Vol-2, Issue-2 PP. 411-418

ISSN: 2394-5788

GLOBAL JOURNAL OF ADVANCED RESEARCH

(Scholarly Peer Review Publishing System)

Evaluating the role of Bio-char application under two levels of water requirements on wheat production under sandy soil conditions

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Abstract

The application of bio-char (charcoal or biomass-derived black carbon) to soil is proposed as a novel approach to improve soil fertility, improve soil water holding capacity and consequently water conservation, and to increase crop production of newly reclaimed sandy soil. To assess these benefits, two field experiments were carried out at the Research and Production Station of the National Research Centre, Al Nubaria district, El-Behaira Governorate, Egypt during 2012/2013 and 2013/2014 winter seasons to study the effect of four levels of bio-char application (control, 2, 4, and 6 tons/feddan) and two levels of water requirements ((2000 m^3/feddan (80%) and 2500 m^3/feddan (100 %)) on growth, yield, and yield components of wheat (Misr 1). The results showed that at 75 days from sowing, flag leaf area (cm^2), and proline content were significantly affected by the two levels of water requirements, however, plant fresh weight (g), number of leaves/plant, chlorophyll a, chlorophyll b, and carotenoides were not significantly affected. On the other hand the bio-char application did not significantly affect flag leaf area (cm^2), number of leaves/plant, and carotenoides, however, it did significantly affect plant fresh weight (g), chlorophyll a, chlorophyll b, and proline content. At the end of the experiment the two levels of water requirements did not significantly affect plant height (cm), spike length (cm), number of spikelets/spike, biological yield (tons/fed.), straw yield (tons/fed.), and harvest index, however, number of grain/spike, grain weight/spike, and grain yield (tons/fed.) were significantly affected. Bio-char application did not significantly affect plant height (cm), spike length (cm), number of spikelets/spike, and harvest index, however, number of grain/spike, grain weight/spike, biological yield (tons/fed.), grain yield (tons/fed.), and straw yield (tons/fed.) were significantly affected. Finally, the addition of bio-char at the rate of 4 tons/feddan could produce high grain yield and saving about 20% of water under sandy soil conditions of Egypt.

Key words: wheat, Bio-char, Charcoal, water requirements.

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1. INTRODUCTION

Wheat (Triticum *aestivum L.*) is considered one of the most important cereal crops both in Egypt and in the world **(Elham *et al.*, 2009).** Its importance rising from using its grain as a main food source for human and its straw as feed for livestock. Land and water resources are limited in Egypt, so that increasing the productivity of wheat from the unit area is an important part in increasing the total production and minimize the gap between consumption and production. **(Ibrahim *et al.*, 2014)** Increasing the production will be achieved by increasing the cultivated area, especially in desert areas such as irrigation, fertilizers cultivating high yield varieties, and adoption of improved cultural practices like adding bio-char.

Bakry, *et al*., (2012) they found that water irrigation requirement of (80 % IR) produced high grain yield per faddan and insignificantly out yielded the water irrigation requirements of (100 % IR). Mousa and Abdel-Maksoud (2004), El-Afandy (2006) and Fang *et al*., (2006) they found that subjecting wheat plants to drought stress resulted in a significant reduction in grain yield and its components of wheat.

Charcoals are produced annually for cooking and industrial purposes. Most of this production is located in the developing countries rather than the developed countries. Charcoal production is often detrimental to the environment, as it leads to deforestation and air pollution. Yet, most developing countries have few alternatives to charcoal production for household fuel. However, significant improvements are possible with viable alternatives as far as wood production, charcoal production with respect to human health and use of charcoal waste is concerned. Additionally, it has been argued that use of charcoal as a fuel replacing wood leads to lower levels of household indoor pollution and an associated reduction in mortality **(Bailis *et al*. 2005).** Charcoal waste can be applied as bio-char to agricultural soils and turned into a valuable resource for improving crop yields on acid and infertile soils where nutrient resources are scarce such as sandy soils. Bio-char can act as a soil conditioner enhances the growth of the plants by supplying and, more importantly, retaining nutrients and improving soil physical and biological properties and consequently improving soil water holding capacity **(Lehmann and Rondon, 2005).**

Application of charcoal to soils is hypothesized to increase bio available water, build soil organic matter, enhance nutrient cycling, lower bulk density, act as a liming agent, and reduce leaching of pesticides and nutrients to surface and ground water (Laird 2008, Glaser, *et al*., 2002, Novak, *et al*., 2009 and Brookes, *et al*., 2010). Leach *et al*., (2010) documented that application of biochar to the soil enabling increases in agricultural productivity without, or with much reduced, applications of inorganic fertilizer.

2. MATERIALS AND METHODS

Two field experiments were carried out at the Research and Production Station of the National Research Centre (NRC), Al Nubaria district, El-Behaira Governorate, Egypt during 2012/2013 and 2013/2014 winter seasons to study the effect of four levels of bio-char application (control, 2, 4, and 6 tons/feddan of charcoal) and two levels of water requirements (WR80%, 2000 m^3/feddan and WR100%, 2500 m^3/feddan) on growth, yield, and yield components of wheat (Misr 1) under newly reclaimed sandy soil (one feddan= 4200 m^2). Physical and chemical properties of the experimental soil (Table 1) were analyzed according to **(Page *et al*., 1982).**

Table 1: Physical and chemical analyses of experimental soil.

Sand, %	Silt, %	Clay,%	Soil texture	pH	E.C. dS/m	Ca CO_3	O.M. %	N, ppm	P, ppm	K, ppm
92.5	3.8	4.8	sandy	7.9	0.56	1.7	0.28	9.6	3.5	22.4

The experimental design was split plot in randomized complete block design where the two levels of water requirements were allocated in the main plots whereas the four levels of bio-char were allocated in the sub plots. Plot area was 10.5 m^2 (3.5 m long and 3 m wide). Phosphorus fertilizer was added before sowing at the rate of 31 kg P_2O_5/feddan as calcium superphosphate (15.5% P_2O_5) while potassium was added at the rate of 24 kg K/feddan as potassium sulphate (48%

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K_2SO_4), nitrogen fertilizer was applied at the rate of 75 Kg N/feddan in the form of ammonium nitrate (33.5%N) in three equal doses, 20 days after sowing, tillering, and heading stages. Sowing was in mid November in both seasons and irrigated just after sowing using sprinkler irrigation system and water was added every 5 days. At 75 days from sowing three plants were taken as samples to record the following characters: flag leaf area (cm^2), plant fresh weight (g), number of leaves/plant, chlorophyll a, chlorophyll b, and carotenoides, and proline.

Photosynthetic Pigments:

Total chlorophyll a and b and carotenoids contents in fresh leaves were estimated using the method of (Lichtenthaler, and Buschmann, 2001). The fresh tissue was ground in a mortar and pestles using 80% acetone. The optical density (OD) of the solution was recorded at 662, 645 and 470 nm (for chlorophyll a, b and carotinoids) using a spectrophotometer (Shimadzu UV-1700, Tokyo, Japan).

Proline:

Proline was assayed according to the method described by (Bates, Waldren and Reare, 1973). Two ml of proline extract, 2 ml of acid ninhydrin and 2 ml of glacial acetic acid were added and incubated for 1 h in a boiling water bath followed by an ice bath. The absorbance was measured at 520 nm using Spekol Spectrocolololorimeter VEB Carl Zeiss. A standard curve was obtained using a known concentration of authentic proline.

At harvest stage, three plants from the two central rows were harvested and the following characters were recorded: Plant height (cm), spike length (cm), number of spikelets/spike, number of grain/spike, grain weight/spike. The whole plot was harvested to determine biological yield (tons/fed.), grain yield (tons/fed.), straw yield (tons/fed.), and harvest index. Data of the experiments were statistically analyzed using the analysis of variance according to method described by **(Snedecor and Cochran, 1982)** since the trend was similar in both seasons the homogeneity test Bartlet's equation was applied and the combined analysis of the two seasons was calculated according to the method described by **(Gomez and Gomez, 1984).**

3. RESULTS AND DISCUSSION

1-Effect of bio-char and water requirements on wheat growth at 75 days from sowing:

The data in Table 2 illustrate that the plants received 100% of its water requirements were significantly different and higher than those which received 80% of its water requirements in flag leaf area (cm^2), and proline, however, they were slightly higher but not significantly different in number of leaves/plant. Chlorophyll a, Chlorophyll b, and carotenoides. On the other hand plants received 80% of its water requirements were not significantly different and slightly higher than those which received 100% of its water requirements in plant fresh weight (g).

Increasing bio-char application resulted in insignificant increase in flag leaf area (cm^2) and significantly increases in plant fresh weight (g), chlorophyll a and chlorophyll b as compared to the control. Number of leaves/plant was insignificantly and slightly decreased as bio-char levels were increased. No specific trend was observed in carotenoides. However, increasing bio-char levels caused a reduction in proline as compared to the control.

Table 2. Effect of four levels of bio-char and two levels of water requirements on wheat growth, combined analysis of 2012/2013 and 2013/2014 seasons.

	Flag leaf area, cm^2	plant fresh weight,g	Number of leaves/ plant	Chlorophyll a	Chlorophyll b	Carotenoides	Proline (µg/100g dry wt.)
WR80%	29.86 b	3.64 a	4.08 a	8.95 a	2.83 a	4.36 a	18.65 b
WR 100%	40.65 a	3.41 a	4.17 a	9.45 a	3.27 a	4.42 a	26.23 a
Control	29.72 a	2.81 b	4.33 a	8.30 b	2.74 b	4.38 a	26.04 a
B1	36.92 a	3.67 a	4.17 a	8.50 b	2.86 b	4.25 a	24.52 a

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B2	37.33 a	3.67 a	4.00 a	9.75 a	3.51 a	4.30 a	20.44 b
B3	37.05 a	3.95 a	4.00 a	10.26 a	3.09 ab	4.63 a	18.77 b

WR80%= 2000 m^3/feddan, **WR 100%**=2500 m^3/feddan
B1= 2 tons bio-char /fed., **B2**= 4 tons bio-char /fed., **B3**= 6 tons bio-char /fed.

2- Effect of bio-char and water requirements on wheat yield and its components at harvest:

The data in Table 3 showed that the plants irrigated with 100% of its water requirements were significantly different and higher than those which received 80% of its water requirements in number of grain/spike, grain weight/spike (g), and grain yield (tons/fed.), and were insignificantly higher in plant height (cm), spike length (cm), biological yield (tons/fed.), straw yield (tons/fed.) and harvest index. However, the plants supplied with 80% of its water requirements insignificantly produced higher number of spikelets/spike. This may be due to at 80% IR is the best case or suitable conditions. These conditions decreased from water stress or drought stress and also achieved excellent distribution for nutrients inside root zone. But at 100% IR we can get lowest water stress but we cannot achieve excellent distribution for nutrients inside root zone because of increasing of leaching rate with increasing volume of applied water.

As the bio-char level increased neither significant difference nor specific trend was observed in plant height (cm), spike length (cm), and number of spikelets/spike. However, grain weight/spike (g) was significantly increased as compared to the control. A step wise and significant increase was observed in biological yield (tons/fed.), grain yield (tons/fed.), and straw yield (tons/fed.) with the increase in bio-char level. When the bio-char was applied at the rate of 2, 4, and 6 tons/feddan the increase in grain yield were 6.25, 21.43, and 20.54 (%) respectively as compared to the control treatment. These results agreed with those obtained by **(Bakry *et al.*, 2014)** who reported similar results in flax when 4 tons/feddan of bio-char was applied.

It is worth to mention that the second level of bio-char was the optimum level where it gave high grain yield with no significant difference as compared to the third level. This increase in grain yield may be due to the increase in grain weight/spike. The results from the current study agree with **(Chan *et al*., 2007)** who reported positive response to bio-char in combination with fertilizer in pot trials, and **(Yamato *et al*., 2006)** who stated that maize and peanut yields were enhanced where bark charcoal was applied in combination with N fertilizer in the field.

Also, the results are in accordance with those obtained by **(Kimetu *et al*., 2008)** who reported positive yield effects from bio-char addition.

Laird (2008), Glaser, *et al*., (2002), Novak, *et al*., (2009) and Brookes, *et al*., (2010) they found that application of charcoal to increase bio available water, build soil organic matter, enhance nutrient cycling, lower bulk density, act as a liming agent, and reduce leaching of nutrients to ground water.

Table 3. Effect of four levels of bio-char and two levels of water requirements on wheat yield and its components, Combined analysis of 2012/2013 and 2013/2014 seasons.

	Plant height, cm	Spike length, cm	Spikelets number/ spike	Grain number /spike	Grain weight/ spike, g	Biological yield, tons/fed.	Grain yield, tons/fed.	Straw yield, tons/fed.	H.I.
WR 80 %	86.58 a	12.83 a	13.42 a	34.17 b	1.30 b	3.90 a	1.23 b	2.68 a	0.29 a
WR 100%	89.92 a	13.75 a	12.42 a	39.50 a	1.42 a	4.37 a	1.27 a	3.10 a	0.32 a
Control	88.83 a	13.00 a	12.67 a	35.50 bc	1.13 d	3.79 b	1.12 c	2.67 c	0.30 a
B1	88.33 a	13.50 a	13.33 a	34.83 b	1.27 c	3.95 b	1.19 b	2.75 bc	0.30 a
B2	87.17 a	13.50 a	12.50 a	40.67 a	1.64 a	4.37 a	1.36 a	3.01 ab	0.30 a
B3	88.67 a	13.17 a	13.17 a	36.33 b	1.41 b	4.46 a	1.35 a	3.12 a	0.31 a

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WR80%= 2000 m^3/feddan, **WR 100%**=2500 m^3/feddan
B1= 2 tons bio-char /fed., **B2**= 4 tons bio-char /fed., **B3**= 6 tons bio-char /fed.

3-Effect of interaction between bio-char and water requirements on wheat growth at 75 days from sowing:

The interaction between bio-char and water requirements had no significant effect on all the studied characters in Table 4 except for chlorophyll b. In general chlorophyll b tended to increase as bio-char level increased except for the third level of bio-char under 80% of water requirements.

Table 4. Effect of interaction between bio-char and water requirements on wheat growth, combined analysis of 2012/2013 and 2013/2014 seasons.

		Flag leaf area, cm^2	plant fresh weight, g	Number of leaves/ plant	Chl. a	Chl. b	Caro.	Proline (µg/100g dry wt.)
WR 80 %	Control	22.97	2.65	4.33	7.75	2.56	4.51	22.36
	B1	32.90	3.65	4.00	7.72	2.72	4.29	21.33
	B2	31.97	3.90	4.00	10.17	3.62	4.31	16.53
	B3	31.60	3.45	4.00	10.16	2.43	4.32	14.40
WR 100 %	Control	36.47	2.98	4.33	8.86	2.93	4.25	29.72
	B1	40.93	3.70	4.33	9.27	3.00	4.21	27.71
	B2	42.70	3.45	4.00	9.33	3.40	4.31	24.35
	B3	42.50	4.45	4.00	10.36	3.76	4.94	23.15
L.S.D. 0.05		**N.S.**	**N.S.**	**N.S.**	**N.S.**	**0.79**	**N.S.**	**N.S**

WR80%= 2000 m^3/feddan, **WR 100%**=2500 m^3/feddan
B1= 2 tons bio-char /fed., **B2**= 4 tons bio-char /fed., **B3**= 6 tons bio-char /fed.

4- Effect of interaction between bio-char and water requirements on wheat yield and its components at harvest:

The interaction between bio-char and water requirements significantly affected all the studied characters in Table 5 except for plant height (cm) and number of spikelets/spike. Also, Spike length (cm), number of grain/spike, and harvest index had no specific trend with increasing bio-char application under both irrigation treatments. However, grain weight/spike tended to significantly increased with increasing bio-char application until the second level. Also, biological yield (tons/feddan), grain yield (tons/feddan), figure 1, tended to significantly increase as bio-char application increased. Straw yield (tons/feddan) was only significantly increased under the 80% water requirements as compared to the control.
It is worth to mention that the increase in grain yield with increasing bio-char application may be due to the increase in grain weight/spike.

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Table 5. Effect of interaction between bio-char and water requirements on wheat yield and its components, combined analysis of 2012/2013 and 2013/2014 seasons.

		Plant height, cm	Spike length, cm	Spikelets /spike	Grain number/ spike	Grain weight/ spike, g	Biological yield, tons/fed.	Grain yield, tons/fed.	Straw yield, tons/fed.	H.I.
WR 80 %	Control	87.00	13.67	13.00	33.00	1.11	3.26	1.13	2.13	0.34
	B1	87.00	13.00	14.33	29.00	1.08	3.66	1.12	2.56	0.31
	B2	84.33	12.00	12.67	40.67	1.61	4.36	1.33	3.03	0.31
	B3	88.00	12.67	13.67	34.00	1.41	4.35	1.35	3.01	0.31
WR 100 %	Control	90.67	12.33	12.33	38.00	1.15	4.32	1.11	3.21	0.26
	B1	89.67	14.00	12.33	40.67	1.47	4.24	1.26	2.97	0.30
	B2	90.00	15.00	12.33	40.67	1.68	4.38	1.39	2.99	0.32
	B3	89.33	13.67	12.67	38.67	1.41	4.56	1.34	3.22	0.29
L.S.D. 0.05		**N.S.**	**1.16**	**N.S.**	**3.38**	**0.11**	**0.67**	**0.05**	**0.66**	**0.05**

WR80%= 2000 m^3/feddan, **WR 100%**=2500 m^3/feddan
B1= 2 tons bio-char /fed., **B2**= 4 tons bio-char /fed., **B3**= 6 tons bio-char /fed.

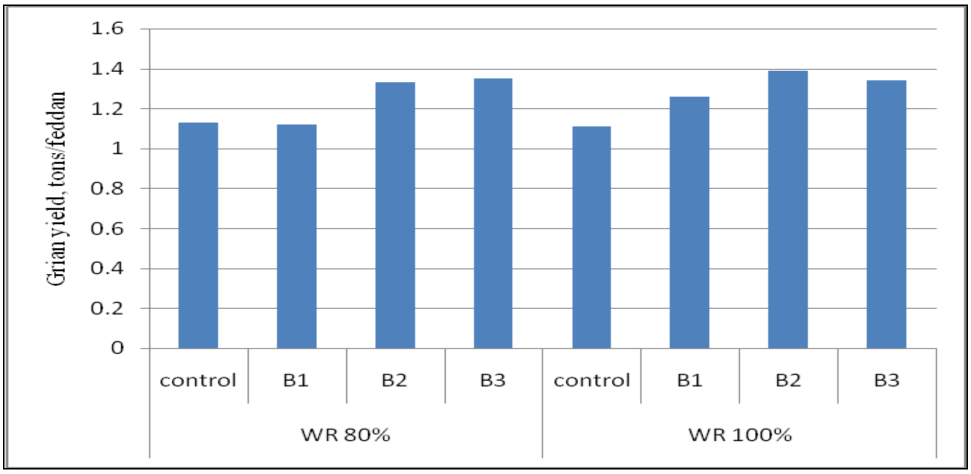

Fig. 1. Grain yield of wheat (tons/fed.) as affected by bio-char and water requirements
WR80%= 2000 m^3/feddan, **WR 100%**=2500 m^3/feddan
B1= 2 tons bio-char /fed., **B2**= 4 tons bio-char /fed., **B3**= 6 tons bio-char /fed.

4. CONCLUSION

The current study confirmed that bio-char application may help in increasing of wheat production under sandy soil conditions through the improving effect of bio-char on some physical and chemical properties such as water holding capacity and nitrogen availability. The production of wheat under sandy soil conditions was not be affected with reducing its water requirements to 80 % (2000 m^3/feddan) of its total water requirements (2500 m^3/feddan) when bio-char was applied at the rate of 4 tons/feddan. So, we recommend the cultivation of wheat by applying 80%IR and using bio-char at rate of 4 tons/feddan.

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