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Effect of poultry litter biochar on Ultisol physical properties

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A study was carried out to investigate the effect of biochar produced from the pyrolysis of poultry litter feedstock in some of the physical properties of a Yellow Red Argisol eutrophic typical (Ultisol), located in the municipality Lagoa Seca, State of Paraiba, Brazil, that is, granulometric analysis, bulk density, porosity and available water capacity. Six doses of biochar (0; 10; 15; 20; 25 and 30 ton ha^{-1}) were incubated into an Ultisol samples during 60 days. All assays were carried out in duplicate. After the incubation period, the soil samples were analyzed in relation to physical properties. The results of this study confirmed that the biochar prepared from the poultry litter improved these properties, that is, modified the granulometric analysis, led to a decrease in bulk density, an increase in total pore volume as well as an increase in water content mainly in matric potential 0.5065 MPa. The biochar dose, 30 ton ha^{-1} was better in soil density and porosity; in the water retention the best biochar dose was 15 ton ha^{-1}; however, as the biochar effects on the physical properties were very small, it suggests to investigate larger amounts of this material in the application of the soils.

Key words: Poultry litter, soil amendment, soil physical, porosity, bulk density.

INTRODUCTION

The organic matter has implications directly or indirectly on some chemical and physical phenomena in the soil. The direct effects are related to the high specific surface area and the large amount of surface charges in organic matter.

Indirectly, organic matter interferes in soil physical behavior by its effects on soil aggregation and consistency, acting on the formation of aggregates and, therefore, on the distribution of pore size, as well as retention and availability of water in the soil. To improve physical soil properties and fertility there is a need to increase soil organic carbon content.

For this purpose, integrated use of organic and inorganic fertilizer is becoming an emerging trend.

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Organic fertilizers such as chicken litter, compost and manure, are used nowadays as a source of organic carbon but their rate of decomposition is very high (Palm et al., 2001). Because of this, there is need to use such organic fertilizer, which is recalcitrant to decomposition for a long period, and maintain the soil organic carbon status.

There is currently a lot of study soil compaction by effecting limiting root growth of plants. Plants are the source of life in the living world. They perform many ecological functions in their environment, and they shape the life of living things in the environment where they live. The life of living things in the world is directly or indirectly dependent on plants (Sevik and Cetin, 2015; Cetin, 2016; Guney et al., 2016). The ability of plants to fulfil their functions primarily depends on the availability of appropriate climatic and edaphic conditions (Guney et al., 2016; Cetin and Sevik, 2016). Therefore, soil is one of the absolutely necessary conditions for plant existence, which is essential for the life of living things.

The soil is defined as "the part of the solid earth that has been altered by the loosening of the earth, humus formation and chemical decomposition, by the transport of humidification and chemical decomposition products". However, when it is examined in detail, the soil is a very complex structure and the biological and biochemical process in the soil is the basis of the terrestrial ecosystem (Cetin and Sevik, 2016; Sevik et al., 2016; Turkyilmaz et al., 2017). In this respect, it is very important to examine the structural change of the soil and to determine its relation with the plant.

Some studies shows that it examined the change of the soil structure in the forests according to the tree species. An attempt to determine some soil characteristics based on tree species and depth of soil was made within the scope of the study. Soil is important for forest and landscape. Enzymes in the soil structure ensure that they are alive in forest areas (Sevik and Cetin, 2015; Cetin and Sevik, 2016).

The poultry sector in Brazil has been expanded as can be seen from 1.7 to 12.3 million tons per year of chicken meat from 1987 to 2013. However, due to prohibition on the use of poultry litter in animal feed, an excess of this residue has been generated (União Brasileira de Avicultura 2007, 2014). Among the alternatives for the final destination of the chicken litter is its direct use in the agricultural soil as a source of organic matter and nutrients, or the production of energy and biofertilizer in biodigesters (Andrade et al., 2015). Biochar obtained by pyrolysis of chicken manure represent an additional option for recycling this waste in agriculture and then it might be applied to soils as an amendment. This waste is of special interest for the production of biochar in Brazil due to the high production generated by year, as Corrêa and Miele (2011) is around 6.8 million m^3.

Biochar is defined simply as charcoal that is used for agricultural purposes. It is a product of thermal decomposition of biomass produced by the slow thermo-chemical pyrolysis of biomass under oxygen-limited conditions. Their properties depend upon the type of biomass used for feed stock and pyrolysis conditions that is, charring time, rate and temperature (Mukherjee and Lal, 2013).

The poultry litter biochar has many agricultural benefits; it is a useful resource to improve the chemical properties of soil, such as, for example, increasing soil pH, cation exchange capacity (Chaves and Mendes, 2016), fertilizer-use efficiency and increase crop production, particularly for long-term cultivated soils (Van Zwieten et al., 2010). However, the growth parameters of crambe, (Vasconcelos et al., 2017), sesame and sunflower plants (Furtado et al. 2016 a,b) decreased with the doses of poultry litter biochar applied in the soil, that is, the doses used in this research harmed the development of plants, probably due to increased salinity in the soil.

According to Jien and Wang (2013), many studies have reported the use of biochar in soil improving the chemical properties in highly weathered tropical soils (Iswaran et al., 1980; Liang et al., 2006). However, few studies have investigated the effects of biochar on soil physical properties (Atkinson et al., 2010). According to Kimetu and Lehmann (2010), the biochar improve the soil aggregation stability because biochar is characterized by recalcitrant C from microbial degradation and by a charged surface with organic functional groups; and, it retains soil moisture, helping plants through periods of drought more easily (Lehmann et al., 2006).

Several researchers studying the effects of organic matter on soil physical properties (clay content, soil density, flocculation power, porosity, and compaction) have found positive results. However, these effects of organic matter and still others on the physical properties of the soils must be different, or not, of the effects of the biochar in them. Therefore, it is necessary to study the effects of the biochar in the physical properties of the soils.

The objective of this study was to evaluate the effects of biochar produced from poultry litter on the physical properties of a predominant soil of the humid region located on the eastern slopes of the Borborema Plateau, with mild climate and rainfall exceeding 1200 mm per year. It is acidic soil with low activity clay intensely cultivated with fruit crops, pastures, sugarcane and various food crops.

MATERIALS AND METHODS

The experiment was carried in Irrigation and Salinity Laboratory of the Department of Agricultural Engineering, UFCG, at May, 2017. The sample soil was collected from the top layer (0 to 0.20 m) of a Yellow Red Argisol eutrophic typical (Ultisol) located in the municipality Lagoa Seca, State of Paraiba, Brazil. The physical-chemical characterization was performed in air-dried soil sample passed through a 10 mesh (2mm) sieve (air-dry fine earth, ADFE) according to the methodology of EMBRAPA (1997) (Table 1).

Table 1. Chemical and physic characterization of Ultisol and biochar samples.

Attributes	Ultisol	Attributes	Biochar
Calcium ($cmol_c$ kg^{-1})	1.56	Calcium (g kg^{-1})	48.3
Magnesium ($cmol_c$ kg^{-1})	1.18	Magnesium (g kg^{-1})	14.6
Sodium ($cmol_c$ kg^{-1})	0.06	Sodium (g kg^{-1})	7.3
Potassium ($cmol_c$ kg^{-1})	0.26	Potassium (g kg^{-1})	47.16
Hydrogen+Aluminum ($cmol_c$ kg^{-1})	1.27	Hydrogen+Aluminum	-
Electrical conductivity (mS cm^{-1})	0.16	Electrical conductivity (mS cm^{-1})	12,69
Organic carbon (g kg^{-1})	8.60	Organic carbon (g kg^{-1})	-
Phosphorus (mg kg^{-1})	4.9	Phosphorus (g kg^{-1})	29.4
pH H_2O (1:2.5)	5.7	pH H_2O (1:2.5)	10.2
Sand (g kg^{-1})	736.0	Sand (g kg^{-1})	836.8
Silt (g kg^{-1})	100.3	Silt (g kg^{-1})	100.0
Clay (g kg^{-1})	163.7	Clay (g kg^{-1})	63.2
Bulk density (g cm^{-3})	1.29	Bulk density (g cm^{-3})	-
Porosity (%)	51.32	Porosity (%)	-

The biochar used in this study were produced from poultry litter (PL), a solid waste resulting from chicken rearing, under slow pyrolysis, by SPPT Technological Research Ltda. The attributes present in Table 1 were found according to the methodology of Andrade and Abreu (2006). The biochar sample was submitted to dispersive energy spectroscopy (DES) (that is, a semi-quantitative quantification of the sample), which identified the presence of the chemical elements (Table 1).

In order to get an impression of the biochar pores, it was visualized the morphology of the chars by electron - microscopic and optical microscopy images using SEM Hitachi TM-1000 and OM Hirox KH-1300, respectively. To evaluate the effect of biochar in soil physical properties, initially, soil and biochar samples were passed through a 10 mesh (2 mm) sieve, then, samples soil (0.4 kg) were placed in plastic pots (experimental units), mixed with biochar according to the treatments (0; 1.6; 2.3; 3.1; 3.9 and 4.6 g, corresponding to 0; 10; 15; 20; 25 and 30 ton ha^{-1}, respectively) and incubated during 60 days using deionized water at about 60% of field capacity.

All assays were carried out in duplicate. After this period, physical properties of samples soil were performed according to the methodology described by EMBRAPA (1997). Particle size was analyzed by densimeter method, also known as hydrometer method, proposed by Bouyoucos. Bulk density (a) was determined by the graduated test tube method, and particle density (b) by the volumetric flask method. The total porosity was calculated as [(b-a) / b] x 100; and moisture contents of the samples were measured at different matric potentials (1.52; 1.01; 0.51; 0.10; 0.033 and 0.01 MPa). The moisture of the samples was determined by the Richard extractor (EMBRAPA, 1997).

RESULTS AND DISCUSSION

The amount of the mineral particles that compose the soil, clay, silt and sand, varied according to the increasing doses of biochar applied to the soil, and the amount of sand increased by around 8.18%, while the amounts of silt and clay decreased by around 40.08 and 12.22%, respectively (Figure 1). Probably this variation is in agreement with the behavior of the biochar; although this material is organic, when analyzed regarding textural behavior presented 836.8; 100.0 and 63.2 g kg^{-1} of sand, silt and clay.

In fact, biochar is not formed by these mineral particles, but according to the size of the particles of biochar, during the particle size analysis, using sodium hydroxide, as a dispersant, behaves as if it were the mineral particles in relation to the size of the particles. Therefore, the increasing application of biochar to the soil increased the amount of particles with the size corresponding to sand in the granulometric analysis of the soil mix with biochar.

The physical properties of the soil evaluated in this study were influenced by the mixture of soil with biochar. Bulk density and the pore space of soil have a significant effect on soil properties as well as on plant growth (Aslam et al. 2014). The results indicated a decrease in bulk density (Figure 2A) and increase in porosity (Figure 2B) in the biochar-amended soil corroborating Jien and Wang (2013) and Abel et al. (2013).

Soil porosity is related to aeration and soil water movement. Aeration refers to the ability of soils to meet the respiratory demand of the biological life of the soil. For this, there is a need for continuous exchange of oxygen and CO_2 between the atmosphere and the soil, which is influenced by the proper porosity of the soil. Besides, the water retention influencing the development of the plants, the movement of the water acts to control the temperature and aeration of the soils.

According to Mukherjee et al. (2013), the soil bulk density varies inversely with the porosity as a function of the application of biochar, this is because porosity of biochar is very high and when it used in soil it significantly decrease bulk density by increasing the pore volume. The higher the number of pores (macro pores) the soil presents, the lower its density.

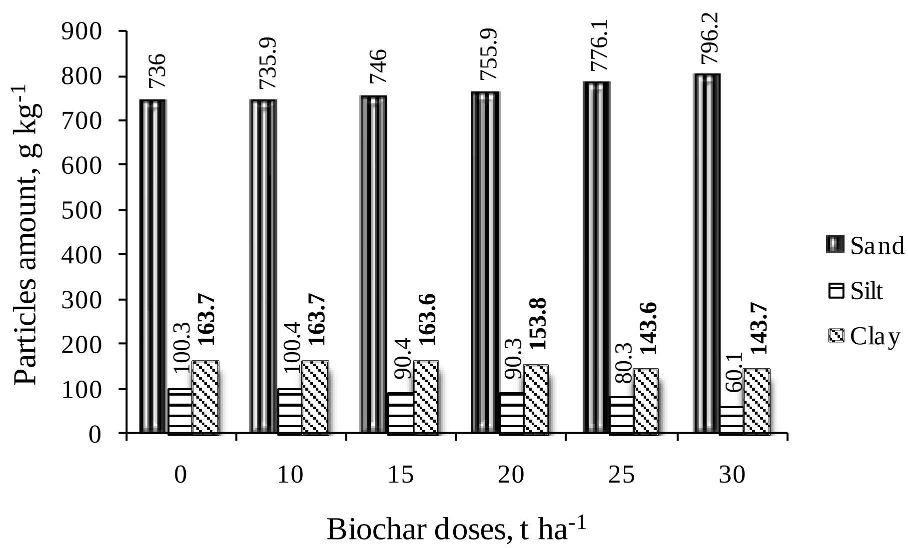

Figure 1. Particle size distribution of mixed soil with biochar

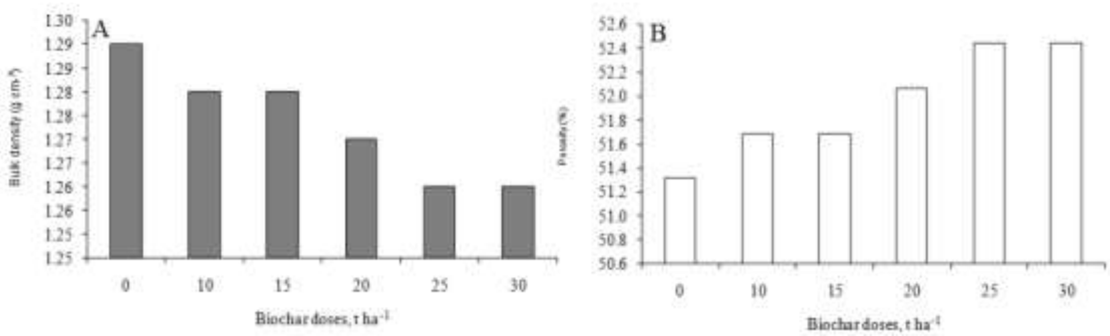

Figure 2. Changes of bulk density (A) and porosity percentage (B) from the biochar-amended soil with 0; 10; 15; 20; 25 and 30 t ha^{-1} application rates.

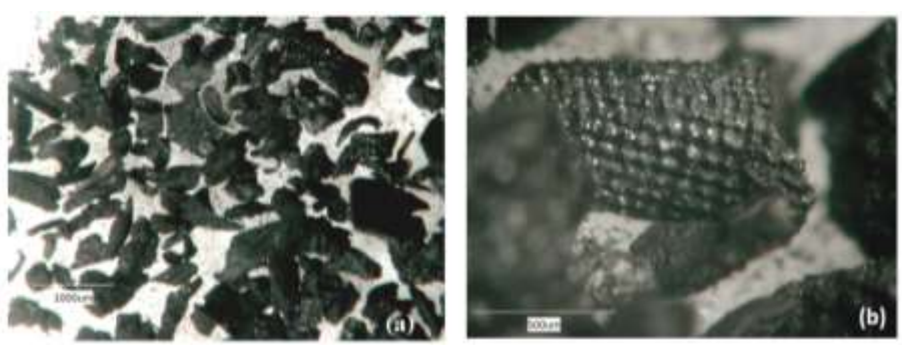

Figure 3. Photomicrographs of the biochar samples obtained by optical microscopy (a) with 1000X magnification; (b) with increase of 2000X.

According to Abel et al. (2013), this variation, probably, occurs due to different sheric shape and structural rigidity of the used chars. Through optical and electron microscopy can observe the different shapes of the biochar used in this work (Figures 3 and 4). In the images, it can observed the shapes and the distribution

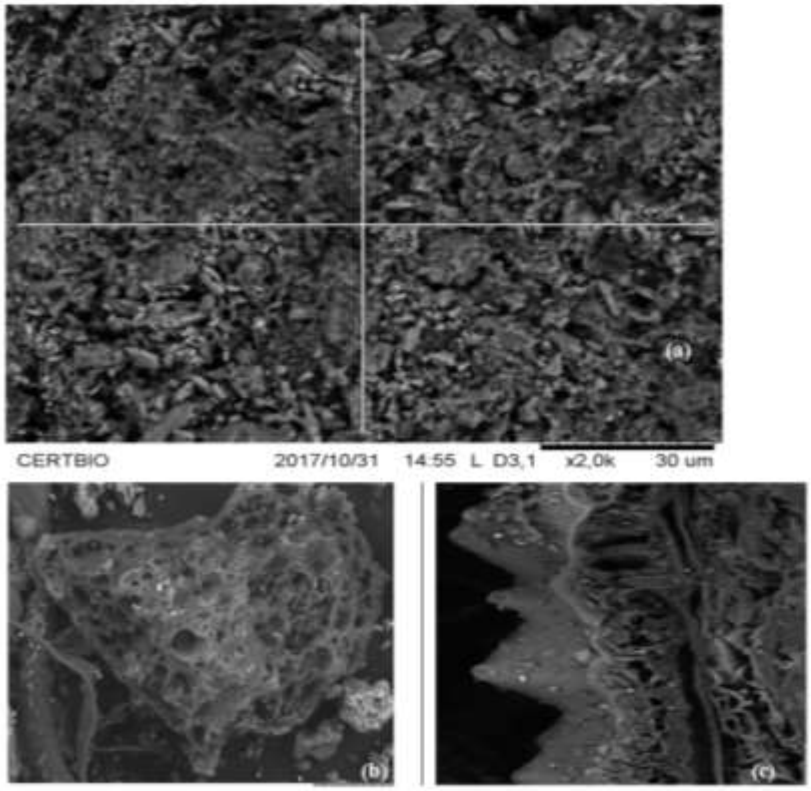

Figure 4. Photomicrographs of the biochar samples obtained by SEM. (a) with increase of 1000X; (b) and (c) with increase of 2000X.

of the particles (Figure 3a), as well as a topographic structure with high roughness (Figure 3b).

Based on Figure 4, it is observed that the morphology of the biochar sample presented a heterogeneous surface, divided into smooth and other rough parts, showing grooves resulting from surface pores for most of its extension. According to the analysis dispersive energy spectroscopy (DES), this sample showed potassium, 3.5%; calcium, 2.3%; nitrogen, 6.0%, chloride, 0.6%, aluminum, 0.8%, phosphorus, 0.6%, magnesium, 0.6%, sodium, 0.6%, silicon 0.2%, and sulfur, 0.1%, with a predominance of 69.9% of carbon and 14.9% of oxygen. Similar results were observed by Abel et al. (2013), Herath et al. (2013) and Jien and Wang (2013), investigating the chemical and physical effects in soils using biochar from feedstock maize, corn stover (*Zea mays*), the wood of white lead tress (*Leucaena leucocephala* (Lam) de Wit), respectively (Figure 4).

With respect to density variation, there was a decrease of 2.32% from the lowest (0 t biochar ha^{-1}) to the highest treatment (30 t biochar ha^{-1}) reaching 1.26 g cm^{-3}, similar to that observed by Laird et al. (2010) using 2 wt % biochar to the soil. The decrease in bulk density as a function of increasing doses of biochar was small, according to Herath et al. (2013) working with biochar produced from the pyrolysis of corn stover feedstock. The higher dose biochar amended soil exhibited higher porosity (52.45%) than the unamended control (51.32%), however this increase corresponded only to 2.2%. According to Herath et al. (2013), this increase in porosity was depend on type of biochar used and soil type where biochar was applied. In general, the increase in soil porosity is due to high porous nature of biochar, as can be seen in the Figures 3 and 4 (Mukherjee and Lal, 2013).

According to Rouquerol et al. (1999), the mesopores with a diameter of 20 to 50 nm in the biochar are associated with the adsorption of liquid and solid compounds, for example water, and once initial hydrophobicity (Bornemann et al., 2007) of biochar is overcome it has the potential to oxidise and absorb and retain water (Cheng et al. 2006). The content of water retained in the soil in a given tension is a specific characteristic of each soil and is the result of the joint and complex action of several factors. It depends on the content and mineralogy of the clay fraction, the organic matter content, the microstructure differences related to them and soil compaction.

The soil water retention curve, essential for the study of soil-water relationships, represents the relationship between the water content and the energy with which it is retained (Figure 5). Moisture contents of the samples soil

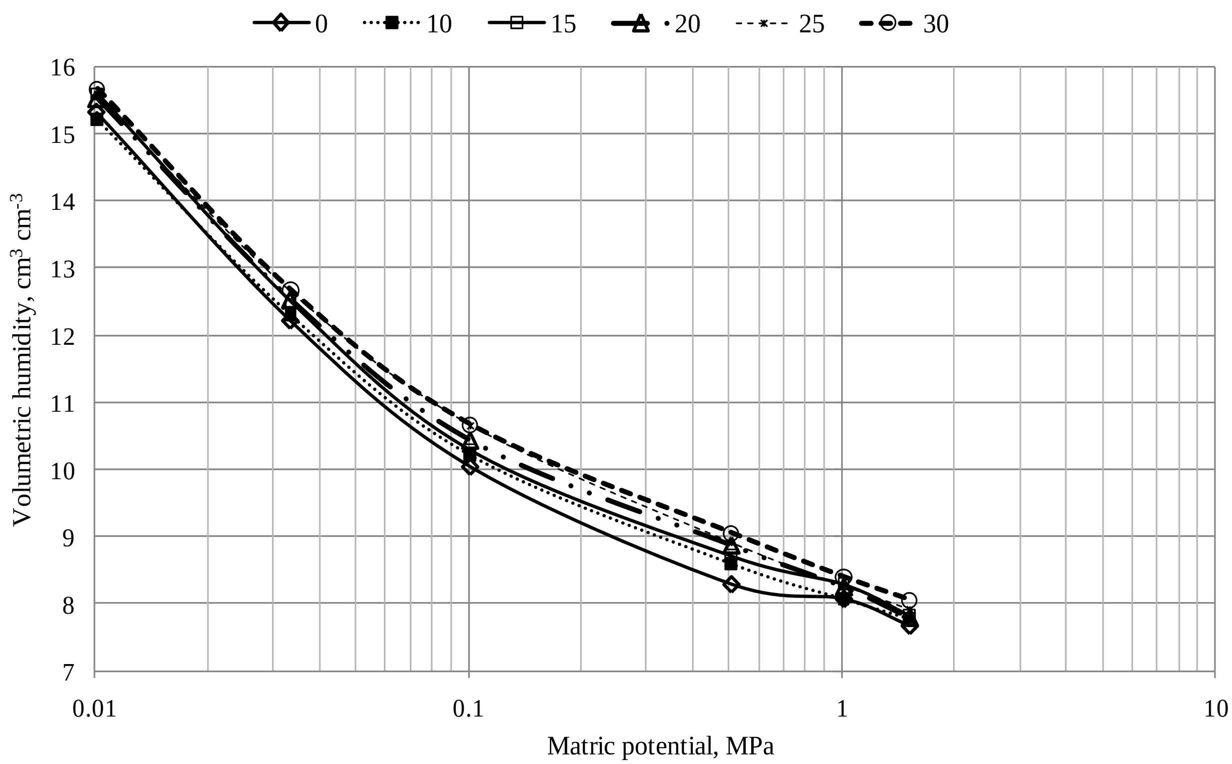

Figure 5. Water retention curve in the soil with different biochar dose.

mixed with biochar measured in the different matric potentials evaluated are observed in the retention curve (Figure 5). The samples amended with higher biochar dose show clearly an increase in moisture content in relation to the control sample in all matric potentials, although the greatest increase was observed in 0.5065 MPa.

The available water capacity is defined as the amount of water held between field capacity (0.01 MPa in sandy soil) and permanent wilting point (1.52 MPa). The highest variation of water available, according to the biochar doses related to the control, corresponded to 1.2% in the dose 15 t ha^{-1} of biochar. Several researchers observed an increase in the available water content as a function of the application of biochar in soil (Laird et al., 2010; Aslan et al., 2014), although most experiments carried out to date on this effect have used high rates of this amendment – as for example, 100 and 200 t ha^{-1} (Kammann et al., 2011) and 50 and 100 t ha^{-1} (Chan et al., 2007), which, according to Herath et al. (2013), are not practically feasible at the farmer level. However, Tryon (1948) and Herath et al. (2013) commented that the increase in the soil water retention capacity is dependent on soil texture and porosity, that is, it is significantly increased in soil water retention capacity in case of sandy soil by biochar application a because it increase soil porosity and also due to adsorptive nature of biochar.

In the present research, the biochar effects on the physical properties were very small, probably, due to the low application of this material in soil. The rate was only about 1% of the soil weight. This suggests for the next researches to increase the application rate to enhance the biochar benefits. In the case of the small increase of available water in the soil, this may also have been influenced by the small increase of the soil porosity with the application of biochar and/or short incubation time of the biochar in the soil. Even so, this small increase in available water can result in the growth and development of plants grown on this soil due to improved physical properties.

Conclusions

The properties of the biochar, in the same way as the effect of the same on the soil characteristics, vary according to the feedstock type in the production of the biochar, pyrolysis conditions and duration of charring. Biochar prepared from poultry litter through slow thermo-chemical pyrolysis, incubated in soil, improved the physical properties of the same, that is, modified the granulometric analysis, led to a decrease in bulk density, an increase in total pore volume as well as an increase in water content mainly in matric potential 0.5065 MPa. The biochar dose, 30 ton ha^{-1} was better in soil density and porosity; in the water retention the best biochar dose was 15 ton ha^{-1}; however, as the biochar effects on the physical properties were very small, it suggests to investigate larger amounts of this material in the application of the soils.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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