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Green waste biochar effects on sandy soil physicochemical properties

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Abstract

The organic amendment of degraded soil in South East of Tunisia was used to restore the chemical, and physical properties of soil quality investigated in this study. Biochar derived from pyrolyzed green waste at 360°C was used like organic amendment. Nines randomized plots with one square meter of the area of each plot in three replicates have been installed in the Institute of Arid Area in Mednine South East of Tunisia, with two rates of biochar 20 and 40 t/ha were investigated: 20 tons/ha (B20) (2 kg/m^2) and 40 tons/ha (B40) (4 kg/m^2). The results showed that biochar had a positive effect on soil's physical and chemical properties compared to non-amended soil (Untreated soil). Biochar supply at rates of 20 and 40 tons/ha, causes a decrease in electrical conductivity to achieve 2.66 mS/cm for the B40 dose after 1 year of amendment, also a decrease in the bulk density at the surface layer (0-20 cm) has been registered, the total porosity which was decreased with depth. The hydraulic conductivity is favored by the incorporation of biochar in the soil which increases the volume of voids and tends to create preferential flow paths.

1. INTRODUCTION

The arid climate of the Tunisian South East region and the excessive land use promotes soil degradation and exerts great pressure on the ecological environment in these regions (Selmi et Abbasi, 2013). Currently, ensuring sustainable agriculture and reducing arable land is becoming the major challenge for scientists, politicians, and farmers (Su et al., 2020; Erbaugh et al., 2019; Adegbeye et al., 2020). Conflicting intensive agriculture, sustainable agriculture is characterized by higher nutrient use efficiencies, increased nutrient recycling, improved agricultural productivity, and minimized environmental burdens (Semida et al., 2019; Adegbeye et al., 2020).

Agricultural residues, which represent a greatly available form of biomass in Tunisia, are essential elements in sustainable agriculture according to their essential role in nutrient recycling at a lower cost. (Li et al., 2016; Chandre and Bhattacharya, 2019). The return of agricultural waste to the soil can improve the soil state and promotes crop production (Sarker et al., 2019). Due to all these benefits, there has been, recently, much interest in biochars through an evident increase in research concerning the use of biochar in sustainable agriculture. Agricultural wastes have been transformed into biochars through thermal conservation and then used as an organic amendment to the soil (Limwikran et al., 2018; Xiao et al., 2018).

Varies studies have shown that biochar has a large surface area (Ahmad et al., 2014), low bulk density (Jain et al., 2017; Liu et al., 2018; Rajapaksha et al., 2016), stable porous structures, and high organic carbon contents (Herath et al., 2013; Jones et al., 2010; Singh et al., 2010a), which can decrease soil bulk density and increase the water holding capacity of the coarse texture soil due to its large surface area (Villagra-Mendoza and Horn, 2018). Biochar can, also, positively affect the physical, chemical, and biological properties of soil, including pH, electrical conductivity (Abujabhah et al., 2016), and cation exchange capacity (Lehmann et al., 2003). Also, biochar can effectively improve soil structure and fertility, reduce greenhouse gas emissions and alleviate the adverse effects of different stresses due to their high stability and beneficial physicochemical properties (Oliveria et al., 2017; Pariyar et al., 2020). Generally, sustainable agriculture can be achieved and evolved by producing biochar from agriculture residues and returning it to the soils (Ibn Ferjani et al., 2019).

Moreover, biochar contains easily degradable carbon which is mineralized and washed in the soil and will be used later by microorganisms existing in the soil (Roberts et al., 2015). Therefore, adding biochar to the soil can increase the amount of soil biomass, microbial biomass, and soil enzyme activity, thereby increasing soil nutrient availability necessary for the good development of plants (abbas et al., 2018).

Simultaneously, the incorporation of biochar into the soil can improve soil quality, increase crop yields in agricultural land, and also have higher ecological and economic benefits (Ouyang et al., 2016; Plaza et al., 2016). Therefore, biochar can be used as a soil amendment to control environmental pollution, increase agricultural carbon sinks, and reduce greenhouse gas emissions to maintain sustainable agriculture development (Chimento et al., 2016; Perez-Cruzado et al., 2011; Wong et al., 2017). In this context, this study aims to investigate the impact of biochar as an organic amendment applied to a sandy soil at 20 and 40 tons ha-1 on some physicochemical parameters of a sandy soil: pH and Electrical conductivity (EC), bulk density, total porosity, and the hydraulic conductivity.

2. MATERIAL AND METHODS

2.1. Biochar production

To realize this experiment, we collected the green waste from the Institute of Arid Regions of Medenine in South Tunisia. The biomass collected, was crushed to obtain fibers between 0.5 to 1 cm in length, then dried and sieved with a 0.5 mm sieve to ensure the uniformity of fragments.

The biochar obtained was prepared on-site at the Institute of Arid Regions in Medenine. Waste with a diameter greater than 0.5 cm was pyrolyzed in a continuous flow kiln at temperatures of 350°C for 3 hours with limited access to air to reduce carbon losses.

The biochar had a pH of 7.63 and contained 81.2 % of organic matter (OM), and 0.608 % of NH4+. extractable phosphorus (P) with a concentration of 2.976 mg.kg-1 and 407.446 mg kg-1 of exchangeable potassium(K+) and 54.6 meq/100g CEC. Physical characteristics of the biochar are also detailed by the determination of water content which is 5.19 %.

2.2. The experimental site and experiment design

The study was conducted in the Institute of Arid Regions of Medenine South East of Tunisia (Fig. 1) (UTM WGS 8- X: 652587- Y: 3707742). The experimental site is characterized by a very little rainfall (less than 200 mm per year), a hot thermal regime from May to September where the temperature reaches its maximum in July and August (45°C), the region is quite windy and these winds are hot and dry in summer which accelerate the evapotranspiration. The soil of the experimental site has sandy soil with a very low water retention capacity. Nine randomized plots with one square meter of area for each plot in three replicates (Fig. 2) have been installed in the study area. Two rates of biochar (20, 40 t/ha) were investigated: 20 tons/ha (B20) (2 kg/m^2) and at 40 tons/ha (B40) (4 kg/m^2). The experiment was carried out from 15 April 2020 to 15 April 2021. The effect of biochar on sandy soil was tested and compared to non-amended soil (Untreated soil).

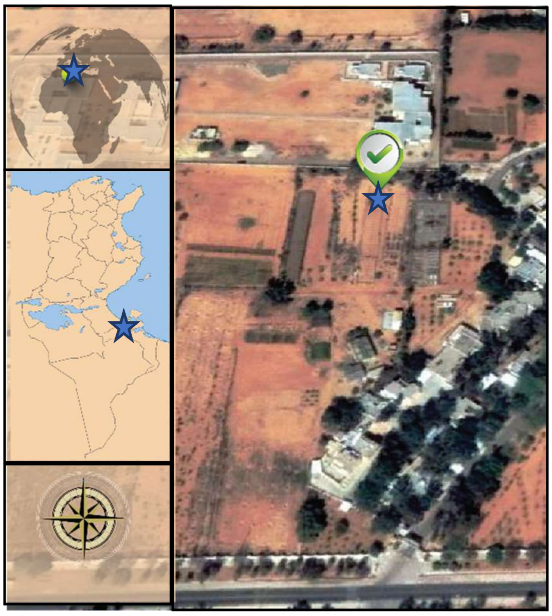

Fig. 1. Localization of the experimental site

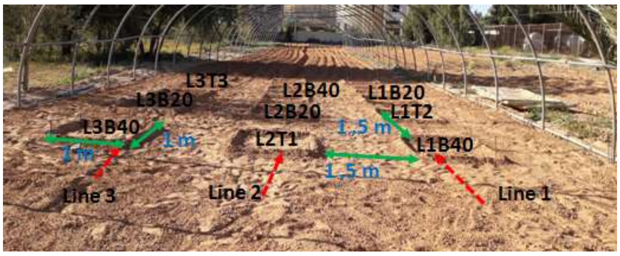

Fig. 2. Experimental design
L: Line; B20: amendement with biochar at 20 tons / ha; B40 : amendement with bichat at 40 tons / ha; T: control without amendent

2.3. Sampling procedures

To determine the bulk density, the total porosity, and the hydraulic conductivity of the undisturbed soil with the use of the cylinder method.

Bulk density (BD) is the ratio of dry mass to undisturbed volume of a soil sample, expressed in grams per cubic centimeter (g/cm3).

$$\text{Soil porosity (P\%)} = 1 - \left(\frac{Bulk\ density}{Real\ density}\right) * 100$$

Sampling was done according to the following procedures: The apparent density and the total porosity are measured in three replicates in each plot every 20 cm up to 60 cm of depth as indicated in the experiment design. For the pH and the EC, soil samples were taken by a manual auger at the same depths every 20 cm. The samples were kept in numbered bags to avoid errors.

3. RESULTS AND DISCUSSION

3.1. Effects of biochar addition on soil physical properties

3.1.1 Soil bulk density

The biochar used during this experiment has a bulk density of 0.26 g/cm3. Fig. 3 shows the variations of bulk density according to the two amendments applied to the soil at 20 and 40 tons/ha and compared to the non-amended soil (untreated) at depths 0-20, 20-40, and 40-60 cm. The bulk density is lower in the soil which received a higher dose of biochar (D40) compared to the untreated soil at different depths of 0-20, 20 - 40, and 40-60 at the beginning of the experiment (T0). On the surface layer (0-20 cm), bulk density was recorded to T0 of the amended soil by B40, and B20 and the controls are as follows: 1.47 g/cm3, 1.57 g/cm3, and 1.68 g/cm3. This finding is supported by the theory that the specific weight of soil varies inversely with organic matter. Indeed, there is a negative correlation between density and soil carbon content, confirming that soil porosity increases with the incorporation of organic matter into the soil. It is also noted that the bulk density increases according to different depths of the tested soils in T0 and T4. This increase in density with depth is due to the effect of irrigation and compaction during the passage of tillage machinery. A high bulk density value means that voids in soil are reduced and the particles are tightly packed. This causes difficulties in the circulation of water and air, a slowing down of the infiltration and drainage processes, as well as difficulties in the growth of roots and the emergence of sowing. The bulk density of the soil reflects the state of compaction of the material and indirectly, the total porosity. When it is high, the soil does not contain the pores necessary for root growth, water capacities are reduced and the circulation of fluids is slowed down (drainage and gas exchange).

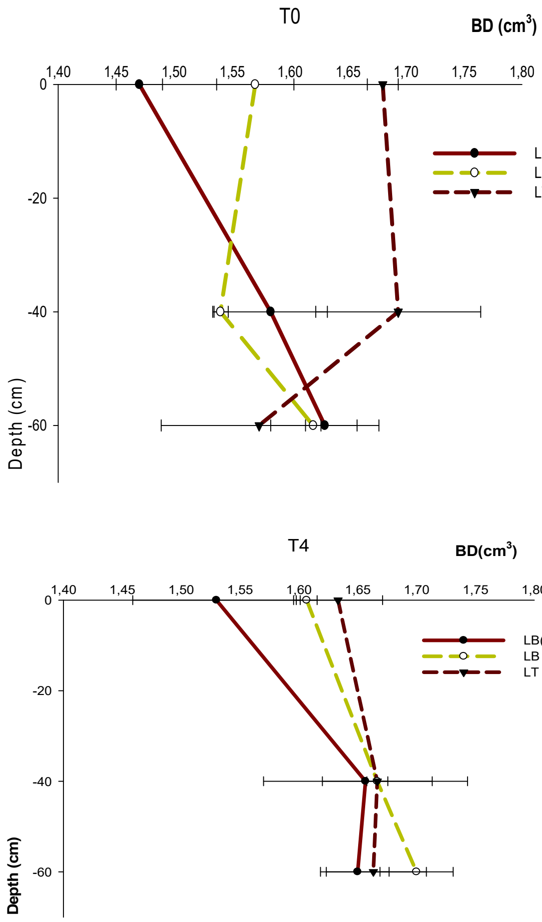

Fig. 3. Variation of soil bulk density according to addition rate (20 and 40 tons/ha) of green waste biochar between the beginning of the experiment (T0) and after one year (T4) at different horizons of soils (0—20cm, 20—40 cm and 40—60 cm).

Based on the results of Laird et al. (2010b) and Chen et al. (2010), biochar applications significantly reduced soil bulk density compared to the control soil. After biochar application, the soil promotes fungal growth and microbial activity and enhances soil agglomeration. In addition, the development of roots also affects soil bulk density (Steiner et al., 2007). It has been proven that adding biochar to soil can significantly reduce the soil bulk density and increase the total porosity which is closely related to biochar type, soil type, biochar particle size, and biochar addition rate (Oguntunde et al., 2008; Qin et al., 2016).

After one year (T4), there is a slight increase in the bulk density compared to T0 at different horizons and for all amendment B40 and B20 doses, but the lowest apparent density is recorded in the soil which received a dose of B40 at horizon 0-20. This increase in density in amended soils with biochar is due to the mineralization of organic matter and the effect of continuous irrigation during the experiment duration.

3.1.2 Soil porosity

According to Fig. 4, the soil porosity at T0 achieve 43.46%, 39.62.% and 35.38% respectively for B40, B20, and the control soil. This confirms that soil porosity increases with the incorporation of organic matter into the soil, which promotes better soil water and gas exchanges and good development for plant roots. In addition, we note that the porosity decreases with depth: for the B40 amendment, the density values decrease from 43.46% in the surface layer (0-20 cm) to 37.31% in the deeper layer (40-60 cm), for the B20 amendment the porosity decreases from 39.62% in the surface layer (0-20 cm) to 37.39% in the deeper layer (40-60 cm). This decrease is due to soil compaction which reduces soil porosity and leads to poor soil aeration, poor drainage, and increases resistance to root penetration which reduces crop growth and yield.

According to many studies, the application of biochar to the soil causes changes in the soil pore size distribution to smaller pore size and positively impacts crop growth (Dokoohaki et al., 2017; Chen and Yuan, 2011; Gul et al., 2015; Oguntunde et al., 2008).

While the addition of biochar to the soil increases the number of macropores and mesopores in the soil and, also, soil particles can be combined with biochar to form stable large agglomerates (Sun and Lu, 2014).

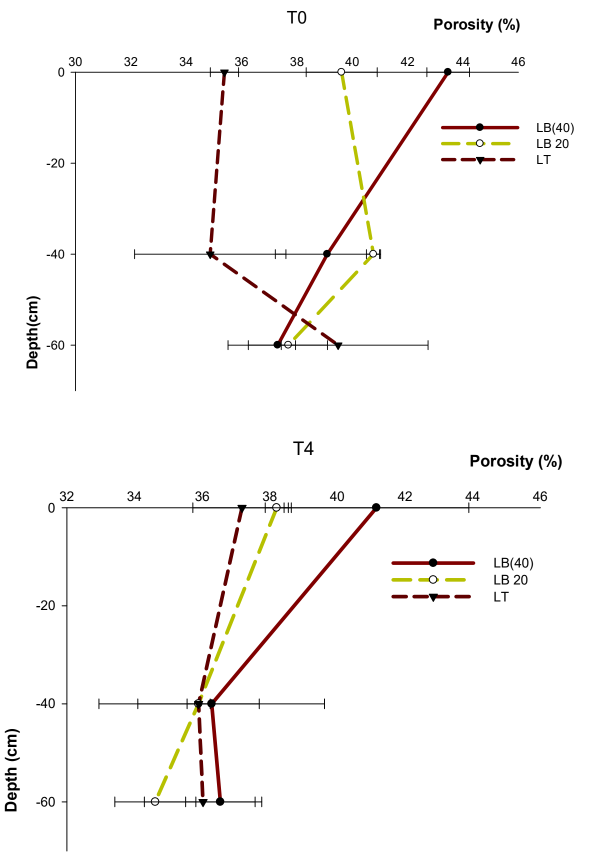

Fig. 4. Variation of total porosity of soils according to addition rate (20 and 40 tons/ha) of green waste biochar between the beginning of the experiment (T0) and after one year (T4) at different horizons of soils (0-20cm, 20-40 cm and 40-60 cm)

3.1.3 Soil saturated hydraulic conductivity (K_{sat})

Fig. 5 illustrates the variations of hydraulic conductivity in saturated soil amended with biochar at different rates. Fig. 5 indicate that the hydraulic conductivity for the surface layer (0-20 cm) at T0 is greater for the B40 treatment (73.34 cm3/h) compared to the B20 treatment (49.12 cm3/h) whereas in the control soil the hydraulic conductivity is around 13.14 cm3/h. This result confirms that the incorporation of organic matter in the soil enhances the circulation of water in the soil and thus increases the rate of oxygen which promotes the biological diversity in the soil (Chen and Yuan, 2011). Also, our results show that the hydraulic conductivity decreases with depth for the two treatments in beginning (T1) and the end of the experiment (T4), and the value of hydraulic conductivity decrease from 73.34 cm3/h to 32.09 cm3/h for the B40 treatment, and from 51.02 cm3/h to

12.93 cm3/h for the B20 treatment. Also, the hydraulic conductivity values of the amended soil are higher than the control which decreases from 13.15 cm3/h to 7.41 cm3/h. This decrease is the result of the mineralization of organic matter and soil compaction.

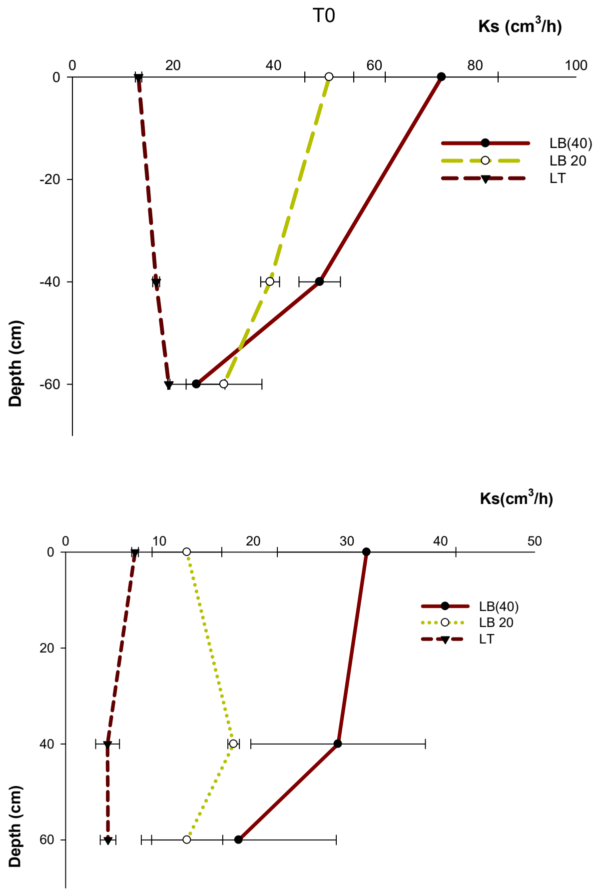

Fig. 5. Variation of soil saturated hydraulic conductivity (K_{sat}) according to addition rate (20 and 40 tons/ha) of green waste biochar between the beginning of the experiment (T0) and after one year (T4) at different horizons of soils (0-20cm, 20-40 cm and 40-60 cm).

Numerous studies have shown, that biochar significantly increases the saturated hydraulic conductivity (Ksat) with different soil textures, such as sandy soil (Ajayi et al., 2016; Lei and Zhang, 2013; Wong et al., 2018; Brockhoff et al., 2010). In addition, the effect of biochar on soil saturated hydraulic conductivity differs according to the types of soil and the difference in the pore and surface structures of biochar, and also related to the application rate (Uzoma et al., 2011). While, powder biochar destroys the pore structure of soil; therefore, adding small particle size biochar does not decrease the water evaporation loss in soil (Zhang et al., 2016).
When the soil has high water conductivity, it can accelerate infiltration and drainage (Abel et al., 2013). The rapid drainage of the soil is beneficial to reduce the occurrence of runoff; however, the penetration speed is too fast, which reduces the opportunity for the nutrients and agrochemicals in the water to be dissolved entirely and filtered (Li et al., 2013). According to several studies, biochar, as a soil amendment, is more durable than other organic additives in improving soil hydraulic conductivity (Abrol et al., 2016; Moragues-Saitua et al., 2017; Trifunovic et al., 2018).

3.2 Effect of biochar on soil chemical properties

3.2.1 pH

The following Fig. 6 shows the variations in pH for the soils amended with biochar at 20 tons/ha and 40 tons/ha and the control soil between the dates T0 (at the beginning of the experiment 15 April 2020) and T4 (after 1 year 15 April 2021).

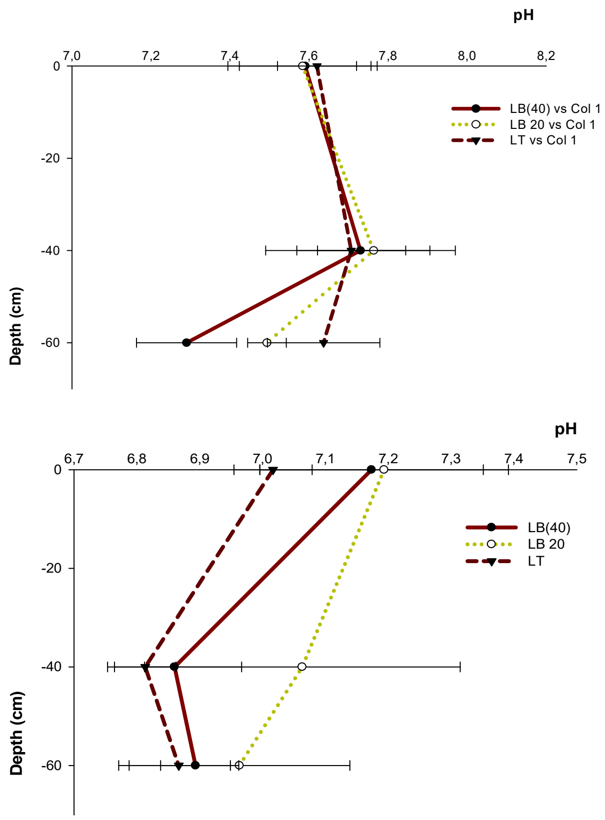

Fig. 6. Variation of pH of soils according to addition rate (20 and 40 tons/ha) of green waste biochar between the beginning of the experiment (T0) and after one year (T4) at different horizons of soils (0-20cm, 20-40 cm and 40-60 cm).

Fig. 6 shows that the pH values decreased slightly with the organic supply between T0 and T4. At T0, the decrease in pH for the surface layer 0-20 changes from 7.57 to 7.17 for the B40 treatment and from 7.58 to 7.19 for the B20 treatment, whereas for the control, the pH goes from 7.62 to 7.02. These pH variations in amended soils are due to the release of acid groups by the biochar and the buffer effect of the soil (Glaser et al., 2002; Van Zwieten et al., 2010; Hossain et al., 2010; Novak et al., 2009; Nielson et al., 2018).

As reported by several authors, the majority of biochars used for soil amendment are alkaline and the pH values range between 4 and 12 (Mukherjee and Lal 2014; Mukherjee et al., 2011; Lehmann, 2011; IBI, 2015; Zwieten et al., 2010). As reported in the literature, biochars produced from the same feedstock and under high temperature (>400°C) are likely to have greater pH values than those produced at low temperature (<400°C) from the same feedstock (Mukherjee et al., 2011; Lehmann et al., 2011; Yuan et al., 2011). Confirming to Chintala et al., (2014) and Jeffery et al., (2017), the pH increased gradually with the increasing application rate of biochar; however, it did not affect alkaline soils. Therefore, the addition of biochar to the soil has positive significance for improving alkaline crops and increases the soil cation exchange capacity (CEC) (Lehmann et al., 2015).

3.2.2 Electrical conductivity (EC)

Fig. 7 shows that the electrical conductivity decreases with the addition of organic matter and this decrease is greater with increasing doses of an organic amendment added to the soil.

The electrical conductivity in the surface layer (0-20 cm) h increased from 4.15 ms/cm to 2.66 ms/cm for the B40 treatment, from 4.52ms/cm to 2.23 ms/cm for B20 treatment, and from 3.68ms/cm to 2.59 ms/cm for the control soil. These decreases in salinity are explained by the incorporation of organic matter in the soil which improves the structural stability and therefore facilitates the leaching of salts.

The electrical conductivity also depends on the feedstock types and the pyrolysis temperature. Therefore, biochar produced at higher pyrolysis temperature generally has higher electrical conductivity values (Cantrell et al., 2012; Claoston et al., 2014; Rehrah et al., 2014). This effect has been attributed to the increase in the concentration of residues or ash caused by the loss of volatile material during pyrolysis (Cantrell et al., 2012).

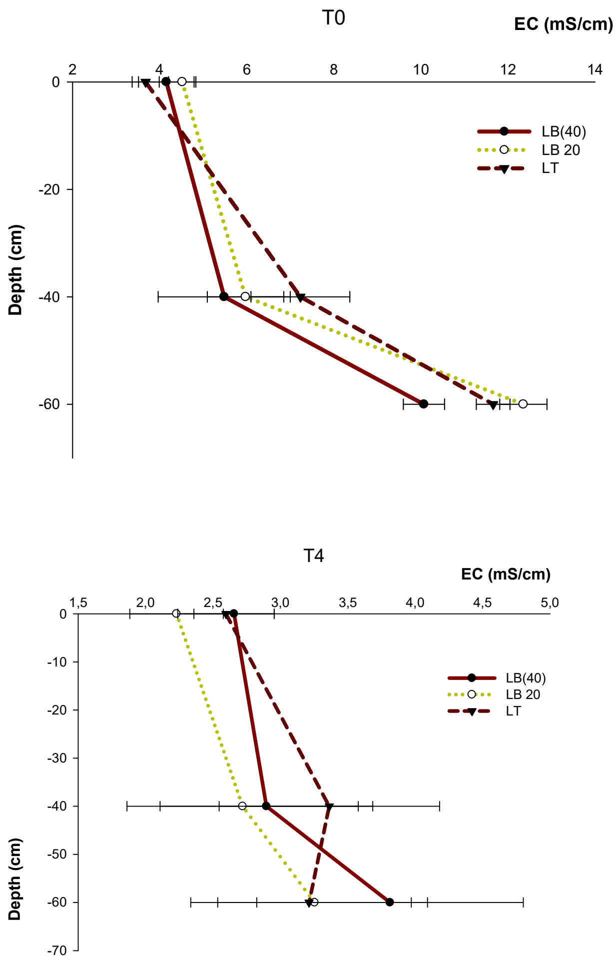

Fig. 7. Variation of EC of soils according to addition rate (20 and 40 tons/ha) of green waste biochar between the beginning of the experiment (T0) and after one year (T4) at different horizons of soils (0-20cm, 20-40 cm and 40-60 cm).

4. CONCLUSION

In summary, biochar addition had a positive effect on soil's physical and chemical properties compared to the non-amended soil (control). Organic amendment at high rates causes the decrease of the soil pH after 1 year of amendments. In addition, a decrease in electrical conductivity was also recorded for the B40 treatment after 1 year of amendment addition.
Results showed also a decrease in the bulk density at the 0—20 horizons and the density remains high at the other horizons 20-40 and 20-60, unlike the total porosity which decreased with depth. The hydraulic conductivity is favored by the incorporation of biochar in the soil which increases the volume of voids and tends to create preferential flow paths.
In future research, quantitative analysis of the mechanism of biochar addition at large scales

and in long-term field trials should be considered.

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