Geoderma 307 (2017) 189–197

Contents lists available at ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

# Soil water retention, air flow and pore structure characteristics after corn cob biochar application to a tropical sandy loam

E. Amoakwah[a,b,*], K.A. Frimpong[a], D. Okae-Anti[a], E. Arthur[b]

[a] Department of Soil Science, College of Agriculture and Natural Sciences, School of Agriculture, University of Cape Coast, PMB, Cape Coast, Ghana
[b] Department of Agroecology, Faculty of Science and Technology, Arhus University, Blichers Allé 20, P. O Box 50, DK-8830 Tjele, Denmark

## ARTICLE INFO

Handling Editor: Morgan Cristine L.S.

## ABSTRACT

Soil structure is a key soil physical property that affects soil water balance, gas transport, plant growth and development, and ultimately plant yield. Biochar has received global recognition as a soil amendment with the potential to ameliorate the structure of degraded soils. We investigated how corn cob biochar contributed to changes in soil water retention, air flow by convection and diffusion, and derived soil structure indices in a tropical sandy loam. Intact soil cores were taken from a field experiment that had plots without biochar (CT), and plots each with 10 t ha$^{-1}$ (BC-10), 20 t ha$^{-1}$ without or with phosphate fertilizer (BC-20 and BC-20 + P respectively). Soil water retention was measured within a pF range of 1 to 6.8. Gas transport parameters (air permeability, $k_a$, and relative gas diffusivity, $D_p/D_0$) were measured between pF 1.5 and 3.0. Application of 20 t ha$^{-1}$ led to significant increase in soil water retention compared to the CT and BC-10 as a result of increased microporosity (pores $< 3$ μm) whereas for soil specific surface area, biochar had minimal impact. No significant influence of biochar was observed for $k_a$ and $D_p/D_0$ for the BC treatments compared to the CT despite the larger values for the two properties in the 20 t ha$^{-1}$ treatments. Although not significant, the diffusion percolation threshold reduced by 34% and 18% in the BC-20 and BC-20 + P treatments, respectively, compared to the CT. Similarly, biochar application reduced the convection percolation threshold by 15 to 85% in the BC-amended soils. The moderate impact of corn cob biochar on soil water retention, and minimal improvements in convective and diffusive gas transport provides an avenue for an environmentally friendly disposal of crop residues, particularly for corn cobs, and structural improvement in tropical sandy loams.

## 1. Introduction

Soil structural stability, which is defined as the spatial heterogeneity of the different components or characteristics of soil (Dexter, 1988), has enormous effects on plant growth and development, through its effects on soil water balance, and soil workability. Soil structure is a key soil quality factor that can influence crop productivity as it affects storage and movement of soil water, nutrients, and gases within the soil matrix. For instance, soil structure determines the characteristics of water movement in the soil ecosystem, and can thus influence the dissolution and availability of nutrients to growing plants. For agriculture purposes, a healthy soil structure is viewed as that which shows a combination of well-developed soil aggregates and pore systems (Bronick and Lal, 2005), enhancing the exchange of gases between soil and atmosphere. Soil structure also determines the ability of soils to carry out essential ecosystem functions and services such as turnover of organic matter, provision of optimal conditions for microbial activity, and C sequestration (Gregory et al., 2007; Lal and Shukla, 2004). Soil pores occurring within (intra) soil aggregates and between (inter) aggregates serve as pathways for soil water and air movement. The movement of water and gas in the soil profile is influenced not only by the amount of pores and their sizes but also by the pore connectivity and tortuosity (Osozawa, 1998), which is to a large extent related to the geometric characteristics of soil pore structure. Soils with low oxygen diffusivity (below a threshold value of 0.02) restrict root development (Deepagoda et al., 2011), which results in stunted growth and poor yield in crops. The interaction between soil self-organizing processes such as renewal of soil gases and solution by exchange with the environment (Targulian and Krasilnikov, 2007) and management strategies such as incorporation of organic amendments determines the extent of pore structure development (Sun et al., 2013).

Several authors have reported improvements in plant yield following biochar application (Biederman and Harpole, 2013; Blackwell et al., 2009; Jeffery et al., 2014). The improved crop yields found in biochar amended soils is partly attributed to positive improvement in soil physical and hydraulic parameters, such as decreased soil

---

[*] Corresponding author at: Department of Agroecology, Faculty of Science and Technology, Arhus University, Blichers Allé 20, P. O Box 50, DK-8830 Tjele, Denmark.
*E-mail address:* amoakwah.2@osu.edu (E. Amoakwah).

http://dx.doi.org/10.1016/j.geoderma.2017.08.025
Received 21 June 2017; Received in revised form 8 August 2017; Accepted 13 August 2017
0016-7061/

penetration resistance, and bulk density (Busscher et al., 2011) and increased water-holding capacity (Kinney et al., 2012). Also, biochar has high porosity and specific surface area, which can affect the total pore space and gas transport at the soil-atmosphere interface and within the soil ecosystem (Sun et al., 2013). In a study conducted by Obia et al. (2016), application of corn cob biochar at rates of 0.8 to 2.5 w/w% to a tropical sandy soil increased total porosity and available water capacity by 2 to 3% respectively. Studies by Sun et al. (2013) showed that birch wood biochar improved soil pore structure indices such as pore tortuosity and pore organization by enhancing convective gas transport and increasing the ratio of macroporosity to total porosity. Comparatively, biochar has a lighter density than mineral soil, and this property of biochar has been reported by Sun et al. (2015) to significantly increase the total pore spaces of soil. Abel et al. (2013) reported increased total pore volume in the soil medium following the incorporation of 1–5 wt% biochar produced from maize feedstock (mixture of whole plant). Although several studies report beneficial effects of biochar application, detrimental effects may also occur. Most biochars have high pH, with the potential to increase soil pH, and this can potentially increase clay dispersibility due to a dominance of repulsive forces between clay minerals (Roth and Pavan, 1991), and in turn result in decreased aggregation and disruption of soil structure. Kumari et al. (2017) found increased content of water dispersible colloids (WDC) following application of birch wood biochar; an observation they attributed to increased soil pH and decreased electrical conductivity in the biochar-treated soils. Busscher et al. (2010) reported a significant decrease in soil aggregation when biochar produced from pecan shells was applied, whereas Fungo et al. (2017) reported absence of an effect of biochar on soil aggregate stability following application of 2.5 t $ha^{-1}$eucalyptus wood biochar pyrolyzed at 550 °C to a Typic Kandiudult. Similarly, rice-straw biochar, when applied to an Ultisol, had no effect on soil structural stability (Peng et al., 2011). Undoubtedly, the above enumerated findings on biochar effects on soil aggregate stability are contrasting, thus emphasizing the need to quantify distinct soil and biochar properties for every situation (Khademalrasoul et al., 2014).

Previous studies have reported the effect of biochar application on the volume and architecture of soil pores, however, the mechanisms underlying these changes are yet to be fully understood (Atkinson et al., 2010; Lehmann et al., 2009). Further, for soils of the humid tropics, research on the effects of biochar on gas transport parameters and soil water retention characteristics is relatively limited (Mukherjee and Lal, 2013). Therefore, the objectives of the study were to examine the mechanisms underlying the effect of corn cob biochar on soil water retention, air flow by convection and diffusion, and derived soil structure indices under a series of controlled matric potentials.

## 2. Materials and methods

### 2.1. Study area and soil characteristics

The research was conducted at the University of Cape Coast Teaching and Research farm located in the coastal savanna agro ecological zone of Ghana (5°07′N, 1°17′W). The area has two seasons; a rainy season where most rainfall events are recorded between April and October, with June being the wettest month (average rainfall of 327 mm), and a dry season where a long dry spell is recorded between November and March, with March being the hottest month (with a maximum temperature of 31 °C). The area is generally characterized by high rainfall (1400 mm per annum) with mean monthly temperatures ranging from 24 °C to 28 °C. The soil is well-drained sandy loam (18, 9 and 73% by weight of clay silt and sand, respectively) developed on sandstones, shales and conglomerates and classified as a *Haplic Acrisol* (IUSS Working Group WRB, 2015). The chemical properties of the soil in the study area prior to biochar application include the following: 0.93% soil organic carbon, 0.073% total nitrogen, total phosphorus, potassium and magnesium contents were $< 0.4$, 11.9 and 9.3 mg 100 $g^{-1}$, respectively, soil pH of 6.1 and an electrical conductivity of 200 μS $cm^{-1}$.

### 2.2. Field experimentation and sampling

#### 2.2.1. Biochar properties

The biochar was produced from corn cob feedstock pyrolyzed in a reactor (Lucia stove) with a temperature of 500–550 °C. The biochar produced was sieved to a $<$ 2 mm particle size to obtain a relatively high surface area to improve its reactivity in the soil. The biochar had 85.3% dry matter, 38.8% total carbon, 0.9% total nitrogen, pH of 10.2, 3.31 mg $kg^{-1}$ polycyclic aromatic hydrocarbons, 3150 mg $kg^{-1}$ phosphorus, with $Ca^{2+}$, $Mg^{2+}$, $K^{+}$ and $Na^{+}$ of 8690, 4510, 31,800 and 2160 mg $kg^{-1}$, respectively (Amoakwah et al., 2017).

#### 2.2.2. Field layout

The study adopted the randomized complete block design with thirty-two (32) plots (four treatments with eight replications for each treatment), with each plot measuring 3 m × 6 m (18 $m^2$). In order to achieve fine tilth, the field was ploughed and harrowed twice, followed by the removal of stubble and weeds. The plots were raised to 15 cm above the natural soil surface to enhance drainage and accommodate access pathways (0.6 m) between plots. Three levels of biochar were used in this study; 10 t $ha^{-1}$ and 20 t $ha^{-1}$, and 20 t $ha^{-1}$ with P (P-enriched biochar), corresponding to 0, 0.34 and 0.68% respectively. The P-enriched biochar was prepared by mixing 50 kg $P_2O_5$ $ha^{-1}$ (Triple super phosphate) with 0.68% of biochar. This treatment was included to examine whether pre-treating biochar with P will minimize P fixation by aluminum ($Al^{3+}$) and hence promote P availability. Investigation into P fixation was not included here since it was not within the scope of this paper. Prior to biochar application, a subsample of the corn cob biochar stock was oven-dried to determine the prevailing water content.

On 7th November 2016, biochar (with and without P fertilizer) was applied by broadcasting on the soil surface of the treatment plots and incorporating it into the soil by plowing to a depth of about 20 cm. To maintain consistency in the treated and untreated plots, all the plots (control and treated) were tilled with a hoe after the biochar application. Hereon, the treatments are denoted by CT, BC-10, BC-20, and BC-20 + P for the 0, 10 t $ha^{-1}$ and 20 t $ha^{-1}$, and 20 t $ha^{-1}$ with P, respectively. Soil sampling was done on 21st May 2016.

### 2.3. Soil sampling

Metal core samplers (0.034 m length, 0.061 m in diameter, 100 $cm^3$ sample volume) were used for intact soil sampling from a depth of 0–20 cm. The sampling for all treatments was done in the center of the plot within rows, avoiding visibly compacted areas. Eight replicate samples were taken for each treatment. At the same locations, disturbed bulk samples were taken for other measurements (texture, organic matter, pH, dry region water retention, etc.)

### 2.4. Laboratory measurements

#### 2.4.1. Soil texture and organic carbon content

Soil texture was determined by a combination of sieving and hydrometer methods (Gee and Or, 2002). Determination of soil total carbon content was done through the oxidation of carbon to $CO_2$ at a temperature of 1800 °C with a FLASH 2000 organic elemental analyzer, which was coupled to a thermal conductivity detector (Thermo Fisher Scientific, MA, USA). Since carbonates were absent in the soils, the soil total carbon was considered as soil organic carbon (SOC).

#### 2.4.2. Soil pH and electrical conductivity

Soil pH was determined by mixing 8 ml of air dried soil and 30 ml of