3)	1.63 ±0.15c	-	88.34
	PT0 (3)	3.07 ±0.32ab	1.44	
	AD0 (3)	1.87 ±0.11c	0.24*	
10	PH10(3)	2.80 ±0.20b	-	27.50
	PT10(3)	3.57 ±0.25a	0.77	
	AD10(3)	2.53 ±0.25b	-0.30*	

[b]Relative soil moisture content values on 38th day of season 1, means that do not share a letter are significantly different at $\alpha = 0.05$: *Not significant at $\alpha = 0.05$

[a]Treatments: AD10 and AD0 = Ox-plough tilled soils with and without biochar respectively

PT10 and PT0 = Power tiller tilled soils with and without biochar respectively

PH10 and PH0 (Controls) = Soils with planting basins with and without biochar respectively

3.2 Effects on Crop Growth Rates

There was no significant difference ($p \geq 0.05$) in plant growth rate among the treatments during the first 33 days of the first season. However, the crop heights observed on the 40th day showed that there was a significant difference in growth rate between some treatments ($p = 0.005$) from the 33rd to the 40th day. This variation was shown by the widening gaps between growth graphs of some treatments on the 40th day (Figure 2). The gaps narrowed and all graphs became parallel thereafter. This shows that there was some factor/s that might have changed between the 33rd and 44th days of the first season. Looking at the soil moisture graphs for various treatments (Figure 1) revealed that by the 33rd day only power tiller tilled soils had MC values above 4. A value lower than 4 is deemed to be detrimental to optimal maize growth, hence the reduction in growth rate observed during this period.

In the second season crop heights on all dataset days showed significant differences between some treatments ($p \leq 0.05$). This means that, unlike in the first season, in the second season the differences in plant growth rates among treatments started at the very beginning of the plant growth. Moreover, the gaps between growth graphs of some treatments, as seen in Figure 2, kept on widening throughout the first 48 days after planting.

This shows that the variation in the factor causing the differences in growth rate among treatments was increasing. The only possible factors that could cause these differences are soil moisture and soil fertility (Asea *et al*., 2014; Mulebeke, Kironchi & Tenywa, 2013). However, unlike the first season, during the second season there was adequate rainfall throughout the first 44 days after planting. The rainfall kept the soil moisture at field capacity, as observed by the mean MC value of seven in all experimental units. Thus soil moisture variation was ruled out leaving soil fertility variation as the major cause of the differences observed in crop growth rate among treatments. There was no fertilization in the second season, implying that all the present nutrients were either released from soil or from residues left from the first season.

The variations on plant growth rates were mainly between biochar enhanced and unenhanced soils in line with what Zhu et al. (2014) had observed. However, crop heights on the 40th day of the first season did not show significant differences among incorporation methods ($p = 0.20$). While on the second season, significant differences among incorporation methods were observed ($p = 0.030$) in crop heights on the 44th day.

On both seasons the interactions between the biochar level and incorporation method were significant (Figure 3). The interaction shows that the effect of tillage method was more pronounced in unenhanced soils than in biochar-enhanced soils in the first season and the opposite was observed on the second season. This suggests that effect of biochar incorporation method increases with time in the same way biochar effect increases with time (Major, Rondon, Molina, Riha & Lehmann**,** 2010).

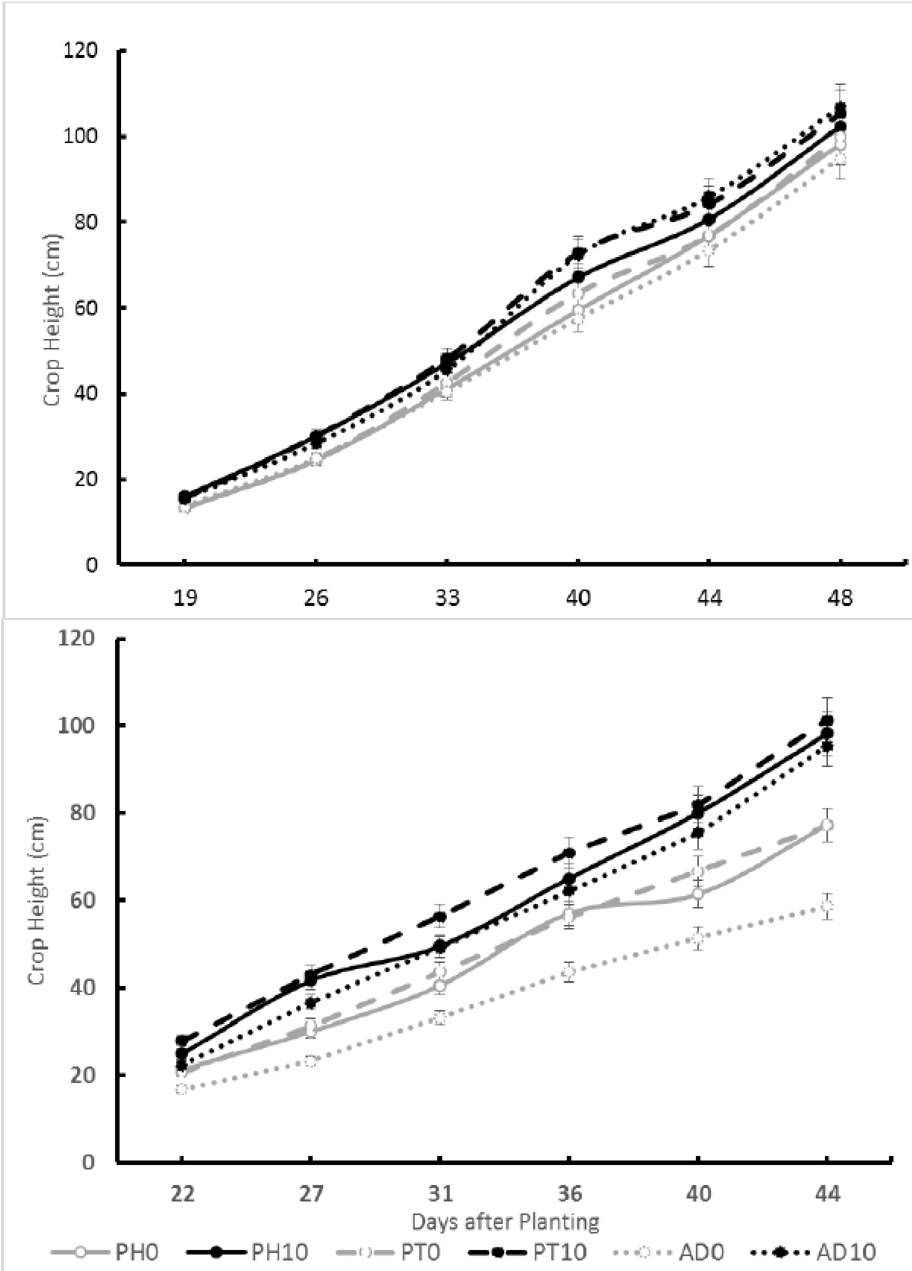

Figure 2. Plant Growth Trends in Various Treatments for the First season (top) and Second Season (bottom)

NOTE: AD10 and AD0 = Ox-plough tilled soils with and without biochar respectively: PT10 and PT0 = Power tiller tilled soils with and without biochar respectively: PH10 and PH0 = Soils with planting basins with and without biochar respectively. The bars stand for percentage error in the values

Biochar level had pronounced effect on crop growth rate in all the three incorporation (tillage) methods. While tillage methods had a noticeable effect on crop growth rate in biochar enhanced soils only. The biochar level main effect was larger than the incorporation method main effect in both seasons (Figure 3).

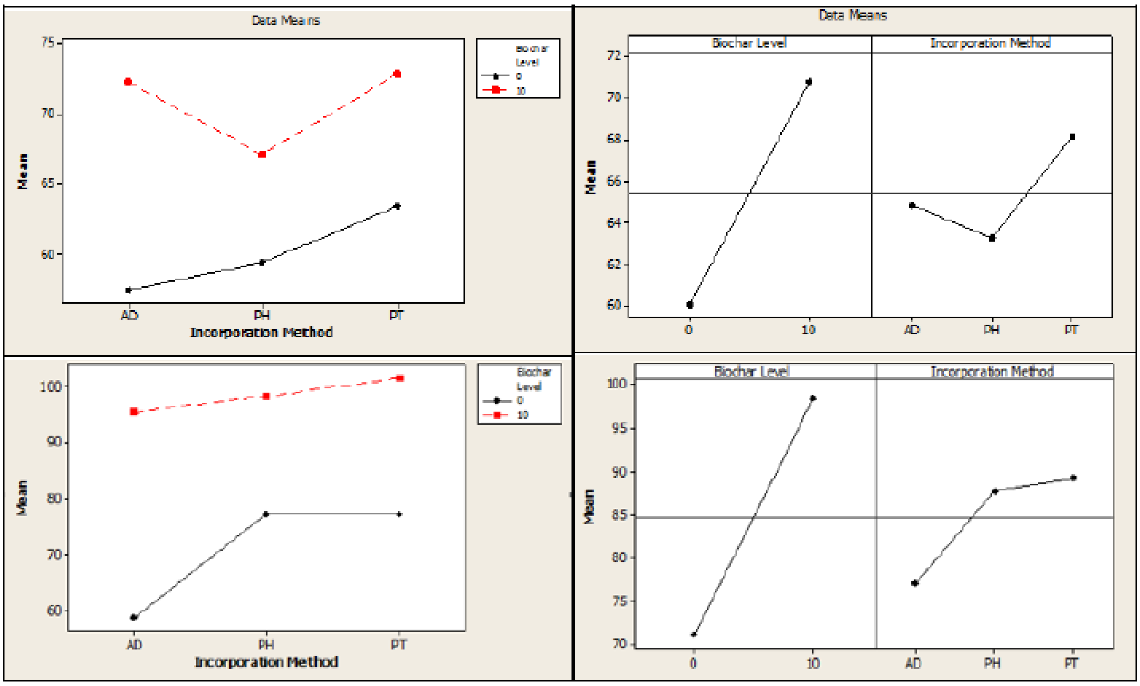

Figure 3. Interaction Plot for Crop Heights in the First (top left) and Second (bottom left) Seasons: Main Effect Plot for Crop Heights in First (top right) and Second (bottom right) Seasons

Incorporation Method: AD = By Ox-plough, PH = By Hands in planting basins (Control) and PT = By Power tiller

However, a pairwise comparison of treatments based on crop heights on the 44th day, on the second season, showed that a significant difference was only observed in unenhanced soils. This showed that when the soils were amended with biochar, tillage (incorporation) method had no effect on crop growth rate up to the second season. Table 2 shows the differences in mean crop heights between the control (PH) stripe and each of the other two stripes. However, all the differences were found to be not significant ($p \geq 0.05$). Therefore, no change was observed in maize growth due to incorporating biochar by power tiller and ox-plough, compared to hand mixing in planting basins.

The results show that when ox-ploughs and power tillers are used to incorporate biochar there is no significate effect on crop growth rate as compared to hand mixing in planting basins up to two seasons. Also when the two tillage methods are used on unenhanced soils, the growth of maize is as when planted in basins up to the second season as long as no tillage is done in the second season.

3.3 Effects on Yield

The results of grain yields for each treatment are presented in Figure 4. It is clear that application of biochar increased yield very significantly during both seasons ($p < 0.001$). However, the average increase on the second season was three times higher than on the first season. Zhang *et al.* (2016) also reported an increase in maize yield of 11.9% and 35.4% on the first and second seasons, respectively, due to the application of biochar in the first season. There was no significant difference in crop yield among the three tillage methods on the first season ($p = 0.081$) in both biochar enhanced soils and unenhanced soil (Figure 4, left).

There was significant differences in yields between some tillage methods ($p = 0.018$) but they were observed in unenhanced soils only (Figure 4, right). Differences between the yields from manually incorporated biochar (pot-holed soils) and each of the other two incorporation methods were observed on both seasons but were not significant ($p = 0.4$ and 0.7 for first and second seasons respectively). Therefore, no effect on yield was seen as a result of incorporating biochar with power tiller or ox-plough.

Table 2. Crop heights on 40th and 44th days of the first and second seasons respectively in various treatments

Treatment[a] (N)	Crop Height[b]	Crop Height[b]	Differences[c]	
	Season 1 (cm)	Season 2 (cm)	Season 1	Season 2
PH10 (3)	67.1 ±3.5ab	98.3 ± 8.5a		
AD10 (3)	72.3 ±4.6a	95.5 ± 2.8ab	5.2*	-2.8*
PT10 (3)	72.9 ±3.3a	101.4 ± 6.7a	5.8*	3.1*
PH0 (3)	59.5 ±2.4b	77.3 ± 8.0bc		
AD0 (3)	57.5 ±7.6b	58.8 ± 8.5c	-2.0*	-18.5*
PT0 (3)	63.5 ±3.2ab	77.3 ±11.5bc	4.0*	0.0

[c]Differences from Controls (PH0 and PH10): [*]Not significant at α = 0.05

[b]Means that do not share a letter are significantly different at α = 0.05

[a]Treatments: AD10 and AD0 = Ox-plough tilled units with and without biochar respectively

PT10 and PT0 = Power tiller tilled units with and without biochar respectively

PH10 and PH0 (Controls) = Units with planting basins with and without biochar respectively

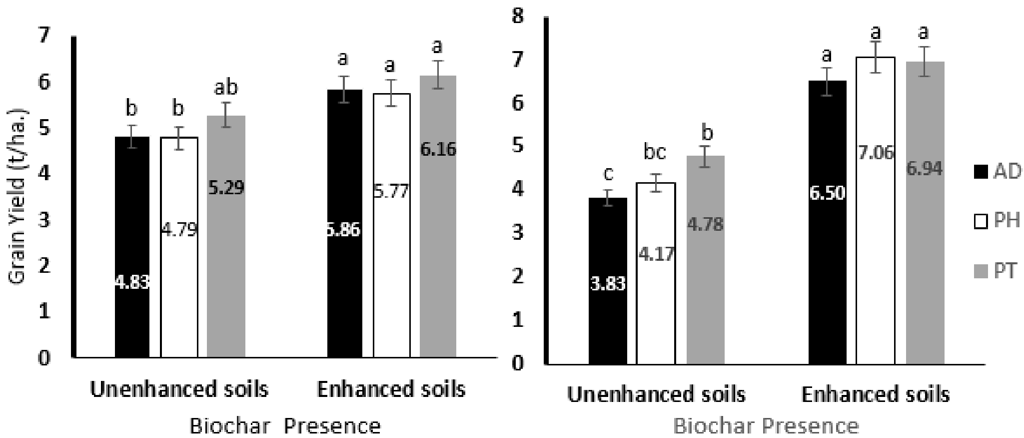

Figure 4. Mean Grain Yields for Various Tillage Methods during First (left) and Second (right) Seasons

Means that do not share a letter are significantly different at α = 0.05

NOTE: AD = Ox-plough tilled soils, PH = Pot-holed soils (Control), and PT = Power tiller tilled soils

Bars stands for percentage error in values

These results mean that incorporating biochar by power tiller and ox-plough had no significant effect on maize growth and yield compared to mixing biochar by hands in planting basins. Cornelissen *et al.* (2013), reported a 444% increase in maize yield when biochar was mixed by hands in planting basins in western Zambia. Deal *et al.* (2012) reported an increase of 63% in maize yield when biochar was mixed by hands in potted plants at Kabanyolo in central Uganda. Kimetu *et al*. (2008) reported an increase of 27% in maize yield when biochar was incorporated, to 10 cm depth, by a hand hoe in Kenya. In Colombia, a disc harrow was used to incorporate biochar to 5 cm depth and a positive effect on maize yield was reported (Major *et al.* 2010). However, in all these and many other reported findings on effects of biochar on maize yield, it was not clear how medium-scale farmers could upscale biochar application to a commercial level. The new findings reveal that even if in the previous trials power tillers or ox-ploughs were used to incorporate biochar, results would have been the same or better. This gives hope to medium scale commercial farmers to participate in biochar technology as they conventionally use power tiller and ox-plough to prepare seedbeds (Kawuyo, Atiku, & Bwala**,** 2012). Dennis & Kou (2014) also used a power tiller to incorporate biochar, to a depth of about 15 cm, in their trial and reported an increase in sugar beet yield due to the application of biochar. An increase of 5.9 t ha^{-1} in maize yield was reported due to the addition of 15 t ha^{-1} biochar incorporated into the soil by a power tiller in Indonesia (Sukartono, Utomo, Kusuma & Nugroho, 2011).

It has been reported that reduced tillage, in form of strip tillage and use of planting basins, improves crop yield through increased soil water availability (Lamm, Aiken & Kheira, 2009). This is especially true when conventional extensive tillage is done in every cropping season. However, this fact does not contradict with the findings here as biochar does not need to be applied every cropping season (Major *et al.*, 2010; Major 2010). It is advisable to extensively till the land after a number of cropping seasons even in zero tillage system. Thus, biochar application through mechanised incorporation described here can still be integrated into zero tillage system doubling the benefits of soil water and nutrients conservation. In their laboratory experiment Yang, Zhao, Gao, Xu and Cao (2016) showed how biochar coagulate soil minerals, a process by which biochar improves soil structure. This process is increased when biochar is distributed all over the field other than when it is localised in planting basins. The results will also help to identify adoptable and effective tillage technologies that can be integrated into biochar application systems (Nsamba, Hale, Cornelissen & Bachmann, 2015). Thereby, increasing scalability and hence adoptability of the technology among medium scale commercial farmers cultivating between 2 and 5 ha, who are majority in land constrained countries like Uganda (Wanyama et al., 2016).

4. Conclusion

The study successfully assessed the effects of incorporating biochar with power tiller and ox-plough on the performance of biochar. The findings have shown that both power tiller and ox-plough can be used to incorporate biochar with the same expected results as hand mixing in planting basins. Commercial medium scale farmers can, therefore, effectively incorporate biochar on 2 to 5 ha fields using conventional, and already necessary, power tiller and ox-plough tillage systems with reasonable timeliness. It is, therefore, recommended here that promotion of biochar technology encompasses the use of power tillers and ox-ploughs to enhance scalability to commercial levels among emergent (medium scale) farmers. Future studies should focus on measuring, quantitatively, the effect of the various incorporation methods on the interaction between biochar and soil biota.

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