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Management strategy for improving the productivity of wheat in newly reclaimed sandy soil

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Abstract: Biochar is a carbon-rich solid material produced during pyrolysis, which is the thermal degradation of biomass under oxygen limited conditions. Biochar can be used as a soil amendment to increase the productivity of low potential soils. Two field experiments were carried out during 2012/2013 and 2013/2014 winter seasons at the Research and Production Station, National Research Centre, El-Nubaria Province, El-Behira Governorate, Egypt to study the effect of foliar application with water, KNO_3 (5g/L), Mg $(NO_3)_2$ (5g/L) and addition of charcoal (4 tons/fed) for improving productivity of wheat plant growing under sandy soil conditions. Results indicated that addition of charcoal, recorded the highest values of all the studied characters in growth, yield and its components, i.e. plant height (cm), number of spikes/m^{2}, blades area (cm^2/m^2) , flag leaf area (cm^2), dry weight of plants (g/m^2), grain yield (tons/fed), straw yield (tons/fed), biological yield (tons/fed), number of grains/spike, dry weight of grains/spike (g), 1000 grains weight (g) as well as the percentage and uptake of N, P, K and crude protein, except for harvest index. The results indicated that both KNO_3 and Mg $(NO_3)_2$ significantly increased all the previous characters, with superiority to KNO_3 which caused the highest increases in plant height (cm), grain yield (tons/fed), straw yield (tons/fed), 1000 grains weight (g), protein yield/fed and crude protein (%) and significantly affected all the studied characters except for harvest index and number of grains/spike. The interaction between charcoal and KNO_3 recorded the highest values for all the studied characters in growth, yield and its components, as well as the percentage and uptake of N, P, K and crude protein content.
Key wards: wheat, foliar application, charcoal, productivity.

Introduction

Wheat (*Triticum aestivum* L.) is one of the most important cereal crops in the world as well as well in Egypt. Wheat represents the main food for more than one third of the world population; in Egypt wheat provides 37% of the total calories for the people and 40% of the protein in the Egyptian diet. Also, it is a major source of straw for animal feeding.

Biochar is the product of thermal degradation of organic materials in the absence of air [1]. There are some researches showing that biochar can be used to improve soil fertility and sequester carbon for reduction of carbon mitigation to mitigate climate change[2, 3, 4]. Charcoal is the dark residue consisting of carbon, and the remaining ash, obtained by removing water and other volatile constituents from vegetation substances[5]. Charcoal is usually produced by pyrolysis at temperatures from 300 to 600 °C[6]. Charcoal has also been shown to change soil biological conditions in terms of the quality and quantity of soil microorganisms[7]. These changes may well have effects on nutrient cycles and soil structure which in turn can lead to differences in plants growth and productivity[7]. The possible connections between biochar properties and the soil biota, and their implications for soil processes have not yet been systematically described[3].

Potassium is an important macronutrients and the most abundant cation in higher plants. It is the target of many researches because it is essential for enzymes activation, protein synthesis and photosynthesis[9, 10]. Furthermore, K is necessary for phloem solute transport and for the maintenance of cation/anion balance in the cytozol as well as in the vacuole. Potassium stimulates root growth and hence, efficient exploration of soil water[11]. Further, it decreases the loss of soil moisture by reducing the transpiration and increasing the retention of water in plants. Potassium plays an important role in the growth and development of plants[12]. It activates enzymes, maintains cell turgor, enhances photosynthesis, reduces respiration, helps transport sugars and starches, aids in nitrogen uptake and is essential for protein synthesis. In addition to plant metabolism, potassium improves crop quality because it helps with grain filling and kernel weight, strengthens straw, increases disease resistance, and helps the plant better withstand stress[13]. Its role is well documented in photosynthesis, increasing enzyme activity, improving synthesis of protein, carbohydrates and fats, translocation of photosynthetic, enabling their ability to resist pests and diseases. Sources of potassium and its effect on growth and yield of crops were studied by Abd El-Aal HA et al who observed yield improvement in plants fertilized with both soil and foliar K. Another possible approach to crop productivity is the foliar application of magnesium which plays several physiological and biochemical roles i.e., chlorophyll formation, activation of enzymes, synthesis of proteins, carbohydrate metabolism and energy transfer.

Magnesium also acts as a catalyst in many oxidation, reduction reactions inside the plant tissues, as well as it may increase crop resistance to drought[15]. In this concern Saad AOM et al stated that foliar application with magnesium sulphate increase net assimilation rates, seed yield and crude protein content of bean plants.

The objective of this work was to evaluate the effect of foliar spraying with KNO_3 and $Mg(NO_3)_2$ in addition to soil application of charcoal on growth, yield and yield components of wheat plants grown under new reclaimed sandy soil.

Materials and Methods

Two field experiments were carried out at the Research and Production Station, National Research Centre, El-Nubaria Province, El-Behira Governorate, Egypt to study the effect of addition of Charcoal (4 Tons/fed) and foliar application with KNO_3(5g/L) or $Mg(NO_3)_2$ (5g/L) on growth, yield and its components as well as the percentage of N, P, K and crude protein of wheat variety (Sakha 93) grown under newly reclaimed sandy soil. Physical and chemical properties of the soil (Table, 1). The experimental design was split plot in randomized complete block design where the charcoal treatments were allocated in the main plots whereas the foliar application 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/fed as calcium superphosphate (15.5% P_2O_5) while potassium was added at the rate of 24 kg K/fed as potassium sulphate (48% K_2SO_4), nitrogen fertilizer was applied at the rate of 75 Kg N/fed 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. The solutions of the micronutrients were sprayed at the rate of (5g/L) KNO_3 or (5g/L) Mg $(NO_3)_2$ in additions to tap water as control tretment. At 75 days from sowing three plants were taken as samples to record the following characters: plant height (cm), number of spikes/m^2, blades area (cm^2/m^2), flag leaf area (cm^2) and dry weight of plants (g/m^2). At harvest, the two central rows were harvested and the following characters were recorded: grain yield (tons/fed), straw yield (tons/fed), biological yield (tons/fed), harvest index (economical yield/biological yield * 100), number of grains/spike, dry weight of grains/spike (g), 1000 grains weight(g), total nitrogen was determined following the micro kjieldhl method according to Association of official agriculture chemist and then total N content was multiplied by 5.75 to obtain the protein content in grain. Protein yield (kg/fed) = protein % * grain yield/fed. Phosphorus was measured colorimetrically by vanadate molybdate yellow method[18]. Potassium was measured by flame photometer according to Chapman HO et al. Grain N uptake (kg fed^{-1}) = Grain N concentration % * grain yield, (kg fed^{-1}). Data were subjected to statistical analysis of variance as described by Snedecor GW et al and the combined analysis of the two seasons results were conducted. Mean values of the recorded data were compared by using the least significant differences (L.S.D. 5%).

Table (1): Mechanical and chemical analyses of experimental soil.

Sand%	Silt%	Clay%	$CaCO_3$%	Organic matter%	E.C., dS/m	pH	Soluble N%	Available P(ppm)	Available K(ppm)
91.2	3.7	5.1	1.4	0.3	0.3	7.3	8.1	3.2	20

Results and Discussion

A-Growth analysis and Growth attributes:

Data in Table (2) show that increases in growth characters were obtained by using charcoal as compared to the other treatments (without charcoal). These results are in agreement with Sohi S et al (2009) who found that charcoal could improve the physical properties of soil. A single application of 20 t/ha biochar to a Columbian savanna soil resulted in an increase in maize yield by 28 to 140% as compared with the untreated (control) in the 2nd to 4th years after application[21]. Similarly, large volume applications of biochar (30 and 60 t/ha) in the Mediterranean basin increased durum wheat biomass and yield by up to 30% [22]. The means by which biochar improves crop response can be attributed to direct effects via biochar-supplied nutrients[23], and to several other indirect effects, including: increased nutrient retention; improvements in soil pH, increased soil cation exchange capacity[24], effects on P (Phosphorus) and S (Sulfur) transformations and turnover, neutralization of phytotoxic compounds in the soil and alteration of soil microbial populations and functions[25]. Moreover, the researchers concluded that biochar provided suitable conditions for mycorrhizal fungi to colonize plant roots[26].

Results in Table (2) also indicated that, foliar application of either Mg or K positively affected all the studied growth characters with superiority to K over Mg. The positive impact of potassium could be to its role in improving physical, chemical and biological condition of soil, its direct effect attributed due to its metabolic activity in plant growth. Therefore when plants were treated with potassium, chlorophyll contents were increased which enhanced overall photosynthetic activities of plants and thereby yield. These results are in agreement with [27]. Who stated that the increase in number of grains/spike by application of K may be due to increase in number of spikelets. It was indicated by many investigators that potassium played a key role in the osmotic adjustment (stomatal opening) of plants under water stress and yield may be improved due to foliar potassium application to plants.

Table (2).Effect of addition of charcoal and foliar application of K^+ and Mg^{2+} on growth of wheat.

Treatment	Plant height(cm)	Number of spikes/m^2	Blades area(cm^2/m^2)	Flag leaf area(cm^2)	Dry weight of plants (g/m^2)
Without charcoal	85.71	335.18	57550.58	41.86	1018.00
Charcoal	89.14	353.44	59550.01	44.33	1064.84
LSD, 5%	NS	NS	298.65	NS	45.36
Tap water	82.93	333.89	56917.79	40.12	999.62
KNO_3	91.87	356.66	60054.84	45.84	1081.54
$Mg(NO_3)_2$	87.48	342.39	58678.26	43.33	1043.11
LSD, 5%	4.65	19.65	315.65	2.66	52.74

Data presented in table (3) show the interaction effect between addition of charcoal and foliar application with Mg or K on wheat growth. Data showed that the highest values for growth were recorded in plants treated with charcoal and sprayed with K. On the other hand the least values were recorded in plants missed charcoal and sprayed with tap water. This could be due to the positive impact of charcoal and K on plant growth[25].

Table (3). Interaction effect of charcoal and foliar application of K^+ and Mg^{2+} on growth of wheat.

Charcoal treatment	Foliar treatment	Plant height (cm)	Number of spikes/m^2	Blades area (cm^2/m^2)	Flag leaf area (cm^2)	Dry weight of plants (g/m^2)
Without	Tap water	81.40	325.12	56423.21	39.21	986.22
	KNO_3	89.55	346.87	58874.36	44.36	1051.72
	$Mg(NO_3)_2$	86.17	333.54	57354.18	42.01	1016.07
Charcoal	Tap water	84.45	342.65	57412.36	41.03	1013.02
	KNO_3	94.18	366.45	61235.32	47.32	1111.36
	$Mg(NO_3)_2$	88.79	351.23	60002.34	44.65	1070.16
LSD, 5%		8.23	34.65	556.32	NS	98.37

B- Yield and its components:

Results in Table (4) clearly show that grain yield (tons/fed), straw yield (tons/fed), biological yield (tons/fed), number of grains/spike, weight of grains/spike and 1000 grains weight (g) gave the highest values by adding charcoal except for harvest index values which is not affected by adding charcoal. The use of charcoal generally, seems to improve crop yield. This increasing in yield could be due to the ability of charcoal for improving soil condition by increasing water holding capacity **and** increasing number of useful soil microorganisms[28]. In another research with charcoal (0, 0.8, 4 tons of charcoal ha^{-1}) in two different type of soil yield increased up to 30% after using of charcoal in both acidic and normal soil[29]. Moreover, another research on durum wheat in the Mediterranean climate condition, with usage of charcoal at the rate of 30 and 60 t ha^{-1}, the results showed that yield increase up to 30%[22]. Results presented in Table (4) also indicated that foliar application with K^+ or Mg^{2+} positively affected yield and yield attributes of wheat crop with superiority to K^+ which significantly affected grain yield (tons/fed), straw yield (tons/fed), biological yield (tons/fed), number of grains/spike, weight of grains/spike and 1000 grains weight (g) except for harvest index which is not affected by foliar application. These results are in agreement with those obtained by Ali Rahimi(2012) [27]. These effects may be due to the role of K in formation of carbohydrates, proteins, photosynthesis translocation regulation, and enzyme action, synthesis of nucleic acid, chlorophyll, oxidative, photophospharylation and translocation of solutions[30].

Table (4). Effect of charcoal, foliar application of K^+, and Mg^{2+}on wheat yield and its components.

Treatment	Grain yield (tons/fed)	Straw yield (tons/fed)	Biological yield (tons/fed)	Harvest index	Number of grains/spike	Dry weight of grains/spike(g)	1000 grains weight (g)
Without charcoal	1.95	2.45	4.40	44.44	53.80	2.53	44.68
Charcoal	2.04	2.71	4.75	42.98	56.89	2.67	46.48
LSD, 5%	NS	0.14	0.22	NS	3.02	NS	NS
Tap water	1.77	2.23	4.00	44.23	52.16	2.38	42.99
KNO_3	2.18	2.79	4.96	43.88	56.19	2.78	47.51
$Mg(NO_3)_2$	2.05	2.72	4.77	43.04	57.69	2.64	46.26
LSD, 5%	0.11	0.16	0.23	NS	3.25	0.12	2.65

Data presented in Table (5) clearly showed that all combined applications of charcoal and foliar application of K and Mg showed a positive impact on yield and yield attributes, application of K^+ appeared greater and significantly affected all the studied characters compared to the control treatment. The efficiency of application of biochar combined with the KNO_3 may be attributed that it is being used as a soil amendment to improve soil quality and to increase crop production. In this regard, an obvious positive attribute of biochar is its nutrient value, supplied either directly by providing nutrients to plants or indirectly by improving soil quality, with consequent improvement in the efficiency of fertilizer use. As a measure of the direct nutrient value of biochar, it is not the total content but, rather, the availability of the nutrient that is an important consideration. Moreover, the indirect nutrient value of biochar is its ability to retain nutrients in the soil and, therefore, to reduce leaching losses, resulting in increased nutrient uptake by plants and higher production. According to Glaser B et al (2002), the indirect nutrient value of biochar is the removal of soil constraints limiting plant growth and production (e.g. the use of lime to overcome soil acidity, with resulting improvement in fertilizer use efficiency and increases in plant production). The obtained results are in agreement with Afifi MHM et al(2013) [32]. The highest values obtained from that treatment may be due to the improvement of soil conditions and the establishing equilibrium among plant nutrients which considered important for soil productivity and plant production. Also, the results from the current study agree with [33] who reported positive response to biochar in combination with fertilizer in pot trials.

Table (5). Interaction effect of charcoal, foliar application of K^+, and Mg^{2+}on wheat yield and its components.

Charcoal treatment	Foliar treatment	Grain yield (tons/fed)	Straw yield (tons/fed)	Biological yield (tons/fed)	Harvest index	Number of grains/spike	Dry weight of grains/spike(g)	1000 grains weight (g)
Without	Tap water	1.72	2.08	3.80	45.26	51.02	2.33	42.32
	KNO_3	2.13	2.65	4.78	44.56	43.02	2.71	46.36
	$Mg(NO_3)_2$	2.01	2.61	4.62	43.51	47.36	2.55	45.36
charcoal	Tap water	1.81	2.38	4.19	43.20	53.30	2.43	43.65
	KNO_3	2.22	2.92	5.14	43.19	59.36	2.84	48.65
	$Mg(NO_3)_2$	2.09	2.82	4.91	42.57	58.01	2.73	47.15
LSD, 5%		0.23	0.31	0.62	4.56	5.48	0.25	4.65

C- Grain quality and chemical compositions:

Data in figure (1) show increases in N%, P% and K% when charcoal was added to soil. improvement of crop response can be attributed to direct effects via biochar-supplied nutrients [23], and to several other indirect effects, including increased nutrient retention, increased soil cation exchange capacity[24], effects on Phosphorus, Potassium and Sulfur, improved soil physical properties including water retention, promotion of mycorrhizal fungi and alteration of soil microbial populations and functions[25]. Addition of biochar increased crude protein content. Also Fig. (1) showed the positive impact of foliar application with K and Mg on the content of N, P, K and crude protein. Similar results were obtained by Glaser B.(2007)[34]. Response to foliar application KNO_3 treatment resulted in the highest values of these traits with significant differences compared with other foliar application treatment. Data in figure (1) illustrate that crude protein as well as N, P, and K percentages in grains were significantly increased by foliar application, KNO_3 associated with a significant increase in grain quality. This improvement in grain quality parameters due to foliar application of KNO_3 may be reflected to the improving growth and dry matter accumulation with increasing the uptake of most nutrients. The results achieved in the current work are partially compatible with those obtained by Allam SA(2005) [35].

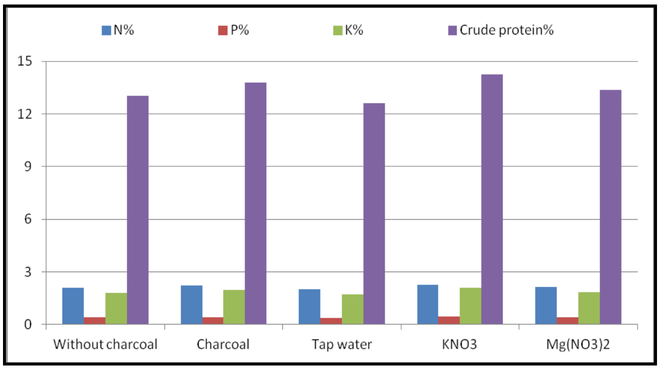

Figure (1) Effect of charcoal, foliar application of K^+, and Mg^{2+} on N, P, K and crude protein content of wheat grain.

Data presented in Table (6) clearly showed that all combined applications of (charcoal and foliar application of KNO_3 significantly affected all studied characters N, P, K and crude protein percentage compared to the control treatment. The highest values were recorded in plants treated with charcoal and sprayed with K.

This could be due to the positive role of charcoal in improving the physical properties of soil and to the impact of potassium on chemical and biological condition of soil as well as its direct effects on plant growth and dry matter accumulation so that improvement in grain quality parameters and increasing the uptake of most nutrients.

Table (6) Effect of charcoal, foliar application of K^+, and Mg^{2+} on N, P, K and crud protein of wheat grains.

Charcoal treatment	Foliar treatment	N%	P%	K%	Crude protein%
Without	Tap water	1.98	0.35	1.68	12.38
	KNO_3	2.18	0.42	1.92	13.63
	$Mg(NO_3)_2$	2.09	0.39	1.77	13.06
charcoal	Tap water	2.06	0.38	1.78	12.88
	KNO_3	2.38	0.43	2.23	14.88
	$Mg(NO_3)_2$	2.19	0.41	1.88	13.69
LSD, 5%		0.25	0.03	0.18	1.34

D- Uptake of N, P, K and crud protein

Data in Fig. (2) Showed that treating wheat plants with charcoal or spraying with K or Mg significantly affected uptake of N, P, K and crude protein content. These results are in agreement with those obtained by Glaser B.(2007)[34] who stated that, since biochar is produced from organic materials, it inherently contains nutrients that are found in its mineral fraction. Therefore, the addition of biochar to soil adds free exchangeable bases such as K, Ca, and Mg to occupy the soil-exchange sites, thus resulting in an increase in soil pH, and readily supplying plant nutrients for growth. Although the soil-biochar mixtures increasing C:N ratios, it is important to note that the total elemental contents of N, which is organically bound, does not reveal the definite plant available N[36]. Biochar inherently contains a high content of soluble P salts formed during the charring of organic materials[37]. Although the amount of available P found in the biochar is high (figure 2).

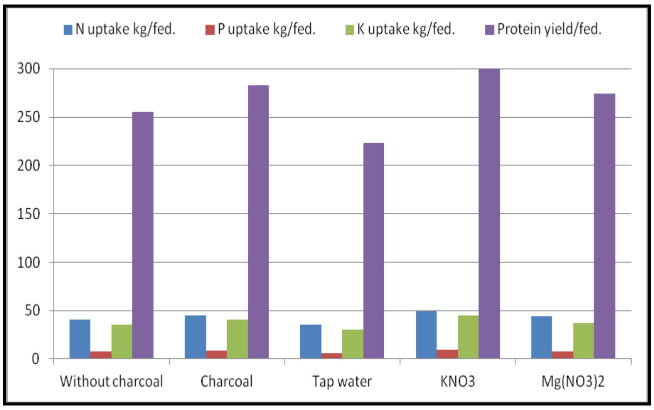

Figure (2) Effect of charcoal, foliar application of K^+ , and Mg^{2+} on N, P, K and crude protein uptake of wheat grains.

Table (7) clearly showed that all combined applications of charcoal and foliar application of KNO_3 significantly affected N, P, K and crude protein uptake compared to the control treatment. The highest values were recorded in plants treated with charcoal and sprayed with K. This could be due to the positive role of charcoal in improving the physical properties of soil and to the impact of potassium on plant growth and dry matter accumulation so that improvement in grain quality parameters and increasing the uptake of most nutrients. The efficiency of application of biochar combined with foliar application of KNO_3 gave the highest values in N, P, K and crude protein. In this regard, an obvious positive effect of biochar is its nutrient value, supplied either directly by providing nutrients to plants or indirectly by improving soil quality, with consequent improvement, the results from the current study agree with Bakry AB et al(1024) and Ibrahim OM et al (2015)[38, 39] who reported positive response to biochar on Flax and wheat production.

Table (7) Effect of charcoal, and foliar application of K^+, and Mg^{++} on N, P, K and crud protein uptake of wheat grain.

Charcoal treatment	Foliar treatment	N uptake kg/fed	P uptake Kg/fed	K uptake Kg/fed	Protein Yield/fed
Without	Tap water	34.056	6.02	28.90	212.85
	KNO_3	46.434	8.95	40.90	290.21
	$Mg(NO_3)_2$	42.009	7.84	35.58	262.56
charcoal	Tap water	37.286	6.88	32.22	233.04
	KNO_3	52.836	9.55	49.51	330.23
	$Mg(NO_3)_2$	45.771	8.57	39.29	286.07
LSD 5%		4.98	1.02	4.65	26.58

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