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Influence of Different Levels of Biochar in Some Soil Physical Properties and Growth Parameters of Oat (*Avena sativa* L.)

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Biochar
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Mean weight diameter
Saturated hydraulic conductivity
Oat plant

Abstract

A pots experiment was performed in the greenhouse of the College of Agriculture, University of Basrah in clay loam soil, to study the effect of the different levels of biochar on some soil physical properties (bulk density, total porosity, moisture content, mean weight diameter and saturated hydraulic conductivity) and some indicators of oat crop growth (height and dry weight of the plant). The experiment included the use of six different levels of biochar: B0 (control), B1 (1%), B2 (1.5%), B3 (2%), B4 (2.5%) and B5 (3%) were added based on the dry weight of the soil. The pots were planted with oat seeds on 1 October 2018, and after 50 days of cultivation, the studied characteristics were measured. The experiment was designed by using a complete randomized design (CRD). The results showed the improvement of the soil physical properties and plant growth with the addition of biochar, as the level exceeded 1.5% (B2) in most of the physical properties of the soil and the studied growth characteristics as it gave the lowest bulk density of soil and the highest values for the total porosity, mean weight diameter, plant height, and dry weight of plant. They were reached 1.033 Mg m^{-3} and 60.71 %, 1.091 mm, 60.87 cm and 2.693 g pot^{-1}, respectively. Whereas, the 3% (B5) level of biochar recorded the highest soil moisture content and saturated hydraulic conductivity and the lowest plant height, they were reached 32.18% and 3.953 cm hour^{-1} and 46.90 cm, respectively. While, the control treatment (B0) gave the highest bulk density of soil and lowest values for the other studied traits compared to all levels of added biochar.

تأثير مستويات مختلفة من الفحم النباتي في بعض الصفات الفيزيائية للتربة وبعض صفات النمو لمحصول الشوفان (*Avena sativa* L.)

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المستخلص

أجريت تجربة في سنادين في البيت البلاستيكي لكلية الزراعة - جامعة البصرة في تربة مزيجة طينية. وذلك لدراسة تأثير اضافة مستويات مختلفة من الفحم النباتي في بعض الصفات الفيزيائية للتربة (الكثافة الظاهرية والمسامية الكلية والمحتوى الرطوبي ومعدل القطر الموزون والايصالية المائية المشبعة) وبعض مؤشرات نمو محصول الشوفان (ارتفاع النبات والوزن الجاف للنبات). تضمنت التجربة استخدام ستة مستويات مختلفة من الفحم النباتي 0% ((B0،(B1) 1% ،(B2) 1.5% ،(B3) 2% ،(B4) 2.5% ،B) 3% 5) تم اضافتها على اساس الوزن الجاف للتربة. زرعت السنادين ببذور نبات الشوفان في 1 اكتوبر / 2018 وبعد 50 يوم من الزراعة تم قياس الصفات المدروسة. نفذت التجربة باستخدام التصميم العشوائي الكامل (CRD). أظهرت النتائج تحسن الصفات الفيزيائية للتربة ونمو النبات مع اضافة الفحم النباتي، اذ تفوق المستوى 1.5% (2B) في اغلب الصفات الفيزيائية للتربة وصفات النمو المدروسة حيث اعطى اقل كثافة ظاهرية واعلى مسامية ومعدل قطر موزون وارتفاع نبات ووزن جاف للنبات بلغت 1.033 ميكا غرام م$^{-3}$ و60.71% و1.091 ملم و60.87 سم و2.693 غم اصيص$^{-1}$ على التوالي. في حين سجل المستوى 3% (5B) اعلى محتوى رطوبي للتربة وايصالية مائية مشبعة واقل ارتفاع

للنبات بلغت 32.18% و3.953 سم ساعة-1 و46.90 سم على التوالي. بينما أعطت معاملة المقارنة (0B) اعلى كثافة ظاهرية واقل قيم للصفات الأخرى المدروسة قياسا مع جميع مستويات الفحم النباتي المضاف.

Introduction

Biochar is a porous organic carbon compound that results from pyrolysis of the biomass at temperatures between 300-1000°c in little or no oxygen conditions (Verheijen *et al*., 2010 and Jeffery *et al*., 2011). Several studies indicated that adding biochar to the soil improves a number of physical properties of the soil including bulk density, total porosity, soil moisture content as well as hydraulic conductivity of the soil (Sohi *et al.*, 2009; Atkinson *et al*., 2010 and Sohi *et al*., 2010). Abrishamkesh *et al*. (2015) observed a laboratory experiment in silty clay soil that adding the biochar (made from rice husks) at levels 0.4, 0.8, 1.6, 2.4 and 3.3% resulted in a decrease in the bulk density of soil by 1.44, 7.19, 15.83, 17.99, 17.99 %, respectively, compared to the control treatment (without addition). He attributed the reason for this to the decrease in the density of biochar and the increase in its porosity compared to the density of soil minerals, while the researcher did not find a significant effect of adding biochar on the soil moisture content and dry weight of the plant. Lim *et al*. (2016) observed that adding biochar at different levels (0, 1, 2, and 5%) in silty clay soil has improved the soil physical properties as the bulk density decreased and the saturated hydraulic conductivity increased with the increase in the level of addition of biochar. Wang *et al*. (2017) also found that adding biochar at a level of 1% in silty loam soil recorded the highest ratio of increase in the mean weight diameter of soil (217%) compared with control level. Obia *et al*. (2018) showed that the addition of biochar with the levels of 2.5 and 5% in heavy clay soil has a significant effect on the decrease of soil bulk density and increase of the total porosity and water conductivity of soil and increase of the dry weight of the yellow corn plant compared with control level (0%).While there was no significant effect of addition levels on the soil moisture content. Jeffery *et al.* (2011) also indicated that adding biochar to the soil, improves most of the physical properties of soil, which in role reflects positively in improving plant growth.

Materials and methods

The experiment was performed in pots in the greenhouse of the College of Agriculture, University of Basrah in clay loam soil. The aim of study was to determine the effect of the different levels of biochar on some soil physical properties (bulk density, total porosity, moisture content, mean weight diameter and saturated hydraulic conductivity) and some indicators of oat crop growth (height and dry weight of the plant).The soil samples used in the experiment were collected from the field located at Qurna district in the north of Basrah, which is located geographically at longitude 30° 56' 24.8" N and latitude 47° 27' 52.0" E. The initial physical and chemical properties of the soil samples at depth of 0-30 cm were analyzed according to Black *et al*. (1965) and Page *et al*. (1982) and presented in table (1). Biochar was made from sugar cane, and it was burned in anaerobic conditions at a temperature of 250-300°C. for 4 hours. The initial properties of biochar used were analyzed and presented in table (2).

The experiment included the use of six different levels of biochar: B0 (0%, control), B1 (1%), B2 (1.5%), B3 (2%), B4 (2.5%) and B5 (3%) were added based on the dry weight of the soil. The soil samples were softened and air-dried, then sieved with a 4 mm diameter sieve, after that the soil mixed with the levels used of biochar. The soil- biochar mixture was added to the pots by 3 kg per pot and with three replicates for each level of addition of biochar. The pots were planted with oat seeds by 5 seeds per pot on 1 October 2018. All pots received NPK fertilization with levels120 kg N ha-1, 30 kg P ha^{-1} and 40 kg K ha^{-1} (Naser and Al-Mothefer, 2018). After 50 days of cultivation (end the experiment), the plants were harvested.

Table (1): The physical and chemical properties of experiment soil at the depth (0-30) cm

Properties		**Value**	**Unit**
Sand		279.95	
Silt		324.1	g kg^{-1}
Clay		395.95	
Texture		Clay Loam	
Bulk density		1.33	Mg m^{-3}
Particle density		2.63	Mg m^{-3}
Porosity		49.18	%
Moisture content		21.42	%
Mean weight diameter		0.25	mm
Saturated hydraulic conductivity		0.39	cm h^{-1}
Organic matter		8.28	g kg^{-1}
Total carbonates		197.78	g kg^{-1}
PH		7.50	
ECe		13.6	dS m^{-1}
Dissolved Ions	Ca^{++}	7.48	mmole L^{-1}
	Mg^{++}	6.33	
	CO_3^{-2}	0	
	HCO_3^-	2.73	
	SO_4^-	6.17	
	Cl^-	28.85	
	Na^+	16.02	
	K^+	0.38	
	N	17.15	mg kg^{-1}
	P	22.90	mg kg^{-1}

Table (2): some initial properties of biochar

Properties	**Value**	**Unit**	**Reference**
PH	7.47	---	Jackson (1958)
N	3.2	g kg^{-1}	Bremner (1970)
P	4.9	g kg^{-1}	Page *et al.* (1982)
K	5.3	g kg^{-1}	
C	708	g kg^{-1}	
C/N	221.25	---	
O.M	1220.59	g kg^{-1}	
EC	2.87	ds m^{-1}	
Bulk density	0.35	Mg m^{-3}	Black *et al.* (1965)

Moisture content	2.39	%
Water holding capacity	646.03	%

The soil properties and indicators of oat growth were measured at the end of the experiment, as follows:

The soil properties:

Bulk density: The bulk density was estimated from using the Core Sampler method from the following equation. (Black *et al.*, 1965).

$$\rho b = \frac{ms}{vt}$$

Where:

ρb : Bulk density (Mg m^{-3})

ms : Weight of the dried soil sample (Mg)

vt : Total volume of the soil sample (m^3)

Total porosity: Total porosity was calculated by using the following equation. (Black *et al.*, 1965).

$$TSP = \left(1 - \frac{\rho b}{\rho s}\right) * 100$$

Where:

TSP: Total soil porosity (%)

ρb: Bulk density (Mg m^{-3})

ρs: Particle density (Mg m^{-3})

Moisture Content: Determine the moisture content of the soil based on the dry weight of the soil by using the following equation. (Black *et al.*, 1965).

$$\rho w = \frac{w}{ms} * 100$$

Where:

ρw : Moisture content of soil (%)

w: Weight of the moisture (Mg)

ms: Weight of the dried soil sample (Mg)

Mean weight diameter: The mean weight diameter of soil was determined by the following equation, (Black *et al.*, 1965).

$$MWD = \sum_{i=1}^{n} xiWi$$

Where:

MWD: Mean weight diameter of soil (mm)

Xi: Average clod diameter in a particular sieve (mm)

Wi: Weight of clods in the size range i as a proportion of total dry weight of sample analyzed (g)

n = Number of sieves

Saturated hydraulic conductivity: The saturated hydraulic conductivity of the soil was measured by the following equation. (Black *et al.*, 1965).

$$Ks = \frac{Q}{At} . \frac{L}{h}$$

Where:

Ks: saturated water conductivity (cm hr^{-1})

Q: volume of water passing through the soil column (cm^3)

L: length of the soil column (cm).

A: Surface area of soil section (cm)

t: time (hours)

h: length of the soil column + the height of the water column above the soil column (cm).

The plant growth indicators:

Plant height: The average height of five plants per pot at the end of the experiment was measured by measuring the height of the plant from the soil surface to the highest peak in the plant.

Dry weight of the plant: All plants per pot were harvested from the soil surface at the end of the experiment, and then dried in the oven at a temperature of 65◦ C for a period of two days to make sure the plants were completely dry, after that according to the dry weight of the plant.

The experiment was designed by using a complete randomized design (CRD). All the obtained data were subjected to analysis of variance using Genstat software, and the average values were compared using RLSD at the level of 0.05. The results of analysis of variance (m.s. and c.v) for all studied properties of soil and plant were presented in table (3).

Table (3): Analysis of variance (m.s.) of the studied properties

S.O.V	**d.f**	P_b	***TSP***	P_W	***MWD***	***Ks***	***Plant height***	***Dry weight of plant***
Levels of Biochar	5	*0.006103*	*8.880*	*13.6744*	*0.20631*	*3.62305*	*180.86*	*0.6128*
Error	12	*0.001411*	*2.023*	*0.2440*	*0.01301*	*0.01987*	*25.63*	*0.1952*
C.V %		3.5	2.4	1.6	14.8	10.9	9.3	21.5

P_b (Bulk density of soil), ***TSP*** (Total soil porosity), P_W (Moisture content of soil), ***MWD*** (Mean weight diameter of soil), K_S (Saturated hydraulic conductivity of soil).

Results and discussion

Bulk density:

The results in figure (1) showed a significant effect ($p < 0.05$) of the levels of the addition of biochar in the soil bulk density. The addition of B5 (3%) was recorded the lowest bulk density of 1.033 Mg m^{-3}, with a significant difference with the B0, B1 and B3 treatments, whereas the B4 and B2 treatments did not differ significantly, while the B0 (control treatment) recorded the highest bulk density of 1.226 Mg and without significant difference with the treatment B1 m^{-3} . The reason for the decrease in the soil bulk density with the addition of biochar compared to the control treatment (B0) is due to the decrease in the biochar density and its increased porosity by compared with the density of soil minerals, this in turn increases the porosity of the soil and reduces its bulk density. In addition, the addition of biochar to the soil is a source of microorganisms that in turn help to link the soil minutes from during the secretions resulting from the decomposition processes that help to improve soil construction as well as the spread of plant roots and branching this in turn, increases the porosity of the soil and reduces its bulk density. These results are consistent with Lim *et al.* (2016); Dokoohaki *et al.* (2017) and Rahim *et al.* (2019), they showed a low bulk density of biochar -treated soils compared to the non-addition treatment. While, Dugan *et al.* (2010) pointed that the large additions of soil biochar levels may adversely affect the construction of the soil through clogging of some soil pores, which may increase its bulk density.

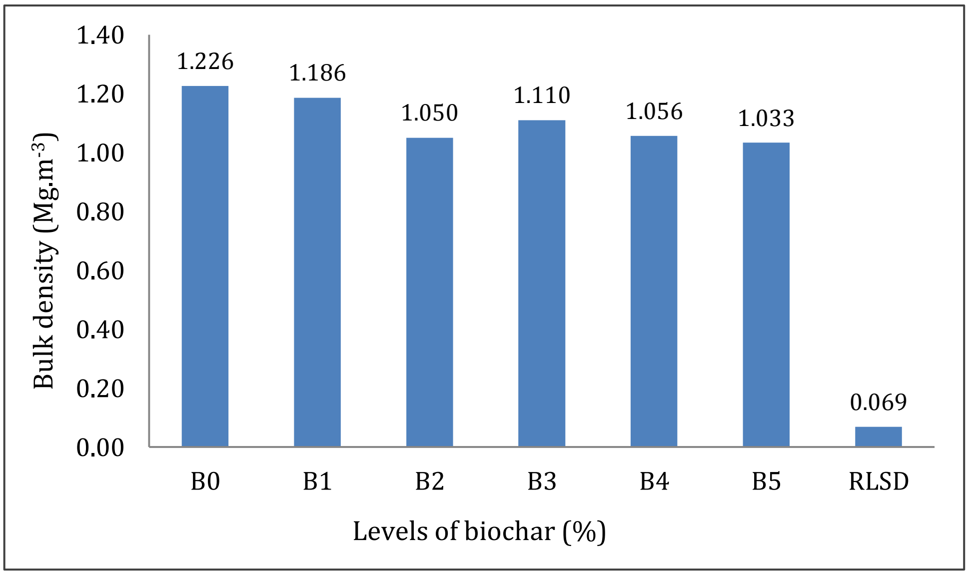

Figure (1): Effect of biochar levels on soil bulk density

Total soil porosity

Figure (2) shows a significant effect ($p < 0.05$) of the levels of biochar addition in the total porosity of the soil, where the B5 treatment outperformed the highest percentage of the total porosity (60.71%) and with a significant difference with other addition treatments except B2 and B4 treatments. While the B0 gave the lowest percentage of total porosity of 53.36% and without significant difference with the treatment B1. The reason for this is due to the low bulk density of soil with the addition of the B5 treatment (Fig. 1) compared to the control treatment, where the total porosity is inversely proportional to the bulk density as well as the high porosity of the biochar and its low bulk density compared to the clay minerals and this, in turn, increases the porosity of the soil. These results are in agreement with Tammeorg *et al*. (2014) and Gamage *et al.* (2016), they found that adding biochar to the soil increases the total soil porosity due to its lower bulk density. While this result differed with the findings of Obia *et al.* (2018) that there was no significant effect of biochar on the total porosity of heavy clay soils.

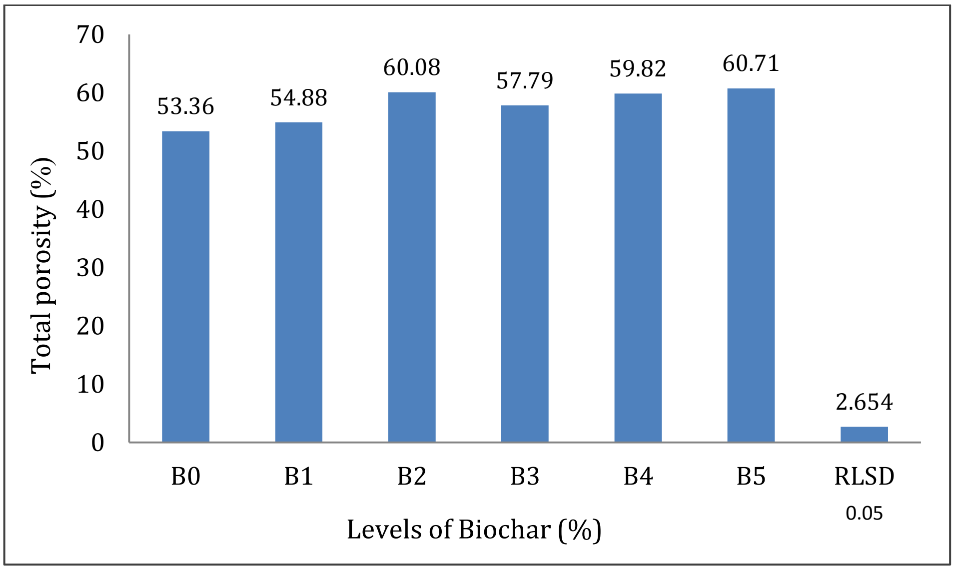

Figure (2): Effect of biochar levels on the total soil porosity

Soil moisture content

The results in figure (3) showed a significant increase in the soil moisture content ($p < 0.05$) with an increase in the level of the addition of biochar. The B5 treatment recorded the highest soil moisture content of 32.18% and with a significant difference with other addition treatments except for B3 and B4 treatments. While, the control treatment (B0) recorded the lowest soil moisture content of 26.07%, which did not differ significantly from the treatment of addition B1. Also, the results showed no significant difference between B2, B3 and B4 treatments. The reason for the increase in soil moisture content with the addition of biochar may be due to the role of biochar in increasing the soil's ability to hold water and increase its moisture content, as well as its porosity and high absorbability of water (Dokoohaki *et al*., 2017). In addition, the addition of biochar to the soil improved the bulk density and soil porosity compared to the control treatment (B0) (Figs. 1 and 2), this in turn increases the susceptibility of the soil to water retention and reduces the loss of moisture by evaporation, especially at high addition levels. This result is identical to the findings of Dugan *et al*. (2010), who showed increased the moisture content of the soil with the addition of biochar.

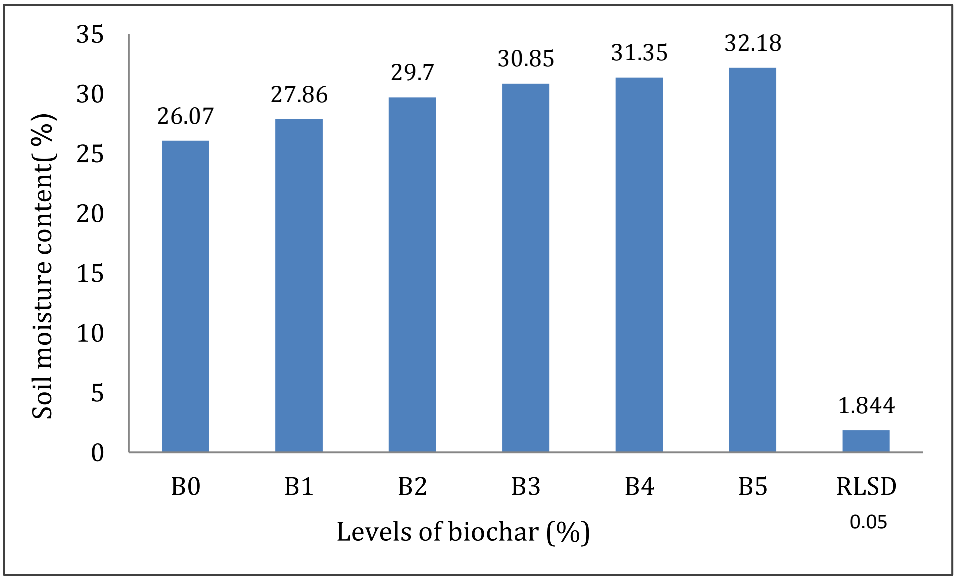

Figure (3): Effect of biochar levels on soil moisture content

Mean weight diameter

The results showed a significant effect ($p < 0.05$) of the levels of biochar addition in the mean weight diameter of soil (Fig. 4). The lowest value of the mean weight diameter of soil was recorded with control treatment (B0) which was 0.385 mm, with a significant difference with other addition treatments except for B1 treatment. Whereas, the B2 treatment achieved the highest mean weight diameter of soil (1.091 mm), an increase of 183.38% compared to the control treatment (B0). The results also showed that there was no significant effect between additive B2 treatment and B3, B4 and B5 treatments on mean weight diameter. The reason for increasing the mean weight diameter with the addition of biochar, especially with B2 treatment, maybe due to the role of biochar in improvement of soil construction due to decreasing the soil bulk density and increasing its porosity (Figs. 1 and 2), which in turn improves the stability of soil and therefore improves the mean weight diameter of soil. In addition to the role of biochar in the holding of organic matter and plant secretions and the spread of roots in the soil, this in turn helps to improve the soil aggregate stability (Herath *et al*., 2013 and Burrell *et al*., 2016). These results were in agreement with Omondi *et al.* (2016), who showed that adding biochar improved the soil aggregate stability by 8.2%.

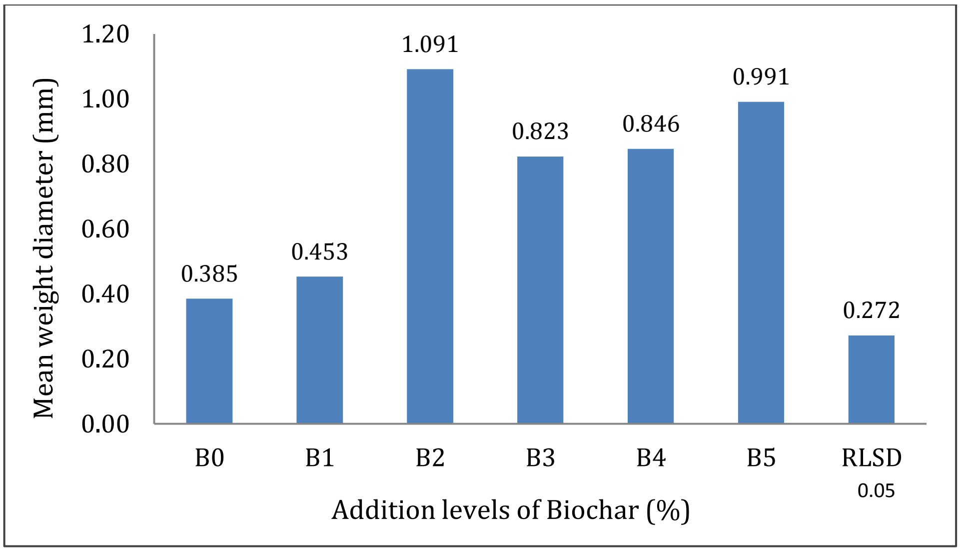

Figure (4): Effect of biochar levels on mean weight diameter of soil

Saturated hydraulic conductivity

Figure (5) shows the effect of adding different levels of biochar on the saturated hydraulic conductivity of the soil. The saturated hydraulic conductivity increased significantly ($p < 0.05$) with an increase in the levels of the addition of biochar. The highest value of the saturated hydraulic conductivity of soil was recorded with B5 treatment (3.953 cm h^{-1}), with a significant difference with other treatments, followed by B4 treatment to increase the saturated hydraulic conductivity. While the B0 recorded the lowest value of the saturated hydraulic conductivity (0.116 cm h^{-1}). Also, the results showed there was no significant difference between the B1, B2 and B3 treatments in the saturated hydraulic conductivity. The reason for increasing the saturated hydraulic conductivity with the addition of biochar may be due to the role of biochar in the improvement of mean weight diameter of soil and soil porosity (Figs. 4 and 2), this in turn increases the saturated hydraulic conductivity of the soil. These results were in agreement with the findings of Asai *et al*. (2009); Barnes *et al*. (2014) and Dokoohaki *et al*. (2017), they showed that the saturated hydraulic conductivity of the soil increases with an increase in the level of addition of biochar.

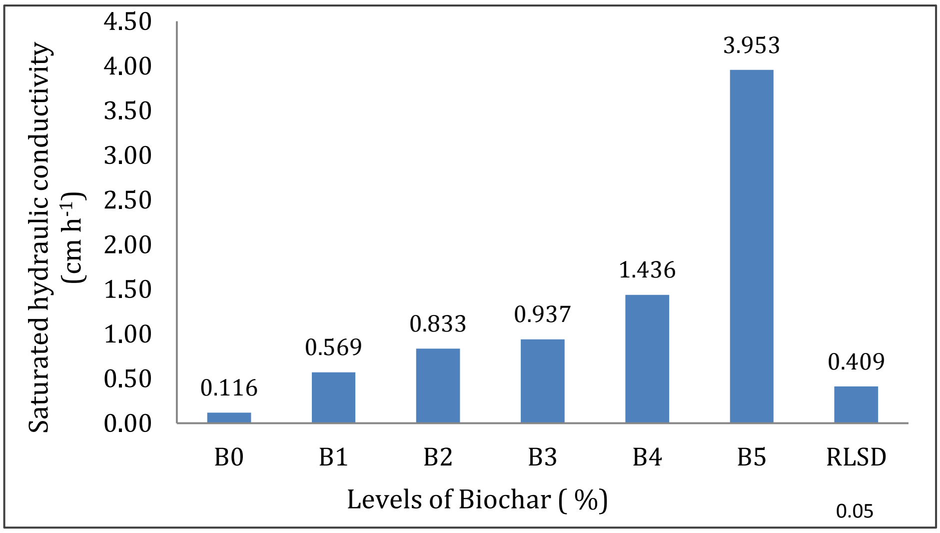

Figure (5): Effect of biochar levels on soil saturated hydraulic conductivity

Plant height

The results in figure (6) showed significant differences ($p < 0.05$) for the levels of biochar addition in the height of the oat plant. The addition of the B2 treatment recorded the highest height of the oat plant reached 60.87 cm and without significant differences with B1 and B4, with a percentage increase of 20.13% over the control treatment (B0). While, the B5 treatment recorded the lowest height of the oat plant (46.90 cm) and without significant difference with B0 treatment (50.67 cm). The reason for the superiority of the treatment of addition B2 in increasing the height of the plant compared with the control treatment (B0) and the other treatments may be attributed to the superiority of the treatment of addition B2 in improving most of the soil characteristics such as low bulk density and increased total porosity and the mean weight diameter of soil (Figures 1, 2 and 4, respectively), which improved the favorable conditions for plant growth in terms of a balance between soil aeration and moisture, and this, in turn, positively reflected in the increase in the height of the plant. While the reason recording the B5 treatment lowest height of the plant may be it gave very high moisture exceeds the field capacity of the soil (Fig. 3), which affected the air and water balance and therefore negatively affected the growth and height Plant. These results agreed with Devereux, *et al*. (2012) and Haider *et al*. (2017) they indicated that the addition of biochar within the appropriate boundaries improves soil characteristics and indicators of plant growth.

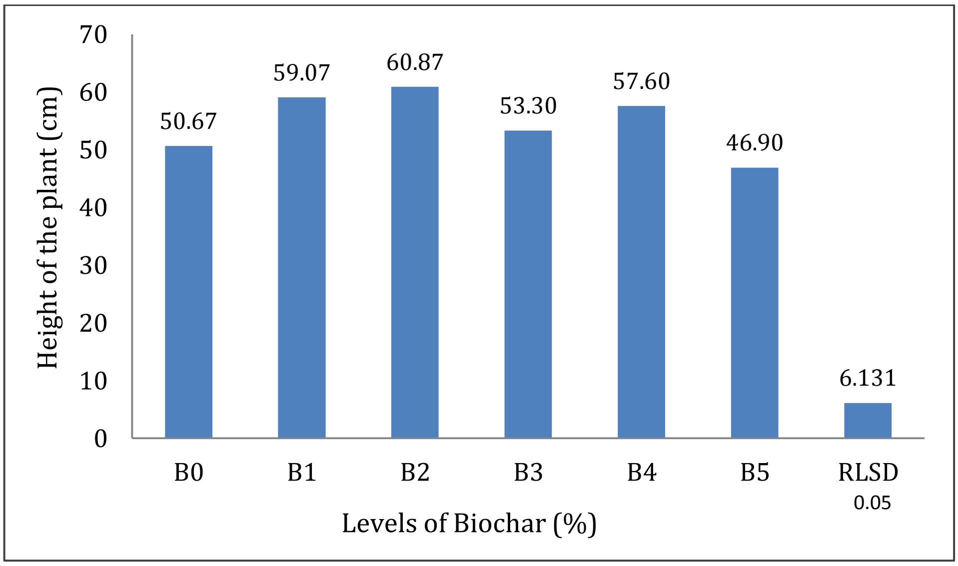

Figure (6): Effect of biochar levels on height of oat plant

Dry weight of the plant

The results showed a significant effect ($p < 0.05$) of the levels of biochar addition in the dry weight of the plant (Fig. 7). Where, the addition of the B2 treatment recorded the highest value of the dry weight of the plant reached 2.693 g pot^{-1} with a significant difference with other addition treatments except B4 treatment. While, the control treatment (B0) recorded the lowest value of the dry weight of the plant reached 1.110 g pot^{-1}. The reason for this may be attributed to the improvement in the physical properties of the soil with the B2 treatment (Figs. 1, 2 and 4) as well as the height of the plant (Fig. 6), which increases the spread of roots and increases the absorption of water and nutrients by the plant compared to other treatments. This, in turn, increases the growth of the plant, which is reflected positively in dry weight. These results were consistent with several studies that showed that adding biochar leads to an increase in the dry weight of the plant due to its effectiveness in providing favorable conditions for plant growth through aeration, water, and root spread (Jeffery *et al*., 2011; Obia *et al*., 2018 and Mayly *et al*., 2019).

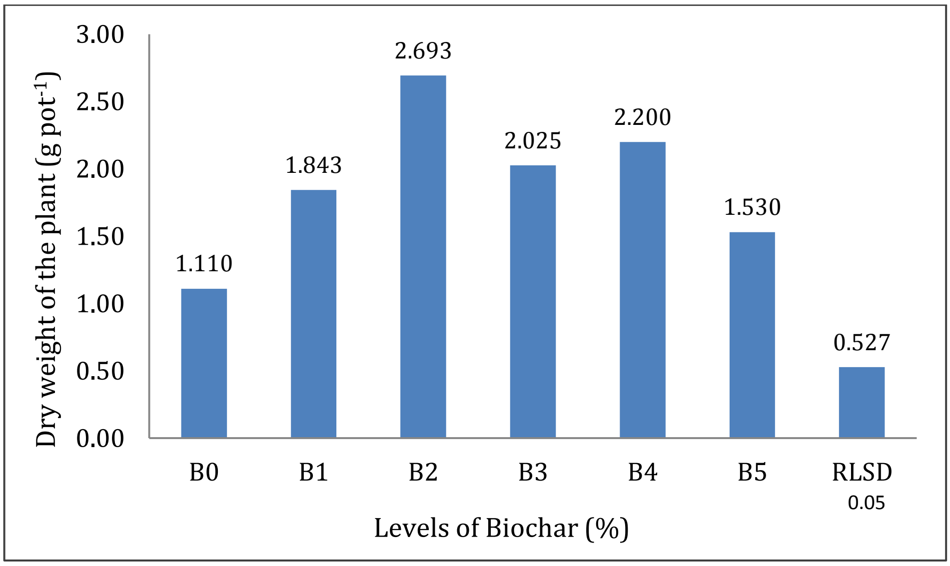

Figure (7): Effect of biochar levels on dry weight of oat plant

Conclusions

We can be concluded from the results of this study that addition biochar to soil has a significant effect in improving the soil physical properties and plant growth indicators compared with the control treatment (without addition), where the addition of biochar led to a decrease in the bulk density and increase in the total porosity, the susceptibility of the soil to water retention, mean weight diameter and saturated hydraulic conductivity of the soil, which was reflected in the improvement of plant growth through an increase in height and dry weight for the plant. The level of addition exceeded 1.5% in the improvement of most of the above characteristics and recorded the highest values of height plant (60.87 cm) and dry weight of plant (2.693 g pot^{-1}), while the level of addition exceeded 3% by giving the highest moisture content and saturated hydraulic conductivity of the soil. We recommend the use of biochar at the level of adding 1.5% under the conditions of the study because it has achieved most of the characteristics of the studied physical of soil and the growth characteristics of the oat plant.

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