

Bio-char from sawdust, maize stover and charcoal: Impact on water holding capacities (WHC) of three soils from Ghana

Emmanuel Dugan^A, Anne Verhoef^A, Steve Robinson^A and Saran Sohi^B

^ADepartment of Soil Science, School of Human and Environmental Sciences, University of Reading, Reading RG6 6D Email: emmdugan@gmail.com

^BUK Bio-char Research Centre, University of Edinburgh, Crew Building, The King's Building, Edinburgh, EH9 3JN.

Abstract

This paper reports part of an on-going investigation into the effects of bio-char on soil physical properties in Ghana. Bio-char from sawdust (B1) and maize stover (B2) were prepared using a muffle furnace. The effect of local charcoal from Ghana (referred to in this paper as B3) was also studied. These three types of bio-char were applied to three soil types from Ghana, at 5, 10 and 15 t/ha. Results indicated that WHC was increased when bio-char was applied at all rates compared to zero application. However, there wasn't much difference in effect on WHC between the rates. It is suggested that water repellency of the bio-char partly explains this behaviour. Improving WHC by bio-char application was more effective in sandy textured soils.

Key Words

Bio-char, water holding capacity, maize stover, sawdust and charcoal

Introduction

This study aims to further the recent research efforts on the evaluation of bio-char as a soil enhancer (e.g. Yeboah *et al.*, 2009) and as a means to mitigate increasing levels of carbon dioxide in the atmosphere. The carbon sequestration benefit results from the fact that bio-char takes carbon from the atmosphere-biosphere pool and transfers it to a slower cycling form that can exist for hundreds of years (Fowles, 2007). The primary benefit of bio-char in Ghana is its positive effect on agricultural productivity, as most soils are acidic and some have problems of aluminium toxicity, a condition amenable to bio-char application (Lehmann *et al.*, 2003). Low soil organic matter content in soils resulting from high temperatures and rainfall, are responsible for the low available water capacity and weak structure of many agricultural soils (Piccolo *et al.*, 1996). Glaser *et al.* (2002) stated that bio-char added to soil may not only change soil chemical properties but also affect soil physical properties, such as soil water retention and aggregation. Hence, there is a need for researchers to gather evidence on the capability of bio-char to improve soil physical properties, notably soil water retention and availability, soil aggregation and infiltration, thereby sustaining agriculture on already converted forest lands in Ghana.

Methods

Soil sampling

The top soil layer (0-15 cm depth) was sampled from three sites in Ghana, followed by the removal of all plant debris. The soil samples were air-dried and sieved through a 2 mm mesh, prior to physical and chemical analysis of the soils.

Soil textural classification

The soil textural analysis was carried out by the Bouyoucos/hydrometer method (Bouyoucos, 1962). After measuring the sand, silt and clay distributions, the soils were assigned to textural classes (Table 1) with the help of a textural triangle.

Soil bulk density

The dry bulk densities (BD) of the soils were determined on intact soil cores (5 cm diameter), sampled from the 1-15cm depth. The cores were oven-dried at 105°C for two days. The bulk densities were calculated using the formula below:

$$\text{Bulk density} \left(\text{gcm}^{-3} \right) = \frac{(W_2 - W_1)}{V \text{cm}^3} \text{g} \quad (1)$$

where W_2 and W_1 are weights of moist and oven-dry soils, respectively, and V is the volume of the cylindrical core.

Charring maize stover and sawdust

Dry maize stover, collected from farmers' fields in Ghana, as well as sawdust obtained from small woodcuts from a local sawmill in Kumasi, Ghana, were exported to Reading University, UK, where they were subjected to carbonization under anoxic conditions using a muffle furnace, operated at atmospheric pressure (method as used by Braadbaart and Poole, 2008, with slight modifications). The stover samples were placed into the furnace at ambient temperature (~20°C) in pre-weighed rectangular aluminium containers and heated to a pre-selected final temperature (420°C for maize stover, being soft wood, and 450°C for the sawdust). The times of exposure were 70 and 75 minutes, respectively. Sawdust (sieved to particle size <0.5 mm) was placed in a cleaned metal syrup tin. A 1mm hole was drilled in the lid and pressed firmly on the tin. This provided a small opening for steam and gas to escape to avoid explosion as the heating progressed. The weight of the filled containers was measured, before placing it in the furnace, so that the initial weight of maize stover and sawdust used could be calculated. As soon as the set temperature was reached and remained over the given time, the furnace was switched off and allowed to cool for about thirty minutes before transferring the samples into a dessicator for further cooling. The samples were then removed for weighing. B3 was not treated in the UK but collected in Ghana from local charcoal makers.

Determination of water holding capacity of soils and soils treated with bio-char

To test the effect bio-char on the soils' water holding capacity – WHC (also known as field capacity), WHC of the soils and soils treated with bio-char were determined. WHC is the maximum amount of water the freely drained soil can hold, which is estimated after a saturated soil has been allowed to drain without allowing its moisture stores to be depleted by evaporation. To do this, 20 grammes of the air- dried soil sample, in triplicate, were put in a plastic container (with a wire mesh at the bottom) and placed in a dish of water. This was allowed to become saturated, for approximately six hours. The container was removed from the water and covered with cling-film to prevent loss of water by evaporation. It was then hanged on a retort stand overnight to allow drainage. All samples were allowed to drain for the same amount of time. Next, soil was carefully removed from the container, put in a pre-weighed container (M_1) and the total weight of moist soil and moisture container (M_2) was taken. The samples were then dried in an oven at 105°C until no further water loss occurred, and reweighed to record the oven-dried sample (M_3). The WHC was determined from:

$$WHC(\%) = \frac{M_2 - M_3}{M_3 - M_1} \times 100 \quad (2)$$

Results

Table 1 summarises the basic physical properties of the soils under study. The relatively high BD of Soil E is consistent with the observed high sand fraction (sandy soils have higher bulk densities compare to loamy and clayey soils, Phogat *et al.*, 1999), low clay fraction and exceptionally low OC content. This condition is typical for Ferric Lixisols (Oguntunde *et al.*, 2004), which have potentially higher infiltration, decreased aggregation and lower water holding capacities compared to Chromic Lixisols (soil A) and Ferric Acrisols (soil K) [Yeboah *et al.*, 2009]). Soils A and K are loams, sandy loam and silt loam respectively.

Table 1. Characteristics of soils from the study sites.

	Soil A	Soil K	Soil E
Textural class	Sandy Loam	Silt Loam	Loamy Sand
Sand %	60.0	30.6	79.8
Silt %	36.6	53.3	18.1
Clay %	3.4	16.1	2.1
Classification (WRB)	Chromic Lixisol	Ferric Acrisol	Ferric Lixisol
Bulk Density (kgm^{-3})	1293.9±32.7	1378.9±48.9	1448.8±20.23

Effect of bio-char on water holding capacity of three soils from Ghana

Figures 1-3 show the effects of applying bio-chars (B1, B2 and B3) at 5, 10 and 15 t/ha to three Ghanaian soil types differing in classification and texture (Table 1).

Figure 1 shows that the maize stover bio-char (B2) increased the WHCs of all three soil types ($P = 0.001$), most significantly for soil E, although WHC at the highest application rate for all soils was lower than that at 5 and 10 t/ha, but still considerably higher than at zero application. The textural class of soil E was earlier described as loamy sand (Table 1), with about 80% sand fraction. Even though soil A and K were also improved in their water retention capabilities (at all rates), the rate of improvement was far greater for soil E. The rate of increase in WHC for soil E ranged from 349-481%, compared to 36-56% for soil A and 27-41% for soil K, clearly confirming observations by Tryon (1948) that moisture retention increased particularly when charcoal (bio-char) was applied to sandy soil. Furthermore, this is also proof of Downie *et al.*'s (2009) proposition that because small pores in bio-char retain moisture, and because small pores (with a relatively large water holding capacity, as this scales with the pore radius) are largely absent in coarser-textured soils, bio-char should have the greatest effect on water retention in sandy soils. Similar observations can be made for sawdust bio-char (B1) as shown in Figure 2.

Similarly, the WHCs of the three soils were improved by B1 bio-char (Figure 2), and very much so in the coarser textured soil E. However, the rate of increase is slowed after 5 t/ha. For all soils, increasing the application rate from 5 to 10 t/ha, decreases the WHC, whereas increasing the application rate to 15 t/ha brings WHCs up to values that are higher than at any of the other application rates. Even though the statistical report (using Duncan multiple test range) indicated a marked difference ($P = 0.001$) between zero bio-char and other rates, no significant difference was reported between 5, 10 and 15 t/ha, suggesting that the optimum rate of bio-char application to improve soil moisture retention was 5 t/ha. Water repellence might have occurred at higher concentrations of the bio-char. Another possible explanation is that addition of more bio-char negatively affected the soil structure and hence the soil's WHC.

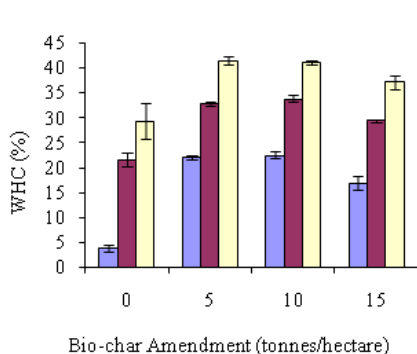


Figure 1. WHC of three soils amended with maize stover bio-char (B2) at three rates.

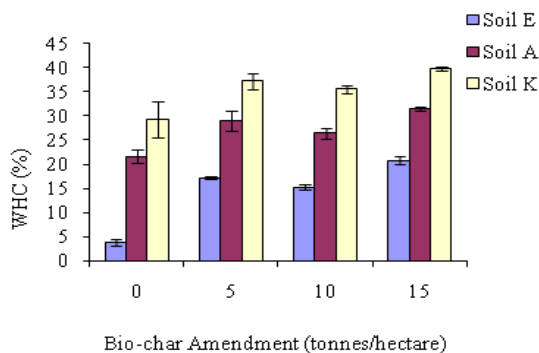


Figure 2. WHC of three soils amended with sawdust bio-char (B1) at three rates.

As evidenced in Figure 3, the WHC of the sandy textured soil E was the least improved by charcoal B3 (36.69% increase at 5 t/ha); after reaching its optimum at 5 t/ha the water retention capabilities of the soil decreased by 31.78% and 0.005% at 10 and 15 t/ha, respectively, as compared to the untreated soil. Many factors may have attributed to this rather unusual observation. Among them is the hydrophobicity due to the hydrophobic polymers [Glaser *et al.*, 2002] present and in such quantities as to cause water repellence after 5 t/ha application rate. These hydrophobic substances might have been redistributed within the soil, much more in sandy soil and at application rates larger than 5 t/ha. Hence, there is an urgent need to investigate and ascertain the type of feedstock used for making B3 in Ghana at the collection site.

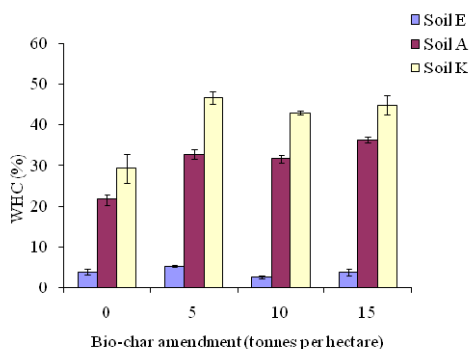


Figure 3. WHC of three soils amended with charcoal (B3) at three rates.

Conclusions

Based on the results, the study could conclude on the following:

WHC was increased when bio-char was applied at 5, 10 and 15 t/ha, compared to zero application of bio-char. However, there was no significant difference between the rates. These results suggest that 5 t/ha is the optimum application rate; Water repellence of the bio-char appears to start playing a role when bio-char application exceeds 5 t/ha; the magnitude of this effect depends on the feedstock characteristics; Improving WHC by bio-char application is more effective in sandy textured soils. It is, however, worthy to note that this may not apply to bio-char from all feedstock. Some feedstock may have hydrophobic substances whose effects may be felt more for a different soil texture, at rates higher or lower than 5 t/ha.

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