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Short communication

Biochar presence in soil significantly decreased saturated hydraulic conductivity due to swelling

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ABSTRACT

The application of biochar on two contrasting soils was tested in order to assess its effects on soil hydraulic properties (SHP) and study the interaction between water and the biochar surface (e.g., the swelling effect).

Two contrasting soil types were enriched with 0, 2 and 5% (wt.) doses of grape stalks biochar in order to prepare soil samples for a 14-days continually saturated laboratory experiment. H_2O bonds to the biochar surface were detected using FTIR spectroscopy.

Results show that water molecules were bound through polar hydrogen bonds to O—H and C—O—H, and these interactions caused (i) intensive swelling, which decreased the bulk density and enhanced the water holding capacity (up to 5% in the case of sandy loam and 5% biochar dose), and (ii) significantly decreased *Ks* in both soils (with a maximum difference of 82.6%).

The results of this laboratory experiment provide useful information about the significant effect of presented biochar in two contrasting soils, and its application appears to be an potential option for addressing drought (especially in coarser soils). Nevertheless, these findings must be verified under field conditions where the presence of biota and long-term effects can be taken into account.

1. Introduction

Among other advantages, biochar has also been recently tested for its potential to affect soil hydraulic properties (SHP) such as saturated hydraulic conductivity (*Ks*) and soil water retention curve (RETC). Lim et al. (2016) and Barnes et al. (2014) reported that biochar addition decrease *Ks* in sandy soils and increase *Ks* in clay-rich soils. Furthermore, water holding capacity (WHC) can be increased (although not always significantly) by the biochar application (see Herath et al., 2013; Burell et al., 2016; Glab et al., 2016). The observed decreasing effect of biochar on *Ks* has been explained by (i) the obstruction of water flow through effective soil pores by biochar particles (Barnes et al., 2014; Lim et al., 2016); (ii) the gradual clogging of soil pores by moving biochar particles (Wang et al., 2013; Barnes et al., 2014); (iii) a decrease in the volume of effective pores by sorbed water (Uzoma et al., 2011; Jeffery et al., 2015); and (iv) an increase in the number of micropores ($< 1\,\mu$m), which bind to water by strong capillary and/or adsorptive forces (Hillel, 1998; Hardie et al., 2014; Lim et al., 2016). The latter two are connected with the interactions of biochar surface and water molecules. In more details, water can be sorbed on the biochar surface: (i) using physical sorption through π interaction to the carbon surface (Shi et al., 2014); (ii) by hydrogen bonds on carboxyl groups (Kutílek and Nilsen, 1994); and/or (iii) by hydration interaction with cations (Kutílek and Nielsen, 1994; Shi et al., 2014). As a result, such water-biochar interactions can also significantly affect the swelling effect which has been usually omitted in the recent studies reflecting the effect of biochar to SHP. As a novel approach we will, therefore, try to fill the gap of knowledge to deeply understand and describe the effect of swelling caused by presented biochar as well as to confirm consequent response in the form of decreased *Ks* value. Specifically, one selected biochar from previous study of Trakal et al. (2014) with high CEC value was tested (Table 1).

The aims of this paper are, therefore, (i) to reveal the biochar effect (with high CEC) on *Ks* variability in two soils of contrasting texture over the period of time; (ii) to evaluate the effect of biochar on water holding capacity at saturation; and mainly (iii) to describe mechanism(s) of the

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Table 1
Initial characteristics of the materials used; data shown are means ± SD (n = 3).

Material used	ρ^a ($g\ cm^{-3}$)	Texture (%) Clay ($< 2\,\mu m$)	Silt ($2\text{-}50\,\mu m$)	Sand ($0.05\text{-}2$ mm)	CEC ($cmol_{(+)}\ kg^{-1}$)	pH (-)
Soil	1.21 ± 0.005^b	8.7 ± 1.0	34.8 ± 4.3	56.5 ± 4.4	9.08 ± 0.42	5.95 ± 0.01
Kaolin clay	0.46 ± 0.007	68.5 ± 2.1	31.5 ± 2.1	< DL	8.51 ± 0.21	5.43 ± 0.04
Biochar	0.16 ± 0.004^c	$/^c$	$/^c$	$/^c$	40.2 ± 0.3^d	10.0 ± 0.1^d

^{a}bulk density; ^{b}undisturbed dried soil sample; ^{c}100% of particles are < 0.50 mm; ^{d}values presented in Trakal et al. (2014).

swelling caused by presented biochar.

2. Materials and methods

2.1. Biochar preparation and analysis

Grape stalks, a common by-product of wine production, were used in this study for the biochar preparation. The production methodology and initial characteristics of the biochar is/are described by Trakal et al. (2014). Additionally, the interaction (i.e., chemical bonds) between water molecules and the biochar surface was identified using an ATR technique (Fourier Transform Infra-Red (FTIR) Nicolet Avatar 360, 1.92 cm^{-1} resolution) in order to more precisely describe the swelling effect (bindings of the sorbed H_2O molecules on the biochar surface). The preparation procedure for FTIR analysis is written in the supplement of this paper.

2.2. Soil and sample ring preparation

The Fluvisol (classified as sandy loam; hereinafter CS) was collected from an uncultivated alluvium (= unaffected soil properties; for more information see the supplement) and such soil was air-dried, sieved (< 2 mm) and homogenised. For the preparation of the contrasting clay-enriched soil (classified as loam; hereinafter CSK), the same soil was thoroughly mixed with 20% (wt.) of kaolin clay with lower plasticity and swelling compared to most other clay minerals (Hillel, 1998).

Next, milled biochar (< 0.50 mm) was then applied to each of the contrasting soils (CS and CSK) at two doses, 2% and 5% (wt.), by careful mixing. The following system was used throughout the experiments to label the samples: control soil (CS); soil amended by 2% and 5% biochar (S2B) and (S5B); kaolin clay-modified control soil (CSK); kaolin clay-modified soil amended by 2% and 5% biochar (SK2B) and (SK5B). Each prepared soil variant was then repacked into a standard stainless-steel ring (volume of 100 cm^3), where five sample rings were filled for each variant.

2.3. Laboratory measurements

The samples were first gradually saturated from bottom in order to eliminate the effects of entrapped air (Jačka et al., 2014). Next, the *Ks* of the samples were measured using the constant head method and calculated according to its primary defining Darcy's equation. The 5 control samples were always measured in parallel against the 5 samples amended by the biochar for each particular measuring at 10 regular time intervals during the 14-day experiment of continual water flow through the samples. Subsequently, each saturated sample was immediately weighed and dried to a constant weight. From the difference in weights, the water holding capacity at saturation (WHC) was then calculated. At the end of experiment, swelling effect was measured as an increase of soil sample over the edge of randomly selected sample rings. The increase in volume of particular sample was then responsible for the swelling.

2.4. Statistical analysis

The normality of each dataset (i.e., individual measurements and soil treatments) was verified using the Shapiro-Wilk test. Next, one-way ANOVA analyses were carried out to assess the differences in initial bulk density, *Ks* (for each specific value at each time step) and WHC among the treatments. When a significant effect was indicated, differences among means were determined using Tukey's test. All statistical analysis was performed in the R software environment at the 0.05 probability level.

3. Results and discussion

3.1. The effect of swelling caused by the biochar presence

The interaction of H_2O molecules with the biochar surface is presented in Fig. 1. The FTIR spectra confirmed water binding on O—H and C—O—H functional groups through polar (hydrogen) bonds which is in agreement with the results presented by Chen et al. (2014). Furthermore, the 4 individual FTIR spectra showed decreasing intensity of the O—H peak, reflecting the release of water during the continuous drying process. The intensity decrease was not visible in the case of water

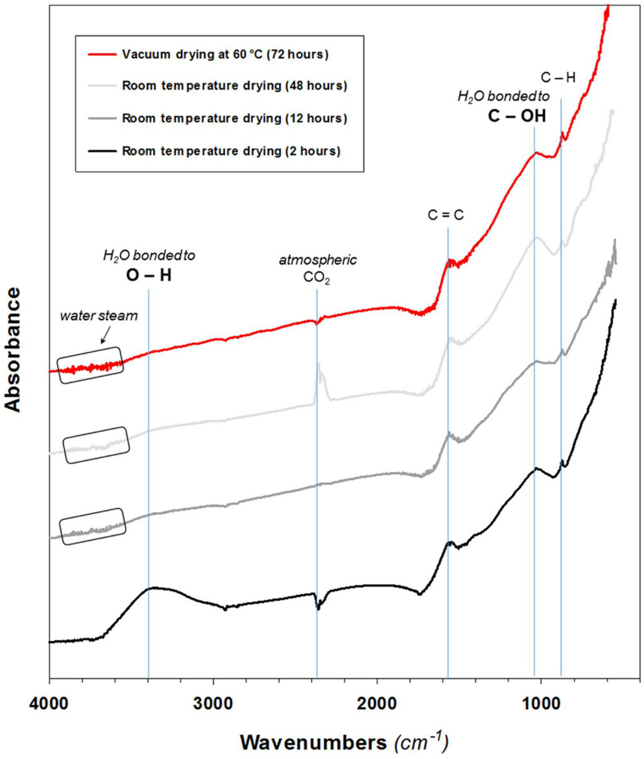

Fig. 1. FTIR spectra of the biochar dropped by pure water at four stages (after 2, 12 and 48 drying under atmospheric conditions and oven drying at 60 °C in vacuum and consequent putting above the water table).