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EFFECT OF POTASSIUM SUPPLY ON DROUGHT RESISTANCE IN SORGHUM: PLANT GROWTH AND MACRONUTRIENT CONTENT

Mohammad R. Asgharipour and Mahmood Heidari

Department of Agronomy, Faculty of Agriculture, University of Zabol, Iran
***Corresponding author's e.mail: moasgharipour@gmail.com**

Nowadays, the main limiting natural resource is widely considered to be water. Therefore, research into crop management practices that enhance drought resistance and plant growth when water supply is limited has become increasingly essential. This study was conducted to evaluate the effect of potassium (K) nutritional status on the drought resistance of grain sorghum during 2009. Drought stress by reducing the yield components, especially the number of panicle per plant and one-hundred grain weight reduced grain yield and greatest yield (3499 kg ha^{-1}) obtained at full irrigation. Potassium sulfate increased grain and biological yield by 28% and 22%, respectively compared to control through improving growth conditions. Drought stress increased the N content, while reduced water availability decreased the K and Na in plant. No K fertilized plants had the lowest leaf K and N and highest Na concentrations. Chlorophyll content increased significantly with increase in K supply and increased frequency of irrigation. Interaction effect of drought stress and potassium sulfate on all studied traits except chlorophyll content was significant and optimum soil K levels protects plants from drought. These observations indicate that adequate K nutrition can improve drought resistance of sorghum.
Keywords: Drought stress, potassium supply, grain sorghum, nutrient content.

INTRODUCTION

Drought is a major factor limiting productivity in agriculture and have caused a collapse in food production by reducing uptake of water and nutrient (Du *et al.*, 2010). Iran is a predominantly arid country. The shortage of fresh water is the main barrier to proper management of soil resources, maximizing the cropping intensities while obtaining higher crop yields, especially in the arid and semi-arid regions of southeastern Iran (Salehi et al., 2008). The region of the present research, Zabol (a city located in southeastern Iran), is a region where also suffers from a deficient water balance especially during summer months due to its increased agricultural activities and higher ambient temperatures. Total irrigated area in this region reaches up to 26,000 ha (Department of Agriculture, Zabol city, personal communications). The area is now partly irrigated with scarce water resources. Surface waters come from the Hirmand River, which is shared between Iran and Afghanistan. It is still the main water source for the domestic, industrial, and agricultural sectors in this region. In coming years, water from it is expected to become scarcer due to the growing consumption of water in Afghanistan

Sorghum (*Sorghum bicolor* (L.) Moench) is a major crop ranked fifth in the world-wide production of cereals (Sato et al., 2004). It is considered a primary staple food crop in the semi-arid tropics of Asia, Africa, and South America. The grain is normally used as food and animal fodder, but recently it has been used as raw material for the production of chemicals, such as levulinic acid (Ganjyal *et al*., 2007). Sorghum is typically cultivated in the arid and semi-arid regions of Iran generally in areas with low precipitation that are not suitable for corn (*Zea mays* L.). Sorghum plants are considered to be relatively resistant to drought, although to achieve optimum growth or yield, sufficient water for irrigation is required.

Potassium (K^+) is an essential element for plant growth and development and is the most abundant cation in plants, making up 3–5% of a plant's total dry weight (Marschner 1995). This macronutrient is essential for many plant processes such as enzyme activation, protein synthesis photosynthesis, osmoregulation during cell expansion, stomatal movements, solute phloem transport, electrical neutralization, regulation of membrane potential, cotransport of sugars, and the maintenance of cation–anion balance in the cytosol as well as in the vacuole (Maser et al. 2002).

Drought is a significant limiting factor for agricultural productivity and generally inhibits plant growth trough reduced water absorption and nutrient uptake. Decreased water availability generally results in reduced growth and final yield in crop plants. Potassium ions contribute significantly to the osmotic potential of the vacuoles even under drought conditions (Marschner, 1995). Thus, adequate K fertilization of crop plants may facilitate osmotic adjustment, which maintains turgor pressure at lower leaf water potentials and can improve the ability of plants to tolerate drought stress (Lindhauer, 1985; Mengel and Arneke, 1982). Studies have shown that optimum K application is beneficial to the growth and development of plants (Davidson, 1969). However, little information is available about the influence of K on whole-plant drought resistance of plants to drought. Thus, information about adequate levels of K fertilizer that would optimize drought resistance in sorghum under those production conditions is lacking. Therefore, the objective of the present study was to investigate the effect of deficient and sufficient levels of K supply on the drought resistance of sorghum, by characterizing plant growth, grain nutrients content and chlorophyll content of plants subjected to drought stress.

MATERIALS AND METHODS

Site description: Field experiment were conducted in 2009 on Agriculture and Natural Resources Research Station of Sistan (61°29´N, 31°2´E, 450 m above sea level), in Southeast Iran. The experiment was established in a sandy loam soil. Table 1 shows some Physiochemical characteristics of the soil and compost.

The experimental site is located in a warm and arid region with mean annual precipitation of 63 mm and an annual mean long-term average temperature of 23 °C. In the year of conducting this experiment (i.e., 2009) the annual precipitation and the mean temperature were 59.9 mm and 22.1 °C, respectively. The preceding crop was winter wheat (*Triticum aestivum*) and there was no history of K application at the soil.

Experimental layout: Seedbed preparation included ploughing, disk harrowing and cultivating. Grain sorghum (*Sorghum bicolor* L.) used in this experiment was released by Seed and Plant Improvement Institute of Iran, called KMF9. The experimental design for this study was a split-plot randomized complete block design with three replicates. Main plot treatments were giving irrigation at 70% FC, 50% FC and 30% FC, in each irrigation 50 mm water was applied through flooding. To determine the soil water-potential within the root zone, the soil water content at the depth of rooting was bi-daily measured using the Time-domain reflectometer (TDR) mounted at the middle of the plots. Subplot treatments consisted of 5 K application rate (treatment A0: plots without K fertilizer; treatment A1: plots K fertilized with the potasium sulfate (K_2SO_4, containg 44.9% K) in a rate of 44.90 kg ha-1 (100 kg ha^{-1} of K_2SO_4); treatment A2: plots K fertilized with K_2SO_4 in a rate of 67.35 kg ha-1 (150 kg ha-1 of K_2SO_4); treatment A3: plots K fertilized with K_2SO_4 in a rate of 89.80 kg ha-1 (200 kg ha-1 of K_2SO_4); and treatment A4: plots K fertilized with K_2SO_4 in a rate of 112.25 kg ha-1 (250 kg ha-1 of K_2SO_4). The treatments were laid out in 2.4*4 m plots and the crops were sown at a spacing of 0.40 m between the rows and 0.05 m within them, giving a plant density of 500,000 plants ha^{-1}.

Seeds of crops were sown manually. Sowing date was August 17th, 2009. Adjacent subplots were separated by a 1.5-meter-wide ridge, and the main plots were separated by a 3-meter-wide ridge. All plots were given 100 kg P_2O_5 ha^{-1} as the triple super phosphate together with half of the N fertilizer (50 kg ha^{-1}) before sowing was uniformly broadcasted and plowed into 15 cm soil. The other half of N fertilizer was applied with irrigation approximately 30 DAP. During the growth period, all plots were weeded manually. No serious incidence of insect or disease was observed and no pesticide or fungicide was applied.

Plant sampling and analysis: At the end of the growth period, 5 plants were sampled and some vegetative growth parameters (including stem height, stem diameter and panicle length) as well as one-hundred grain weight and grain number ($panicle^{-1}$) were separately recorded.

At maturity, plants were harvested from each plot, sun dried for approximately 10 days to around 10% moisture content, threshed and weighed to determine grain yield. Total vegetative above-ground dry matter was determined by collecting all remaining above ground biomass from the same plots.

Harvested samples of plant tissue were washed-up and oven-dried at 55 °C for 72 h and the dried leaves were ground to powder. A large quantity of 1.0 g powder of each sample was digested with 10 N HNO3, and for determining sodium (Na) and K contents, a flame photometer (model, JENWAY-PFP7) was used. Total nitrogen (N) concentration in leaves samples were estimated at the end of growth season following micro-Kjeldhal method.

Chlorophyll content was measured at anthesis stage by the chlrophyll content meter device (Hansatech Instruments - model-Cl-01, Tokyo, Japan).

Leaf tissue was used for Relative Water Content (RWC) determination, as follows. A composite sample of leaf discs is taken and the fresh weight is determined, followed by flotation on water for up to 4 hr. The turgid weight is then recorded, and the leaf tissue is subsequently oven-dried to a constant weight at about 85 °C. RWC calculated according to Smart and Bingham (1974).

Table 1. Physicochemical characteristics of soil

EC	pH	Organic C	N-No$_3$	P	K	Na	Clay (<2 µm)	Silt (2-20 µm)	sand (20-2000 µm)
(dS m^{-1})		(%)	(g kg^{-1})				(%)		
2.0	7.8	0.11	2.9	2.2	156	1.4	19	21	60

$$\text{RWC (\%)} = \frac{\text{(fresh weight - dry weight)}}{\text{(turgid weight - dry weight)}} \times 100$$

Proline content was determined using a colorimetric method modified from Li (2000) with minor modifications. The fine powder of freeze-dried plant tissues (0.2 g) was treated with 5ml of 3% Sulphosalicylic acid and maintained at 100 ◦C for 10 minutes. The supernatant (2 ml) was added to a solution of 2 ml of glacial Acetic plus 2 ml of 2.5% (w/v) acidic Ninhydrin, and kept at 100 ◦C for 25 minutes. After the liquid was cooled down, it was added to 4 ml of Toluene. The photometric absorbance of the Toluene extract was read at 520 nm. Contents were calculated to ηg g-1 dry matter.

For determination of soluble Carbohydrate contents, embryonic tissues were ground in 80% Ethanol, boiled for 30vminutes at70 °C, and then centrifuged at 8000g for 10 minutes at 41°C. The supernatants were used as samples to determine total soluble Carbohydrate glucose and Fructose (Dishe and Borenfreund, 1951). Calibration curves were obtained using Sigma standards.

Statistics

Data collected were subjected to the analysis of variance (ANOVA). Test of significance of the treatment difference was carried out on a basis of a *t*-test. The significant differences between treatments were compared with the critical difference at *P*=95% confidence level.

RESULTS

Plant growth and yield:

(a) Vegetative growth: Results of vegetative growth parameters (stem height, stem diameter and panicle length) as affected by different irrigation treatments and K application are presented in Table 2.

Stem height, stem diameter, and panicle length all differ among the irrigation treatments; irrigation at 70% FC, in this study produced the largest plants (140.40 cm height, 7.82 cm stem diameter and 10.50 cm panicle length). Plants irrigated at 70% FC had 33% greater height, 8% greater stem diameter and 18% greater panicle length than those irrigated at 30% FC.

Among K application treatments, the least growth was observed in plots without K fertilizer. Plots fertilized with the K_2SO_4 in a rate of 200 kg ha^{-1} resulted in a greater plant growth compared to the other fertilizer treatment. The greatest growth parameters (123.67 cm height, 8.06 cm stem diameter and 9.71 panicle length) were obtained with application of 200 kg ha^{-1} K_2SO_4while lowest (113.44 cm height, 6.36 cm stem diameter and 8.42 cm panicle length) were obtained with the control (plots without K fertilizer).

A significant interaction between irrigation water treatments and K application was observed on the vegetative growth parameters (Table 4). In the partition of this interaction, it was evident that plants fertilized with 200 kg ha^{-1} K_2SO_4 had significantly higher growth rates within irrigation at at 30%

Table 2. Effects of different irrigation regimes and potassium fertilization on vegetative growth parameters, yield and yield attributes of sorghum plants

treatments	Plant height (cm)	Stem diameter (cm)	Panicle length (cm)	100 grain weight (g)	Grain ($panicle^{-1}$)	Grain yield (kg ha^{-1})	Biological yield (kg ha^{-1})
Irrigation regimes							
70% FC	140.40a	7.82a	10.50a	2.50a	1225.07a	3499.40a	14464.80a
50% FC	118.13b	7.36ab	8.82b	2.30b	924.33b	2733.40b	12129.47b
30% FC	94.47c	7.21b	8.56b	2.13c	654.13c	1453.20c	10495.73c
Potassium fertilization							
Control	113.44c	6.36c	8.42b	2.14d	746.78c	1963.67c	9761.56c
100 kg K ha^{-1}	117.56b	7.14b	9.27a	2.27c	775.67c	2463.22b	11805.56b
150 kg K ha^{-1}	119.89b	7.97a	9.65a	2.55a	987.67b	2513.11b	11998.89b
200 kg K ha^{-1}	123.67a	8.06a	9.71a	2.35b	1043.44b	2964.00a	14376.11a
250 kg K ha^{-1}	113.78c	7.72a	9.45a	2.61c	1119.00a	2906.00a	13874.56a
Two way ANOVA							
***F*-Value**							
Irrigation	1236.64	11.63	22.66	64.45	231.84	577.65	191.80
Potassium	25.98	39.43	3.38	27.72	46.56	52.70	97.95
***P*-Value**							
Irrigation	<0.0001	0.0003	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Potassium	<0.0001	<0.0001	0.0250	<0.0001	<0.0001	<0.0001	<0.0001

Means followed by a similar letter within a column are not significantly different at the 0.05 level probability by Duncan's Multiple Range Test. Results are an average of three replicates ± S.D.

FC or 50% FC than those without K fertilizer.

(b)Yield attributes: Data related to sorghum plant yield and yield attributes are presented in Table 2. There were significant differences among various irrigation treatments regarding the grain number (panicle^{-1}) and one-hundered grain weight (g). Irrigation at 70% FC significantly increased the grain number (panicle^{-1}) and one-hundered grain weight compared with the irrigationa at 50% FC and 30% FC. Yield attributes parameters at irrigation at 50% FC were generally higher than those found at irrigation at 30% FC.

Potassium sulfate application on yield attributes showed rather remarkable differences (Table 2). Plots fertilized with the K_2SO_4 in a rate of 250 kg ha^{-1} increased grain number (panicle^{-1}) of sorghum by 50% over those of the control (without K fertilizer). The size of grain with K_2SO_4 treatment was different, and plants fertilized with the K_2SO_4 in a rate of 150 kg ha^{-1} exhibited the greatest one-hundered grain weight.

Significant interaction between irrigation regimes and K fertilizer treatments on all studied yield-attributes parameters were observed (Table 4).

Grain and biological yields of plants, too, were significantly affected with the irrigation regimes treatments. Grain and biological yields for the plants irrigated at 70% FC were 22% and 16% greater than the yields of the plants irrigated at 50% FC. The grain and biological yields in 50% FC were also 47% and 13% higher than the plots irrigated at 30% FC. Plots fertilized with the K_2SO_4 in a rate of 200 kg ha^{-1} increased grain and biological yields by 33.8% and 32.1%, respectively compared with those of the control (without K fertilizer). Significant interaction between irrigation regimes and K fertilizer treatments was observed for grain and biological yields (Table 2). Irrigation at 70% FC along with application of K_2SO_4 in a rate of 200 and 250 kg ha^{-1} and irrigation at 30% FC along with no K fertilizer application exhibited greatest and least grain and biological yields, respectively.

Nutrient concentrations and chlorophyll content in plants: Mean concentrations of N, K and Na in the leaves as well as chlorophyll content of leaves as affected by irrigation regimes and K fertilizer application are presented in Table 3. Total N concentration of leaves in plants irrigated at 30% FC was significantly higher than those found within irrigation at 50% FC, while irrigation at 70% FC had the least concentrations. The concentrations of N in leaves significantly differ due to K fertilizer application. Even though, plant fertilized with the K_2SO_4 in a rate of 200 or 250 kg ha^{-1} had the greatest concentration of N, while no K fertilized plants exhibited the least concentration of N.

Table 3. Effects of different irrigation regimes and potassium fertilization on macronutrient (N, K and Na) of grain, relative water content (RWC), carbohydrate, proline and Chlorophyll of sorghum plants

	N (mg kg^{-1} grain)	K (mg kg^{-1} grain)	Na (mg kg^{-1} grain)	RWC (%)	Carbohydrate (mg kg^{-1} grain)	Proline (mg kg^{-1} grain)	Chlorophyll (mg kg^{-1} grain)
Irrigation regimes							
70% FC	7.78c	9.52a	0.82a	80.77a	2.10c	7.08c	22.20a
50% FC	8.09b	7.92b	0.81a	82.21a	2.56b	9.01b	20.01a
30% FC	8.50a	7.02c	0.80a	77.81a	2.72a	11.83a	20.65a
Potassium fertilization							
Control	7.48e	5.37d	0.96a	76.30c	1.68d	10.26a	17.80c
100 kg K ha^{-1}	7.89d	7.84c	0.80b	81.58ab	2.44c	9.77a	20.73b
150 kg K ha^{-1}	8.21c	8.79b	0.77c	83.70a	2.65b	9.06b	24.30a
200 kg K ha^{-1}	8.58a	9.36a	0.75c	78.32bc	2.79a	8.72b	21.62ab
250 kg K ha^{-1}	8.46b	9.41a	0.77c	81.42ab	2.74ab	8.70b	20.31b
Two way ANOVA							
***F*-Value**							
Irrigation	10196.7	151.68	1.38	3.40	152.94	227.69	1.68
Potassium	9347.13	159.64	56.46	3.48	182.92	11.21	4.41
***P*-Value**	72.13	1.91	4.90	2.93	4.00	3.24	0.88
Irrigation	<0.0001	<0.0001	0.2701	<0.0001	<0.0001	<0.0001	0.2067
Potassium	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0082

Means followed by a similar letter within a column are not significantly different at the 0.05 level probability by Duncan's Multiple Range Test. Results are an average of three replicates ± S.D.

Table 4. Irrigation regimes and potassium fertilization interaction on vegetative growth parameters, yield and yield attributes of sorghum plants

		Plant height (cm)	Stem diameter (cm)	Panicle length (cm)	100 grain weight (g)	Grain (panicle^{-1})	Grain yield (kg ha^{-1})	Biological yield (kg ha^{-1})
70% FC	**Control**	140.33	5.10	10.50	2.34	1075.67	2560.67	11929.33
	100 kg K ha^{-1}	139.00	6.83	10.38	2.41	1057.00	3489.00	13684.00
	150 kg K ha^{-1}	144.33	7.40	10.77	2.81	1303.00	3783.33	15747.00
	200 kg K ha^{-1}	141.33	8.52	10.97	2.57	1289.33	3762.67	16438.00
	250 kg K ha^{-1}	137.00	8.19	9.90	2.35	1400.33	3901.33	14525.67
50% FC	**Control**	111.67	6.84	7.20	2.43	689.67	2227.00	9693.33
	100 kg K ha^{-1}	111.33	7.26	8.37	2.20	743.33	2615.67	11580.00
	150 kg K ha^{-1}	121.67	8.32	9.52	2.55	983.33	3239.67	14420.67
	200 kg K ha^{-1}	132.33	7.42	9.55	2.25	1124.33	3148.67	14006.33
	250 kg K ha^{-1}	113.67	6.93	9.44	2.27	1081.00	2436.00	10947.00
30% FC	**Control**	86.33	7.12	7.55	1.83	475.00	1103.33	7662.00
	100 kg K ha^{-1}	102.33	7.33	9.06	2.18	526.67	1285.00	10152.67
	150 kg K ha^{-1}	93.67	8.46	8.84	2.28	676.67	1869.00	11456.00
	200 kg K ha^{-1}	97.33	7.96	8.42	2.24	716.67	1806.67	12684.00
	250 kg K ha^{-1}	80.67	8.03	9.01	2.16	875.67	1202.00	10524.00
Two way ANOVA								
***F*-Value**	**I × K**	14.83	12.66	1.65	4.38	11.53	7.32	2.65
***P*-Value**	**I × K**	<0.0001	<0.0001	<0.0001	0.0023	0.0283	<0.0001	0.0307

Results are an average of three replicates

Table 5. Irrigation regimes and potassium fertilization interaction on macronutrient (N, K and Na) of grain, relative water content (RWC), carbohydrate, proline and chlorophyll of sorghum plants

		N (mg kg^{-1} grain)	K (mg kg^{-1} grain)	Na (mg kg^{-1} grain)	Chlorophyll (mg kg^{-1} grain)
70% FC	**Control**	7.14	6.30	0.97	17.93
	100 kg K ha^{-1}	7.52	9.23	0.83	20.08
	150 kg K ha^{-1}	7.81	10.17	0.77	24.32
	200 kg K ha^{-1}	8.29	11.13	0.77	25.51
	250 kg K ha^{-1}	8.13	10.77	0.76	23.15
50% FC	**Control**	7.46	5.43	0.95	17.73
	100 kg K ha^{-1}	7.77	7.89	0.85	20.05
	150 kg K ha^{-1}	8.27	8.44	0.80	23.67
	200 kg K ha^{-1}	8.55	8.82	0.70	20.15
	250 kg K ha^{-1}	8.42	9.03	0.76	18.46
30% FC	**Control**	7.85	4.38	0.95	17.74
	100 kg K ha^{-1}	8.36	6.40	0.73	22.05
	150 kg K ha^{-1}	8.56	7.73	0.74	24.94
	200 kg K ha^{-1}	8.89	8.14	0.79	19.21
	250 kg K ha^{-1}	8.82	8.44	0.78	19.33
Two way ANOVA					
***F*-Value**	**I × K**	72.13	101.91	4.90	0.88
***P*-Value**	**I × K**	<0.0001	<0.0001	0.0011	0.5477

Results are an average of three replicates ± S.D.

Higher K concentrations of leaves were monitored in sorghum plants when grown on plots irrigated at 70% FC; the constant trend in their concentrations in order of decreasing was as follows: irrigation at 70% FC, irrigation at 50% FC and irrigation at 30% FC. Potassium concentrations in the leaves differ after K fertilization and concentrations of K were drastically high in the plants which received K_2SO_4.

Sodium concentration of leaves in plants irrigated at 70% FC was slightly higher than those produced in plants irrigated at 50% and 30% FC; this difference, after all, was not statistically significant. Sodium concentration of leaves was significantly affected with the K fertilization. Plots fertilized with the K_2SO_4 in a rate of 200 kg ha^{-1} exhibited the least Na concentration, while no K fertilized plants had the greatest Na contencentration (Table 3).

There was significant interaction of irrigation regimes and K fertilizer application treatment on all the nutreients (Table 5).

Chlorophyll content in leaves of sorghum at anthesis stage increased markedly due to increasing soil water and enhanced supply of K. No statistically significant difference has been found to exist between interaction of irrigation regimes and K fertilizer application treatments on macro-nutrients concentrations (Table 5).

DISCUSSION

The main purpose of this work was to determine the effect of drought stress and application of K fertilizer on sorghum growth and a number of nutrients concentrations in plant tissues.

Plant growth, grain and biological yields of sorghum plants were decreased by drought induced by increasing irrigation interval. Deleterious effects of drought on plant growth are well known, and have been documented for number of plant species (Garg et al., 2004; Samarah et al., 2004).

In general, K ferttilization is associated with increasing crop growth because of the positive effect of this nutrient in osmotic adjustment, stomatal regulation, photosynthesis, and protein synthesis (Ashraf and Naz 1994, Quintero et al., 1998).

The lack of significant increase in plant growth with increase in K supply from 200 to 250 kg ha^{-1} K_2SO_4, reveals that 200 kg ha^{-1} K_2SO_4 is sufficient for adequate growth of sorghum under the drought conditions imposed in this study. Furthermore, sorghum plants grown at 200 kg ha^{-1} K_2SO_4 showed no symptoms of nutrient deficiency and are, therefore, of acceptable commercial quality. Similar K effects were reported for sunflower (*Helianthus annuus*) (Lindhauer, 1985) and alfalfa (*Medicago sativa*) (Peoples and Koch, 1979). In a related study, Ruan et al. (1997) reported increased survival, improved DM production and yield of moisture stressed tea (*Camellia sinensis*) plants at higher, compared to lower, K supply. These authors also observed that the effect of K application on tea yields was significantly greater under soil moisture stress than adequate water supply. In maize (*Zea mays*) plants, Estes et al. (1973) found a significant positive correlation between K concentration in external solution, K concentration of leaf tissue and DM increase. Potassium deficiency reduced shoot DM and LA of tomato plants (Behboudian and Anderson, 1990) and the growth of potato (Cao and Tibbitts, 1991). Also, Eakes et al. (1991) found that substrate K concentration significantly affected the shoot DM of the herbaceous bedding plant, *Salvia*. In common bean (*Phaseolus vulgaris*) grown for 30 days, Arneke (1981) reported an increase in shoot fresh mass, when the nutrient solution contained 0.1–4.0 mM K, corresponding to 8.8–35.5 mg K g^{-1} DM.

The data obtained from this study suggest that there is a close relationship between K application status and the resistance of growth to drought stress in sorghum plant. The effect of K supply on growth was significant under drought stress conditions since vegetative growth parameters, yield and yield attributes of plants irrigated at 30% FC were greater at Plots fertilized with the K_2SO_4 in a rate of 200 and 250 kg ha^{-1} than control (without K fertilizer). This results are consistents with Sen Gupta et al. (1989) noted that the effect of drought was much less severe on the growth and photosynthesis of wheat (*Triticum aestivum*) plants supplied with 6 mol m^{-3} K than of those supplied with 2 mol m^{-3} K.

Having adequate K fertility was important for increasing sorghum K uptake (Table 3). This is expected since K reaches sorghum roots mainly by diffusion, and adding K fertilizers increases plant availability by shortening the diffusion distance (Barber 1985). Although soil K influenced K uptake, our study also showed that water availability was important (Tables 3 and 5). Reduced water availability increases the path length of K to the root, can make K positionally unavailable, and reduce uptake (Barber 1995). Similarly, increasing soil-K levels without maintaining adequate water did not allow the crop to take full advantage of the added fertility (Table 5). This finding supports field observations indicating temporary plant K deficiency during dry periods despite adequate soil K fertility levels (Fernández and Hoeft 2009). In this study, plant K accumulation was increased substantially only when adequate fertility was combined with sufficient-water availability (Tables 3 and 5). Thus, coupling optimum-K fertility with sufficient water availability was essential to improve sorghum plant K accumulation.

The importance of adequate water supply was also illustrated by the fact that growth parameters, yield attributes, biological and grain yield was reduced by insufficient water. Similar results were observed by Salama and Sinclair (1994).

The antagonistic relationship between K and Na uptake has been observed by others (Hallmark and Barber 1981). Shabala and Hariadi (2005) explained that the ions K^+ and Na^+ compete for the same non-selective cation channels for uptake. It is possible that a surplus of K^+ ions lowered the uptake potential for Na^+ ions and resulted in less Na content in plant tissues.

The concentrations of Na in plant tissue among the irrigation regimes treatment were somewhat similar and plants grown on different irrigation regimes did not considerably differ in the concentration of Na. Nevertheless, increased frequency of irrigation led to lower concentration of Na in the leaves when compared with the control (though not significantly). Drought stress apparently increased the N concentration in the plant tissues of sorghum (Tables 3 and 5). This was in part due to dilution effect caused by the higher growth rates of plants irrigated at 70% FC than those irrigated irrigation at 50% or 30% FC (Table 2).

In general, chlorophyll content of sorghum leaves were increased markedly due to drought and enhancement supply of K. The similar increase in these pigments at more watering regimes was in accordance with some earlier studies reflecting that increasing chlrophyll content with increase soil water stuatus in most crop species (Garcia et al. 1987, Estill et al. 1991, Ashraf et al. 1994).

During the reproductive stage of crop growth the high demand for photoassimilates by developing seeds and fruits is often accompanied by severe chlorosis in the leaves (Table 2). These chlorotic symptoms are the consequence of inhibited translocation of photoassimilates from leaves via the phloem to the seeds or fruits and are observed particularly at low nutritional status in K, Mg or Zn (Marschner and Cakmak 1989). Late K foliar application in banana (*Musa acuminata*) and sugar cane (*Saccharum officinarum*) increased the chlorophyll content in leaves (Yadov 2006).

CONCLUSION

The results from this study on sorghum, contributes additional valuable information to the continuing effort to determine the influence of K fertilizer on the responses of plants to drought stress. Application of K fertilizer within the sufficiency range (150 to 250 kg K_2SO_4 ha^{-1}) was beneficial in alleviating the effect of drought on the growth and nutrients uptake of sorghum, since vegetative growth and yield attributes of plants increased with increasing supply of K under water deficit. Potassium supply within this range increased the growth of macronutrient concentrations of leaves, as well as enhanced the chlorophyll content of plants. Potassium fertilization programs in the sorghum farms can benefit from this study on crop growth protections from the effects of drought. Without doubt further field studies with different crops are needed in this area of applied research.

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