Geoderma 243–244 (2015) 175–182

Contents lists available at ScienceDirect

Geoderma

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

Effects of biochar and manure amendments on water vapor sorption in a sandy loam soil

E. Arthur [a,*], M. Tuller [b], P. Moldrup [c], L.W. de Jonge [a]

[a] Department of Agroecology, Faculty of Science and Technology, Aarhus University, Blichers Allé 20, P.O. Box 50, DK-8830 Tjele, Denmark
[b] Department of Soil, Water and Environmental Science, The University of Arizona, 1177 E. 4th Street, Tucson, AZ 85721-0038, USA
[c] Department of Civil Engineering, Aalborg University, Sofiendalsvej 11, DK-9200 Aalborg SV, Denmark

ARTICLE INFO

Article history:
Received 10 September 2014
Received in revised form 24 December 2014
Accepted 3 January 2015
Available online 14 January 2015

Keywords:
Specific surface area
Water retention
Organic carbon
Adsorption
Desorption
Hysteresis

ABSTRACT

Over the last decade, the application of biochar (BC) as a soil amendment to sequester carbon and mitigate global climate change has received considerable attention. While positive effects of biochar on plant nutrition are well documented, little is known about potential impacts on the physical properties of soils, especially on water retention at low matric potentials. To overcome this knowledge gap, the effects of combined BC (0 to 100 Mg ha^{-1}) and manure (21 and 42 Mg ha^{-1}) applications on water vapor sorption and specific surface area were investigated for a sandy loam soil. In addition, potential impacts of BC aging were evaluated. All considered BC-amendment rates increased water retention, especially at low matric potentials. The observed increases were attributed to a significant increase of soil organic matter and specific surface area (SSA) in BC-amended soils. Hysteresis of the water vapor sorption isotherms increased with increasing BC application rates. Biochar age did not significantly affect vapor sorption and SSA.

1. Introduction

Over the last decade, the practice of amending agricultural soils with biochar to sustain and improve fertility has gained increasing attention and has led to a surge in soil and environmental science research. Biochar (BC) incorporation into soils is now generally accepted as a management tool for carbon sequestration and the mitigation of global climate change (Larson, 2007; Sohi et al., 2010). While numerous studies have demonstrated benefits of biochar amendments for plant nutrition (e.g., increased nutrient retention, decreased leaching capacity, increased pH (Laird et al., 2010; Ventura et al., 2013)), and soil remediation (e.g., heavy metal sequestration (Jiang et al., 2012; Uchimiya et al., 2011)) knowledge about the effects of biochar on the physical plant growth environment is lagging behind (Atkinson et al., 2010).

Biochar amendments have been shown to decrease soil bulk density (Laird et al., 2010) thereby increasing air-filled porosity (Sun et al., 2013). An increase in water holding capacity has also been reported for wet conditions, when matric potentials (ψ) exceed −1.5 MPa (Abel et al., 2013; Ibrahim et al., 2013). The effects of biochar amendments on saturated hydraulic conductivity (k_{sat}) and air permeability (k_a) are much less clear; some studies have reported increases (Asai et al., 2009; Sun et al., 2013), while others have demonstrated decreases (Devereux et al., 2012; Kumari et al., 2014b) in k_{sat} and k_a following BC application.

With one exception (Sun et al., 2013), all relevant studies about effects of BC on soil water retention have focused on the wet-end of the soil water characteristic (SWC). The primary reasons for this are difficulties related to dry-end measurements and the focus on plant available water only. The effect of BC on the dry-end of the SWC ($\psi < -15$ MPa or > pF 5; pF $= \log_{10}(|\psi|)$, where ψ is the matric potential in cm) is thus barely documented. The water vapor sorption isotherm of a soil describes the relationship between relative humidity and the equilibrium water content obtained at a given temperature. The dry-end of the SWC is synonymous to water vapor sorption isotherms (WSI) since relative humidity and soil matric potential can be directly related via the Kelvin equation. Knowledge about WSIs for soils is crucial for understanding and modeling numerous soil processes including volatilization of volatile organic compounds and pesticides, and water vapor transport (Amali et al., 1994; Arthur et al., 2014a; Chen et al., 2000). The field study of Sun et al. (2013) considering a sandy loam soil amended with birch wood BC at 20 tons ha^{-1} for seven months, showed no effect of BC application on the dry-end SWC (pF 5 to 6.8), nor on soil specific surface area (SSA). Conversely, SSA was reportedly greater for black carbon rich soils when compared to adjacent soils (Liang et al., 2006), and for BC-amended soils in a 500-day column

Abbreviations: BC, biochar; SWC, soil water characteristic; WSI, water vapor sorption isotherm; SSA, specific surface area; PS, pig slurry; TC, total carbon; SOC, soil organic carbon; SPN, single-parameter non-singularity model; α, water vapor sorption hysteresis index.

* Corresponding author.
E-mail addresses: emmanuel.arthur@agro.au.dk, quamena2001@yahoo.com (E. Arthur).

http://dx.doi.org/10.1016/j.geoderma.2015.01.001

experiment with 5 to 20 g BC kg^{-1} (Laird et al., 2010). This disagreement about the effect of BC on SSA could be due to the differences in physicochemical biochar properties (due to differences in biomass and pyrolysis temperatures), the BC application rates, and/or the soil textures investigated in various studies.

Characterization of WSI hysteresis, defined as the difference between the adsorption and desorption branches of the sorption isotherm, is important for modeling biological processes below the plant wilting point matric potential (Prunty and Bell, 2007) and to accurately simulate processes in the soil–plant–atmosphere system (Globus and Neusypina, 2006). While data about the effect of BC on water vapor sorption is clearly lacking, there are a few studies detailing BC effects on sorption hysteresis of pesticides and herbicides in the aqueous phase (Martin et al., 2012; Yu et al., 2010).

Biochar, due to its mostly inert nature, is often applied to soils in conjunction with organic or mineral fertilizers (e.g. Asai et al., 2009; Laird et al., 2010). Furthermore, observed effects of BC may depend on its residence time within the soil prior to sampling and analysis. It is important to consider biochar aging as results obtained in field or laboratory studies a short time after BC application do not necessarily represent conditions in the same field after an extended period of time. For example, for 19-month aged birch wood biochar-amended soils, phenanthrene sorption was significantly lower than for seven-month aged soils (Kumari et al., 2014a), while diuron sorption seemed unaffected by aging (Yang et al., 2006). This emphasizes the importance of aging when evaluating the impact of BC on other soil properties.

The primary objective of the present study was to evaluate the combined effect of biochar (0 to 100 Mg ha^{-1}) and pig manure (21 and 42 Mg ha^{-1}) amendments on water vapor sorption (−10 to −480 MPa; pF 5.0 to pF 6.6), hysteresis of the water vapor sorption isotherms, and the specific surface area of a sandy loam soil. The secondary objective was to assess potential effects of biochar age on WSIs.

2. Methodology

2.1. Field site, treatments and sampling

The experimental field plot was located in Kalundborg, Denmark (55°42′N, 11°18′E). The soil texture was classified as sandy loam (Table 1). The applied biochar was composed of birch wood pyrolyzed at 500 °C (Skogens Kol AB, Kilafors, Sweden) and exhibited the following physicochemical properties: carbon, 81%; nitrogen, 0.24%; pH, 8.8; specific surface area, 322 m^2 g^{-1}; polycyclic aromatic hydrocarbons (PAH) < 0.88; particle size distribution, 6, 74, and 19% for the < 4, 4–8, and > 8 mm particle sizes, respectively (Sun et al., 2013). The experiment consisted of 12 plots (6 × 6 m) with different levels of BC and manure (pig slurry; PS) amendments.

Further details about the plot design are reported in Sun et al. (2014). Four of the 12 plots, designated as "2011 (+21 PS)", had 21 Mg PS ha^{-1} and 0, 10, 20, and 50 Mg BC ha^{-1}, both applied in April 2011. The next four plots, designated as "2012 (+21 PS)", had 21 Mg PS ha^{-1} applied in April 2011 and 0, 10, 20, and 50 Mg BC ha^{-1} applied in April 2012. The last four plots, designated as "2011 + 2012 (+42 PS)", had 42 Mg PS ha^{-1} applied in April 2011 and 0, 10, 20, and 50 Mg BC ha^{-1} applied both in 2011 and 2012, doubling the applied amounts to 0, 20, 40, and 100 Mg BC ha^{-1}, respectively. The nutrient content of the PS was determined as 105 kg N ha^{-1}, 21 kg P ha^{-1}, and 6 kg S ha^{-1} for the rate of 21 Mg PS ha^{-1}. The dry matter (DM) content of the PS was 6% with carbon contributing 40% of the DM. Biochar for all plots was incorporated via harrowing to a depth of 10 cm. To ensure uniformity among treatments, the control plots were also harrowed. Maize was grown on all fields during the experimental period and results have shown no effect of biochar on maize biomass yields. Details about biomass yields are reported in Sun et al. (2014). Sampling of bulk soil from all plots (six equally-spaced sampling grid points per plot) was conducted in October, 2012. Thus, for the 2011 (+21 PS) plots, sampling occurred 19 months after BC application, whereas for the 2012 (+21 PS) and 2011 + 2012 (+42 PS) plots, sampling was conducted seven months after BC application. All bulk soil samples from each particular plot were combined, thoroughly homogenized, air-dried, crushed, sieved (<2 mm), and stored in plastic bags for subsequent analyses. The obtained composite samples were then used for all subsequent measurements described below.

2.2. Laboratory measurements

2.2.1. Soil texture, organic carbon, and specific surface area

Soil texture was analyzed with a combination of sieving and hydrometer methods (Gee and Or, 2002). Total carbon (TC) was determined by means of oxidation of carbon to CO_2 at 1800 °C with a FLASH 2000 organic elemental analyzer coupled to a thermal conductivity detector (Thermo Fisher Scientific, MA, USA). Total carbon (TC) was considered as soil organic carbon (SOC) since no carbonates were detected. For soil texture and TC two subsamples from the homogenized samples were analyzed. If obtained results considerably differed a third subsample was analyzed. Soil specific surface area, denoted SSA_{EGME}, was measured in triplicate by means of EGME adsorption (Pennell, 2002) without removing organic carbon prior to analysis (Cihacek and Bremner, 1979; de Jonge et al., 2000).

Table 1
Texture, organic carbon content (OC), specific surface area (SSA), model parameters of the SPN model (N_a, N_d), and water vapor sorption hysteresis parameter (α) for the control and combined biochar-manure amended plots.

Application year	Biochar rate	Clay (<2 μm)	Silt (2–50 μm)	Sand (50–2000 μm)	OC	SSA_{EGME}	SSA_{TO}	N_a	N_d	α (N_a/N_d)
	Mg ha^{-1}	%				m^2 g^{-1}		(−)		
2011[a]	0	8	23	69	1.59	20.5 ± 0.6	26.0	0.83	0.77	1.07
	10	10	25	65	1.81	29.4 ± 0.2	33.7	0.86	0.80	1.07
	20	10	26	63	2.19	27.3 ± 0.3	33.1	0.89	0.79	1.12
	50	11	28	61	2.71	32.7 ± 1.3	36.1	0.92	0.82	1.12
2012[a]	0	9	24	67	1.48	21.9 ± 1.1	25.9	0.87	0.80	1.09
	10	10	27	62	1.74	31.1 ± 1.8	32.2	0.88	0.79	1.11
	20	12	28	60	2.25	33.1 ± 0.3	32.5	0.90	0.81	1.11
	50	12	29	60	3.50	33.7 ± 1.2	34.1	0.90	0.79	1.14
2011 + 2012[b]	0	9	23	69	1.64	18.9 ± 1.6	31.4	0.88	0.80	1.10
	20	9	23	68	2.37	27.6 ± 1.9	34.6	0.86	0.77	1.11
	40	9	25	66	3.14	31.7 ± 1.0	37.3	0.85	0.75	1.23
	100	10	24	66	4.76	40.0 ± 0.8	37.4	0.92	0.75	1.23

Soil texture and organic carbon data adapted from Sun et al. (2014). ± indicates standard error of the mean ($n = 3$).
[a] Pig slurry applied at 21 Mg ha^{-1}.
[b] Pig slurry applied at 42 Mg ha^{-1} in 2011.