Agricultural Water Management 163 (2016) 190–196

Contents lists available at ScienceDirect

Agricultural Water Management

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

Field application of pelletized biochar: Short term effect on the hydrological properties of a silty clay loam soil

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ARTICLE INFO

Article history:
Received 23 July 2015
Received in revised form
14 September 2015
Accepted 18 September 2015
Available online 4 October 2015

Keywords:
Pelletized biochar
Available water capacity (AWC)
Water retention curve (WRC)
Soil conditioner
Pore size distribution

ABSTRACT

The field application of pelletized biochar is seldom employed and its effect on soil hydrological behavior scarcely investigated. Biochar is usually added in powdered or granular form to improve the homogeneity of distribution, meanwhile favoring its interaction with soil matrix. In this paper we evaluated the possibility of applying pelletized biochar as soil conditioner during a single cropping season of a tomato cultivation. For that purpose, the water retention curves (WRCs) were determined three months after the addition of two differently pyrolysed biochars (B1 and B2), at the rate of 14 Mg ha^{-1}, to a silty clay loam soil prone to compaction. Starting from the WRCs the pore size distribution was determined. The gravimetric water content at both field capacity (FC) and wilting point (WP) was also measured on biochar samples to assess their available water capacity (AWC).

In both the treatments, soil bulk density (BD) was significantly lower compared to control (Co), apparently as direct consequence of the addition of low density pellets. Actually, excluding the intrinsic biochar porosity from soil bulk density calculation, BD values of the treated soils remain lower of around 10% over Co. Such findings suggest that a modification of soil structural characteristics might have been induced by pellet addition. Data of the SWRCs indicate a significant increase in transmission (500–50 μm), storage (50–0.5 μm) and AWC pores (30–0.2 μm) for the amended soils. The pyrolysis process seemed to differentiate the extent of direct biochar contribution expressed by AWC values The addition of pelletized biochar was able to enhance the soil water retention properties even in the short term, and such improvement might be correlated to both the inherent biochar retention capacity and to a more functional rearrangement of soil aggregates/particles with pellets.

1. Introduction

Several specific trials have been carried out to study the effects of biochar application on soil physical properties at both laboratory and field scale. The main recurrent soil physical properties investigated to assess the effect of biochar employment, included specific surface area (SSA), bulk density (BD), porosity, aggregate stability, but also hydrological properties such as saturated hydraulic conductivity (Ks) and available water capacity (AWC). When applied to coarse textured soils with low soil organic carbon content, a soil SSA increase was commonly observed (Liang et al., 2006; Laird et al., 2010; Mukherjee and Lal, 2013), as well as a reduction in BD and, conversely, a porosity increase (Oguntunde et al., 2008; Laird et al., 2010; Masulili et al., 2010; Eastman, 2011; Abel et al., 2013; Herath et al., 2013; Jien and Wang, 2013; Hardie et al., 2014). In addition, an enhanced soil hydrological behavior was observed after biochar employment in terms of both AWC (Eastman, 2011; Liu et al., 2012; Abel et al., 2013; Herath et al., 2013; Ouyang et al., 2013), soil moisture (Akhtar et al., 2014) and Ks (Uzoma et al., 2011; Herath et al., 2013; Jien and Wang, 2013; Hardie et al., 2014; Lim et al., 2015). Therefore, while Uzoma et al. (2011) observed a general AWC increase and a Ks decrease in a sandy soil, both Herath et al. (2013) and Jien and Wang (2013) found a general improvement of Ks in a poorly drained silty loam and in a silty clay soil, respectively.

In such studies, therefore, the modifications induced to the soil are dependent from soil properties (*in primis* texture), biochar

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http://dx.doi.org/10.1016/j.agwat.2015.09.017
0378-3774/

characteristics and rate of application. Actually, biochar can differentiate each other for several features: pyrolysis process (temperature and residence time), feedstock material and size (powder, granules, pellet). With regard to the size, biochar is typically distributed to soil in powdered or granular form to improve its incorporation and interaction with the soil matrix (Lehmann and Joseph, 2009; Novak et al., 2009). Pelletized biochar is seldom employed because of the difficulties in guaranteeing either its homogeneous distribution or interaction with soil matrix; nevertheless, there are some examples of pellets use as substrate in greenhouse crop production (Dumroese et al., 2011; Vaughn et al., 2013). Therefore, the majority of works refer to the employment of fine particles of biochar.

The application of biochar might increase soil porosity and, indirectly, improve soil hydrology by three main mechanisms: (a) direct contribution due to intrinsic biochar porosity, as suggested by several authors (Downie et al., 2009; Major et al., 2009; Atkinson et al., 2010; Sohi et al., 2010; Verheijen et al., 2010); (b) interaction with soil matrix and improvement of soil structure and its stability as suggested by Verheijen et al. (2010); (c) creation of packing, or accommodation, pores as indicated by Hardie et al. (2014).

The first physical mechanism can potentially and directly promote soil porosity; nevertheless, the hydrological efficacy of biochar should depend on the features of its pores (size, shape, continuity). With that regard, Verheijen et al. (2010) indicated that most of biochars have a porosity mainly characterized by very small pores and by only very few pores within the AWC range. Nevertheless, Hardie et al. (2014) did not find any AWC increase after the application of a biochar (47 Mg ha^{-1}) characterized by pore diameters within AWC range. Similarly, Jeffery et al. (2015) did not registered any AWC improvement as consequence of the high hydrophobicity of the biochar employed.

The second mechanism involves the improvement of soil structure and its stability as a consequence of the soil matrix–biochar interaction. In this case, provided the physico-chemical and biological nature of the process involved, the possibility of register such evidences is strictly dependent on the incubation time, soil and biochar characteristics being equal. The third mechanism might improve soil hydrology by the creation of accommodation pores between biochar particles and surrounding soil aggregates. Hardie et al. (2014) outlined that the size and extent of such new pores mainly depend on soil texture and biochar size, along with the degree of settling following the incorporation. For instance, Eastman (2011) observed that biochar application to a silt loam soil increased either fissures of 1500 μm, similarly to tillage, or retention pores (0.5 μm). On the contrary, Jones et al. (2010) noticed as the addition of fine biochar particles significantly reduced soil macroporosity in a coarse textured soil by a partial filling of the voids. Provided the merely mechanical nature of such process, it could occur even in the short term (Eastman, 2011; Novak et al., 2012) and be promoted by the employment of larger biochar size. Therefore, the questions about the optimal size of biochar particles able to improve soil moisture retention and the mechanism involved has yet been answered (Major, 2010).

The present paper shows the results of a field experiment aimed at assessing the hydrological effects induced by the incorporation of two differently-processed pelletized biochars on the structure of a silty clay loam soil prone to compaction. The choice of using pelletized biochar, instead of the more common powdered or granular forms, was motivated by the greater availability of pellets of wheat bran destined to livestock in the study area and by the need of better understanding the mechanisms by which the incorporation of coarse biochar particles may affect, even in the short term, soil hydrological behavior.

2. Materials and methods

2.1. Biochar and field experiment

The choice of pelletized wheat-bran as feedstock for biochar production was made considering the availability of such biomass in the district, an important area for pasta production, therefore simulating a realistic biochar production chain. In the present experiment two types of biochars (B1 and B2), obtained by the same feedstock material but differing for pyrolysis process, were employed. B1 was produced in a transportable kiln provided by Blucomb srl (http://www.blucomb.com) through a pyrolysis process at 800 °C with average residence time of 3 h; B2 was produced in an industrial plant (AGT, http://www.agtgasification.com/) through a pyrolysis process at 1200 °C with average residence time of 0.5 h. Biochar pellet density was on average equal to 0.62 and 0.56 g cm^{-3}, in B1 and B2, respectively, while their cylindrical shape had approximately sizes of 5 mm in diameter and 16 mm in length. The field trial was carried out during the spring-summer season of 2013 in an experimental farm (Azienda Stuard http://www.stuard.it) close to the city of Parma, Italy (Lat. 44°48′23″N; Long. 10°16′30″E; 58 m a.s.l.). The soil was a silty clay loam (Haplic Calcisol, IUSS Working Group WRB, 2010), under processing tomato (*Lycopersicon esculentum* Mill., cultivar Pietrarossa). At the beginning of May, a randomized block design with 8 replicates for each treatment was set up. Individual plot size measured 10 m^2, with a 0.5 m buffer. Three treatments were compared: (i) Control (Co) without biochar application, (ii) soil added with biochar B1, and (iii) soil added with biochar B2. Both the biochars were manually applied at a rate of 14 Mg ha^{-1} (dry weight) one week before tomato transplanting, and partially buried with a rotary hoe tiller at 0.15 m depth. This was in line with application rates often reported in the literature (e.g., Liu et al., 2013).

2.2. Soil sampling

At the end of the crop growing season 24 undisturbed soil samples were collected from the uppermost 0.10 m, by which both bulk density and water retention properties were determined. Metal cylinders of 122 cm^3 (7.2 cm diameter, 3 cm height) with a sharpened edge were used, sealed up and stored to prevent both moisture loss and formation of soil structural artifacts.

2.3. Soil water retention analysis

The water content at saturation was measured on sand box (Clement, 1966), whereas further nine retention measurements at the matric potentials of −4, −10, −33, −50, −100, −200, −500, −1,000 and −1,500 kPa were determined by means of pressure plate extractors (Klute and Dirksen, 1986). The moisture content at each matric potential was then expressed as percentage by weight of the dry soil (θ_d).

The retention data at field capacity (FC) (−10 kPa) and wilting point (WP) (−1500 kPa) were used to determine the available water capacity (AWC = FC–WP).

On the same soil samples, at the end of the analysis soil BD was determined according to Blake and Hartge (1986), removing the contribution of skeletal and roots, which particle density was assumed equal to 2.65 and 0.70 g cm^{-3}, respectively. The bulk density values were then used to convert the gravimetric water content data on a volumetric basis (θ_v) by applying Eq. (1) (Gardner, 1986)

$$\theta_v = \theta_d \frac{\mathrm{BD}}{\rho_\mathrm{w}} \tag{1}$$

where ρ_w is the density of water.