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Effect of Mycorrhizal Inoculation and Potassium Fertilization on Grain Yield and Nutrient Uptake of Sweet Sorghum Cultivated under Water Stress in Calcareous Soil

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DROUGHT stress, which is the most serious environmental factor reduces crop productions, might be balanced by some free living and symbiotic soil microorganisms. The physiological response of sweet sorghum plants to inoculation with arbuscular mycorrhizal (VAM) fungi and three potassium fertilizer levels (75, 100 and 125% of recommended rate) was evaluated under three different irrigation intervals (*i.e.,* 8, 12, and 16 days). A factorial experiment was conducted based on a randomized complete block design (RCBD) with three replications in sandy loam calcareous soil at the El-Nubaria region. The results evidenced that water deficit stress inhibited the growth, biomass of vegetative and reproductive parts, and grain and sugar yield. In all inoculated and uninoculated plants, decreased 1000 grains weight, stalk, grain, biomass, dry matter and sugar yields with increasing irrigation intervals. At the same time, inoculation of sweet sorghum with mycorrhiza resulted in a significant increase in the root colonization, number of mycorrhizal spores, alkali phosphatase, the biomass and sugar yield. Also, increase significantly the content of N, P and K nutrients in plant tissue underwater deficit in calcareous soils compared with non-inoculated plants. Potassium fertilizer in combination with mycorrhizal inoculant on all measured traits could make the plants more tolerant to water stress higher than non-mycorrhizal treatments. In general, the results of this study presented that the sweet sorghum plants inoculated with mycorrhiza and 115 kg K_2O ha^{-1} of potassium sulphate fertilizer improved water stress tolerance, increased the sweet sorghum biomass and sugar yield under water deficit stress in comparison to uninoculated plants.

Keywords: Sweet sorghum, Mycorrhiza, Water deficit, Potassium, sugar

Introduction

Sweet sorghum is like grain sorghum in grain production and almost similar to sugarcane for sugar-rich stalk and high sugar accumulation (Dayakar Rao et al., 2004). Sweet sorghum ranks as important cereals among world and primarily grown in the warm dry climates. The crop is adapted to the arid and semi-arid tropics and dry-temperate areas of the world. Sweet sorghum grain is used as poultry feed; the stems for sugar extraction; the whole biomass for bio-fuels, fiber extraction and feed for animals (Nokerbekova et al., 2018 and Sher et al., 2013). The content of sugars in sweet sorghum plants is significantly influenced by the conditions of their cultivation. The ability of plants to accumulate a large amount of soluble sugars in the stem makes them a potential source of raw materials for the food industry (She et al., 2010).

Regarding to the concentrations of sugar in the stalks, sorghum can be separated into saccharin-type and syrup-type sweet sorghum. The Saccharin-type yields a juice with high sucrose sugar content relating to other sugars, and this can be readily transformed to white crystal sugar (Alhajturki et al., 2012 and Wang et al., 2015)

Sugar production in Egypt from sugarcane is 61.2% and 38.8% from sugar beet of the total local production which covering about 67.6% of the domestic consumption. Nevertheless, the

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consumption reaches 2.60 million tons, which indicates a gap of 843 thousand tons that can be achieved through boosting the local production of sugar through increasing the cultivated areas of sugar beet and sweet sorghum. Sweet sorghum, also called ‘‘sugar cane of desert’’, has emerged as a smart dual purpose and alternative crop providing food, feed, sugar and second generation bio-fuel without hurtful food security and natural resources (Farag et al., 2017).

Drought is a predominant cause of low crop yields. There is an urgent need for more water efficient cropping systems facing large water consumption of irrigated agriculture (Bodner et al., 2015). Bio-fertilizers based on arbuscular mycorrhizal fungi (AMF) currently have great ecological and economic importance in agriculture. The preparation of microbial inoculants is great importance such as biotechnology in agriculture, even if particularly those with economic viability (Smith and Read, 2008). The symbiotic association between VAM fungi and plant roots are known to protect host plants from the harmful effects of drought (Tauschke et al., 2015) and can improve the nutrient uptake and growth of plants under water stress conditions. One of the function of the mycorrhizal symbiosis on host plant water balance is the increases of root biomass, plant size and yield (Subramanian et al., 2006). Also improved phosphorus nutrition by VAM fungi during the periods of water deficit has been suggested as a primary mechanism for enhancing host plant drought tolerance and potential to increase the growth and plant productivity (Almodares et al., 2013).

Investigation of the influence of a commercial mycorrhizal inoculum on water use efficiency and biomass production of sweet sorghum was accomplished by Eulenstein et al., 2017. They found that VAM inoculated plants were more successful in terms of dry matter production and water use than the non-VAM plants. Also, the results indicate that inoculation with VAM and preferment of the naturally abundant mycorrhiza in agricultural production systems can significantly contribute to a sustainable production of crops.

To enhance the drought tolerance in sorghum, nutrient application could be useful, particularly in the semi-arid regions. Potassium plays an important role to reduce negative effects of drought (Cakmak, 2005). It is a macronutrient absorbed by crop plants which plays a vital role in plant growth and development as activation of more than 60 enzymes takes place by this element. Potassium creates immunity in plants body against drought and high temperature as well as diseases. All plants which produce high carbohydrates require more potassium. On the other hand, Impairment in stomatal regulation, transfer of light energy into chemical energy, transport of assimilates from source to sink and disturbance in photosynthetic are the main disorders of potassium deficiency (Aslam et al., 2013). Provision of potassium to crop plants under drought environments develops tolerance to drought in its body by using soil moisture efficiently as compared to potassium deficient plant. Potassium regulates osmotic pressure, turgor potentials and stomatal functioning under drought stress. It also increases photosynthetic rate, growth and yield under water deficit stress conditions. Hence, potassium is an essential nutrient for plant’s internal functioning under drought conditions (Aslam et al., 2013 and Cakmak, 2005).

In view of the above, the present study was conducted to evaluate the advantages of VAM Mycorrhizal inoculation and potassium fertilization to reduce the negative effect of water stress on sweet sorghum establishing.

Materials And Methods

A summer season field experiment was carried out at El-Nubaria region (30° 40′ 54.12″ N 30° 08′ 32.64″ E), Egypt during 2016 season to study the effect of irrigation intervals, potassium fertilizer rate and inoculation with mycorrhizal fungi on growth, yield and its components of sweet sorghum, Giza1, variety. The soil of the experimental site is calcareous sandy soil.

Experimental Design

The experiment was laid out in randomized complete block design (RCBD) with three replications. The total experimental area was 567 m^2. The area was divided into 54 plots, each 3.0 x 3.5 m (10.5 m^2) with 0.5 m belt between plots. The area was cultivated with sweet sorghum (Giza 1). Planting was carried out at 25 May 2016 by hand sowing (0.5 m apart between ridges, 0.15 m between plants). The soil was hoed i as usually, and phosphorus fertilization was applied prior seed bed preparation at the rate of 240 kg calcium super phosphate per hectare (15.5% P_2O_5). 90 kg N /ha in form of ammonium nitrite (33%N) was applied. The nitrogen fertilizer was split into three equal doses. All the other agronomic practices were followed as usually done for the sweet sorghum crop. The irrigation intervals and potassium fertilization treatments were as follows:

Irrigation intervals

Three irrigation intervals namely irrigation every 8, 12 and 16 days (I1, I2 and I3, respectively), were studied. The irrigation treatments were applied 30 days from sowing date. Furrow irrigation was used and water was added at each irrigation treatments to raise the soil moisture to field capacity.

Potassium fertilizer rates

Three rates (K1, K2 and K3), [70 (75%), 90 (100%) and 115 (125%) kg K_2O ha^{-1} of potassium sulphate (50 % K_2O)] was applied and splitted into three equal doses. Nitrogen and potassium fertilizers add at 3–4 leaf stage (1/3 total N + 1/3 total % K_2O at 7–8 leaf stage (1/3 total N + 1/3 total % K_2O and the remained fertilizers was applied 20 d after the last fertilization

Soil samples were collected from experimental site prior to sowing and at the end of experiment to determine the chemical and chemical analysis of the soil according to standard methods of (Klute, 1986 and Page et al., 1982) and presented in Table 1.

At ripe stage, five individual guarded plants were chosen at random from the middle ridges of each plot to measure stalk height from base to tip of the panicle (cm), Stalk fresh weight (g), Brix was measured by refractometer (a measure of the mass ratio of soluble solids to water, is a widely used approximation for sugar content). Stalk yield sugar yield. The latter was estimated by multiplying stalk yield by sucrose percentage.

Bio-analyses

Spores from soil samples were isolated according to the method of Gerdemann and Nicolson (1963) of wet sieving and decantation. Samples were centrifuged and permanent slides prepared according to Schenck and Perez (1990).

Three plants per plot were collected for VA-mycorrhizal infection assessment. The staining method of Phillips and Hayman (1970) was used for preparing root samples for microscopic observation. The gridlines intersect method of Giovannetti and Mosse (1980) was used to estimate the VA-mycorrhizal infection percentage.

$$Mycorrhizal\ Colonization\ (\%) = \frac{Total\ number\ of\ root\ segments\ colonized}{Total\ Number\ of\ root\ segments\ studied}\ x\ 100$$

For determination of phosphatase activity, disodium phenyl phosphate served as enzyme substrate (Öhlinger, 1996).

Plant samples were taken at harvesting from each treatment for the determination of N, P, K as follows: Total nitrogen using the micro Kjeldahl method (Bremner and Mulvaney, 1982), total phosphorus content was determined using Vanado-Molybdate yellow color method as described by Jackson (1973) and total potassium content was determined using Flame photometer according to Page (1982).

Water efficiency analysis

Analysis of the water efficiencies was carried out using the efficiency parameters defined by Hillel, (1998) and Schneider and Howell (1999) as follows:

$$Biomass\ Water\ Use\ Efficiency\ (Bio-WUE) = \frac{Biomass\ Yield\ (kg\ ha^{-1})}{Water\ Consumptive\ use\ (m^3 ha^{-1})}$$

$$Sugar\ Water\ Use\ Efficiency\ (Sugar-WUE) = \frac{Sugar\ Yield\ (kg\ ha^{-1})}{Water\ Consumptive\ use\ (m^3 ha^{-1})}$$

TABLE 1. Mean soil chemical and physical characteristics at the experimental site

Depth (cm)	Particles size distribution (%)				pH§	E.C (dSm^{-1})	$CaCO_3$ %	Chemical analysis							
								Soluble cations (meq/l)				Soluble anions (meq/l)			
	Sand	Silt	Clay	Texture				Na^+	Ca^{++}	Mg^{++}	K^+	CO_3^-	HCO_3^-	Cl^-	SO_4^{--}
30	71.2	24.8	4.0	SL±	8.14	1.62	12.7	7.0	5.6	3.7	0.4	--	4.0	7.4	5.3
60	72.2	22.8	5.0	SL±	8.21	1.63	15.3	7.2	5.4	3.5	0.4	--	3.9	7.1	5.5

Available nutrients (mg/kg)

Depth (cm)	N	P	K	Zn	Mn	Fe	Cu
30	130	1.8	112	0.26	0.36	1.87	0.12
60	124	1.5	108	0.22	0.28	1.79	0.11

§ soil pH: water suspension (1:2.5)

± Sandy Loam

Water consumptive use was calculated by Cropwat program using Penman-Monteith equation and weather data for the area under investigation.

Potassium Efficiency Analysis

Analysis of the potassium fertilizer efficiencies were carried out using the efficiency parameters defined by Huggins and Pan (2003) as follows:

$$\mathit{Biomass\ Potassium\ Use\ Efficiency\ (Bio-KUE)} = \frac{\mathit{Biomass\ Yield\ (kg\ ha^{-1})}}{\mathit{Potassium\ Supply\ (kg\ ha^{-1})}}$$

$$\mathit{Sugar\ Potassium\ Use\ Efficiency\ (Sugar-KUE)} = \frac{\mathit{Sugar\ Yield\ (kg\ ha^{-1})}}{\mathit{Potassium\ Supply\ (kg\ ha^{-1})}}$$

Relative water content (RWC) was determined using a measured fresh weight of excised leaf and fully soaked into test tube fully of water. Leaf was taken out of test tube after 24 hours. Water on the surface of leaf was swiped out with tissue paper and weight of leaf was measured. The samples were then dried in an oven at 80°C for 24 hours and weighed to measure the dry weight. The RWC was measured by following formula:

$$RWC = \frac{FW - DW}{TW - DW} * 100$$

Where: FW is the fresh weight of sample, DW is the dry weight of sample and TW is the turgid/soaked weight of sample.

Statistical analyses for the collected data were carried out using CoStat 6.4 Software (CoHort-Software, Copyright© 1998-2008). Analysis of Variance (ANOVA) was used to test all collected data of sweet sorghum. The differences between the means were compared by Duncan's multiple range test as described in Gomez et al. (1984).

Results and Discussion

Root colonization and number of spores in soil rhizosphere

Analysis of variances for the effects of K-fertilizers, irrigation water ;levels and microbial inoculants were shown in Table 2. The root colonization and number of spores/g soil were enhanced significantly by the influence of VAM inoculation compared to un-inoculation treatments. Where, VAM root infection was increased significantly by 111% compared by uninoculated treatments. At the same time, the highest mycorrhizal infection and number of spores/g under potassium fertilizers treatments were observed in K3 treatment followed by K2 and K1 treatment in number of spores while no significance differences found in root infection. Similarly, the highest mycorrhizal infection and number of spores/g under irrigation treatments were observed under I1 and I2 (44.47% and 11.48 spores/g soil, respectively). Also, the lowest percentage was observed in I3 (35.38%) for root colonization and I1 (10.13 spores/g soil) for number of spores. Seed inoculation with AMF? highly enhanced the degree of root colonization. Inoculation with mycorrhiza not only enhanced the VAM root infection and spores count in soil measured, but also influenced the alkali phosphatase content. Inoculation with VAM increase the alkali phosphatase by 8.6% compared with un-inoculation treatments. Similar data were observed by Ghorchiani et al. (2018). They reported that root colonization of sorghum decreased under drought condition. The contrasting effect of drought stress on root colonization has been reported in other crops including wheat (Al-Karaki et al., 2004) and tomato (Subramanian et al., 2006). Under drought stress, shortage water in the soil can reduce and/or delay AMF spore germination and thereby mycorrhiza development which ultimately results in less activity of mycorrhiza in a dry soil (Al-Karaki et al., 2004).

Stalk length, diameter, fresh and dry weight

As shown in Table 2, VAM inoculant treatments caused a significant increase in stalk length, diameter, fresh and dry weight compared to un-inoculant treatments. Inoculation with VAM significantly increase stalk length, diameter, fresh and dry weight by 4.47, 2.06, 11.12 and 12.20 %, respectively compared to uninoculated treatments. Eulenstein et al. (2017) concluded that inoculation with mycorrhiza and promotion of thenaturally abundant mycorrhiza in agricultural production systems can significantly contribute to asustainable production of sweet sorghum. Potassium treatment K3 (125% of recommended) has the highest results of stalk length, diameter, fresh and dry weight when compared to K2 and K1 (100% and 75% of recommended fertilizer) treatments. No significant differences found between K3 and K2 in case of stalk diameter and fresh weight while significant differences found between K3 and K1 in all parameters. This is due to the lack of experiment area in the potassium element. Also, irrigation treatment I2 (12 days' intervals) has the highest results of stalk length, diameter, fresh and dry weight when compared to I1 and I2 (8- and 16-days' intervals) treatments. No significant differences found between I2 and I1 treatment in stalk diameter, fresh and dry weight. While significant differences noticed between I2 and I3 treatment. Almodares et al., (2013) reported that increasing irrigation intervals reduced plant height and plant diameter of sweet sorghum. These results are agreement with (Abd El-Lattief, 2011 and El-Hawary et al., 2012).

Yield parameters and sugar yield

Data in Table 3 indicated that the yield parameters (1000 grains weight, stalk, grain, biomass, dry matter and sugar yields) increased significantly with inoculation with VAM under potassium and irrigation water treatments when compared with uninoculated treatments. the 1000 grains weight, stalk, grain, biomass, dry matter and sugar yields increased significantly by 3.04, 14.87, 4.55, 14.30, 15.33 and 15.55% when compared with uninoculated treatments. Potassium fertilizer treatment K3 increased significantly the weight ranges of 1000 grains, grain, biomass, dry matter and sugar yields by 2.47 - 13.36%, 7.91 - 18.40%, 1.95 - 6.82%, 2.93 -12.75%, and 3.24 - 10.78% when compared with K2 and K1.,respectively. While no significant difference noticed in stalk yield between K3 and K2. Where K3 and K2 increased stalk yield significantly by 6.18 and 4.52% when compared with K1 treatment. Irrigation treatment I1 increased significantly 1000 grains weight, stalk, grain and biomass yields by 3.52 and 17.95%, 1.85 and 9.68%, 1.67 and 64.38% when compared with I2 and I3,, respectively. No significance difference between I1 and I2 treatments in grain, biomass and sugar yield parameters. At the same time, I1 and I2 treatments increased significantly biomass and sugar yield by 9.54 and 9.52%, 7.67 and 6.76% when compared to I3 treatment. On the other hand, I2 treatment increased significantly dry matter yield by 4.34 and 9.22% when compared with I1 and I3 treatment, respectively. Generally, when compare means of all treatments, we can conclude

TABLE 2. Effect of mycorrhiza, potassium and irrigation treatments on VAM infection and count, Alkali phosphatase, stalk length, diameter, fresh and dry weight of sweet sorghum

Treatments	VAM infection (%)	VAM count /g soil	Alkali phosphatase (μg phenol g^{-1} hr^{-1})	Stalk length (cm)	Stalk diameter (cm)	Stalk fresh wt. (g/plant)	DM content (%)	Stalk dry wt. (g/plant)
Bio Fertilizer ±								
un-inoculate	25.78 b	9.17 b	38.00 b	218.67 b	1.94 b	636.78 b	25.35 a	161.47 b
inoculate	54.43 a	12.66 a	41.27 a	228.44 a	1.98 a	707.56 a	25.58 a	181.17 a
f-test	***	***	***	***	**	***	N.S.	***
Potassium Fertilizer §								
K1	39.83 b	10.65 c	38.70 b	207.83 c	1.92 b	634.17 b	24.63 b	156.14 c
K2	39.68 b	10.93 b	39.87 a	229.33 b	1.98 a	687.33 a	25.78 a	177.10 b
K3	40.80 a	11.15 a	40.33 a	233.50 a	1.98 a	695.00 a	26.00 a	180.73 a
f-test	**	***	***	***	***	***	***	***
Irrigation □								
I1	44.47 a	10.13 c	37.47 c	222.67 b	1.99 a	678.83 a	24.37 b	165.6 b
I2	40.47 b	11.48 a	41.68 a	234.50 a	1.99 a	675.5 a	25.91 a	175.20 a
I3	35.38 c	11.12 b	39.75 b	213.50 c	1.88 b	662.17 b	26.11 a	173.14 a
f-test	***	***	***	***	***	*	***	***
Interactions								
Bio x Potassium	***	N.S.	N.S.	N.S.	N.S.	***	N.S.	***
Bio x Irrig.	**	***	***	N.S.	N.S.	N.S.	N.S.	N.S.
Potassium x Irrig.	**	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Bio x Potassium x Irrig.	*	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

Means in the same column followed by the same letter are not significantly different at $p \leq 0.05$

(±) inoculation with VAM

(§) potassium fertilizer rates (75, 100 and 125% of recommended rate)

(ξ) Irrigation treatments (I1, I2 and I3 are 8, 12- and 16-days intervals) that, inoculation with VAM, K3 and I1 are the best treatment under experiment conditions to get the highest of 1000 grain weight, stalk, grain and dry matter yields of sweet sorghum. Whereas, inoculation with VAM, K3 and I2 are the best treatment under experiment conditions to get the highest biomass and sugar yields of sweet sorghum (Figs. 1 and 2). These data were on agreement with finding by Heitman et al. (2018). Also Serrão et al. (2012) found a positive correlation between N, P and K and sweet sorghum biomass and sugar yield. Almodares et al. (2013) reported that when the irrigation intervals increased, sucrose content decreased significantly. The conversion of sucrose to invert sugar under drought stress could be due to the metabolic compatibility of plant. One of the compatibilities of plant under drought stress is osmotic adjustment that plant protects turgid pressure via increasing solution elements such as sugar, organic acids, ions etc. Abdelaziz (2017) found that the total sugar content increased with increasing drought irrigation of carrot roots. Ali et al. (2019) concluded that increasing irrigation intervals from 8 to 14 and 20 days decreased the sugar beet yield and application of potassium silicate reduced the effect of water deficit.

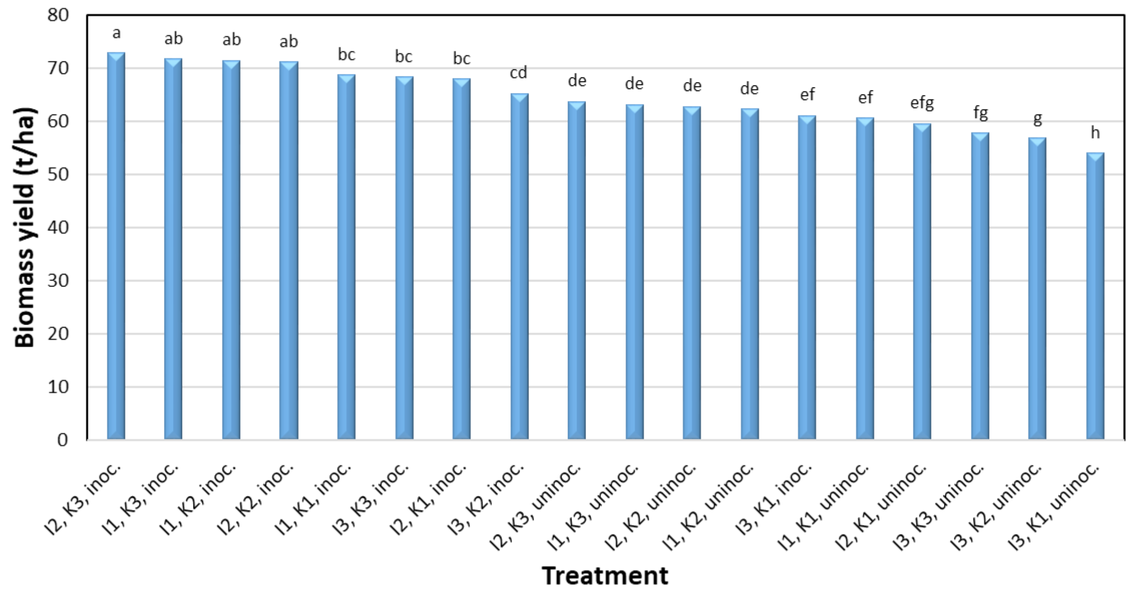

Fig. 1. Effect of mycorrhiza, potassium and irrigation levels on biomass yield of sweet sorghum

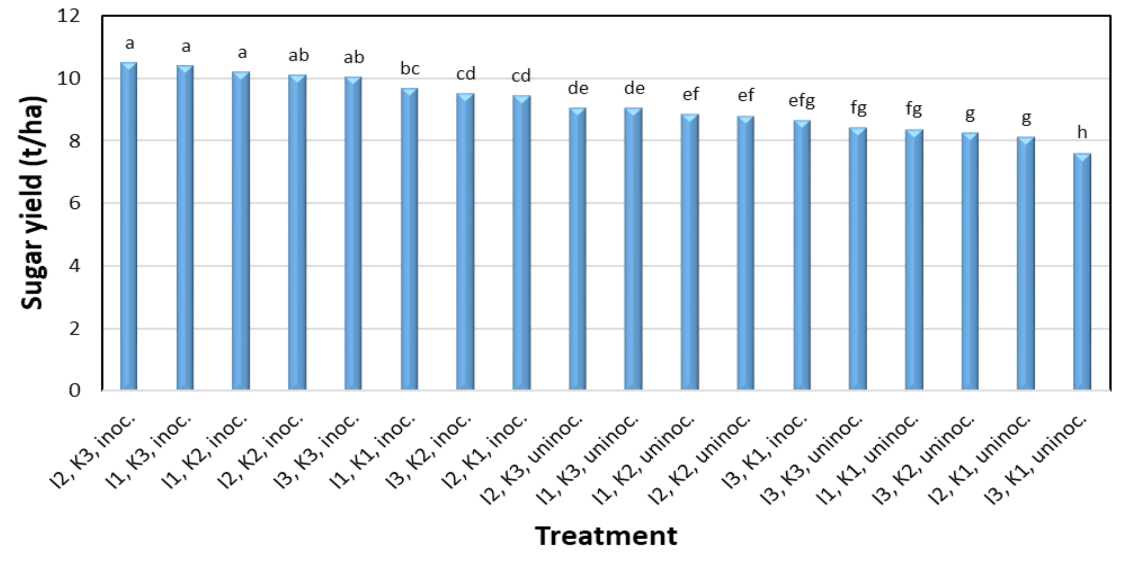

Fig.2. Effect of mycorrhiza, potassium and irrigation treatments on sugar yield of sweet sorghum

TABLE 3. Sweet sorghum stalk, grain, biomass, sugar yields and Brix as affected by irrigation, potassium and VAM treatments

Treatments	wt of 1000 seeds (g)	Stalk yield (t/ha)	Grain yield (t/ha)	biomass yield (t/ha)	DM yield (t/ha)	Brix %	sugar yield (t/ha)
Bio Fertilizer ±							
un-inoculate	38.54 b	50.98 b	3.08 b	60.25 b	15.27 b	16.64 a	8.49 b
inoculate	39.71 a	58.56 a	3.22 a	68.87 a	17.61 a	16.76 a	9.81 a
f-test	***	***	***	***	***	N.S.	***
Potassium Fertilizer §							
K1	36.23 c	52.88 b	2.88 c	62.15 c	15.30 c	16.32 b	8.63 c
K2	40.08 b	55.27 a	3.16 b	65.13 b	16.77 b	16.77 a	9.27 b
K3	41.07 a	56.15 a	3.41 a	66.39 a	17.26 a	17.02 a	9.56 a
f-test	***	***	***	***	***	***	***
Irrigation ξ							
I1	41.72 a	56.78 a	3.66 a	66.49 a	16.22 b	16.55 a	9.40 a
I2	40.30 b	55.75 b	3.61 a	66.48 b	17.24 a	16.70 a	9.32 a
I3	35.37 c	51.77 c	2.19 b	60.70 c	15.87 c	16.85 a	8.73 b
f-test	***	***	***	***	***	N.S.	***
Interactions							
Bio x Potassium	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Bio x Irrigation	N.S.	N.S.	**	N.S.	N.S.	N.S.	N.S.
Potassium x Irrigation	*	N.S.	***	N.S.	N.S.	N.S.	N.S.
Bio x Potassium x Irrigation	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

Means in the same column followed by the same letter are not significantly different at $p \leq 0.05$

(±) inoculation with VAM

(§) potassium fertilizer rates (75, 100 and 125% of recommended rate).

(ξ) Irrigation treatments (I1, I2 and I3 are 8, 12- and 16-days intervals)

Nutrient content in leaves, stalks and grains

Results in Table 4 observed that leaves, stalks and grains nitrogen concentrations were much higher in the inoculated plants than uninoculated ones. The VAM inoculation treatments recorded significantly the highest leaves, stalks and grains nitrogen content (15.92, 3.16 and 16.74 g/kg) which increases by 9.49, 21.54 and 2.83% compared with uninoculated treatment. On the other hand, potassium fertilizer treatments did not affect significantly the nitrogen content in leaves and grains, but K2 treatment significantly increased the nitrogen content in stalks by 3.51 and 4.24% when compared with K3 and K1, respectively. Irrigation treatment I2 increased significantly nitrogen content in leaves, stalks and grains by 2.69 and 5.25%, 4.48 and 12.22%, 2.00 and 2.94% when compared with I1 and I3, respectively. Chen et al. (2018) reported that the contribution of VAM fungi to plant nitrogen nutrition varies widely in diverse symbiotic systems, but VAM fungi can transfer substantial amounts of nitrogen to their hosts.

Mycorrhizal inoculation increases significantly phosphorus concentration in leaves, stalks and grains by 22.66, 22.06 and 22.04% compared to un-inoculation treatments. Potassium treatment K2 also increase phosphorus concentration in in leaves, stalks and grains by 3.52 and 8.29%, 3.95 and 9.72%, and 4.50 and 8.44% compared to un-inoculation treatments, respectively. At the same time, irrigation treatment I2 gives the highest phosphorus concentration in stalks and grains. no significant differences in leaves phosphorus concentration between irrigation treatments were observed.

Also, it is clear in Table 4 that the inoculation with VAM increased significantly the leaves, stalks and grains potassium concentration by 4.75, 3.96 and 4.66% compared with uninoculated. Data also declare that potassium treatment K3 increases significantly potassium concentration in leaves, stalks and grains by 4.19 and 17.17%, 3.13 and 16.35, and 4.29 and 17.44% compared to K2 and K1 treatments, respectively. No significant differences between I2 and I1 irrigation treatments on potassium concentration in leaves, stalks and grains. While treatments I2 and I1 increase significantly potassium concentration in leaves, stalks and grains compared with I3 treatment. Increase the irrigation intervals in I3 treatment may reduce the fertilizer solubility and absorbance by plants. Earlier results of studies indicate that the VAM fungi are commonly associated with sweet sorghum and, therefore, increase the root surface area that results increases in plant nutrient uptake (Zhang et al., 2016). P application could leads to large increase in early root growth that results severely P deficient in soils, following for early mycorrhizal colonization and a subsequent significant contribution of VAM to increase plant growth and nitrogen uptake. The present results are in agreement with the findings by Bagayoko et al. (2000), Heitman et al. (2018), Singh et al. (2012) and Wight et al.(2012). Sary and Elsokkary (2019) clear that the application of effective microorganisms reduce the bad effect of drought on NPK concentration in olives leaf.

RWC and Water and potassium use efficiencies

Relative water content (RWC) values were shown in Table (5). The RWC had high values at I1 water regime compared to I2 and I3 levels. The reduction in RWC was concomitant to the levels of soil water content. The RWC values were lower by 6.86 and 11.44% for the I2 and I3, respectively as compared to I1. This could be attributed to the high evaporative demand of the atmosphere, and also to relatively low root ability to absorb water from the soil. Generally, VAM inoculations were effective in improving RWC under low soil moisture i.e., I2 as well as I3 because mycorrhiza increases the absorbance root surface. Also, the higher potassium fertilizer K2 and K3 increase significantly the RWC by 3019 and 4.66% compared to K1 treatment, while no significance differences noticed between K2 and K3. The recent results are in agreement with Aggag et al. (2015) which found that low water regime reduces significantly relative water content (RWC) of tomato leaves.

Biomass water use efficiency (Biomass WUE) and sugar water use efficiency (sugar WUE) has the highest values under VAM inoculation and increased significantly by 14.47 and 15.15% when compared to uninoculated treatments (Table 5). The lower water amount treatment, I3, has the highest value of biomass and sugar WUE which increased by 9.73 and 26.43%, and 13.38 and 31.97% compared to I2 and I1, respectively. On the other hand, the highest potassium application K3 has the highest biomass and sugar WUE which increased significantly by 2.11 and 7.07%, and 2.78 and 10.45% compared to K2 and K1 treatments, respectively. The water use efficiency was improved for plants with a high percentage of mycorrhizal colonization. Mycorrhizal plants required less water than noncolonized plants to produce 1 kg of dry matter (Eulenstein et al., 2017).

Table 5 showed that the biomass potassium use efficiency (Biomass KUE) and sugar potassium use efficiency (sugar KUE) have the highest values under VAM inoculation and they increased significantly by 14.15 and 15.53%, respectively, compared to uninoculated treatments. The highest water amount treatment I1 has the highest value of biomass and sugar KUE which increased by 2.07 - 12.50%, and 1.17 -8.19% compared to I2 and I3, respectively. On the other hand, the lowest potassium application K1 has the highest biomass and sugar KUE which increased significantly by 24.49 - 54.67%, and 21.50 - 49.21% compared to K2 and K3 treatments, respectively. Ordookhani et al., (2010) studied the influence of PGPR and AMF on antioxidant activity, lycopene and potassium contents in tomato. They found that the inoculation increased the shoot and fruit potassium content.

Conclusion

This study revealed that mycorrhizal inoculants with potassium fertilizer can be used to reduce the depress effect of water deficit. These applications improve the vegetative, root colonization, number of mycorrhizal spores in soil, alkali phosphatase, the biomass and sugar yield of sweet sorghum, and content of N, P and K nutrients in plant tissue under water deficit compared with non-inoculated treatments.Whereas, using mycorrhiza can serve as biofertilizer, decreasing chemical fertilization that is currently used to achieve the high yield and as powerful tool for sustainable plant growth under water deficit conditions in calcareous soils.

TABLE 4. Nitrogen, phosphorus and potassium contents (mg/kg) of dry leaves, stalks and grains of sweet sorghum under different soil water levels, potassium fertilizers and VAM treatments

Treatments	plant N (mg/kg)			plant P (mg/kg)			plant K (mg/kg)		
	Leaf	Stalk	Grain	Leaf	Stalk	Grain	Leaf	Stalk	Grain
Bio Fertilizer ±									
un-inoculate	14.54 b	2.60 b	16.28 b	2.03 b	0.68 b	4.22 b	5.69 b	3.36 b	5.79 b
inoculate	15.92 a	3.16 a	16.74 a	2.49 a	0.83 a	5.15 a	5.96 a	3.49 a	6.06 a
f-test	***	***	***	***	***	***	***	***	***
Potassium Fertilizer§									
K1	15.18 a	2.83 b	16.42 a	2.17 c	0.72 c	4.50 c	5.32 c	3.12 c	5.39 c
K2	15.25 a	2.95 a	16.62 a	2.35 a	0.79 a	4.88 a	5.96 b	3.52 b	6.07 b
K3	15.27 a	2.85 b	16.50 a	2.27 b	0.76 b	4.67 b	6.21 a	3.63 a	6.33 a
f-test	N.S.	***	N.S.	***	***	***	***	***	***
Irrigation ξ									
I1	15.22 b	2.90 b	16.45 b	2.25 a	0.75 b	4.66 b	5.85 a	3.43 a	5.97 a
I2	15.63 a	3.03 a	16.78 a	2.28 a	0.77 a	4.75 a	5.88 a	3.42 a	5.98 a
I3	14.85 c	2.70 c	16.30 b	2.25 a	0.76 ab	4.65 b	5.74 b	3.42 a	5.84 b
f-test	***	***	**	N.S.	*	*	*	N.S.	*
Interactions									
Bio x Potassium	N.S.	N.S.	N.S.	***	***	***	N.S.	N.S.	N.S.
Bio x Irrigation	N.S.	N.S.	N.S.	***	***	***	N.S.	N.S.	N.S.
Potassium x Irrigation	N.S.	N.S.	N.S.	***	***	***	N.S.	N.S.	N.S.
Bio x Potassium x Irrigation	N.S.	***	N.S.	***	***	***	N.S.	N.S.	N.S.

Means in the same column followed by the same letter are not significantly different at $p \leq 0.05$

(±) inoculation with VAM

(§) potassium fertilizer rates (75, 100 and 125% of recommended rate).

(ξ) Irrigation treatments (I1, I2 and I3 are 8, 12- and 16-days intervals)

TABLE 5. Relative water content and water and potassium use efficiencies of sweet sorghum inoculated with mycorrhizal Fungi and under different water, potassium fertilizers treatments.

Treatments	RWC	Biomass WUE	Sugar WUE	Biomass KUE	Sugar KUE
Bio Fertilizer ±					
un-inoculate	67.89 b	9.33 b	1.32 b	412.17 b	57.87 b
inoculate	71.67 a	10.67 a	1.52 a	470.50 a	66.86 a
f-test	***	***	***	***	***
Potassium Fertilizer §					
K1	68.00 b	9.61 c	1.34 c	540.43 a	75.04 a
K2	70.17 a	10.09 b	1.44 b	434.15 b	61.76 b
K3	71.17 a	10.30 a	1.48 a	349.43 c	50.29 c
f-test	***	***	***	***	***
Irrigation ξ					
I1	74.33 a	8.66 c	1.22 c	455.50 a	64.23 a
I2	69.17 b	10.15 b	1.42 b	454.40 b	63.49 a
I3	65.83 c	11.19 a	1.61 a	414.11 c	59.37 b
f-test	***	***	***	***	***
Interactions					
Bio x Potassium	N.S.	N.S.	N.S.	N.S.	*
Bio x Irrigation	N.S.	*	*	N.S.	N.S.
Potassium x Irrigation	N.S.	N.S.	*	**	**
Bio x Potassium x Irrigation	N.S.	N.S.	N.S.	N.S.	N.S.

Means in the same column followed by the same letter are not significantly different at p □ 0.05

(±) inoculation with VAM

(§) potassium fertilizer rates (75, 100 and 125% of recommended rate).

(ξ) Irrigation treatments (I1, I2 and I3 are 8, 12- and 16-days intervals)

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تأثير التلقيح بالميكوريزا والتسميد البوتاسى على إنتاجية الذرة السكرية ومحتواها من العناصر الغذائية المزروعة تحت الاجهاد المائى في أرض جيرية

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الاجهاد المائى يعد عالمياً من أخطر العوامل البيئية حيث يخفض من إنتاجية المحاصيل والذى يمكن التقليل من مخاطره بواسطة بعض الكائنات الحية الحرة والكائنات الحية التكافلية في التربة. تم تقييم الاستجابة الفسيولوجية لنباتات الذرة السكرية للتلقيح بفطريات الميكوريزا الداخلية (VAM) وثلاثة مستويات من التسميد البوتاسي (٧٥ و ١٠٠ و١٢٥ ٪ من المعدل الموصى به) تحت ثلاث مستويات من الرجيم المائى (الري على فترات ٨ و ١٢و١٦ يوم). أجريت تجربة عامليه فى ثلاثة عوامل تحت تصميم قطاعات عشوائية كاملة (RCBD) فى ثلاث مكررات في تربة لومية رملية جيرية في منطقة النوبارية.

أظهرت النتائج أن الإجهاد الناجم عن نقص المياه تحت ظروف التجربة قد اعاق نمو الكتلة الحيوية والانتاجية وكذلك محصول الحبوب والسكر فى نباتات الذرة السكرية. جميع النباتات الملقحة والغير ملقحة انخفض وزن ١٠٠٠ حبة وكذلك محصول السيقان والحبوب والكتلة الحيوية والمادة الجافة والسكر مع زيادة الفترة بين الريات. وفى نفس الوقت، أدى تلقيح الذرة السكرية بفطريات الميكوريزا الى زيادة معنوية فى نسبة اصابة النباتات بالميكوريزا وعدد جراثيم الميكوريزا بالتربة وكذلك انزيم الفوسفاتيز القلوى والمحصول الحيوي ومحصول السكر للذرة السكرية. وايضاً أدى لزيادة معنوية فى محتوى عناصر النيتروجين والفوسفور والبوتاسيوم (N, P and K) فى أنسجة النبات تحت نقص المياه فى التربة الجيرية وذلك بالمقارنة بالنباتات الغير ملقحة. أثرت معاملات التسميد البوتاسى مع التلقيح بفطريات الميكوريزا على جميع الصفات المقاسة بجعل النباتات أكثر مقاومة للإجهاد المائى عن النباتات الغير ملقحة بالميكوريزا.

عموماً أظهرت نتائج هذه الدراسة أن نباتات الذرة السكرية الملقحة بفطريات الميكوريزا و ١١٥ كجم K_2O للهكتار من سماد كبريتات البوتاسيوم قد عملت على تحسين مقاومة الإجهاد المائي للنباتات ومن ثم زيادة الكتلة الحيوية ومحصول السكر لنباتات الذرة السكرية تحت إجهاد نقص المياه وذلك بمقارنتها مع النباتات الغير الملقحة بالميكوريزا.