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Combined effects of NPK fertilizers, biochar and fulvic acid on wheat growth in sandy soil

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***Abstract:* - Background**: Wheat production in sandy soil is affected by the losses of applied mineral fertilizers and environmental stresses. We hypothesized that combining NPK fertilizers with biochar and fulvic acid (FA) could improve wheat growth and reduce nutrients losses. **Methods:** We conducted a pot experiment during 2017/2018 under wheat (Triticum aestivum cv., Misr 1). Four rates of mineral fertilizers were applied including 160, 310, 475 and 635 kg ha-1 of super phosphate, 143, 190, 240 and 285 kg ha-1 of potassium sulphate and 120, 180, 240, 300 kg ha-1 of ammonium nitrate. Biochar was applied at rates 0, 15 and 30 Mg ha-1. Fulvic acid was foliar applied on wheat plants at a rate of 0.2 g L^{-1}. **Result**: Our results showed that combined application of highest NPK rate with 30 Mg ha-1 biochar and FA resulted in the maximum straw and grains N, P and K contents (2.37, 0.59, 2.36, 2.88, 0.97 and 2.31%, respectively). Applying the maximum rate of NPK fertilizers, 30 Mg ha-1 of biochar and FA resulted in increasing plant height by 27% and duplicated grain yield and biological yield as compared with no amendments. In conclusion, we recommended combining NPK fertilizers with biochar and FA for optimizing wheat growth and productivity in sandy soils.

Keywords: *Mineral fertilizers; biochar; fulvic acid; NPK uptake; wheat crop.*

I. INTRODUCTION

Notable increase in food demand is detected due to the massive raising in population, which is accompanied by limited land resources. Wheat (Triticum sp.) is one of the most strategic crops in Egypt and increasing its yield is a national target to meet consumption needs. A pronounced efforts and attention by the Egyptian government and scientists have been paid to decrease wheat security gap (1). Most of land resources are not suitable for horizontal expansion as around 47% are sandy soils based on World Reference Base (2). Sandy soils are pervasive covers almost world area (9×108 ha), especially in semi-arid and arid regions (3) like Egypt. Sandy soils contains more than 700 g sand kg-1 and colloidal particles less than 150 g clay kg-1 (2), which results in poor physical, biological and chemical properties of these soils. Thus, sandy soils have low capacity to retain water and nutrients and less supplying power of nutrients including N, P and K. Accordingly, amendments have been widely investigated to raise the use efficiency of fertilizers and thus improving plant growth and productivity (4).

Biochar is carbonaceous material produced by thermal decomposition of crops residues or burning under limited oxygen by exposure to pressure (5). Biochar plays a key role in soil fertility and plant nutrition, such as improving soil cation exchange capacity, conserving nutrients against losses for a longer period and increase their utilization efficiency by plants (6). Biochar has high porosity, specific surfaces and the high ability maintain water and exchange cations, which improves soil fertility and availability of nutrients for plant uptake (7).

Decomposition of organic materials such as plant wastes produces various organic acids such as fulvic acid (8). One of the main peculiar features of FA is possessing a low molecular weight and high oxygen contents (9). Fulvic acid -as humic substances- could increase soil nutrients availability, enhance plant growth under environmental stresses, especially in semi-arid and arid regions, which in turns promotes nutrients utilization and growth. Therefore, our study aimed at assessing the influence of biochar and FA on increasing N, P and K use efficiencies and promoting wheat growth and productivity in sandy soil under semi-arid conditions.

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II. MATERIALS AND METHODS

A pot trial was carried out under the greenhouse conditions at the research farm of the Faculty of Agriculture, Zagazig University, Egypt. The sandy soil samples were collected from the trial site in Alkhatrh, Sharkia Governorate, Egypt. Table 1 shows physical and chemical properties of the soil. Soil was prepared and 10 kg of soil samples were packed in closed bottom plastic pots with internal dimensions of 0.25×0.2 m. Wheat (*Triticum aestivum* cv., Misr 1) seeds were planted during the growth season of 2017/2018, where 50 seeds were sown per each pot. The seedlings were thinned to 20, 10 and 5 homogenous plants at the tillering, booting and maturity stages, respectively. We mixed the soil thoroughly with biochar at rates 0, 15 and 30 Mg ha^{-1}, potassium sulphate (500 g kg^{-1} K_2O) at rates 143, 190, 240 and 285 kg ha^{-1} and super phosphate (150 g kg^{-1} P_2O_5) at rates 160, 310, 475 and 635 kg ha^{-1} before filling the pots while preparing soil samples. We applied ammonium nitrate (33 g kg^{-1} N) at rates 120, 180, 240, 300 kg ha^{-1} at four equal doses. The first dose applied 15 days after planting, while the second, the third and the fourth doses were foliar added every 21 days after that. Fulvic acid was foliar applied on wheat plants at two equal doses after seed sowing by 30 and 60 days at a rate of 0.2 g L^{-1}. Irrigation water was applied to have soil moisture content at 75% of field capacity. Each treatment was triplicated and distributed as completely block design.

Soil samples were directly collected after wheat harvesting from each pot, air dried, crushed, sieved through a 2 mm sieve and stored in polythene bags after air drying for analysis. We carried out the following soil analyses:

Particle size distribution was determined using the pipette methods **(10).** Soil reaction (pH) was measured in the soil paste by a glass electrode pH meter (**11).** Soluble ions and electrical conductivity (EC, dSm^{-1}) were determined in soil paste extract following **Jackson (11).** Soi organic matter content was determined using the method of **Black *et al.* (12).** Cation exchange capacity (CEC) was tested according to **Jackson (11)**. Available N was determined using steam-distillation procedure with MgO - Devarda alloy following Bremner and Keency methods (**12**). Available P in the soil solution was extracted with 0.5 N $NaHCO_3$ at pH = 8.5 (**13**); and calorimetrically determined by the ascorbic acid methods **(14).** Available K was extracted with 1 N ammonium acetate (pH = 7.0) and determined using the flame photometer (**11).**

Wheat growth and grain yield parameters such as plant height (cm), grain yield (Mg ha^{-1}), biological yield (Mg ha^{-1}) were measured and recorded. After wheat harvesting at maturity, we calculated the biological yield by weighing the above ground biomass including straw and grains. Both roots and shoots were dried carefully with tissue paper to measure the plant height. We collected the whole plant after maturity and divided it into straw and grains. Then, we dried pants in the oven at 68 °C until a constant weight. We ground the dried samples by a tissue mill and sieved through a 0.2 mm sieve to get fine powder for digestion. The total N content was determined by the micro-Kjeldahl method (**11**). The total P content was measured calorimetrically by the ascorbic acid methods according to **Watanabe and Olsen (14)**. The total K content was tested using the flame photometer (**11**). Harvest index (HI) as percentage was calculated by dividing the grain dry mass by the total above ground plant dry mass.

The data were statistically analyzed following **Gomez and Gomez (15)** and using MSTAT-C. (1991), where analysis of variance (ANOVA) was done to determine effects of NPK rates, biochar and FA on the investigated parameters. The means of treatments were compared at 0.05 level of probability by the least significant differences (LSD) test (**16**).

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Table 1: Physical and chemical properties of the investigated soil.

Property	Value
Particle size distribution (g kg^{-1})	
Clay	110.2
Silt	95.9
Sand	783.9
Texture class is Loamy sand	
Air dried soil moisture ,%	1.91
Saturation percent ,%	43.5
Total porosity	39.8
Volume expansion	6.71
Real density (g cm^{-3}) Organic matter (g kg^{-1})	2.69 4.95
$CaCO_3$ (g kg^{-1})	4.80
EC (dSm^{-1}) [Soil water extract 1:5]	0.35
pH [Soil suspension 1:2.5]	8.01
Soluble ions ($mmol_c$ l^{-1})	
Na^+	1.31
K^+	0.39
Ca^{2+}	1.39
Mg^{2+}	0.55
Cl^-	1.15
HCO_3^- CO_3^{2-}	1.04 --
SO_4^{2-}	1.43
Total nutrients (g kg^{-1})	
N	0.38
P	0.02
K	1.11
Available nutrients (mg kg^{-1})	
N	26.6

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P	3.12
K	107

III. RESULTS AND DISCUSSION

Effects of NPK rates, biochar and fulvic acids on wheat straw and grains uptakes macronutrients

Results induced significant improvements in straw and grains N, P and K contents (SNU, SPU and SKU and GNU, GPU and GKU, respectively with raising NPK rates (Table 2). The highest SNU, SPU, SKU, GNU, GPU and GKU values (1.92, 0.46, 2.01, 2.54, 0.72 and 1.90 %, respectively) were obtained by the maximum fertilization rate (level 4). Increasing biochar rate from 0 to 30 Mg ha^{-1} resulted in significant increments in SNU, SPU, SKU, GNU, GPU and GKU, which augmented significantly to 1.82, 0.38, 1.88, 2.60, 0.54 and 1.73%, respectively under 30 Mg biochar ha^{-1} as compared with no biochar amendments (1.25, 0.28, 1.51, 1.88, 0.37 and 1.37%, respectively) (Table 2). Straw and grains contents of N, P and K (SNU, SPU, SKU, GNU, GPU and GKU) increased also significantly when applying FA to the highest values (1.68, 0.39, 1.83, 2.36, 0.53 and 1.69%) as compared with no FA which recorded the lowest values (1.47, 0.27, 1.56, 2.14, 0.38 and 1.41%, respectively) (Table 2). Combining 15 Mg biochar ha^{-1} with FA caused higher increases in SNU, SPU, SKU, GNU, GPU and GKU than individual applications of biochar at both rates (15 or 30 Mg ha^{-1}) or FA. Values of SNU, SPU, SKU, GNU, GPU and GKU were 1.75, 0.40, 1.86, 2.32, 0.53 and 1.69 % under the application of 15 Mg ha^{-1} biochar combined with FA, while using the highest biochar rate (30 Mg ha^{-1}) resulted in superior effect on SNU, SPU, SKU, GNU, GPU and GKU to have the highest values (1.93, 0.43, 2.00, 2.65, 0.61 and 1.86%) (Table 2).

Increasing NPK fertilizers rate raised the of N, P and K availability for wheat plant uptake. Applying the recommended doses of N, P and K fertilizers maximized their contents (**17**). Additionally, **Godebo et al. (18)** reported that grains P content of wheat crop was augmented by raising N level with K at 50 kg than none applications. These increments were maximized by biochar addition due to its role in improving soil chemo-physical and biological properties and reducing nutrients losses in parallel with increasing their availability for plant uptake (**19**). Biochar reduced ammonia volatilization by 25% from applied N fertilizers to wheat crop (**20**), which indicates more N use efficiency and contents in straw and grains. On the other hand, **Asai et al. (21)** noted how biochar application may offset the effect of N fertilizer. Biochar is classified by low N content and high C/N ratios which can lower N availability for plants uptake (**22**). Interestingly, application of biochar had increasing effects on plant P uptake, due to the increases in the resin-extractable phosphate concentration. Biochar seems to present a meaningful source of available P for crops uptake (**21**). **Atkinson et al. (7)** reported several mechanisms, which can improve P use after biochar addition to soil. It is a source of soluble and exchangeable P forms and decreases P flocculation by changes in soil pH or improve microbial activity and affecting changes in P availability.

We noticed less responses of nutrients contents to the combined addition of low NPK rate with biochar, which are likely due to its nature: a carbon-rich but nutrient-poor material (**23**). The highest N, P and K contents were recorded under biochar and FA within the same fertilizer level. Furthermore, applying FA increased transport rate of phosphorus to grains, which presumably was accompanied by a high rate of transport of organic substances (**24**).

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Influences of NPK rates, biochar and fulvic acids on wheat biological attributes

There was an increased general trend in plant height, grain yield and biological yield with raising NPK fertilization rate from level 1 to 4 (Table 3). The highest values of plant height (cm), grain yield (Mg ha^{-1}), biological yield (Mg ha^{-1}) (69.48, 4.71 and 9.16, respectively) were obtained with the highest NPK rates. Contrarily, the harvest index reduced significantly with raising the NPK rate, where the minimum harvest index (51.01 %) was obtained by adding the maximum NPK rates (level 4). On the other hand, the lowest NPK rates caused the minimum harvest index (60.71%) (Table 3). Plant height, grain yield, biological yield and harvest index recorded various responses to biochar addition at both rates as compared with no biochar addition when neglecting the impact of fertilization rate and FA (Table 3). Plant height and biological yield recorded their highest values (64.33 cm and 8.18 Mg ha^{-1}, respectively) under the addition of 30 Mg biochar ha^{-1}, while they minimized (60.58 cm and 7.14 Mg ha^{-1}, respectively) without biochar addition. The highest grain yield and harvest index (4.56 Mg ha^{-1} and 57.88%) were recorded by the addition of 15 Mg ha^{-1} of biochar, while adding 30 Mg ha^{-1} of biochar increased grain yield more than no biochar application to 4.45 Mg ha^{-1}. Alternatively, the minimum harvest index (54.38%) was recorded under the addition of 30 Mg ha^{-1} biochar. Addition of the highest biochar rate (30 Mg ha^{-1}) combined with FA increased plant height and biological yield (64.45 cm and 8.02 Mg ha^{-1}, respectively) as compared with 15 Mg biochar ha^{-1} combined with FA (63.05 cm and 7.98 Mg ha^{-1}, respectively). Furthermore, addition of 15 Mg biochar ha^{-1} with FA caused higher grain yield and harvest index values (4.61 Mg ha^{-1} and 57.79 %, respectively) than combined addition of 30 Mg biochar ha^{-1} with FA (4.26 Mg ha^{-1} and 52.94 %, respectively).

Uptake of *N, P and K by wheat straw and grains*

We reported significant increases in plant height, grain yield and biological yield with raising NPK fertilization rate due to their key role in plant growth, grain formation and filling. These results are in harmony with that reported by **El-Sobky and Abdo (23**), who pointed out that the highest plant height (98 cm) was achieved by NPK rates 200-150- 125 Kg ha^{-1} as compared with no fertilizer addition. Conversely, HI decreased with increasing the rate of NPK fertilizers, which presented more increases in the aboveground dry mass accompanied by lower increments in grain dry mass. Similarly, **Rakshit et al. (25)** recorded notable decreases in wheat HI with raising the fertilization rate, due to proportionate content of these nutrients by straw and grains.

Yield attributes of wheat were affected by the biochar application and it raised by increasing biochar rate might be owing to adequate and balanced nutrition. These results are in the same consent with the findings by **Zhang et al. (26),** who reported that the biochar amended soils showed significant improvements in maize yield and yield attributes. Contrarily, **Alburquerque et al. (27)** indicated that biochar increased wheat grains under no mineral fertilization by 3-42 % comparing with the control soil. These increments were significantly less than those obtained by the use of mineral fertilizers (149 and 281 %) as compared control. Plant height may increase due to more phosphorus availability, enhanced root growth and increased nutrient adsorption (**21**). Biochar can improve crop growth, plant height, spike length and tillers (**28**).

Our results reported significant increases in wheat growth under all treatments combined with FA. FA increased net photosynthesis, transpiration rate, and the intercellular concentration of CO_2, effects that were related to plant growth promotion (**29**). Decreasing the negative effects of stresses by improving

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proline content with FA under semi-arid conditions accompanied with improving plant photosynthesis caused improvements in wheat growth and productivity.

Table 2. Interaction effects of NPK fertilizers, biochar and fulvic acid on plant nutrients uptake.

Main effects and interactions	SNU (%)	SPU (%)	SKU (%)	GNU (%)	GPU (%)	GKU(%)
NPK levels (NPK)						
N1P1K1	1.34 d	0.22 d	1.44 d	1.82 d	0.25 d	1.21 d
N2P2K2	1.41 c	0.27 c	1.54 c	2.19 c	0.33 c	1.40 c
N3P3K3	1.74 b	0.38 b	1.79 b	2.44 b	0.51 b	1.68 b
N4P4K4	1.92 a	0.46 a	2.01 a	2.54 a	0.72 a	1.90 a
F-test	**	**	**	**	**	**
Biochar effect:						
B0	1.25 c	0.28 c	1.51 c	1.88 c	0.37 c	1.37 c
B1	1.66 b	0.33 b	1.69 b	2.28 b	0.45 b	1.55 b
B2	1.82 a	0.38 a	1.88 a	2.60 a	0.54 a	1.73 a
F. test	**	**	**	**	**	**
Fulvic acid effect:						
F0	1.47 b	0.27 b	1.56 b	2.14 b	0.38 b	1.41 b
F1	1.68 a	0.39 a	1.83 a	2.36 a	0.53 a	1.69 a
F. test	**	**	**	**	**	**
Interactions:						
B1 x F1	1.75 b	0.40 b	1.86 b	2.32 b	0.53 b	1.70 b
B2 x F1	1.93 a	0.43 a	2.00 a	2.65 a	0.61 a	1.86 a
F. test	**	**	**	**	**	**

** indicates statistically significant at 0.05 levels and insignificancy of differences, respectively.

Table 3. Interaction effects on plant biological attributes.

Main effects and interactions	Plant height (cm)	Grain yield (Mg ha^{-1})	Biological yield (Mg ha^{-1})	Harvest index (%)
NPK levels (NPK)				
N1P1K1	55.19 d	3.83 d	6.24 d	60.71 a
N2P2K2	60.15 c	4.28 c	7.36 c	57.72 b
N3P3K3	65.05 b	4.56 b	8.17 b	55.56 c
N4P4K4	69.48 a	4.71 a	9.16 a	51.01 d
F-test	**	**	**	**
Biochar effect:				
B0	60.58 c	4.03 c	7.14 c	56.49 b
B1	62.50 b	4.56 a	7.87 b	57.88 a
B2	64.33 a	4.45 b	8.18 a	54.38 c
F. test	**	**	**	**

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Fulvic acid effect:				
F0	62.07 b	4.41 a	7.75 a	56.96 a
F1	62.87 a	4.28 b	7.71 b	55.54 b
F. test	**	**	**	**
Interactions:				
B1 x F1	63.05 b	4.61 a	7.98 b	57.79 a
B2 x F1	64.45 a	4.26 b	8.02 a	52.94 b
F. test	**	**	**	**

** indicates statistically significant at 0.05 levels and insignificancy of differences, respectively

IV. CONCLUSION

Mineral fertilizers applied into sandy soil are subjected to losses and has to be accompanied by other amendments to decrease these losses and enhance plant productivity under semi-arid conditions. Our results showed alternative enhancements in wheat nutrients contents and growth attributes in response to N, P and K rates. These improvements were maximized when combining NPK fertilizers with biochar and Fulvic acid (FA). Biochar and FA increased straw and grains contents of N, P and K and optimized yield attributes not only within the same fertilization rate but also equalized the effect of NPK at rates 3 and 4. It is strongly advocated to apply 240, 475 and 240 kg ha^{-1} of ammonium sulphate, super phosphate and potassium sulphate with 15 Mg ha^{-1} of biochar and FA than single application of 300, 635 and 285 of them, respectively to maintain maximum wheat growth and yield in sandy soil under semi-arid climate conditions.

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