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Effects of wheat straw biochar and irrigation water on hydraulic and chemical properties of a sandy loam soil after faba bean cultivation

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ABSTRACT- Nowadays, applying soil amendments is one of the most important ways to cope with water shortages and improve soil physical properties. In this regard, a greenhouse experiment was conducted to study the effect of different levels of irrigation water and wheat straw biochar on physical and chemical properties of a sandy loam soil, after harvesting faba bean. The experiment was performed with 5 biochar levels (0, 8, 16, 24 and 32 g kg^{-1}) and 3 irrigation levels (100%, 75% and 50% of crop water requirement) using completely randomized design in three replications. Lowering the irrigation level to 50% did not influence soil physical and chemical properties except for saturated hydraulic conductivity (K_s), as K_s was significantly declined under 50% irrigation water levels as compared with full irrigation. Soil bulk density and particle density of 32 g kg^{-1} biochar treatment (B_{32}) was reduced by 47% and 27%, respectively, while soil porosity and K_s increased as compared to no biochar application (B_0). Under B_{32} treatment, the saturated electrical conductivity increased 5.6 times, and the cation exchange capacity and sodium adsorption ratio (SAR) was increased by 40.3% and 53.6% in comparison with B_0, respectively. This made the soil saline (EC_e>4 dS/m) but not sodic (SAR<13 (meq $L^{-1})^{1/2}$). It can be concluded that although, biochar level of 24 g kg^{-1} did not considerably increase soil water holding capacity compared to B_0, it significantly improved the other soil physical and chemical properties, therefore, it can be used as soil amendment.

INTRODUCTION

Lack of rainfall and poor soil structure negatively affects agricultural production in arid and semi-arid regions (Munodawafa, 2012). Furthermore, lack of vegetation cover in these regions decline the fertility of soils. Fars province is located in south of Iran, with average annual rainfall of 300 mm and mean temperature of 17.6 °C, in capital city, Shiraz (Gandomkar and Dehghani, 2012). It was reported by Abbaspour and Sabetraftar (2005) that around 70% of rainfall is directly evaporated before it enters into water system. Due to the climate condition (semi-arid) and recent drought in this area, the agricultural production was negatively affected. One way to overcome this problem is to manage irrigation water by performing deficit irrigation and increasing water productivity (Alizadeh and Keshavarz, 2005). Deficit irrigation provides a means of reducing water consumption while minimizing the adverse effects on yield and environment (Zhang et al., 2004). Besides, the low nutritional status of soils in arid and semi-arid regions (such as Iran) are very common, resulting in severe decline in grain yield (Alloway, 2008). One of the applicable solutions to overcome these problems in arid and semi-arid regions is to apply plant residue into soil, instead of leaving them on the agricultural land (Bot and Benites, 2005) or burning them (Andreae and Merlet, 2001), leading to improve soil organic matter contents (Thorburn et al., 2001). Almost all crop residues contain nitrogen (N), phosphorus (P), potassium (K), sulfur (S) and micronutrients. The nutrients in crop residues ultimately are recycled via soil organic matter improving soil fertility (Schoenau and Campbell, 1996). Further, soil organic matter composition affects soil structure and porosity, water infiltration rate, water holding capacity of soils and plant nutrient availability (Bot and Benites, 2005). Beside, leaving crop residue on the soil releases C (in form of CO_2) and N (in form of N_2O) into the atmosphere, thus increasing greenhouse gas (GHG) emissions (Forster et al., 2007).

One way to reduce the negative effect of crop residue application is to incorporate them in the soil or use them as biochar. Biochar is a carbon-rich material produced via pyrolysis of biomass under limited or no oxygen condition. Feedstock quality, pyrolysis process and temperature all play a crucial role in influencing the physical and chemical properties of the biochar (Mašek et al., 2013; Lattao et al., 2014). Several studies showed the potential of biochar in enhancing soil fertility and quality. Adding biochar to soil increased soil porosity (while reduced soil bulk density), water holding capacity, water sorption and soil nutrient (Lehmann et al., 2006; Lehmann, 2007; Arthur et al., 2015). It was indicated that high surface area and porosity of biochar influenced soil structure, porosity, bulk density, and pore size distribution (Major et al., 2010a), and therefore, could affect soil hydraulic properties (Ouyang et al., 2013). Application of biochar further increased crop yield under different conditions (Steiner et al., 2007; Chan et al., 2008). It was reported that biochar consisted of recalcitrant carbon (C) (Chan et al., 2008), which may remain in soil for 100–1000 years, and thus, incorporation of biochar could be an effective approach to increase soil carbon sequestration, thereby reducing GHG (Lehmann, 2007; Sohi et al., 2010; Chowdhury et al., 2014). It is also well proven that biochar application was more effective in coarse-textured soils (Jeffery et al., 2014; Burrell et al., 2016), causing an increase in cation exchange capacity, sorption of organic matter and changes in soil structure.

Therefore, the objective of this study was to evaluate the effect of different levels of wheat straw biochar and irrigation water on some physical and chemical properties of a coarse-textured soil.

MATERIALS AND METHOD

An experiment was conducted under controlled condition in a glasshouse of the Drought Research Center, School of Agriculture, Shiraz University, Shiraz, Iran in 2014. The geographical coordinates of the research station are 52º 32´ E and 29º 36´ N, respectively, with an altitude of 1810 m above mean sea level. The factorial experiment was conducted to find out the effect of different levels of biochar and irrigation regimes on soil physical and chemical characteristics using a completely randomized design. The soil type was sandy loam collected from Garbaygan area, near Fasa city in Fars province. Some basic characteristics of the soil and biochar are shown in Table 1.

The treatments included five levels of wheat straw biochar including 0, 8, 16, 24 and 32 g per kg soil (named as B_0, B_8, B_{16}, B_{24} and B_{32}, respectively) and three levels of irrigation including 100, 75 and 50% of crop water requirement (named $I_{100\%}$, $I_{75\%}$ and $I_{50\%}$, respectively) with 3 replications. The biochar was produced from wheat straw at 550 °C under restricted oxygen conditions for 24 hours. Forty five pots of 16 cm diameter and 20 cm height filled with 6 kg of the mixture of biochar and air dried soil (passed through 2 mm sieve). Soil and biochar chemical properties obtained from laboratory analysis are shown in Table 2. Seven faba bean (*Vicia faba* L.) seeds (cv. Barkat) were sown (Sep. 2014) in each of all 45 pots and thinned to three plants, after crop establishment. Irrigation treatments were initiated three weeks after sowing. The amount of irrigation water for $I_{75\%}$ and $I_{50\%}$ irrigation treatments were calculated and applied based on the amount of irrigation for $I_{100\%}$ at each biochar levels. The measurements were performed after the final harvest (May 2015).

Table 1. Some basic properties of soil and biochar used in this study

	Soil	Biochar
soil texture	Sandy loam	–
Sand (%)	70	–
Silt (%)	18	–
Clay (%)	12	–
Bulk density (g cm^{-3})	1.54	0.25
Volumetric water content at saturation (%)	33	–
Volumetric water content at field capacity (%)	21	–
Volumetric water content at wilting point (%)	8	–

Table 2. Some of chemical properties of water, soil and biochar used in this study

Attribute	Water	Soil	Biochar
Fe (mg/kg)	----	0.09	190.6
Cu (mg/kg)	----	2.45	4.30
Zn (mg/kg)	----	0.34	69.45
Mn (mg/kg)	----	2.81	55.25
Na (mg L^{-1})	19.2	2.18	1.67
K (mg L^{-1})	1.95	0.65	48.04
Ca (meq L^{-1})	1.15	2.00	2.30
Mg (meq L^{-1})	2.10	5.10	3.80
CEC (meq $100g^{-1}$)	----	13.59	25.76
N (%)	----	0.02	0.25
EC_e (dS m^{-1})	0.55	0.66	9.30*
pH	7.00	7.44	8.18*

Measured Parameters

Field Capacity (FC) and Permanent Wilting Point (PWP)

Gravimetric soil water content (P_w, %) of different treatments was obtained by taking soil samples from each pot using core samplers. The samples were then put on saturated pressure plate and saturated from the bottom. Then, pressure applied at 0.033 and 1.5 MPa for field capacity (FC) and permanent wilting point (PWP) measurements, respectively. Gravimetric soil water content at FC and PWP was determined. Dry weight of soil samples (m_s) was determined at 105 °C for 24 h.

Thereafter, volumetric soil water content (θ) at FC and PWP was calculated by multiplication of P_w and soil bulk density (ρ_b) of each treatment. Under no biochar application, the θ_{FC} and θ_{PWP} for all irrigation treatments were considered as 21 and 8 %, respectively. The θ_{FC} and θ_{PWP} for biochar level of 24 g kg^{-1} and all irrigation treatments were not reported in the results (Fig. 1) due to an error during the measurements.

Therefore, both B_0 and B_{24} level were not considered in statistical analysis on volumetric water content at FC and PWP and soil water holding capacity (SWHC) (Fig. 1).

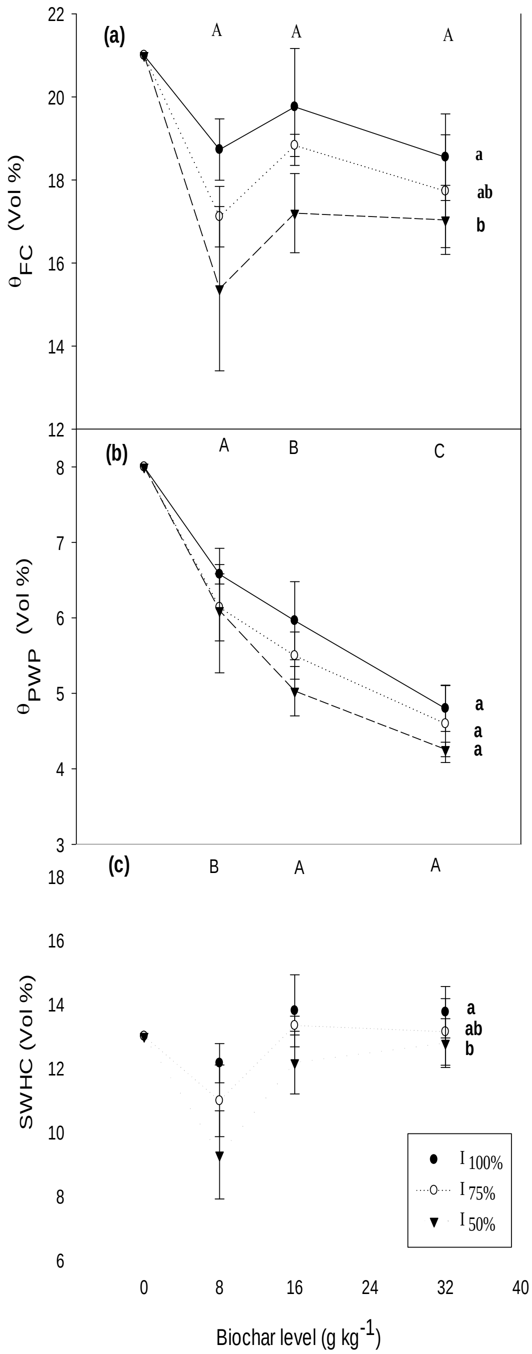

Fig.1. Volumetric water content at (a) field capacity (θ_{FC}, Vol%), (b) permanent wilting point (θ_{PWP}, Vol%) and (c) soil water holding capacity (SWHC, Vol%) under different biochar and irrigation levels. $I_{100\%}$, $I_{75\%}$ and $I_{50\%}$ related to 100, 75 and 50 % of crop water requirement, respectively. Error bars shows standard error of the mean. Different capital and bold small letters indicate significant differences ($p < 0.05$) between the mean effects of biochar (8, 16 and 32 g kg^{-1}) and irrigation treatments.

Bulk and Particle Density and Soil Porosity

To measure the soil bulk density (ρ_b) of all treatments, undisturbed soil samples were taken by core sampler with a known volume and put them in the oven at 105 °C for 24 h to obtain the dry soil weight. The soil bulk density (g cm^{-3}) was calculated by dividing soil dry weight by total soil volume. The volume of dry soil particle was measured by determining the volume of water displaced by solid soil in a pycnometer. The particle density (ρ_s, g cm^{-3}) was then calculated by dividing soil dry weight by volume of dry soil particles. Finally, soil porosity was determined using the measured ρ_b and ρ_s.

Saturated Hydraulic Conductivity

Saturated hydraulic conductivity was determined using the constant head method (Eq. (1)) (Amoozegar and Warrick, 1986).

$$K_s = \frac{V \times L}{h \times A \times t} \tag{1}$$

where K_s is the saturated hydraulic conductivity (m s^{-1}), V is the volume of water drained from the sample (m^3) during time t (s), L is the length of the soil sample (m), A is the cross-section of the permeameter (m^2) and h is the difference of hydraulic head (m).

Soil Saturated Electrical Conductivity (EC_e) and Acidity (pH)

The air dried soil samples from all treatments were used to prepare the saturated extract and thereafter, the saturated electrical conductivity of all soils measured by EC meter (Rhoades, 1996) and soil pH was determined by pH meter in the saturated extract.

Cation Exchange Capacity (CEC)

Cation exchange capacity (CEC) was measured using Bower method (Bower et al., 1952). Four grams of each soil sample was placed in a centrifuge tube, 33 ml of sodium acetate was added, and pH was adjusted to 8.2. The soil suspension was shaken for 5 minutes and then centrifuged until the supernatant liquid was clear. The supernatant was then discarded completely. Excess salt of sodium acetate was washed four times by adding 33 ml 95% ethanol to the tube each time. The adsorbed sodium replaced by three extractions with 33 ml of 1.0 M ammonium acetate each time, shaked and centrifuged, then liquid supernatant was collected in a 100 ml volumetric flask. Finally, sodium concentration was measured useing a flame photometer. The cation exchange capacity was calculated by Eq. (2).

$$CEC = \frac{[Na] \times r}{m_s \times 100} \times 1000 \tag{2}$$

where CEC is the cation exchange capacity (meq 100g^{-1}), $[Na]$ is the sodium concentration (meq L^{-1}), r is the dilution and m_s is the dry soil weight (g).

odium Adsorption Ratio (SAR)

The concentration of Na from soil saturation extract of all treatments was determined using the flame photometer (Richards, 1954), while the concentration of Ca^{2+} and Mg^{2+} were measured by EDTA titration (Knudsen et al., 1982). The sodium adsorption ratio was calculated by Eq. (3).

$$CEC = \frac{[Na] \times r}{m_s \times 100} \times 1000 \quad (3)$$

where *SAR* is the sodium adsorption ratio ($(\text{meq L}^{-1})^{1/2}$) and Na^{+}_{sol}, Ca^{2+}_{sol}, and Mg^{2+}_{sol}, are, respectively, the sodium, calcium, magnesium concentration (meq L^{-1}) of soil saturation extract. A soil is classified as a sodic soil, when SAR is greater than 13 (Horneck et al., 2007).

Statistical Analysis

Statistical analysis was performed using SAS 9.0 program (SAS Institute Inc. 2007). The data were analyzed statistically by analysis of variance and the means were compared using Duncan's Multiple Range Test (DMRT) at the 5% level of probability.

RESULTS AND DISCUSSION

Volumetric Soil Water Content at FC (θ_{FC}) and PWP (θ_{PWP})

The results showed that increasing in biochar level significantly increased both gravimetric soil water content at field capacity and permanent wilting point (data now shown), whereas, this trend was not observed for volumetric soil water content at field capacity (θ_{FC}) and permanent wilting point (θ_{PWP}) (Fig. 1). This was mainly due to the reduction in bulk density (Fig. 2a). The volumetric soil water content is more applicable for irrigation scheduling and management; therefore, this parameter is presented and discussed in this section. Increasing biochar levels from 0 (B_0) to 32 g kg^{-1} (B_{32}) reduced θ_{FC} by 15%. Increasing in biochar to 8, 16 and 32 g kg^{-1}, decreased the θ_{PWP} by 22, 31 and 43% compared to B_0, respectively. The result of θ_{PWP} as influenced by biochar was similar to that reported by Koide et al. (2015), who showed that 1% by weight (10 g kg^{-1}) switchgrass biochar application significantly decreased water content at permanent wilting point of a sandy loam soil. They further indicated that decreasing in θ_{PWP} as a result of using biochar was due to the fact that prior to wilting, the plants were able to extract more water from soil when it was mixed with the biochar. In line with our results, Major et al. (2012) found that incorporation of 20 Mg ha^{-1} biochar had no significant effect on soil moisture retention parameters. On the other hand, Abel et al. (2013) reported increasing in water content at the permanent wilting point when biochar was applied (feedstock maize produced biochar at 750 ^{o}C). These differences about the effect of biochar application on θ_{PWP} were mainly due to distinct hydraulic properties of different biochars and how they were produced. Amoakwah et al. (2017) studied the effect of corn cob biochar (20 Mg ha^{-1}) on soil water retention of tropical sandy loam and found no significant difference between the biochar treatments and control (without biochar) treatment when matric potential was pF≤1.5, whereas, between pF of 2.0 and 3.0, biochar treatments had significantly higher water contents than control. Decreasing in irrigation level to $I_{50\%}$ significantly reduced θ_{FC} (this was mainly occurred due to presence of biochar); whereas, no significant difference was observed between $I_{100\%}$ and $I_{75\%}$. Decreasing in irrigation level to $I_{50\%}$ did not affect θ_{pwp}.

The results of soil water holding capacity (SWHC=θ_{FC}-θ_{PWP}, %) showed that decreasing irrigation level to $I_{50\%}$ significantly reduced SWHC; whereas, no significant difference was observed between $I_{100\%}$ and $I_{75\%}$. Furthermore, increasing in biochar to the highest level, increased the soil water holding capacity as compared with 8 g kg^{-1} biochar (Gaskin et al., 2007; Major et al., 2009). The SWHC for B_{32} (13.22%) was ca. 1.7% higher than SWHC of B_0 (13%). Similar to results of this study, Kinney et al. (2012) indicated that application of different types of biochar (dried magnolia tree leaves and apple wood chips) increased soil water holding capacity (SWHC); whereas Gaskin et al. (2007) found that application of pine-chip biochar at 11 and 22 Mg ha^{-1} had no significant effect on soil water holding capacity of a loamy sand soil. Karhu et al. (2011) indicated that application of 9 Mg ha^{-1} birch biochar (at 400 ^{o}C), enhanced soil readily available water by 11%.

In another study, the biochar application increased the movable soil water content (difference between saturated and residual soil water content) by 5.2% for a silty clay soil and 10.6% for a sandy loam soil (Ouyang et al., 2013). Further, the water content values vs. the different suctions were in the order of silty clay soil+biochar > silty clay soil > sandy loam soil+biochar> sandy loam soil during the incubation period. With the biochar application, the water contents over different suctions of the sandy loam soil changed more than those of the silty clay soil on all sampling days (Ouyang et al., 2013).

Soil Bulk Density and Porosity

The results of bulk and particle density for different biochar and irrigation levels are shown in Fig. 2. The results showed that increasing biochar from B_0 to B_{32} significantly reduced both soil bulk density (Fig. 2a) and soil particle density (Fig. 2b), however the degree of reduction was higher in bulk density (47 and 27% declined in bulk density and particle density of B_{32} compared to B_0, respectively). It was reported that decreasing in bulk density was one of the positive points for biochar application, as it increased the soil porosity and improves soil stability (Franzluebbers, 2002). Similar to the results of this study, Abrishamkesh et al. (2015) indicated that soil particle density declined by application of different amount (0.4, 0.8, 1.6, 2.4, 3.2 weight%) of biochar made from rice husk.

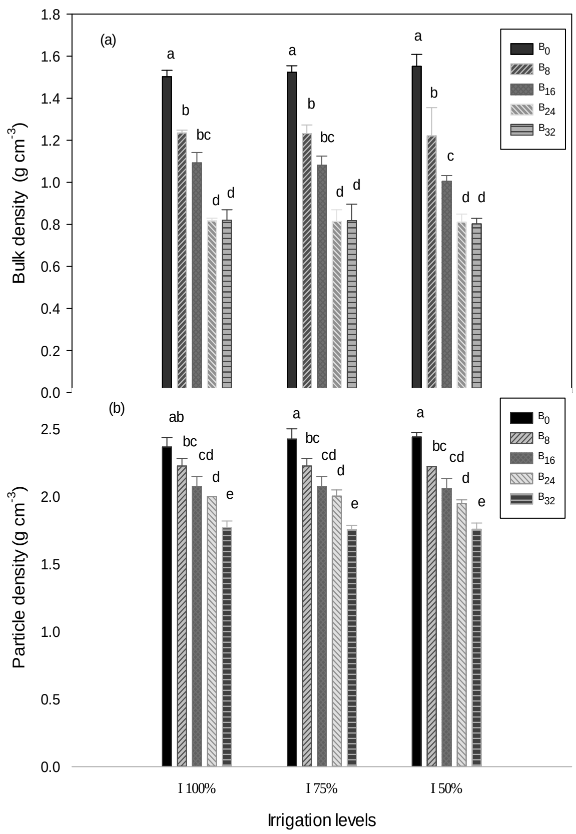

Fig. 2. Soil bulk density (a) and soil particle density (b) under different levels of biochar and irrigation levels. B_0, B_8, B_{16}, B_{24} and B_{32} indicated biochar levels of 0, 8, 16, 24 and 32 g kg^{-1} and $I_{100\%}$, $I_{75\%}$ and $I_{50\%}$ related to 100, 75 and 50 % of crop water requirement, respectively. Error bars shows standard error of the mean. Different letters indicate significant differences (p < 0.05) between the interaction effects of treatments (irrigation ×biochar).

Furthermore, Githinji (2014) applied five levels of biochar (0%, 25%, 50%, 75% and 100% v/v) to a loamy sand soil and showed that bulk density and particle density decreased from 1.3 to 0.36 g cm^{-3} and from 2.6 to 1.6 g cm^{-3}, respectively, while porosity increased from 0.5 to 0.8 cm^3 cm^{-3}, for the non-amended soil and 100% biochar-amended soil. Arthur and Ahmed (2017) studied the effect of rice straw biochar (3% w/w) on bulk density and porosity of sand soil, 3 and 15 months after biochar application. Their results showed that 3 and 15 months after biochar application, soil bulk density significantly reduced by 32 and 12% in comparison with that of the control treatment (without biochar) at the same duration; whereas, soil porosity significantly increased by 22 and 16% in comparison with that of the control treatment (without biochar) at the same duration, respectively. In current study, decreasing in irrigation levels from $I_{100\%}$ to $I_{50\%}$ did not significantly affect the bulk density and particle density.

The results of this study indicated that soil porosity varied between 36.4% (the lowest in $B_0I_{50\%}$) to 59.4% (the highest in $B_{24}I_{75\%}$) (Table 3). No significant effect of irrigation levels was observed on porosity; whereas, increasing biochar level to 24 g kg^{-1} increased the soil porosity (Zheng et al., 2013), while further increase in biochar level to 32 g kg^{-1} declined the porosity in comparison with B_{24}. Moreover, in each irrigation level, no significant difference was observed between the porosity of B_{24} and B_{32}.

Soil Saturated Hydraulic Conductivity

Variations in soil saturated hydraulic conductivity (K_s) in different biochar and irrigation treatments are shown in Table 4. The K_s values varied between ca. 2.8 cm d^{-1} in $B_0I_{50\%}$ to 8.6 cm d^{-1} in $B_{24}I_{100\%}$. The K_s value for $B_0I_{100\%}$ was 5.1×10^{-5}cm s^{-1}; whereas, Atkinson et al. (2009) observed K_s of 1.86×10^{-3} cm s^{-1} in a sandy loam soil, and Hillel (1998) reported K_s of around 10^{-6} to 10^{-7} cm s^{-1} for the same soil type. The results of this study indicated that increasing biochar in all irrigation levels significantly increased the K_s. Considering the main effect of biochar, there was no significant difference between the K_s of B_{24} and B_{32} (Table 4). The biochar application significantly increased the amount of macro-aggregates (Herath et al., 2013) and decreased soil bulk density (Fig. 2a), which may result in significantly higher K_s values; whereas, Tuli et al. (2005) believed that the K_s was mainly affected by the pore size distribution along flow paths. Ouyang et al. (2013) showed that there was no significant difference between the K_s of sandy loam soil and silty clay soil with and without biochar (p > 0.05) and also they did not observe any difference in K_s values in the temporal measurements. Although, Major et al. (2010a) reported that addition the biochar to soil increased the saturated hydraulic conductivity from 2.7 to 13.4 cm h^{-1}, Laird et al. (2010) showed that biochar amendments did not significantly affect the saturated hydraulic conductivity of a typical Midwestern agricultural soil.

Chemical Properties

Interaction effects of biochar and irrigation water on the chemical properties of the studied soil are shown in Table 5. The results showed that in each biochar level, decreasing in irrigation levels reduced the electrical conductivity of saturated extract (EC_e); whereas, the difference was not significant at lower biochar levels (B_0 and B_8). This might be due to the fact that less salt was accumulated under lower applied irrigation water. However, increasing the biochar level, significantly affected the EC_e, as the EC_e of B_{32} was 5.6 times more than that of B_0. The latter occurred mainly due to the salinity of biochar (9.3 dS m^{-1}). Increasing in biochar and irrigation level increased the pH values, although the difference between irrigation levels at each biochar level was not significant (Table 5). Increasing in pH as a result of biochar was due to higher pH value of biochar in comparison with the pH of the soil without biochar.

Table 3. Soil total porosity (%) under different levels of biochar and irrigation levels

		Biochar levels (g kg^{-1})					
		0	8	16	24	32	Mean
Irrigation levels	$I_{100\%}$	36.4±2.2 ^{c*}	44.5±1.0 ^{bc}	47.2±3.1 ^{b}	59.2±0.7 ^{a}	53.6±2.5 ^{ab}	48.2 ^{A}
	$I_{75\%}$	37.0±3.2 ^{c}	44.6±1.8 ^{bc}	47.6±3.4 ^{b}	59.4±2.7 ^{a}	53.4±2.7 ^{ab}	48.4 ^{A}
	$I_{50\%}$	36.4±2.7 ^{c}	45.1±6.0 ^{bc}	51.0±2.6 ^{ab}	58.4±1.7 ^{a}	54.2±2.3 ^{ab}	49.0 ^{A}
	Mean	36.6 ^{D}	44.7 ^{C}	48.6 ^{C}	59.0 ^{A}	53.7 ^{B}	

*Different superscripted small and capital letters indicate significant differences ($p < 0.05$) between the interaction effects of treatments (biochar×irrigation) and main effect of treatments, respectively.

Table 4. Soil saturated hydraulic conductivity (K_s, cm d^{-1}) under different levels of biochar and irrigation levels

		Biochar levels (g kg^{-1})					
		0	8	16	24	32	Mean
Irrigation levels	$I_{100\%}$	4.38±0.5 ^{f*}	6.18±0.2 ^{de}	7.39±0.5 ^{bc}	8.64±0.2 ^{a}	8.15±0.5 ^{ab}*	6.95 ^{A}
	$I_{75\%}$	3.41±0.3 ^{fg}	5.61±0.3 ^{e}	6.70±0.3 ^{cd}	7.22±0.4 ^{bcd}	7.06±0.4 ^{cd}	6.00 ^{B}
	$I_{50\%}$	2.84±0.30 ^{g}	4.03±0.4 ^{fe}	6.14±0.2 ^{de}	7.18±0.2 ^{bcd}	6.79±0.2 ^{cd}	5.40 ^{C}
	Mean	3.54 ^{D}	5.27 ^{C}	6.74 ^{B}	7.68 ^{A}	7.33 ^{A}	

*Different superscripted small and capital letters indicate significant differences ($p < 0.05$) between the interaction effects of treatments (biochar×irrigation) and main effect of treatments, respectively.

Table 5. Soil saturated electrical conductivity (EC_e, dS m^{-1}), pH, cation exchange capacity (CEC, meq $100g^{-1}$) and sodium adsorption ratio (SAR, (meq $L^{-1})^{1/2}$) under different levels of biochar and irrigation.

Biochar level (g kg^{-1})	Irrigation level	EC_e (dS m^{-1})	pH	CEC (meq $100g^{-1}$)	SAR (meq $L^{-1})^{1/2}$
0	$I_{100\%}$	2.28±0.28 ^{fg} *	7.63±0.05 ^{ef}	16.49±0.36 ^{e}	2.38±0.38 ^{de}
0	$I_{75\%}$	1.89±0.06 ^{fg}	7.63±0.12 ^{ef}	16.49±0.48 ^{e}	2.16±0.14 ^{ef}
0	$I_{50\%}$	1.45±0.17 ^{g}	7.48±0.10 ^{f}	16.85±0.31 ^{de}	1.79±0.04 ^{f}
8	$I_{100\%}$	4.18±0.24 ^{e}	7.96±0.08 ^{abcd}	18.12±0.18 ^{de}	2.78 ±0.07 ^{bcde}
8	$I_{75\%}$	3.72±0.35 ^{e}	7.84±0.04 ^{cde}	18.12±0.48 ^{de}	2.86±0.33 ^{abcd}
8	$I_{50\%}$	2.89±0.38 ^{ef}	7.81±0.12 ^{de}	18.66 ±0.18 ^{cd}	2.62±0.17 ^{cde}
16	$I_{100\%}$	8.14±0.62 ^{c}	8.00±0.06 ^{abcd}	20.29±0.79 ^{bc}	3.38±0.08 ^{ab}
16	$I_{75\%}$	7.00±0.26 ^{cd}	7.93±0.03 ^{abcd}	20.47±0.72 ^{bc}	3.19±0.13 ^{abc}
16	$I_{50\%}$	6.38±0.32 ^{d}	7.88±0.12 ^{bcde}	19.83±0.36 ^{b}	2.88±0.11 ^{abcd}
24	$I_{100\%}$	9.49±0.51 ^{b}	8.13±0.09 ^{ab}	21.56±0.79 ^{ab}	3.31±0.16 ^{abc}
24	$I_{75\%}$	8.24±0.41 ^{c}	8.09±0.04 ^{abc}	21.56±0.79 ^{ab}	3.15±0.07 ^{abc}
24	$I_{50\%}$	7.76±0.69 ^{c}	8.06±0.09 ^{abcd}	21.92±0.18 ^{ab}	2.99±0.32 ^{abcd}
32	$I_{100\%}$	11.05±0.67 ^{a}	8.15±0.02 ^{a}	23.19±0.96 ^{a}	3.54±0.22 ^{a}
32	$I_{75\%}$	10.70±0.6 ^{ab}	8.16±0.04 ^{a}	23.37±0.31 ^{a}	3.26±0.24 ^{abc}
32	$I_{50\%}$	9.84±0.23 ^{ab}	8.09±0.03 ^{abc}	23.37±1.13 ^{a}	2.91±0.16 ^{abcd}

*Different superscripted small letters indicate significant differences ($p < 0.05$) between the interaction effects of treatments (biochar×irrigation).

Cheng et al. (2008) indicated that the high pH of applied biochar in soil in comparison with pH of the soil without biochar influenced the pH of amended soil. For example, adding biochar with pH of 7-9 to the soil, which had lower pH, yielded to increase the final pH and improved the amended-soil cation exchange capacity (CEC).

Cation exchange capacity (CEC) was measured for all the treatments and the results are shown in Table 5. As a result of higher surface content of biochar in higher biochar levels, the maximum CEC value obtained in B_{32} treatment and the lowest value was in B_0 treatment. Besides, no significant difference was observed between the CEC of irrigation levels at each biochar level. Jien and Wang (2013) indicated that application of biochar to soil significantly increased the CEC in the amended soils, which further improved soil fertility and nutrient retention. They further discussed that the CEC improvement can be related to the high specific surface area of the biochar due to its porous structure (Lehmann, 2007). The effects of biochar and irrigation levels on SAR are shown in Table 5. The maximum and minimum SAR was obtained in $B_{32}I_{100\%}$ (3.54 (meq $L^{-1})^{1/2}$) and $B_0I_{50\%}$ (1.79 (meq $L^{-1})^{1/2}$), respectively.

Although, increasing biochar level to B_{32} increased SAR in comparison with B_0, while no significant difference was observed between the SAR of B_{16}, B_{24} and B_{32}. In addition, irrigation levels at each biochar did not cause significant effect on SAR except between $I_{100\%}$ and $I_{50\%}$ in B_0 treatment. Although, application of biochar increased EC_e from 2.3 to 11.1 dS m^{-1} in $I_{100\%}$ treatment, the SAR values were below 13 (meq $L^{-1})^{1/2}$ and it was reported that it did not make the soil sodic (Horneck et al., 2007).

CONCLUSION

Decreasing irrigation levels to 50% crop water requirement did not significantly influence physical and chemical properties of the studied soil except for saturated hydraulic conductivity. High porosity was observed in higher levels of biochar (as a result of lower bulk density), and it made the soil more porous, which enhanced its ability to store more water (compared with lower level of biochar i.e., 8 g kg^{-1}) and made it more useful for the soils in dry regions. The soil saturated hydraulic conductivity was also improved by application of biochar, made the soil to be more permeable and it might decline soil erosion and water runoff. Furthermore, application of biochar enhanced the soil chemical properties such as soil CEC, which might positively affect the crop productivity. However, as the EC_e of biochar itself was very high, it increased the soil salinity (EC_e>4 dS/m) but not sodic (SAR<13 (meq $L^{-1})^{1/2}$), therefore it is highly important to use appropriate amount and kinds of biochar. According to the results of this study, biochar level of 24 g kg^{-1} was the best level to improve the soil physical and chemical properties. Finally, it can be concluded that application of biochar in arid and semi-arid regions together with proper management can enhance the soil structure, fertility and productivity of these regions.

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دانشگاه شیراز

اثر بیوچار تولید شده از کاه و کلش گندم و آب آبیاری بر ویژگی‌های هیدرولیکی و شیمیایی در خاک لوم شنی بعد از کشت باقلا

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هدایت هیدرولیکی اشباع

چکیده- امروزه کاربرد اصلاح کننده‌های خاک یکی از مهمترین راهکارهای سازگاری با کمبود آب و افزایش ویژگی‌های هیدرولیکی خاک می‌باشد. لذا، در یک آزمایش گلخانه‌ای، به بررسی اثر سطوح مختلف آب آبیاری و بیوچار بر ویژگی‌های فیزیکی و شیمیایی خاک لوم شنی بعد از برداشت باقلا پرداخته شد. این آزمایش با پنج سطح بیوچار (صفر، ۸، ۱۶، ۲۴ و ۳۲ گرم بر کیلوگرم) و سه سطح آبیاری (۱۰۰درصد، ۷۵ درصد و ۵۰ درصد نیاز آبی) در قالب طرح کاملاً تصادفی با سه تکرار انجام شد. کاهش در میزان آبیاری تا ۵۰٪ تاثیری بر ویژگی‌های فیزیکی و شیمیایی خاک نداشت، بجز در مقدار K_s که تحت تیمار آب آبیاری ۵۰٪ به صورت معنی‌داری نسبت به آبیاری کامل کاهش یافت. در تیمار ۳۲ گرم بر کیلوگرم بیوچار (B_{32}) نسبت به تیمار بدون بیوچار (B_0)، مقدار وزن مخصوص ظاهری و حقیقی به ترتیب ۴۷ و ۲۷ درصد کاهش یافت، درحالی‌که سبب افزایش تخلخل خاک و K_s خاک گردید. در تیمار B_{32}، مقدار هدایت الکتریکی اشباع ۵/۶ برابر و مقدار ظرفیت تبادل کاتیونی و نسبت جذبی سدیم (SAR) به ترتیب ۴۰/۳ و ۵۳/۶ درصد در مقایسه با B_0 افزایش یافت، که این مساله سبب شور شدن (EC_e>4 dS/m) و غیر سدیمی شدن (SAR<13 (meq $L^{-1})^{1/2}$) خاک گردید. می‌توان نتیجه گرفت که هرچند سطح بیوچار ۲۴ گرم بر کیلوگرم افزایش قابل ملاحظه‌ای در میزان ظرفیت نگهداری آب خاک در مقایسه با B_0 نداشت، اما سبب بهبود معنی‌دار ویژگی‌های فیزیکی و شیمیایی خاک گردید و در نتیجه می‌توان از این سطح بیوچار به عنوان اصلاح کننده خاک استفاده نمود.