Assiut Journal of Agricultural Sciences 55 (1) 2024 (236-254)
ISSN: 1110-0486 / EISSN: 2356-9840
Website: http://ajas.journals.ekb.eg/
E-mail: ajas@aun.edu.eg

(Original Article)

Enhancing the Agronomic Performance of Potassium Fertilizer and Potassium-Bearing Minerals in Sandy Loam Soil by Adding Humic Acids and Mycorrhiza

Kassem A.S. Mohammed[1], Mohamed S.M. Eid[1] and Adel R.A. Usman[2*]

[1]Natural Resources Department, Institute of African Research and Studies, Aswan University
[2]Department of Soils and Water, Faculty of Agriculture, Assiut University, Assiut 71526, Egypt

*Corresponding author: adelosman@aun.edu.eg
DOI: 10.21608/AJAS.2023.243994.1303

Abstract

Potassium (K) is a vital macro-nutrient needed for proper growth and development of plants. Therefore, the objective of this study is to evaluate the agronomic performance of potassium fertilizer and potassium-bearing minerals added with humic acids and mycorrhiza on wheat plant growth and nutrient uptake in sandy loam soil. The field experiment was conducted on low-potassium-content sandy soil. The sandy soil was treated with potassium sulfate (KS) or feldspar (FS) either alone or in combination with humic acid and/or mycorrhiza fungi. Applying KS and FS either alone or in combination with humic and/or inoculation with mycorrhiza significantly enhanced plant growth parameters (plant height, spike length, and weight of 100 seeds) and yield than those of control soil. Applying treatments significantly increased straw yield by 126-401%, grain yield by 155-806%, and total yield by 138-559% than those of control soil. From the obtained results, the treatments of mycorrhizal inoculation and humic acid significantly increased plant growth parameters, yield, and harvest index, but the mycorrhizal inoculation combined with humic acid had better effects in growth parameters, yield, biochemical properties (protein, carbohydrates, and total sugar content) and nutrients (NPK) uptake. It could be concluded that both humic acid and/or mycorrhiza increased the plant uptake of macronutrients in the experimental soil and improved soil productivity. Therefore, our findings suggest that the application of feldspar mineral combined with mycorrhiza and humic acid could be considered as an alternative and a replacement for K-mineral fertilizers in sandy soils.

Keywords: *Growth of plants, Nutrients uptake, Feldspar, Microbial inoculation*

Introduction

Potassium (K) is a vital macro-nutrient needed for proper growth and development of plants (Hasanuzzaman *et al*., 2018). Its absence and less availability in the soil cannot be compensated by any other nutrient. Potassium deficiency significantly affects plant growth and development. Furthermore, K is an important ingredient in food production since it is required for a variety of

Received: 22 October 2023/ Accepted: 24 December 2023/ Published online: 2 January 2024

biochemical and physiological processes that are responsible for protein synthesis, glucose metabolism, and enzyme activation, as well as plant growth and development (Wang *et al*., 2013; Sardans *et al*., 2021).

Overall, K chemical fertilizers should be applied in big quantities to increase crop output per unit area and to make up for soil K declines. The high expense of potassium fertilizers also drives up manufacturing costs and contributes to environmental damage. Natural potassium fertilizer is a low-cost source of potassium that can be used as a fertilizer in agriculture (Ciceri *et al*. 2019). Potassium is an essential nutrient for plant growth and development, and feldspar can provide this nutrient to the soil (Ciceri *et al*. 2019; Bell *et al*., 2021). Several experiments have shown that feldspar releases enough potassium to compete with potash for certain agricultural uses (Wang *et al*., 2022). Feldspar-derived potassium fertilizer varieties can be engineered to meet varied soil conditions, making it a versatile option for farmers.

On the other hand, bio-fertilizers, which are applied to soil or plants, are an effective way to reduce the usage of chemical fertilizers while also increasing food safety for human consumption (Youssef and Eissa, 2017; Meena *et al*., 2016; Wang *et al*., 2022). In this context, rocky biofertilization is a process that involves the use of rock materials and biofertilizers to improve soil fertility and crop yield (Abou-El-Seoud *et al*. 2012; Schütz *et al*, 2018). The application of microbial inoculants, also known as biofertilizers, can help reduce the use of conventional inorganic fertilizers (Schütz *et al*, 2018; Wang *et al*., 2022). Biofertilizers can fix nitrogen (N) and help access nutrients such as N, P, and K from organic fertilizers and soil (Schütz, *et al*, 2018). The synergistic effects of soil fertilization with rock K substances and co-inoculation with K-dissolving bacteria have been evaluated in several studies (Abou-El-Seoud *et al*., 2012; Wang *et al*., 2022; Stamford *et al*., 2006). K-dissolving bacteria of *(Bacillus cereus*) could dissolve potassium from K-feldspar minerals by generating organic acids such as tartaric, citric, and oxalic acid accelerating the mineral's K release (Hu *et al*., 2021; Buragohain *et al*., 2018; Wange *et al*., 2022). Generally, rock biofertilizers are a promising technology that can improve soil fertility and crop yield.

For optimal plant growth, a combination of rock K substances and co-microbial inoculation that solubilizes them may give K more promptly and continuously. Though there are several investigations on using rock K and co-inoculation with K-dissolving bacteria (Singh, V. K., *et al*. 2022), the combined effects of rock substances and mycorrhiza co-inoculation on mineral availability in high pH sandy soils, mineral content, and wheat plant growth are not well studied. Therefore, in the current study, the main objective of this work is to evaluate the efficiency of K chemical fertilizer and potassium-bearing mineral (feldspar) combined with organic acids (humic acid) and mycorrhiza fungi (AMF) on the growth parameters and yield of wheat plants grown in sandy loam soil as well as nutrients and biochemical parameters of the wheat plant have been investigated.

Materials and Methods

Sampling, preparation, and characterization of soil samples and materials

The soil samples were collected from the agricultural farm located in El-Kajooj, Kom Ombo, Aswan Governorate, Egypt. The samples were air dried and sieved with a (2 mm). The particle size distribution was measured by the pipette method according to Dewis and Feritas (1970). The physical and chemical soil properties were determined according to Dewis and Fertais (1970) and Sparks (1996). Soil pH was determined in soil paste. Soil EC was determined in soil paste extract. Total Calcium carbonate was determined using Collin's calcimeter method according to Dewis and Fertais, (1970). Organic matter content was determined using the Anne method (modified Walkely's Black method) according to Mathieu and Pieltain, 2003). Soil available N was measured by Kjeldahal method after soil sample extraction with 2 M KCl. Soil available P was measured colorimetrically by spectrophotometer after soil samples extraction with 0.5 M $NaHCO_3$. Soil available K were measured by flame photometer after soil samples extraction with 1 M NH_4OAc. Some physical and chemical properties of a representative soil sample for the experiment were determined and are shown in Table (1). The data for soil analyses showed that the soil samples have 52.61% sand, 35.65% silt, and 16.8% clay, and the level of organic matter accounted for 0.24% and a high $CaCO_3$ content of 3.02%. The soil pH had a value of 7.96 and EC_e had a value of 1.62 dS m^{-1}. The available N, P, and K in soil accounted for 35.16, 6.88, and 121 mg kg^{-1}, respectively.

Table 1. Physicochemical properties of the experimental soil

Soil Properties	Value
Mechanical analysis	
Sand%	52.61
Silt%	35.65
Clay%	11.74
Soil texture	Sandy loam
Chemical properties	
pH	7.96
EC_e dSm^{-1}	1.43
$CaCO_3$	3.02
OM %	0.24
Available Nutrients ($mgKg^{-1}$)	
Nitrogen (N)	35.16
Phosphorus (P)	6.88
Potassium (K)	121.32

A sample of K-feldspar with a chemical composition of $KAlSi_3O_8$, containing potassium (K), aluminum (Al), silicon (Si), and oxygen (O), was obtained from one of the areas where feldspar ore is found in Wadi El-Alaqi, 180 km south of Aswan. The sample was ground into a powder and its chemical analysis, including its constituent elements (K, Al, Si, and O), was determined using X-ray fluorescence (XRF). The percentage of K_2O in the sample was estimated to be

7.10%. Furthermore, the percentage composition of other chemical elements in the ore is also significant. The ore contains a high percentage of SiO_2 (75.85%), which is an essential compound for the development of plant cell walls. It also contains Al_2O_3 (10.89%), which is necessary for the formation of clay minerals, and CaO (0.80%), which is important for soil health and pH balance.

For sieve analysis, the feldspar sample was sorted into three size ranges using sieve analysis. The results showed that the particles with a size of 0.20 mm made up 20.7% of the sample, and the particles with a size of 0.080 mm made up 34.65% of the sample. Meanwhile, particles with a size smaller than 0.080 mm (or -0.080 mm) made up 44.65% of the sample. Based on the given information, however, the sample contains particles of 3 different sizes, with the majority (79.30%) falling within the range of 0.080 mm and -0.080 mm.

The field experiment

The objective of the field experiment is to investigate the effect of potassium sulfate (KS), or feldspar (FS) either alone or in combination with humic (HA) and/or w potassium content, cultivated in the agricultural farm located in El-Kajooj village - Kom Ombo - Aswan Governorate, Egypt at latitude and longitude during the wheat growing season of 2022/2023, as a first experiment, so it was laid out in 27 randomly repeated plots each plot size was 3.0 m long and 1.5 m wide.

The treatments of potassium sulfate (KS), or feldspar (FS) either alone or in combination with humic (HA) and/or inoculation with mycorrhiza (AMF) were applied randomly. The wheat seeds (*Triticum aestivum*) were planted in rows spaced 15 cm apart on Nov. 21, 2022. Abuscular mycorrhizal fungus, Glomus mosseae was obtained from the Agricultural Research Center in Dokki, Cairo. Potassium (K) was applied at 100 kg K/hectare (ha) from two sources, potassium sulfate (51% K_2O) and feldspar ore powder (7.09% K_2O). Nitrogen (N) and phosphorous (P) were applied at the recommended dose (Granulated Urea Fertilizer 46.5% Nitrogen) and (super phosphate 51% P_2O_5) respectively. The first dose of nitrogen and full doses of phosphorus and potassium were applied at sowing. The second dose of N was applied at the stem elongation stage. The third dose of N was applied at the booting stage. The inoculum containing 250 spores/g soils together with mycelium and mycorrhizal root fragments, was used at a rate of 7 kg/ha. Meanwhile, humic acid was applied at a rate of 5 kg/ha.

At the harvesting stage, plant height, spike length, weight of 100 seeds, and straw and grain yield were estimated. Additionally, biochemical parameters of protein, carbohydrate, and total sugar were measured in wheat plant samples. The collected samples of straw and grain from each treatment were dried at 70 °C, grinded, and then digested using the wet digestion procedure (H_2SO_4-H_2O_2) according to Parkinson and Allen (1975) for further nutrients (N, P, and K) analysis. The Kjeldahl method was used to measure the total nitrogen content of straw and grain samples. Additionally, the concentrations of K in digests were measured using a flame photometer, and the concentrations of P were measured colorimetrically using a spectrophotometer.

Statistical analysis

The collected data was statistically analyzed using the R programming language. The analysis of variance (ANOVA) was performed on the data. LSD (Least significant difference) test at 0.05 level was used to compare the treatment effects.

Results

Treatment effect on plant growth parameters and yield

Data in Table (2) represent the effect of potassium sulfate (KS), or feldspar (FS) either alone or in combination with humic and/or inoculation with mycorrhiza on yield and components of wheat plants. Applying fertilizer with 100% KS and 100% FS either alone or in combination with humic and/or inoculation with mycorrhiza significantly enhanced plant growth parameters and yield than those of control soil.

Table 2. Treatment effect on plant growth parameters and yield

Treatments	Symbol	Plant height	Spike length	Weight of 100 seeds	Yield			HI
					Straw	Grain	Total	
		cm		g		Kg/ha		%
Control	CK	45.3 e	5.2 d	3.33 f	1192 e	763 f	1955 e	39.1 c
K_2SO_4	T1	69.7 bcd	9 c	4.3 d	2715 d	1944 e	4659 d	41.7 c
K_2SO_4 + Humic Acid	T2	70.8 bcd	10 bc	4.23 d	2869 d	2865 d	5734 d	50 b
K_2SO_4 + Mycorrhiza Fungi	T3	72.8 bc	10.8 ab	4.97 ab	4193 c	4363 c	8556 c	50.3 ab
K_2SO_4 + Mycorrhiza Fungi + Humic Acid	T4	73.3 abc	11.5 a	4.9 ab	5968 a	6909 a	12877 a	53.6 a
Feldspar	T5	64.5 d	9 c	3.73 e	2690 d	2004 de	4694 d	42.7 c
Feldspar + Humic Acid	T6	68.3 cd	9.8 bc	4.6 c	3953 c	3966 c	7919 c	50.1 b
Feldspar + Mycorrhiza Fungi	T7	75.5 ab	10.2 bc	4.77 bc	3605 c	3816 c	7421 c	51.5 ab
Feldspar + Mycorrhiza Fungi + Humic Acid	T8	80 a	10.7 ab	5.13 a	5133 b	5874 b	11007 b	53.4 ab
LSD at p < 0.05		12.3	1.6	0.33	1180	1471	2603	3.94

a, b… : Different letters in the same column between treatments mean that there are significant differences (P<0.05).

The all-investigated treatments showed a significant increase in plant height, spike length, and weight of 100 seeds by 53.9%-76.6%, 73.1%-108%, and 29.1%-54.1% compared to the control (CK). However, compared to potassium sulfate fertilizer (KS), the treatments of mycorrhizal inoculation and humic acid increased plant growth parameters and yield, but the significant increases in plant height were pronounced only for T8. Amendment of T3 (KS+ Mycorrhiza Fungi), T4 (KS+ HA + Mycorrhiza Fungi), and T8 (FS+HA+ Mycorrhiza Fungi) resulted in a significant increase in spike length for plant height by 20%, 27.8%, and 18.9% compared to KS. Meanwhile, treatments of T3, T4, T7, and T8 showed a significant increase in weight of 100 seeds compared to KS. The percentage of these increases accounted for 15.6% (T3), 14% (T4), 10.9% (T7), and 19.3% (T8) compared to KS.

Regarding wheat yield, applying treatments significantly increased straw yield by 126-401%, grain yield by 155-806%, and total yield by 138-559% than those of control soil. Nevertheless, as compared to KS, the addition of T3 (KS+ Mycorrhiza Fungi), T4 (KS+ HA+ Mycorrhiza Fungi), T6 (FS+HA), T7 (FS+ Mycorrhiza Fungi), and T8 (FS+HA+ Mycorrhiza Fungi) significantly increased total yield by 83.6%, 176.4%, 70%, 59.3%, and 136.3%, respectively. The plots with no potash treatment exhibited the lowest wheat straw and grain production, with values of 1192 and 763 kg ha^{-1}, respectively.

Treatment effects on nutrients and biochemical composition

Data in Tables (3 and 4) present the effect of potassium sulfate (KS) or feldspar (FS) either alone or in combination with humic and/or inoculation with mycorrhiza on the nutrients (NPK), protein, carbohydrates, and total sugar content of wheat plants.

The difference in the performance of wheat nutrients under various treatments is shown in Table (3). The application of KS or FS alone increased NPK content, but not significantly in most cases compared to control. Meanwhile, the treatments of mycorrhizal inoculation and humic acid significantly increased NPK content in both straw and grain, but the combined treatment of mycorrhizal inoculation and humic followed by the mycorrhizal inoculation treatment had better effects than humic acids alone, KS or FS in NPK content. The application of mycorrhiza combined with humic acid exhibited the highest level of straw N (29.4 and 29.6 g/kg), grain N (18.7 and 18.4 g/kg), straw P (3.88 and 3.83 g/kg), grain P (3.10 g/kg), straw K (31.1 and 30.9 g/kg), grain K (29.7 and 29 g/kg) in soils treated with KS and FS, respectively, followed by the individual application of mycorrhiza. Compared to KS, amendment of T4 (KS+ HA+ Mycorrhiza Fungi) and T8 (FS+HA+ Mycorrhiza Fungi) resulted in a significant increase in straw N by 14.8%, and 14%, respectively. Meanwhile, treatments of T3, T4, and T8 showed a significant increase in grain N concentration compared to KS. The percentage of these increases in grain N accounted for 8% (T3), 12.5% (T4), and 9.8% (T8) compared to KS. Except for straw P with T5 and grain P with T6, the majority of examined treatments demonstrated a significant increase in P concentration in grain by 2.5-11.5% and straw P by 2.6-11.2% compared to KS. For straw K concentration, treatments of T2, T3, T4, T7 and T8 showed a significant increase by 7, 12.2, 14.8, 8.6 and 14% compared to K, respectively.

Regarding NPK uptake by straw and grain of wheat plants, as shown in Table (3), all examined treatments demonstrated significant increases compared to CK. The treatments of mycorrhizal inoculation and humic acid significantly increased NPK uptake in both straw and grain, but the combined treatment of mycorrhizal inoculation and humic followed by the mycorrhizal inoculation or humic acid treatments had better effects.

Table 3. Treatment effects on straw and grain nutrient (NPK) concentrations and uptake

Treatment	Symbol	Straw			Grain		
		N	P	K	N	P	K
Concentration (g/kg)							
Control	CK	24.5 e	3.29 g	25.3 f	14.1 f	2.6 e	24.9 f
K_2SO_4	T1	26.4 cde	3.49 f	27.1 de	16 de	2.8 d	26.4 def
K_2SO_4 + Humic Acid	T2	27.4 abcd	3.65 de	29 bc	16.9 bcd	2.9 cd	27.3 bcde
K_2SO_4 + Mycorrhiza Fungi	T3	28.7 abc	3.79 bc	30.4 ab	17.8 abc	3 b	28.5 abc
K_2SO_4 + Mycorrhiza Fungi + Humic Acid	T4	29.6 a	3.88 a	31.1 a	18.7 a	3.1 a	29.7 a
Feldspar	T5	25.6 de	3.41 f	26.2 ef	15.2 ef	2.7 e	25.6 ef
Feldspar + Humic Acid	T6	28 abcd	3.58 cd	28.2 abc	17.6 abcd	2.9 c	26.9 cde
Feldspar + Mycorrhiza Fungi	T7	27.1 bcd	3.73 e	29.43 cd	16.4 cde	2.9 cd	28.1 abcd
Feldspar + Mycorrhiza Fungi + Humic Acid	T8	29.4 ab	3.83 ab	30.9 a	18.4 ab	3.1 ab	29 ab
LSD		2.87	0.1	2.08	1.94	0.084	2.36
Uptake (mg plant)							
Control	CK	29.1 e	3.92 g	30.12 e	10.79 e	2.01 e	18.95 e
K_2SO_4	T1	71.63 d	9.47 f	73.54 d	31.11 de	5.42 de	51.41 de
K_2SO_4 + Humic Acid	T2	78.6 d	10.47 def	83.15 cd	48.57 cd	8.28 cd	78.28 cd
K_2SO_4 + Mycorrhiza Fungi	T3	120.57 bc	15.86 bc	127.14 b	78.57 b	13.14 b	123.78 b
K_2SO_4 + Mycorrhiza Fungi + Humic Acid	T4	176.66 a	23.14 a	185.62 a	129.36 a	21.49 a	205.08 a
Feldspar	T5	73.94 d	9.78 ef	75.37 d	31.23 de	5.55 de	52.64 de
Feldspar + Humic Acid	T6	110.5 c	14.17 cd	110.85 bc	69.34 bc	11.29 bc	106.46 bc
Feldspar + Mycorrhiza Fungi	T7	97.78 cd	13.46 cde	105.94 bc	62.64 bc	10.91 bc	107.38 bc
Feldspar + Mycorrhiza Fungi + Humic Acid	T8	150.28 ab	19.68 ab	158.24 a	108.34 a	18 a	170.98 a
LSD at $p < 0.05$		36.14	4.62	33.5	29.65	4.41	42.22

a, b… : Different letters in the same column between treatments mean that there are significant differences ($P<0.05$).

Regarding biochemical parameters, applying fertilizer with 100% KS and 100% FS either alone or in combination with humic and/or inoculation with mycorrhiza significantly increased protein, carbohydrates, and total sugar content compared to control soil (Table 4). Among all treatments, T4 (KS+ mycorrhiza +humic acid) or T8 (FS+ mycorrhiza +humic acid) showed the highest increases in protein, carbohydrates, and total sugar compared to other treatments. The control treatment had the lowest protein, carbohydrates, and total sugar content of 8.11%, 63.84%, and 2.28%, respectively, whereas the treatments including mycorrhizal inoculation and/or humic acid significantly enhanced the levels of these parameters with no significant differences between them. Applying treatments including mycorrhizal inoculation and/or humic acid significantly increase protein, carbohydrates, and total sugar compared to control soil, which accounted for 9.74% (KS+HA), 10.25% (KS+ Mycorrhiza Fungi), 10.77% (KS+HA+ Mycorrhiza Fungi), 10.10% (FS+HA), 9.41% (FS+ Mycorrhiza Fungi), and 10.58% (FS+ HA+ Mycorrhiza Fungi). However, compared to applying KS alone, only T4 (KS+HA+ Mycorrhiza Fungi) or T8 (FS+ HA+ Mycorrhiza Fungi) showed significant increases in the content of protein, carbohydrates, and total sugar.

Table 4. Treatment effects on protein, carbohydrates, and total sugar

Treatments	Symbol	Protein	Carbohydrates	Total sugar
		%		
Control	CK	8.11 f	63.84 e	2.28 f
K_2SO_4	T1	9.2 de	66.58 cd	2.48 de
K_2SO_4 + Humic Acid	T2	9.74 bcd	67.01 bcd	2.6 cd
K_2SO_4 + Mycorrhiza Fungi	T3	10.25 abc	67.6 abc	2.78 ab
K_2SO_4 + Mycorrhiza Fungi + Humic Acid	T4	10.77 a	68.67 a	2.91 a
Feldspar	T5	8.74 ef	65.94 d	2.38 ef
Feldspar + Humic Acid	T6	10.1 abcd	67.52 abc	2.72 bc
Feldspar + Mycorrhiza Fungi	T7	9.41 cde	66.83 cd	2.55 cde
Feldspar + Mycorrhiza Fungi + Humic Acid	T8	10.58 ab	68.49 ab	2.84 ab
LSD at $p < 0.05$		1.12	1.78	0.21

a, b… : Different letters in the same column between treatments mean that there are significant differences ($P<0.05$).

Treatment effects on potassium use efficiency (PUE)

The amount of nutrients in the soil that plants require to achieve their maximum yield varies depending on their nutrient efficiency. A lower internal nutrient demand for optimum growth or a higher absorption efficiency of the plant may be responsible for the changes in external nutrient requirements. Therefore, In the current study, potassium use efficiency based on external K acquisition (KUE_e) and internal K utilization (KUE_i) has been calculated. Figure 1 shows the impact of K sources treated by AMF and HA and their combination on KUE_e and KUEi. The results for KUE showed that there were significant differences in the KUE_e and KUEi values based on applied treatment. The wheat plants showed a strong yield increase due to K fertilization in combination with HA and/or AMF. Although there were no significant differences in the PUE between potassium sulfate alone and feldspar treatments when applied alone, applications of humic acid and humic acid + AMF under soil treated with potassium sulfate fertilization resulted in statistically higher KUE_e than those under soil treated with feldspar. The numerical values of the KUE_e index with K sources studied with treatments of humic and/or mycorrhiza were greater (20.6-47.8%) than KS (15.3%) or FS (18.3%) when applied alone (without humic and/or mycorrhiza) in the order: AMF+HA > HA or AMF > KS or FS. On the contrary, the KUEi index with K sources studied with treatments of humic and/or mycorrhiza showed lower ratio of (33.5-36.4) than KS (37.3) or FS (38.5) when applied alone (without humic and/or mycorrhiza) in the order: AMF+HA < AMF < HA < KS or FS. Our results suggest that humic acid combined with mycorrhiza has maximized the soil K availability to plant roots that enhanced the K content of wheat roots and consequently showed the highest KUE_e value of 47.8% for treatment of KS+. Humic acid + mycorrhiza, followed by treatment of FS+. Humic acid + mycorrhiza (40.3%).

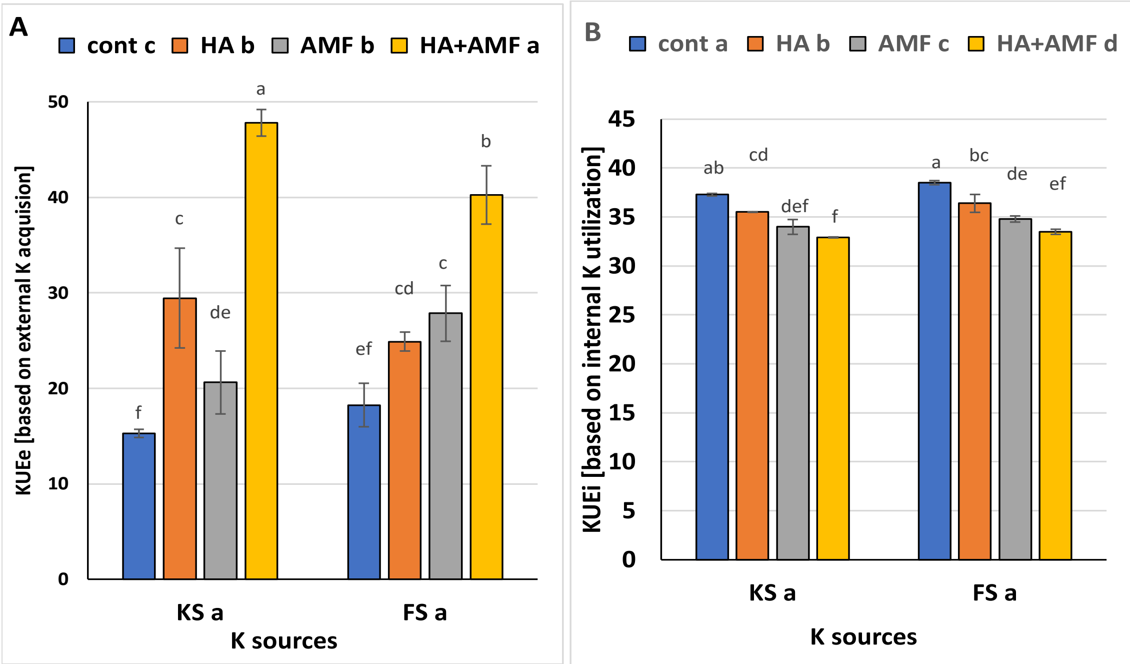

Figure 1. Impact of K sources treated by AMF and HA and their combination on KUE_e (A) and KUE_i (B). Different letters refer to the least significant differences ±SD.

Discussion

Generally, it was observed that the application of potassium (K) increased growth and improved crop yield. Our research trial's findings align with the results obtained by (Soumare *et al*. 2022), possibly due to enhanced levels of potash fertilizer application. The presence of sufficient potassium in the growing medium promoted the activation of enzymes and photosynthesis, leading to increased biomass yield. Conversely, the absence of K supplementation resulted in deformities in vegetative growth and reduced biomass yield in wheat crops. These results are consistent with the findings of numerous other researchers in this field, including (Guo *et al*. 2019; El-Mageed *et al*. 2023; El-Nahas *et al*. 2019). They found that K fertilization had increased the yield of wheat growth and development. Additional research by (Bahmanyar, *et al*. 2008) showed how potassium fertilizer enhanced wheat crops' growth characteristics and productivity. Maurya, Shri, *et al*. (2015) stated that crops receiving 80 kg K_2O ha^{-1} of K had increased vegetative biomass and displayed the highest biomass production.

In terms of enhancing total yield, treatments may be arranged as follows: T4 > T8 > T3 > T7 > T6 > T2 > T5 > T1 > CK. From the obtained results, the treatments of mycorrhizal inoculation and humic acid significantly increased plant growth parameters, yield, and harvest index, but the mycorrhizal inoculation combined with humic acid had better effects on growth parameters. The positive effects of mycorrhizal inoculation and humic acids on plant growth were also confirmed by prior studies (Franczuk *et al*., 2023; Khafagi *et al*., 2018; Khan *et al*., 2018; Sadhana, *et al*. 2014). Understanding the role of humic acids on crop performance has been reviewed by Ampong *et al*. (2022), revealing that HA application has potentially significant effects on crop agronomic performance and soil quality parameters. Humic acid is a type of organic substance that is being introduced to the soil to improve its properties and increase water and nutrient uptake by plant roots, resulting in plant growth improvement. According to Khan *et al*. (2010), combining HA with NPK significantly boosted wheat plant height, spike length, and yield in a field trial. In comparison to the control, Khan *et al*. (2018) also found that the application of HA boosted wheat growth and grain yield. Dinçsoy and Sönmez (2019) found that potassium fertilizer with increased HA application on wheat plant growth criteria had a substantial impact on biological yield, grain yield, and harvest index.

The results of the current study showed also that fungi inoculation enhances plant growth such as plant height, spike length, and weight of 100 seeds as well as the yield better than those treatments of CK, KS, FS, KS+HA, and FS+HA. Beneficial can improve the nutrient status of crops and their yield. AMF (fungi mycorrhiza inoculation) treatment has been reported as a considerable potential for enhancing crop yield (Sabia *et al*., 2015; Lu *et al*., 2015; Hijri, 2016; Wu *et al*., 2004). As a long-term approach to enhancing plant development, nutrition, root growth, and reactions to external stress factors, the use of mycorrhiza as a bio-fertilizer has been proposed (Sadhana, *et al*. 2014). These could result from mycorrhiza's positive impact on boosting microflora populations and increasing microbial biomass, which would improve soil fertility and increase crop production (Bahadur *et al*. 2016). The potential involvement of AMF in increasing plant nutrient and water uptake, improving nutrient usage efficiency, and producing better biomass and yield has been widely documented in literature (Seutra *et al*., 2021; Droh *et al*., 2016; Grümberg and Urcelay, 2015)

Among all these treatments, T4 (KS+ mycorrhiza +humic acid) followed by T8 (FS+ mycorrhiza +humic acid) showed the highest increases in plant growth parameters and yield than those of other treatments. The findings suggest that humic compounds may act as an environmental stimulant for arbuscular mycorrhizal fungus in soil. According to a previous study by Gryndler *et al*. (2005), adding humic acid to the non-soil substratum significantly increased mycorrhizal colonization. According to our findings, HA and AMF work together to benefit plants.

Regarding NPK uptake by straw and grain of wheat plants, as shown in Table (3), all examined treatments demonstrated significant increases compared to CK. The treatments of mycorrhizal inoculation and humic acid significantly increased NPK uptake in both straw and grain, but the combined treatment of mycorrhizal inoculation and humic followed by the mycorrhizal inoculation or humic acid treatments had better effects. This supports the findings of (Olaniyan, 2022), which emphasized the effectiveness of potassium fertilizers and microbial inoculation in promoting concentrations of NPK. Furthermore, the use of mycorrhiza as a bio-fertilizer has been proposed as a long-term approach to enhancing plant development, nutrition, root growth, and resilience to external stress factors (Berruti *et al*. 2016). The use of mycorrhiza as a bio-fertilizer can be a sustainable solution for enhancing plant development and nutrient uptake in agricultural systems indicating that the combination of K fertilizer, mycorrhiza, and humic acid is highly effective in improving the nutrient concentration in leaves. This result is consistent with previous studies that reported the positive effect of mycorrhizal fungi and humic acid on plant nutrient uptake and availability (Sharma *et al*. 2013; García de León *et al*. 2020). Several investigators have described the importance of AMF in soil nutrient uptake, particularly N and P, which can successfully enhance host plant development (Smith *et al*., 2011; Wang *et al*., 2018). AMF enhances plant nutrition by enhancing nutrient availability and translocation (Rouphael *et al*., 2015). Bücking and Kafle (2015) have reviewed the function of arbuscular mycorrhizal fungus in plant nitrogen uptake. They stated that arbuscular mycorrhizal fungi can actively transfer nitrogen to plants. Regarding the role of mycorrhizal fungi in the solubilization of soil potassium. Sharma *et al*. (2013) explained that mycorrhizal fungi can increase potassium uptake by plants. By enhancing potassium absorption, the connection of AMF with the plant may improve nutritional status and soil exploration capacity (Evelin *et al*., 2019). According to Balliu *et al*. (2015), AMF has increased nitrogen, potassium, calcium, and phosphorus levels, which indicate improved plant growth. AMF forms symbiotic relationships with host plant roots to absorb essential nutrients from the host plant and thus, provide minerals like N, P, K, Ca, Zn, and S in return. Therefore, even under unfavorable circumstances, AMF provides nutritional support to the plants inside the root cells. Arbuscules, a type of fungal structure produced by AMF, aid in the interchange of inorganic minerals and carbon and phosphorus-containing compounds, giving host plants a significant amount of vigor (Begum *et al*., 2019; Prasad *et al*., 2017). As a result, they can considerably increase the phosphorus concentration in both roots and shoots (Al-Hmoud and Al-Momany, 2017). Moreover, mycorrhizal hyphae growing through soil environments release exudates including low-molecular-weight sugars and organic acids (Abou El Seoud *et al*. 2012). These released exudates might be able to solubilize nutrients from soils or rock nutrient powder, such as feldspar through plant production and excretion of soil organic acids or chelate silicon ions to bring nutrients into solution (Bahadur *et al*. 2016). Generally, protons or ligand-mediated processes may directly accelerate the release of K from feldspar when organic acids are present. Indirectly, they can improve dissolution by forming complexes in solution, which in turn raises the chemical affinity of the entire dissolving process (Ullman and Welch, 2000; Seddik, 2011). These could result from mycorrhiza's positive impact on boosting microflora populations and increasing microbial biomass, which would improve soil fertility and increase crop production (Bahadur *et al*. 2016).

On the other hand, the current study's significant enhanced effect of HA on raising the concentration of nutrients in the tissues of wheat plants raises the possibility that HA can raise the availability and uptake of nutrients from the soil by plants. The relationship between soil-plant nutrient availability and plant nutrient uptake following HA application has been reported (Ampong *et al*., 2022). According to Dinçsoy and Sönmez (2019), the effects of humic acid and potassium on the nutritional element concentrations of straw and grain P, K, Ca, and Mg of wheat were largely favorable. Plant nutrients like P are complexed by HA's chelating process, increasing their availability to plants. According to Wang *et al*. (1995), adding HA to fertilizer applications increased the amount of water-soluble P in the soil, which might boost plant uptake of P. Sharma *et al*. (2013) found that HA application improves soil microbial phosphatase activity, which in turn promotes soil P solubilization. HA also reduces the sorption of soil phosphate ions while boosting their desorption, which raises the concentration of P in the soil solution (Zhu *et al*., 2018). Additionally, HA molecules contain nitrogen, which after being applied to the soil, is made available to plants (Billingham, 2012). In general, humic acid treatments encourage root growth, enhance cell membrane permeability, and boost nutrient intake (Dinçsoy and Sönmez, 2019).

Overall, the treatments that included the combination of K_2SO_4 or feldspar with mycorrhiza fungi and humic acid (T4 and T8) showed the highest increases in N, P, and K concentrations in the leaves of wheat plants. This suggests that there might be synergistic effects between K fertilizer and mycorrhiza/humic acid on plant growth and nutrient uptake, leading to improved nutrient concentrations in the plant tissues. Abo–Baker Basha and Hassan (2017) reported also that the sandy loam soil's estimated parameters, including the availability of phosphorus and potassium in the soil to plants and various growth parameters for plants, are improved by the combined application of phosphorus/potassium mineral materials, microbial inoculation, humic substances, and the obtained results of yield and nutrient uptake gave highly significant increases compared to their applications.

Overall, it can be concluded that applying fertilizers, especially treatments of humic and/or mycorrhiza had a significant positive effect on the protein, carbohydrate, and total sugar content of the wheat plants. These findings are consistent with work done by other researchers who reported that applying potassium fertilizer and mycorrhiza improves nutrient uptake, amino acids, and carbohydrates (Lamlom *et al*., 2023). Additionally, according to El-Bassiouny *et al*. 2014; Delfine, *et al.* 2005). humic acid helps to stimulate plant growth and carbohydrate metabolism by enhancing photosynthesis, which leads to increased protein content. According to Van Tol de Castro *et al*. (2021), the aromatic and aliphatic functional groups of HA were responsible for enhancing N absorption and soluble sugars, increasing yield. Therefore, these treatments can be used as a strategy to improve the nutritional quality of wheat plants. Moreover, results showed that there are no significant differences between feldspar treatments and KS treatments either alone or in combination with HA and/or mycorrhiza in most cases. This suggests that utilization of feldspar (especially in combination with humic acid and/or mycorrhiza) might be considered as an alternative source of potassium fertilizers and a beneficial cheap source of K-fertilization for agriculture in sandy soils. From the obtained results, it could also be concluded that both humic acid and/or mycorrhiza increased the availability of macronutrients in the experimental soil and improved soil productivity.

Regarding the effect of mycorrhizal fungi on enhancing the use efficacity of potassium and other nutrients, mycorrhizal fungi play a crucial role. The hyphae of the fungi release organic acids and enzymes that facilitate the weathering process by breaking down the mineral structure. This results in the release of essential elements such as potassium, calcium, and phosphorus, increasing their availability to plants, and subsequently their use efficiency, which are vital for plant growth. (VanBreemen, *et al.* 2000). The combined effect of potasium fertilizers or feldspar with mycorrhizal fungi/humic acid enhances levels of essential nutrients, especially potassium, which is a nutrient for plant growth. It can improve soil fertility, enhance plant growth and development, and promote overall crop productivity (Bindschedler and Verrecchia 2019). The released nutrients become available for uptake by the plant roots, enhancing their nutrient absorption capacity. Additionally, the mycorrhizal fungi themselves can also directly absorb and transfer these nutrients to the plant roots. (Wild, Gerrits and Bonneville 2022) (Bindschedler and Verrecchia 2019).

Conclusion

Applying fertilizer with 100% KS and 100% FS either alone or in combination with humic and/or inoculation with mycorrhiza significantly enhanced plant growth parameters and yield than those of control soil. From the obtained results, the treatments of mycorrhizal inoculation and humic acid significantly increased plant growth parameters, yield, and harvest index, but the mycorrhizal inoculation combined with humic acid had better effects on growth parameters. Our findings suggest that the application of feldspar mineral combined with mycorrhiza and humic acid could be considered as an alternative and a replacement for K-mineral fertilizers in sandy soils.

References

Abo-Baker Basha, A.A. and Hassan, M.S (2017). Evaluation of rock phosphate and potassium feldspar with biological and organic amendments and its effect on soil phosphorus and potassium availability and uptake, growth and yield of canola. Int J Plant Soil Sci 14:1–14. https://doi.org/10.9734/IJPSS/2017/31347

Abou-el-Seoud, I.I., and Abdel-Megeed, A. (2012). Impact of rock materials and biofertilizations on P and K availability for maize (Zea Maize) under calcareous soil conditions. Saudi Journal of Biological Sciences, 19(1): 55-63. https://doi.org/10.1016/j.sjbs.2011.09.001

Al-Hmoud, G. and Al-Momany, A. (2017) Effect of four mycorrhizal products on squash plant growth and its effect on physiological plant elements. Adv Crop Sci Tech 5:260. https://doi.org/10.4172/2329-8863.1000260.

Ampong, K., Thilakaranthna, M.S. and Gorim, L.Y. (2022) Understanding the role of humic acids on crop performance and soil health. Front Agron 4:848621. https://doi.org/10.3389/fagro.2022.848621.

Bahadur, I., Maurya, B.R., Kumar, A., Meena, V. and Raghuwanshi, R. (2016). Towards the soil sustainability and potassium-solubilizing microorganisms. In: Potassium Solubilizing Microorganisms for Sustainable Agriculture, Eds. Meena VS, Maurya

BR, Verma JP, Meena RS, pp. 249–261. Springer India: New Delhi1.https://doi.org/10.1007/978-81-322-2776-2_18.

Bahmanyar, M.A. and Ranjbar, G.A. (2008). The role of potassium in improving growth indices and increasing amount of grain nutrient elements of wheat cultivars. J Appl Sci 8:1280–1285. https://doi.org/10.3923/jas.2008.1280.1285.

Balliu, A., Sallaku, G. and Rewald, B. (2015). AMF inoculation enhances growth and improves the nutrient uptake rates of transplanted, salt-stressed tomato seedlings. Sustainability 7:15967–15981. https://doi.org/10.3390/su71215799.

Begum, N., Qin, C., Ahanger, M.A., Raza, S., Khan, M.I., Ashraf, M., Ahmed, N. and Zhang, L. (2019). Role of arbuscular mycorrhizal fungi in plant growth regulation: implications in abiotic stress tolerance. Front Plant Sci 10:1068. https://doi.org/10.3389/fpls.2019.01068.

Bell, M.J., Murrell, T.S., Mikkelsen, R.L., Sulewski, G., Norton, R. and Thompson, M.L. (eds) (2021). Considering soil potassium pools with dissimilar plant availability. In: Improving potassium recommendations for agricultural crops. Springer, Cham, pp 147–166. https://doi.org/10.1007/978-3-030-59197-7_7.

Berruti, A., Lumini, E., Balestrini, R. and Bianciotto, V. (2016). Arbuscular mycorrhizal fungi as natural biofertilizers: let’s benefit from past successes. Front Microbiol 6:1559. https://doi.org/10.3389/fmicb.2015.01559.

Billingham, K.L. (2012). Humic products-potential or presumption for agriculture? Can humic products improve my soil? In: 27th Annual Conference. Grassland Society of NSW Inc., Orange NSW. https://core.ac.uk/works/78777726.

Bindschedler, S. and Verrecchia, E.P. (2019). Fungal weathering. In: Encyclopedia of astrobiology. Springer, Berlin, Heidelberg, pp 1–5. https://doi.org/10.1007/978-3-642-27833-4_5400-2.

Bücking, H. and Kafle, A. (2015). Role of arbuscular mycorrhizal fungi in the nitrogen uptake of plants: current knowledge and research gaps. Agronomy 5:587–612. https://doi.org/10.3390/agronomy5040587.

Buragohain, S., Nath, D.J., Devi, Y.B., Bhattacharyya, B. and Dutta, S. (2018). Molecular characterization of potassium solubilizing bacteria from crop rhizosphere of the North Eastern Region of India. Curr Sci https://doi.org/10.18520/cs/v114/i12/2543-2548.

Ciceri, D., Close, T., Barker, A. and Allanore, A. (2019). Fertilizing properties of potassium feldspar altered hydrothermally. Commun Soil Sci Plant Anal 50:1–10. https://doi.org/10.1080/00103624.2019.1566922.

Delfine, S., Tognetti, R., Desiderio, E. and Alvino, A. (2005). Effect of foliar application of N and humic acids on growth and yield of durum wheat. Agron Sustain Dev 25:183–191. https://doi.org/10.1051/agro:2005017.

Dewis, J. and Feritas, F. (1970). Physical and chemical methods of soil and water analysis. FAO, Rome, Soil Bulletin No. 10.

Dinçsoyand Sönmez, F. (2019). The effect of potassium and humic acid applications on yield and nutrient contents of wheat (Triticumaestivum L. var. Delfii) with same soil properties. J Plant Nutr 42:2757–2772. https://doi.org/10.1080/01904167.2019.1658777.

Droh, G, Kouassi, A.B., Kouadjo, Z.C.G., Zeze, A., Nguetta, A.S. and Sanders, I.R. (2016). Effect of two AMF on growth of cocoa seedlings (*Theobroma cacao* L.) in greenhouses. Glob J Adv Res 3:157–164. ResearchGate.

El-Bassiouny, H., Bakry, B., El-Monem, A.A. and Abd Allah, M. (2014). Physiological role of humic acid and nicotinamide on improving plant growth, yield, and mineral nutrient of wheat (*Triticum durum*) grown under newly reclaimed sandy soil. Agric Sci 5:687–700. https://doi.org/10.4236/as.2014.58072.

El-Mageed, T.A., El-Sayed, S.A., El-Sayed, M.A., El-Sayed, A.A. and El-Sayed, S.M. (2023). Coupling effects of potassium fertilization rate and application time on growth and grain yield of wheat (*Triticum aestivum* L.) plants grown under Cd-contaminated saline soil. J Soil Sci Plant Nutr 23: https://doi.org/10.1007/s42729-022-01104-3.

El-Nahas, B.H., El-Metwally, I.M., Abd El-Aal, M.F. and Abd El-Hady, M.S. (2019). Effect of potassium sources and soil amendments with silicate dissolving bacteria on availability of potassium in clayey soil cultivated with wheat plants. Zagazig J Agric Res 46: https://doi.org/10.21608/ZJAR.2019.47077.

Evelin, H., Devi, T.S., Gupta, S. and Kapoor, R. (2019). Mitigation of salinity stress in plants by arbuscular mycorrhizal symbiosis: current understanding and new challenges. Front Plant Sci 10:470. https://doi.org/10.3389/fpls.2019.00470.

Franczuk, J., Tartanus, M., Rosa, R., Zaniewicz-Bajkowska, A., Debski, H., Andrejiová, A. and Dydiv, A. (2023). The effect of mycorrhiza fungi and various mineral fertilizer levels on the growth, yield, and nutritional value of sweet pepper (*Capsicum annuum* L.). Agriculture 13:857. https://doi.org/10.3390/agriculture13040857.

García de León, D., Vahter, T., Zobel, M., Koppel, M., Edesi, L., Davison, J., Al-Quraishy, S., Hozzein, W.N., Moora, M., Oja, J., Vasar, M. and Öpik, M. (2020). Different wheat cultivars exhibit variable responses to inoculation with arbuscular mycorrhizal fungi from organic and conventional farms. PLoS One 15:e0233878. https://doi.org/10.1371/journal.pone.0233878.

Grümberg, B.C. and Urcelay, C. (2015). The role of inoculum identity in drought stress mitigation by arbuscular mycorrhizal fungi in soybean. Biol Fertil Soils 51:1–10. https://doi.org/10.1007/s00374-014-0942-7.

Gryndler, M., Hršelová, H., Sudová, R., Gryndlerová, H., Řezáčová, V. and Merhautová, V. (2005). Hyphal growth and mycorrhiza formation by the arbuscular mycorrhizal fungus Glomus claroideum BEG 23 is stimulated by humic substances. Mycorrhiza 15:483–488. https://doi.org/10.1007/s00572-005-0352-7.

Guo, J., Jia, Y., Chen, H., Zhang, L., Yang, J., Zhang, J. and Zhou, Y. (2019). Growth, photosynthesis, and nutrient uptake in wheat are affected by differences in nitrogen levels and forms and potassium supply. Scientific reports, 9(1): 1248. https://doi.org/10.1038/s41598-018-37838-3.

Hasanuzzaman, M., Borhannuddin Bhuyan, M.H.M., Nahar, K., Hossain, M.S., Mahmud, J.A., Hossen, M.S., Masud, A.A.C., Moumita and Fujita, M. (2018). Potassium: A vital regulator of plant responses and tolerance to abiotic stresses. Agronomy 8:31. https://doi.org/10.3390/agronomy8030031.

Hijri, M. (2016). Analysis of a large dataset form field mycorrhizal inoculation trials on potato showed highly significant increase in yield. Mycorrhiza 2:209–214. https://doi.org/10.1007/s00572-015-0661-4.

Hu, H., Umbreen, S., Zhang, Y., Bao, M., Huang, C., and Zhou, C. (2021). Significant association between soil dissolved organic matter and soil microbial communities following vegetation restoration in the Loess Plateau. Ecological Engineering, 169, 106305.https://doi.org/10.1016/j.ecoleng.2021.106305.

Khafagi, E.Y., El-Abeid, S.E., Soliman, M.S., El-Nahas, S.E.S.M., and Ahmed, Y. (2018). Role of Arbuscular Mycorrhizae Fungi and humic acid in controlling root and crown rot of strawberry. Plant Pathology Journal (Faisalabad), 17(2): 65-74. https://doi.org/10.3923/ppj.2018.65.74.

Khan, R.U., Khan, M.Z., Khan, A., Saba, S., Hussain, F., and Jan, I.U. (2018). Effect of humic acid on growth and crop nutrient status of wheat on two different soils. Journal of plant nutrition, 41(4): 453-460. https://doi.org/10.1080/01904167.2017.1385807.

Khan, R.U., Rashid, A., Khan, M.S., and Ozturk, E. (2010). Impact of humic acid and chemical fertilizer application on growth and grain yield of rainfed wheat (Triticum aestivum L.). Pakistan Journal of Agricultural Research, 23(3-4). http://cabi.org.

Lamlom, S.F., Irshad, A. and Mosa, W.F. (2023). The biological and biochemical composition of wheat (Triticum aestivum) as affected by the bio and organic fertilizers. BMC Plant Biology, 23(1): 111. https://doi.org/10.1186/s12870-023-04120-2.

Lu, F.C., Lee, C.Y., and Wang, C.L. (2015). The influence of arbuscular mycorrhizal fungi inoculation on yam (Dioscorea spp.) tuber weights and secondary metabolite content. PeerJ, 3, e1266. https://doi.org/10.7717/peerj.1266.

Mathieu C. and Pieltain F. (2003). Chemical analysis of soils. Selected methods, France, 387.

Maurya, S.P., Yadav, M.P., Yadav, D.D., Verma, S.K., Kumar, S., and Bahadur, S. (2015). Effect of Potassium Levels on Growth and Yield of Wheat (*Triticum aestivum* L.) Varieties. Environment and Ecology, 33(2): 726-729. https://drive.google.com/file/d/1IySegkLjjFFN_nSBB8jdND6pezUH_hkN/view?pli=1

Meena, V.S., Maurya, B.R., Verma, J.P. and Meena, R.S. (2016). Potassium solubilizing microorganisms for sustainable agriculture. Springer, Uttar Pradesh, India, 17. https://doi.org/10.1007/978-81-322-2776-2.

Olaniyan, F.T., Alori, E.T., Adekiya, A.O., Ayorinde, B.B., Daramola, F.Y., Osemwegie, O.O., and Babalola, O.O. (2022). The use of soil microbial potassium solubilizers in potassium nutrient availability in soil and its dynamics. Annals of Microbiology, 72(1): 45. https://doi.org/10.1186/s13213-022-01701-8.

Parkinson, J.A., and Allen, S.E. (1975). A wet oxidation procedure suitable for the determination of nitrogen and mineral nutrients in biological material. Communications in soil science and plant analysis, 6(1): 1-11.. https://doi.org/10.1080/00103627509366539.

Prasad, R., Bhattacharyya, A., and Nguyen, Q.D. (2017). Nanotechnology in sustainable agriculture: recent developments, challenges, and perspectives. Frontiers in microbiology, 8, 1014. https://doi.org/10.3389/fmicb.2017.01014.

Rouphael, Y., Franken, P., Schneider, C., Schwarz, D., Giovannetti, M., Agnolucci, M., ... and Colla, G. (2015). Arbuscular mycorrhizal fungi act as biostimulants in horticultural crops. Scientia Horticulturae, 196, 91-108. https://doi.org/10.1016/j.scienta.2015.09.002.

Sabia, E., Claps, S., Morone, G., Bruno, A., Sepe, L. and Aleandri, R. (2015). Field inoculation of arbuscular mycorrhiza on maize (*Zea mays* L.) under low inputs: preliminary study on quantitative and qualitative aspects. Italian Journal of Agronomy, 10(1): 30-33.https://doi.org/10.4081/ija.2015.607.

Sadhana, B. (2014). Arbuscular mycorrhizal fungi (AMF) as a biofertilizer-a review. Int J CurrMicrobiol App Sci 3:384–400.https://www.ijcmas.com/vol-3-4/B.Sadhana.pdf.

Sardans, J. and Peñuelas, J. (2021). Potassium control of plant functions: ecological and agricultural implications. Plants 10:419. https://doi.org/10.3390/plants10020419.

Schütz, L., Gattinger, A., Meier, M., Müller, A., Boller, T., Mäder, P., and Mathimaran, N. (2018). Improving crop yield and nutrient use efficiency via biofertilization—A global meta-analysis. Frontiers in Plant Science, 8, 2204. https://doi.org/10.3389/fpls.2017.02204.

Seddik W.M.A. (2011). Evaluation of vinasse, organic manure and natural minerals as alternative natural fertilizers. J Bio Chem Environ Sci 6:269–292.

Seutra Kaba, J., Abunyewa, A.A., Kugbe, J., Kwashie, G.K., Owusu Ansah, E., and Andoh, H. (2021). Arbuscular mycorrhizal fungi and potassium fertilizer as plant biostimu-lants and alternative research for enhancing plants adaptation to drought stress: Op-portunities for enhancing drought tolerance in cocoa (*Theobroma cacao* L.). Sustain-able Environment, 7(1): 1963927. https://doi.org/10.1080/27658511.2021.1963927.

Sharma, S.B., Sayyed, R.Z., Trivedi, M.H., and Gobi, T.A. (2013). Phosphate solubilizing microbes: sustainable approach for managing phosphorus deficiency in agricultural soils. SpringerPlus, 2, 1-14. https://doi.org/10.1186/2193-1801-2-587.

Singh, V.K., Gill, A.A.S., Singh, A., Singh, O., and Singh, T. (2022). Natural Potassium Fertilizers for Sustainable Agriculture. https://doi.org/10.1007/978-981-16-4921-9_262-1

Smith, S.E., Jakobsen, I., Grønlund, M., and Smith, F.A. (2011). Roles of arbuscular mycorrhizas in plant phosphorus nutrition: interactions between pathways of phosphorus uptake in arbuscular mycorrhizal roots have important implications for understanding and manipulating plant phosphorus acquisition. Plant physiology, 156(3): 1050-1057. https://doi.org/10.1104/pp.111.174581.

Soumare A., Sarr D., Diédhiou A.G. (2022). Potassium sources, microorganisms, and plant nutrition—challenges and future research directions: a review. Pedosphere 33:105–115. https://doi.org/10.1016/j.pedobi.2021.11.001.

Sparks, D.L. (1996). Methods of soil analysis part 3: chemical methods. Soil Science Society of America, American Society of Agronomy, Madison.

Stamford, N.P., Lima, R.A., Santos, C.R.S., and Dias, S.H.L. (2006). Rock biofertilizers with Acidithiobacillus on sugarcane yield and nutrient uptake in a Brazilian soil. Geomicrobiology Journal, 23(5): 261-265. https://doi.org/10.1080/01490450600760658.

Ullman, W.J., and Welch, S.A. (2000). Organic Ligands and Feldspar Dissolution [book chapter]. College of Marine Studies, University of Delaware, Lewes, DE (US). https://www.osti.gov/biblio/805075.

Van Breemen, N., Finlay, R., Lundström, U., Jongmans, A. G., Giesler, R., and Olsson, M. (2000). Mycorrhizal weathering: a true case of mineral plant nutrition? Biogeochemistry, 49, 53-67. https://doi.org/10.1023/A:1006256231670.

Van Tol de Castro, T.A., Berbara, R.L.L., Tavares, O.C.H., Mello, D.F.D.G., Pereira, E.G., Souza, C.D.C.B.D., Espinosa, L.M., and García, A.C. (2021). Humic acids induce a eustress state via photosynthesis and nitrogen metabolism leading to a root growth improvement in rice plants. Plant Physiology and Biochemistry, 162, 171-184. https://doi.org/10.1016/j.plaphy.2021.02.043.

Wang, M., Zheng, Q., Shen, Q. and Guo, S. (2013). The critical role of potassium in plant stress response. Int J Mol Sci 14:7370–7390. https://doi.org/10.3390/ijms14047370

Wang, X.J., Wang, Z.Q. and Li, S.G. (1995). The effect of humic acids on the availability of phosphorus fertilizers in alkaline soils. Soil Use and Mange 11: 99-102.

Wang, J., Ding, Z., AL-Huqail, A.A., Hui, Y., He, Y., Reichman, S.M., ... and Abou-Zaid, E.A. (2022). Potassium source and biofertilizer influence K release and fruit yield of Mango (*Mangifera indica* L.): A three-year field study in sandy soils. Sustainability, 14(15): 9766. https://doi.org/10.3390/su14159766.

Wang, X. X., Wang, X., Sun, Y., Cheng, Y., Liu, S., Chen, X., ... and Kuyper, T.W. (2018). Arbuscular mycorrhizal fungi negatively affect nitrogen acquisition and grain yield of maize in a N deficient soil. Frontiers in microbiology, 9, 418. https://doi.org/10.3389/fmicb.2018.00418.

Wild, B., Gerrits, R., and Bonneville, S. (2022). The contribution of living organisms to rock weathering in the critical zone. npj materials degradation, 6(1): 98. https://doi.org/10.1038/s41529-022-00312-7.

Wu, Q.S. and Xia, R.X. (2004). Effects of arbuscular mycorrhizal fungi on plant growth and osmotic adjustment matter content of trifoliate orange seedling under water stress. J Plant Physiol Mol Biol 30:583–588. PMID: 15627714. https://europepmc.org/article/med/15627714.

Youssef, M.A. and Eissa, M.A. (2017). Comparison between organic and inorganic nutrition for tomato. J Plant Nutr 40:1900–1907. https://doi.org/10.1080/01904167.2016.1270309

Zhu, J., Li, M. and Whelan, M. (2018). Phosphorus activators contribute to legacy phosphorus availability in agricultural soils: a review. Sci Total Environ 612:522–537. https://doi.org/10.1016/j.scitotenv.2017.08.095.

تحسين أداء سماد البوتاسيوم والمعادن الحاملة للبوتاسيوم في التربة الطميية الرملية بإضافة الأحماض الدبالية والميكوريزا

قاسم احمد سعيد محمد[1]، محمد صلاح الدين محمد عيد[1]، عادل ربيع أحمد عثمان[2]

[1]قسم الموارد الطبيعية، معهد البحوث والدراسات الافريقية، جامعة اسوان، مصر.

[2]قسم الاراضي والمياه، كلية الزراعة، جامعة اسيوط، مصر.

الملخص

يعتبر البوتاسيوم (K) من العناصر الغذائية الكبرى اللازمة لنمو وتطور النباتات. ولذلك فإن الهدف من هذه الدراسة هو تقييم أداء سماد البوتاسيوم والمعادن الحاملة للبوتاسيوم المضافة مع حامض الهيوميك والميكوريزا على نمو نبات القمح وامتصاص العناصر الغذائية في تربة طميية رملية (محتواها منخفض من البوتاسيوم). عوملت التربة بسماد كبريتات البوتاسيوم (KS) أو الفلسبار (FS) إما بمفردها أو بالاشتراك مع حمض الهيوميك و/أو فطريات الميكوريزا. إن إضافة معاملات KS وFS إما بمفرده أو بالاشتراك مع حامض الهيوميك و / أو التلقيح بالميكوريزا عزز بشكل كبير نمو النبات (ارتفاع النبات وطول السنبلة ووزن 100 بذرة) والإنتاج مقارنة بتلك الموجودة في تربة الكنترول. أدى إضافة المعاملات إلى زيادة معنوية في محصول القش بنسبة 126-401%، ومحصول الحبوب بنسبة 155-806%، والمحصول الكلي بنسبة 138-559% مقارنة بمعاملة الكنترول. من النتائج المتحصل عليها، أدت معاملات KS و FS مع التلقيح بالميكوريزا و حمض الهيوميك إلى زيادة معنوية في نمو النبات والمحصول والخصائص البيوكيميائية (البروتين والكربوهيدرات والنسبة المئوية) وامتصاص العناصر الغذائية (NPK). يمكن أن نستنتج أن كلا من حمض الهيوميك و/أو الميكوريزا زادا من امتصاص النبات للمغذيات في التربة وتحسين إنتاجية التربة. لذلك، تشير النتائج التي توصلنا إليها إلى أن إضافة معدن الفلسبار مع الميكوريزا وحمض الهيوميك يمكن اعتباره بديلاً للأسمدة المعدنية K في التربة الرملية.