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THE INFLUENCE OF PISTACHIO SHELL BIOCHAR AND BARLEY RESIDUES ON SOIL PROPERTIES

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Abstract. This research was conducted to evaluate the effects of biochar and barley residues on some physicochemical properties of silty loam soil and water erosion using water erosion simulator. Biochar was produced from pistachio shells under slow pyrolysis at 500°C under anaerobic condition. Biochar and barley residues were mixed to soils at three rates of 0, 0.5 and 1% (by weight), and 6.5 kg of soil was filled in trays with length, wide and height of 35 × 20 × 10 cm, respectively. The experiments were performed in 3 repetitions for 4 months as a completely randomized design. The results showed that application of 1% of biochar significantly increased P (phosphorus), K (potassium) and OC (organic carbon) of the soil in comparison with control. Also, application at both levels (0.5 and 1%) of barley residues significantly increased P, K, TN (total nitrogen), and OC. Application of biochar and barley residues significantly increased the mean weight diameter of aggregates, plant available water content, and saturated moisture content and significantly decreased water dispersible clay ($p < 0.05$). Consequently, the amount of water erosion decreased at the rainfall intensity of 60 mm·h⁻¹ during 20 minutes. Generally, the effect of barley residues to improve soil properties was higher than the biochar.

Keywords: pistachio shells, barley residues, runoff, soil physical properties, sediment

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INTRODUCTION

In recent years, research on biochar has focused on enhancing soil fertility, carbon sequestration, activities of microorganisms, agricultural production, mitigating climate change, soil contamination and many other aspects (Solaiman *et al.* 2012). Biochar is charcoal produced from plant biomass and agricultural wastes during the pyrolysis process. This process is a slow burning of organic material in the deficiency of oxygen or even without it (Nabavinia *et al.* 2015). There is intense interest in using this biochar as a means to sequester C in soils as a tool for offsetting anthropogenic carbon dioxide (CO₂) emissions, and as a soil amendment due to its potential agronomic benefits (Lehmann and Joseph 2009).

Biochar improves soil fertility, and mitigates greenhouse gases in the atmosphere (Wu *et al.* 2013) and has high C sequestration potential in soils as compared to wheat straw and manures (Qayyum *et al.* 2012). The high presence of carbon chains in biochar and their combination causes the more stability of biochar in comparison to other organic materials. The decomposition of biochar is then estimated to be more than thousands of years (Abel *et al.* 2013). Biochar can increase soil C storage and potential C sink, improve soil nutrient retention and nutrient availability, decrease nutrient leaching and maintain the balance of soil ecosystem by adding high aromatic structure in soil humus (Solaiman and Anawar 2015). Lehmann *et al.* (2003) found that during the producing process of biochar, large amount of nutrients such as Ca, Mg, K and P and also the half of N and S in biomass remain in biochar and enter into the soil. Application of biochar in soil influences the availability of nitrogen and phosphorous (Lehmann *et al.* 2003, DeLuca *et al.* 2009, Nabavinia *et al.* 2015). Tryon (1948) reported the significant increase in soil phosphorous due to adding biochar to sandy and loamy soils. High organic carbon due to biochar has been also reported by Nigussie *et al.* (2012).

Application of biochar to the soil with different textures, e.g. clay, loam and sand leads to an increase in water holding capacity of the soil and improves the soil structure (Glaser *et al.* 2002). High capability of biochar water retention and nutrients maintenance results from its physical properties, i.e. porous structure and high specific surface area. This property causes the availability of water and nutrients for plant and preventing water loss and nutrients leaching (Yang and Sheng 2003). Ouyang *et al.* (2013) found enhanced macro aggregate formation in a sandy loam soil (containing 0.73% of organic carbon) amended with biochar produced from dairy manure. It was suggested that the relatively higher C/N ratio of the biochar enhances aggregate stability (Bossuyt *et al.* 2001). Nevertheless, data are scarce on the development of aggregate stability in biochar-amended soils (Mukherjee and Lal 2013) and, as a relatively new soil amendment, its effect on soil physical properties still requires further research (Atkinson *et al.* 2010). As the improvement in soil structure and the formation of coarse aggregates is a vital factor, then biochar may reduce the soil erosion.

Also, biochar can increase the available water capacity and water content at permanent wilt point. Glaser *et al.* (2002) reported that the water holding capacity of the clay soil which was treated with biochar was 18% higher than in the adjacent soils without biochar. Uzoma *et al.* (2011) found that a high amount of water maintained in pores of biochar, will be available for plants.

Burning the crop residues can accelerate soil erosion, decrease soil fertility and contaminate the environment, while the suitable application of crop residues may save the energy, lead to the nutrients recycling and increase soil fertility (Singh and Kaur 2012). Mandal *et al.* (2004) found that incorporation of the crop residues into the soil with different soil textures and wide range of organic matter content increased the soil potassium content. Mbah and Nneji (2011) added 0.96 organic carbon to a sandy clay loam soil, and concluded that the maximum potassium was obtained in the soil. Kumar and Goh (1999) stated that the addition of crop residues to the soil increased the level of available phosphorous, because crop produces anions and calcium complexes which decrease the phosphorous precipitation. Blevins *et al.* (1983) stated that the level of soil phosphorous increased due to returning crop residues to the soil at the end of a 10-year period. Generally, incorporation of crop residues leads to the increase in carbon supply in the soil. The influence of biochar and plant residues on physicochemical properties of soil has been studied, but the biochar of pistachio shells have not been considered yet and its effect did not refer to barley residues. In addition, pistachio is cultivated in eastern and central regions of Iran (especially Kerman, Yazd, Fars, Khorasan provinces) and annually a large amount of its shells is disposed, while its biochar can be used as suitable amendment to improve soil properties in arid regions such as Iran which had low organic matter and fertility. Therefore, the present research was conducted to study the effects of biochar pistachio shells and barley residues on physicochemical properties of soil and runoff and soil loss under simulated rainfall.

MATERIALS AND METHODS

The experiment was conducted as a completely randomized design with 3 replications. Experimental treatments included pistachio shells biochar at 3 levels of 0 (B_0), 0.5 ($B_{0.5}$) and 1% (B_1) and barley residues at 3 levels of 0 (Pr_0), 0.5 ($Pr_{0.5}$) and 1% (Pr_1). The pistachio shells were used to produce biochar. For this purpose, the pistachio shells were washed and placed into a metal pan and its lid was completely sealed using fireproof grease to create anaerobic conditions. In order to prevent the probable fire, the metal pan was wrapped with aluminum foil. The pan containing the pistachio shells was placed in an electrical oven under slow pyrolysis at 500°C for 2 hours. To obtain the homogenous biochar the prepared biochar was ground, passed through a 2 mm sieve, and then it was mixed into soil.

Table 1. The initial properties of soil

Soil properties	Content	Soil properties	Content
Sand (%)	24.42	pH _{1:5}	8.5
Silt (%)	60.7	EC _{1:5} (d Sm ⁻¹)	2.12
Clay (%)	14.88	Total nitrogen (mg Kg ⁻¹)	590
Texture	Silt loam	Available phosphorous (mg Kg ⁻¹)	7
Organic carbon (%)	0.35	Available potassium (mg Kg ⁻¹)	151

Note: pH_{1:5} and EC_{1:5} were measured in 1:5 soil to water ratio.

Table 2. Some properties of barely residues and pistachio shell biochar

Properties	Unit	Value	
		barely residues	biochar
pH _{1:5}	9.1	-	8.5
EC _{1:5}	4.36	dS m ⁻¹	3.8
Total nitrogen	0.95	%	2.6
Phosphorous	558.8	mg Kg ⁻¹	780
Potassium	980	mg Kg ⁻¹	0.16
Organic carbon	18.2	%	47.58

Note: pH_{1:5} and EC_{1:5} were measured in 1:5 water to biochar/barley residues ratio.

Silt loam soil was taken from the depth of 0 to 20 cm. Soil sample was air dried and passed through a 2 mm sieve. Biochar and barley residues were mixed into soils at three rates of 0, 0.5 and 1% (weight), and 6.5 kg of soil was filled in trays with length, wide and height of 35 × 20 × 10 cm, respectively. All samples were irrigated (surface irrigation) and reached field capacity 14% (by weight) for a period of 4 months. In order to achieve the best condition for decomposition of crop residues, soil treatments were kept in field capacity water content. For this purpose, irrigation was made every 2 days. After this period, the physicochemical properties of treated soil, soil loss and runoff of different treatments were measured. Chemical properties including total nitrogen, available phosphorous and potassium of the soil and also organic carbon were measured (Page *et al.* 1982). Soil physical properties including percentage of water dispersible clay, mean weight diameter of aggregates and plant available water were determined. Mean weight diameter of wet aggregates (MWD) (Kemper and Rosenau 1986) was calculated using the following equation:

$$MWD = \sum_{i=1}^k w_i \bar{x}_i$$

Where:

w_i is the weight ratio of stable aggregates on the sieve i

\bar{x}_i is the arithmetic mean of aggregates size on the sieve i

Plant available water content (PAWC), and water dispersible clay were measured. PAWC was calculated by subtracting the moisture contents of field capacity (pressure head 33 kPa) from permanent wilting points (pressure head 1,500 kPa) (Klute 1986). Water dispersible clay was measured by Marchuk *et al.*'s (2013) method. 20 g of soil (<2 mm) was placed in a 250 ml cylinder and 200 ml of distilled water was added slowly down the sides of the cylinder. After 12 h, any particles that had dispersed from the soils were gently stirred into suspension and left to stand for 2 h. 10 ml of suspension was taken with a pipette from a depth of 10 cm (15 cm cylinder height), dried in the oven at 105°C for 24 h, and DC in relation to total clay was determined.

Measurement of the runoff and soil loss

In order to measure the runoff and soil loss (SL), trays containing soil samples were put under the rainfall simulator at very low 5% slope for 20 min. Two intensities of rainfall were simulated: 45 mm·h⁻¹ (almost the erosive rainfall intensity in semi-arid areas), and 60 mm·h⁻¹ (erosive rainfall intensity). The height of rainfall simulator was 1.8 m and it contained fixed nozzles with the constant drop size (2 ± 0.05 mm) and distance of 7 cm. The Christiansen uniformity coefficient was used to determine the rainfall uniformity, and kinetic energy for each rainfall intensity was considered as a percentage (uniformity coefficient) of kinetic energy calculated based on the Wisheimer and Smith equation. The tap water (EC = 0.5 dS·m⁻¹ and pH = 7.1) was used for the rainfall simulator. Because the time of constant rate of runoff was not equal in all treatments, the equal time of 20 min was considered to compare the treatments. There were 6 holes at the bottom of trays to exit the infiltrated water from the outlets and some plastic tubes were inserted to collect the runoff and sediments in the soil surface. After collecting runoff, its volume was measured. Then, the runoff was oven dried at 105°C for 24 h, and weight of soil loss was measured.

Statistical analysis

Data analysis was performed based on a completely randomized design in a factorial arrangement with 3 replications. Data of soil loss, runoff volume and cumulative water infiltration were analyzed using SPSS software.

RESULTS AND DISCUSSION

Influence of biochar and barley residues on soil total nitrogen

The initial properties of studied soil before applying the treatments are shown in Table 1. According to this table, the studied soil contains low organic matter and macro nutrients (nitrogen, phosphorous, and potassium). The results of means' comparison indicated that the application of biochar at both 0.5 and 1% levels in the soil significantly ($p < 0.05$) increased the total nitrogen in comparison with the control (Fig. 1) by 80 and 120%, respectively. Also, the difference between both biochar levels was significant. In addition, the application of barley residues at both levels significantly increased ($p < 0.05$) the soil total nitrogen in comparison with the control by 120 and 140%, respectively, while the increase in nitrogen content due to the application of 1% biochar was not significantly different from barley residues at the two levels of 0.5 and 1%. Generally, the effect of barley residues on the increment of soil nitrogen was more than pistachio shell biochar, because the nitrogen content in barley residues was more than that of biochar (Table 2). Biochar is a source of soil nitrogen and can crease the soil nitrogen (Zheng *et al.* 2010). However, an addition of biochar to soils results in slower mineralization of the biochar materials than the uncharred biomass (Knoblauch *et al.* 2012), decrease net N mineralization (Dempster *et al.* 2012). Furthermore, addition of biochar to soils can mitigate N₂O emissions (Spokas and Reicosky 2009, Singh *et al.* 2010, Schouten *et al.* 2012). Also, plant residues and biochar contain nitrogen, therefore, it releases and consequently increases the level of nitrogen in the soil (Rondon *et al.* 2007).

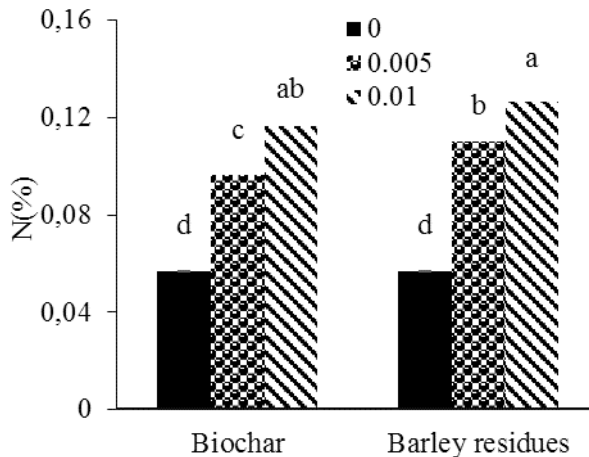


Fig. 1. The interaction effect of biochar and barley residues on soil nitrogen

Influence of biochar and barley residues on available soil phosphorous

Both levels of barley residues increased the soil phosphorous level significantly in comparison with the control, and the maximum phosphorous content was found in Pr_1 (15.30% more than the control). Also, there was a significant difference between both levels of $Pr_{0.5}$ and Pr_1 . B_1 also increased the soil phosphorous by 5.05% in comparison with the control. There was not any significant difference between the phosphorous content in B_1 and $Pr_{0.5}$ and the difference between $B_{0.5}$ and the control was not significant (Fig. 2). Barley residues increased the level of phosphorous more than the pistachio biochar due to higher content of phosphorous in the barely residues (Table 2). Laboski and Lamb (2003) have reported that decomposition of organic materials and biochar can decrease phosphorous precipitation. Besides, during the decomposition of biochar in soil, CO_2 was produced and it may increase the solubility of Ca and Mg phosphates in soils with high pH, consequently increase the level of available phosphorous in the soil (Zheng *et al.* 2010). Kumar and Goh (1999) found that the addition of plant residues to the soil increased the soil available phosphorous due to lower phosphorous precipitation. On the other hand, the incorporation of barley residues into the soil leads to the production of anions and calcium complexes which decreases the phosphorous precipitation. Blevins *et al.* (1983) stated that the soil phosphorous content increased after a 10-year period due to returning the plant residues. Applications of biochars taken from different feedstocks were found to increase the availability of phosphorous in the soils (Parvage *et al.* 2013).

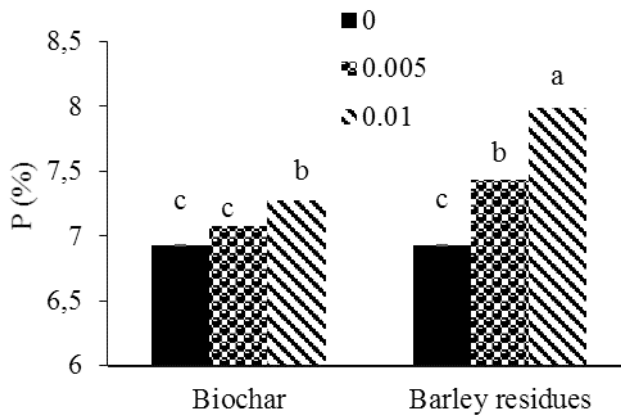


Fig. 2. The interaction effect of biochar and barley residues on soil phosphorous

Influence of biochar and barley residues on soil potassium

The results of comparison of means indicated that adding 1% of biochar to the soil significantly increased the potassium up to 40 and 31% ($p < 0.05$) in comparison with the control and $B_{0.5}$ treatments, respectively. Also, adding 0.5% of biochar increased the soil potassium 6.7% more than the control but the difference was not significant (Fig. 3). Application of two levels of barley residues (0.5 and 1%) significantly increased the potassium content up to 20 and 46.66% more than the control, and the difference between $Pr_{0.5}$ and Pr_1 was significant ($p < 0.05$), too. Also, the difference between 1% of biochar and barley residues was not significant ($p < 0.05$). Generally, the influence of barley residues on the increment of the soil potassium was more than that of biochar because the potassium content in the barley residues was higher than that of biochar (Table 2). Mandal *et al.* (2004) reported that the mixing of plant residues into soil increased the potassium content. Biochar is a source of soluble cations including Ca^{+2} , Mg^{+2} and K^{+} , when biochar was added to soil it could increase the concentrations of these cations. Mbah and Nneji (2011) concluded when plant residues mixed into the soil, the maximum potassium content in soil was obtained. According to our results, high amounts of biochar increased the level of soil potassium significantly but low amounts of biochar had no significant effect on soil potassium. It has been reported that biochar application could facilitate potassium uptake and growth of crops (Oram *et al.* 2014, Abu Zied Amin 2016), in which improved soil potassium availability played an important role. Wang *et al.* (2018) concluded that biochar application could be a feasible soil amendment to improve soil potassium availability. It has been found that potassium from biochar application might not be available beyond the first year after application (Angst and Sohi 2013).

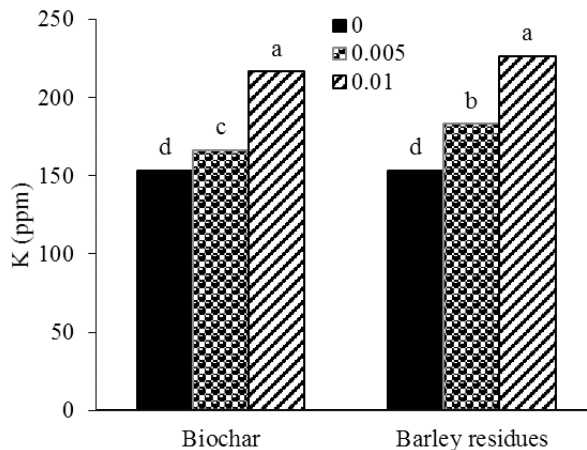


Fig. 3. The interaction effect of biochar and barley residues on soil potassium

Influence of biochar and barley residues on soil organic carbon

The results of comparison of means showed that $Pr_{0.5}$ and Pr_1 treatments significantly increased the soil organic carbon in comparison with the control, so that the maximum increased was found in Pr_1 (80% more than the control) and there was a significant difference between the two levels of the barley residues. Although the addition of 0.5% of biochar to the soil increased the soil organic carbon up to 11.42% in comparison with the control, their difference was not significant. However, 1% of biochar significantly increased the soil organic carbon in comparison with the control. Despite the influence of barley residues on the increase in the soil organic carbon was more than that of biochar, the same rates of biochar and the barley residues were not significantly different (Fig. 4). The higher increase in soil organic carbon due to the addition of the barley residues to the soil could be attributed to high organic carbon and C:N ratio which in barley residues was more than in the biochar. Generally, the application of cereals residues caused a considerable increase in the carbon supply in soil at a depth of 0–20 cm so that the higher percentage of plant residues', the higher increase in soil organic carbon (Mbah and Nneji 2011).

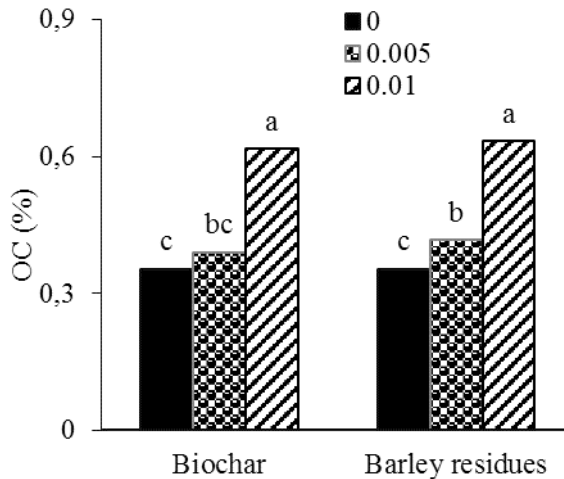


Fig. 4. The interaction effect of biochar and barley residues on soil organic carbon

Influence of biochar and barley residues on mean weight diameter of aggregates

Application of barley residues led to a significant ($p < 0.05$) increase in the mean weight diameter of aggregates in comparison with the control (Fig. 5). The fact that the mean weight diameter of aggregates increased up to 29.09 and 181.81% by application of 0.5 and 1% of barley residues, respectively in com-

parison with the control and difference between the two levels of barley residues was significant. Also, addition the biochar to the soil increased the mean weight diameter of aggregates in comparison with the control; however, the significant difference was observed only by using 1% of biochar. This treatment led to MWD increase up to 109.09% in relation to the control. The increase in MWD could be attributed to the soil organic carbon. Organic carbon of barley residues decompose more quickly than that of biochar which can flocculate soil particles and create coarse aggregates. When the soil organic carbon increases, coarse aggregates lead to increase of MWD (Emami and Astaraei 2012, Ghaemi *et al.* 2014, Emami *et al.* 2014, Ranjbar *et al.* 2016). The biochar could also improve soil aggregation by binding to other soil constituents (Herath *et al.* 2013, Soinne *et al.* 2014).

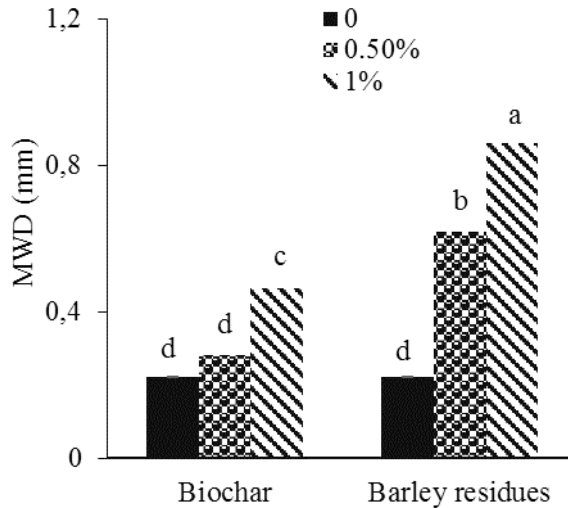


Fig. 5. The interaction effect of biochar and barley residues on the mean weight diameter of soil aggregates

Influence of biochar and barley residues on water dispersible clay

Biochar and barley residues significantly decreased the water dispersible clay in comparison with the control ($p < 0.05$), so the maximum and minimum decrease of water dispersible clay in comparison with the control by 58.76 and 32.66% was found when 1% of barley residues and 0.5% of biochar were applied in the soil, respectively (Fig. 6). Although 0.5 of biochar and barley residues led to the decrease of water dispersible clay, no significant difference in terms of the control was observed. Generally, the influence of barley residues on decreasing the water dispersible clay was more than that of biochar. The decrease in water dispersible clay is due to aggregation (Zaker and Emami 2019,

Farahani *et al.* 2018a, 2018b, 2019), because application of organic materials could bind soil particles, especially clay particles, and consequently decrease the dispersible clay. Emami *et al.* (2014) found that organic and inorganic conditioners decreased the water dispersible clay. Nabavinia *et al.* (2015) reported that biochar decreased the water dispersible clay, too.

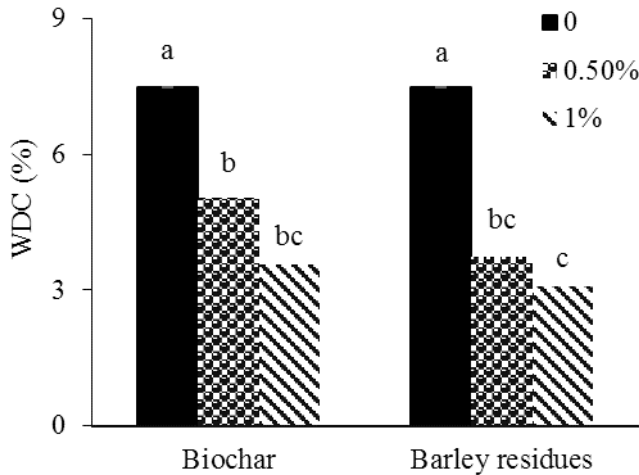


Fig. 6. The interaction effect of biochar and barley residues on the water dispersible clay

Influence of biochar and barley residues on the saturated moisture content

The barley residues significantly increased saturated moisture content (θ_s). The application of 1 and 0.5% of the barley residues increased θ_s by 31.13 and 18.91% in comparison with the control. Also, the addition of 1% of biochar to the soil increased θ_s by 8.1% in comparison with the control and the difference was significant but it was not significantly different from 0.5% of biochar. What is more, there was no significant difference between $B_{0.5}$ and the control (Fig. 7). The increased θ_s is due to the application of the barley residues which could be attributed to the increasing level of the soil organic carbon. Organic carbon leads to creating the aggregates, to improvement of the soil structure, therefore, to increasing soil porosity, macro pores, and θ_s . The increased θ_s (as a result of 1% of biochar) is due to the organic carbon and bivalent cations of biochar. However, the level of released organic carbon and bivalent cations from biochar is lower than barely residues in short time therefore, biochar has the less effect on aggregation, soil porosity and θ_s than the barely residues. When biochar was added to the soil, there was a significant increase in water retention capacity of the soil (Glaser *et al.* 2002, Lehmann *et al.* 2003, Karhu *et al.* 2011, Zhang and

You 2013, Tammeorg *et al.* 2014). In general, biochar could increase the water content in soil when applied to soils through two ways. One way is that it can increase the soil water retention by retaining water in its pores by capillary force and reduce the mobility of the water (Karhu *et al.* 2011). Because of the high porosity, biochar was thought to have much stronger water holding capacity than the soil (DeLuca *et al.* 2009). The other way was by changing the hydraulic properties of the soil (Karhu *et al.* 2011). Biochar could retain water in the pores with capillary forces, which is one of the important mechanisms explaining why biochar could improve the water holding capacity of soil (Karhu *et al.* 2011). It is thus reasonable to deduce that the water content ratios in soil layers may have a close relationship with the ratio of biochar porosity when compared to that of the soil (Zhang *et al.* 2016).

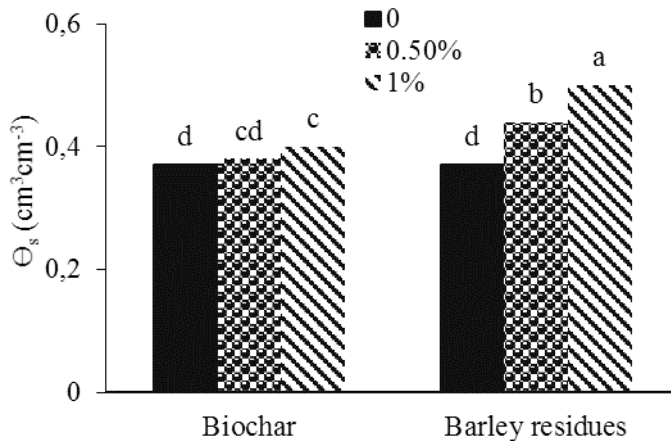


Fig. 7. The interaction effect of biochar and the barley residues on saturated moisture content

Influence of biochar and barley residues on available water content

The plant available water content (PAWC) is obtained from the subtraction of soil moisture contents of field capacity from a permanent wilting point. The application of 0.5 and 1% of barley residues significantly increased PAWC by 16.14 and 29.68%, respectively in comparison with the control ($p < 0.05$). Also, the addition of 1% of biochar to the soil significantly increased PAWC (15.1% increase), while the application of 0.5% of biochar had no significant effect on PAWC in comparison with the control. In addition, the PAWC, due to 0.5% of the barley residues, was the same as 1% of biochar (Fig. 8). Generally, the influence of barley residues with regard to the increase of PAWC was more than that of biochar. The increase in PAWC due to barley residues could be attributed to water retention as a result of increasing the organic matter. Bescansa *et*

al. (2006) found that the more soil organic materials, the more available soil water. The main reason for the lower PAWC in biochar treatments is the lower organic matter and its lower influence on the soil porosity. Also, it can be stated that biochar needs longer time to affect the soil physical properties including available water.

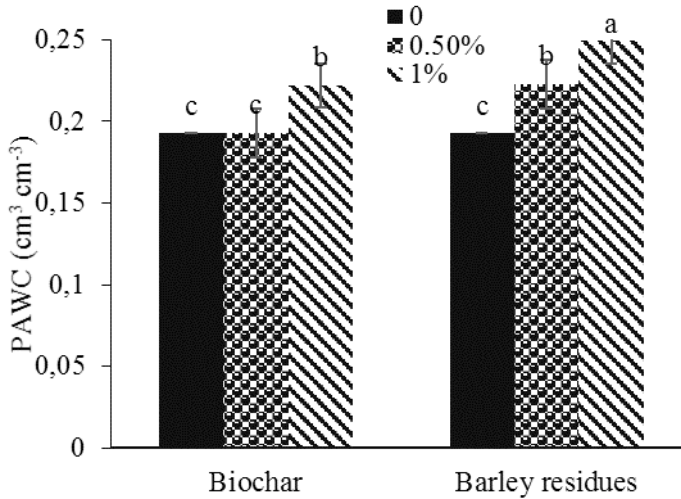


Fig. 8. The interaction effect of biochar and the barley residues on the plant available water content

Influence of biochar and barley residues on runoff

Due to application of biochar and barley residues, runoff significantly decreased with the rain intensity of $60 \text{ mm}\cdot\text{hr}^{-1}$ ($p < 0.05$), so the maximum decrease of runoff volume up to 25.51% was found when 1% of barley residues was applied, and the minimum decrease up to 10.43% was found when 0.5% biochar was added to the soil (Fig. 9). Also, the comparison of the comparable treatments of biochar and barley residues were not significantly different in terms of runoff as far as this rain intensity is concerned. The decreased runoff with the rain intensity of $60 \text{ mm}\cdot\text{hr}^{-1}$ due to barley residues was more than biochar.

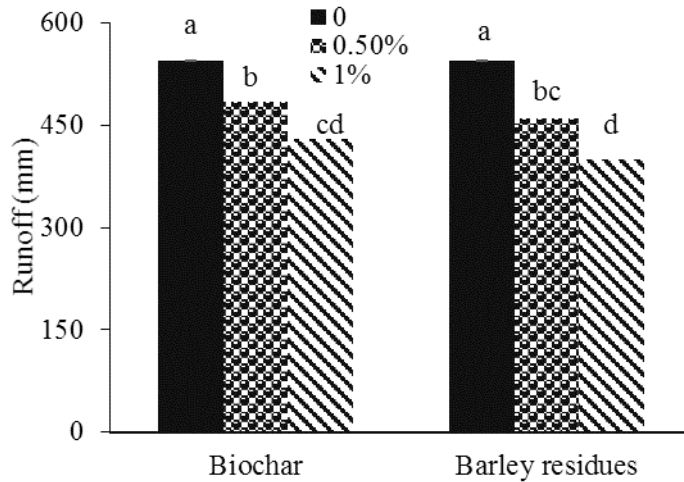


Fig. 9. The interaction effect of biochar and the barley residues on runoff at rain intensity of 60 mm hr^{-1}

Influence of biochar and barley residues on sediment load

According to the results of comparisons of means, both levels of barley residues significantly reduced the sediment load, while in the case of pistachio biochar there was only a significant difference between Pr_1 and the control ($p < 0.05$). There was no significant difference between 0.5% of biochar and the barley residues. Also, there was no difference between B_1 and $B_{0.5}$ and the two levels of barley residues (Fig. 10). Pr_1 and B_1 decreased the sediment load by 29.22 and 22.73% in comparison with the control, respectively. Generally, the barley residues were more effective in terms of the decrease of the sediment load than biochar and the barley residues produced less runoff and sediment load than those of biochar at $60 \text{ mm} \cdot \text{hr}^{-1}$.

As mentioned before, the effect of barley residues on improving soil physical (organic carbon, aggregation, water dispersible clay, soil porosity, and macropores) properties was more than that of biochar. Therefore, its effect on decreasing the runoff was more than that of biochar. The increasing of the soil organic carbon and porosity leads to the decrease in the soil degradation and erosion. Lal (2009) suggested that the maintenance of crop residues on the soil affected the soil physical, mechanical and hydraulic properties considerably, so that the soil organic carbon, soil porosity, macropores, and resistance against rain increased and bulk density decreased. Shaver (2010) stated that crop residues had positive influence on physical and hydraulic properties of soil, for example, returning the crop residues into the soil decreased the bulk density and increased the soil porosity, water infiltration rate. Soil erodibility depends

on the soil texture, structure, organic materials and water infiltration rate (Wischmeier and Smith 1978). By increasing the macro aggregates and their stability, the resistance of soil particles to detachment increases too (Schwab *et al.* 1993). Under the conditions of intensive rainfall, unstable aggregates are easily detached under rain drops and the detached particles fill the surface soil, create surface crusts; as a result the water infiltration rate considerably decreases and the runoff is increased. Barley residues and pistachio biochar, by improving soil physical and structural properties, prevent crust formation and increase the water infiltration rate, consequently, decrease the runoff volume. For example, organic material in the soil decreases its sensitivity to soil erodibility through soil aggregates stability and the improvement the hydraulic conductivity and water holding capacity (Tejada and Gonzalez 2007).

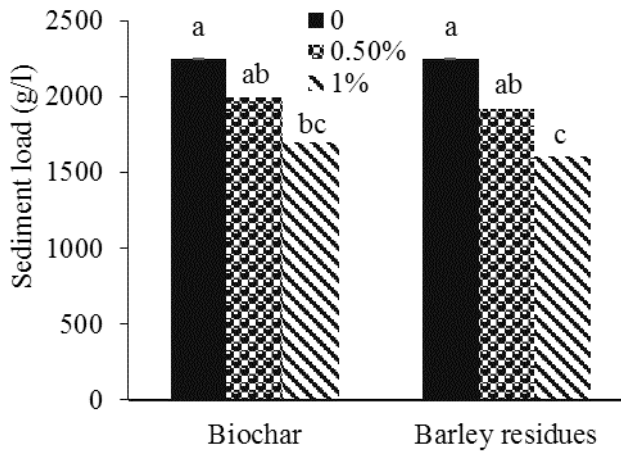


Fig. 10. The interaction effect of biochar and the barley residues on sediment load at rain intensity of 60 mm hr⁻¹

During the process of biochar production, the water holding capacity increases, therefore, soil erosion decreases (Braida *et al.* 2006). High ability of organic material to retain water is a result of its physical properties including porous structure and high specific area. As a result, water and nutrients will be available for plants and the runoff and nutrients leaching will be prevented (Yang and Sheng 2003). Addition of biochar to the soil leads to the water holding capacity increase and soil structure improvement (Glaser *et al.* 2002). Improvement of soil structure and formation of macro aggregates are important factors to decrease runoff and soil erosion (Gholoubi *et al.* 2019, Shahab *et al.* 2018, Gholoubi *et al.* 2018a, 2018b, Amiri Khaboushan *et al.* 2017). Nabavinia *et al.* (2015) showed that the addition of biochar as an organic treatment led to the constant increase of aggregates and constant decrease of runoff. Glaser *et al.* (2002) and Brodowski *et al.* (2006) also indicated that the soil organic car-

bon acted as a flocculating agent between soil particles aggregates, increase of the stability of soil aggregates and the decrease of the runoff and soil erosion. The more runoff, the higher transportation of detached soil particles, and consequently, the more sediment load.

CONCLUSIONS

The results of the present study showed that both organic materials, i.e. barley residues and biochar – especially the former – improved soil properties. The soil concentration of nutrient (N, P, and K), organic carbon, mean weight diameter of aggregates, water holding capacity, and the plant available water content increased, whereas water dispersible clay, runoff, and sediment load at rainfall intensity of at $60 \text{ mm} \cdot \text{hr}^{-1}$ decreased as a result of application of these materials. It seems that due to using of barley residues and biochar, the level of organic carbon and aggregation increased, and soil physical condition improved therefore, and runoff and soil erosion decreased. It can be concluded that organic resources are necessary to improve soil physical and fertility condition and in case of lack of organic carbon in most soils of arid regions such as Iran, plant residues can be used to improve physicochemical properties of soil in the short term. On the other hand, pistachio are cultivated in arid regions of Iran. High amounts of pistachio shell are produced there, which can later be used as soil amendments. They had positive influence on soil properties, therefore, producing the biochar of pistachio and its incorporation into soil is recommended for improvement of soil properties.

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