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Response of Sunflower (*Helianthus annuus* L.) to Drought Stress under Different Potassium Levels

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Abstract: In order to study the effects of potassium levels on growth, grain yield and yield components of sunflower under drought stress, an experiment was conducted in Research Farm of College of Agriculture, Islamic Azad University, Karaj Branch located in Karaj/Iran during summer 2009. The experimental treatments were arranged as split plots based on a Randomized Complete Block Design with three replications. The main plots were allocated to three different irrigation regimes. The irrigation regimes comprised of: Full irrigation (IR_1), Moderate drought stress (IR_5) and Severe drought stress (IR_2). The subplots were allocated to four potassium chemical fertilizer (potassium nitrate) levels consisting of K_1 = 25, K_2 = 50, K_3 = 75 and K_4 = 100% recommended. The results showed that the drought stress decreased significantly plant height, head diameter, seed number per head, 1000-grain weight, biological yield, grain yield, harvest index and oil yield, but potassium increased significantly seed number per head, harvest index and oil yield. Finally, potassium application in dry lands that are exposed to drought stress could be helpful for oil yield improvement in sunflower.

Key words: Drought stress · Potassium fertilizer · Sunflower · Grain yield

INTRODUCTION

Sunflower is one of the most important oil crops and due to its high content of unsaturated fatty acids and a lack of cholesterol, the oil benefits from a desirable quality [1]. Since Iran is located on a dry and semi-dry region and has different climates and limited rainfall or shortage of water for irrigation during the growing season constraints its grain yield with significant reductions, the recognition of traits related to growth, yield as well as adaptation of sunflower, especially in relation to drought stress, can remarkably affect the development of planting area and its yield increase. Drought stress significantly limits plant growth and crop productivity. However, in certain tolerant-adaptable crop plants, such as sunflower, morphological and metabolic changes occur in response to drought, which contribute towards adaptation to such unavoidable environmental constraints [2, 3]. The fact that drought stress effects on growth and yield are genotype-dependent is well known [4]. The effects of drought stress depend on timing, duration and magnitude of water deficiency [5]. Identification of the critical irrigation timing and scheduling of irrigation, based on a timely and accurate basis to the crop, is the key for conserving water and improving irrigation performance and sustainability of irrigated agriculture [6, 7]. Nezami *et al.* [8] indicated that plant height, biological yield, stem diameter, head size, seed number per head and 1000-grain weight under dry and semi-dried conditions declined. Razi and Asad [1] indicated that irrigation led to an increase in days to physiological maturity, head size, stem diameter, number of leaves per plant, plant height, 1000-grain weight, grain yield and harvest index. Also drought stress at flowering stage was observed to be a limiting factor for grain filling, so significant reduction of unfilled grains was observed as a result of irrigation. D'Andria *et al.* [9] concluded that yield components of sunflower were affected by irrigation

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treatments. In their experiment, treatments with two or three times of irrigation during growing season produced higher grain weight as compared to control (no irrigation). The results from Anwar *et al.* [10] anderia and Chiaranda [11] showed a decrease in head diameter with increasing drought stress. Flenet *et al.* [12] demonstrated that decreasing the level of irrigation resulted in decreasing the seed number per head. According to Daneshian *et al.* [13] 1000-grain weight decreased due to drought stress. Human *et al.* [14] concluded that drought stress in stages of flowering, fertilization and grain filling in sunflower caused the most reduction of grain yield. Yegappan *et al.* [15] found that drought stress reduced number of leaf, head diameter, leaf area, 1000-grain weight and grain yield significantly. Khalilvand and Yarnia [16] reported that drought stress conditions increased stomatal resistance as a result of relative closing of stomata, consequently this condition increases the total resistance of the given plant against its H_2O movement in comparison to CO_2.

Nitrogen, phosphorous and potassium are major elements essential for plant growth and development. To date use of chemical fertilizers has been confined mainly to the application of nitrogen and phosphorous and due attention has not been paid to the potassium [17]. Plants treated by potassium maintained their leaf water potential in drought stress conditions. They also maintained their moisture and osmotic potential in a higher and lower level, respectively. During drought period, potassium was prominent ion in compare with other ions in tropical grasses, soybean and corn and it had also an osmotic regulator role [18]. Cakmak [19] reported that in legumes and gramineae sufficient potassium consumption in dry condition causes grain yield reduction through effect on photosynthesis process. Anderson and Behboudian [11] reported that potassium maintains the balance of electric charge in chloroplast in order to form ATP requirements. Therefore, potassium causes the transmission of radiated energy into primary energy in the forms of ATP and NADPH. The objective of this experiment was to investigate sunflower response to drought stress conditions and the role of potassium rates application in decrease of drought stress effects.

MATERIALS AND METHODS

The experiment was initiated in Research Farm of College of Agriculture, Islamic Azad University, Karaj Branch /Iran in 2009. Karaj is classified among the temperate climatic regions in the country with average rainfall of 256 mm per year. The soil physical and chemical characteristic of the experimental area is presented in Table 1.

The experimental treatments were arranged as split plots based on a Randomized Complete Block Design with three replications. The main plots were allocated to three different irrigation regimes. The irrigation regimes comprised of:

Full Irrigation (IR_1) (Control): The plots in this treatment were irrigated after depleting 50 percent of soil available moisture up to the end of the growing period.

Moderate Drought Stress (IR_5): The plots in this treatment were irrigated after depleting 50 percent of soil available moisture up to the start of the R_5 stage, after this stage irrigation was cut off.

Severe Drought Stress (IR_2): The plots in this treatment were irrigated after depleting 50 percent of soil available moisture up to the start of the R_2 stage, after this stage irrigation was cut off.

The subplots were allocated to four potassium chemical fertilizer (potassium nitrate) levels consisting of K_1 = 25% (25 kg.ha^{-1}), K_2 = 50% (50 kg.ha^{-1}), K_3 = 75% (75 kg.ha^{-1}) and K_4 = 100% recommended (100 kg.ha^{-1}).

Seed bed preparation was done in early autumn. Seeds of sunflower (cv. Azargol) were sown in experimental plots of 3 × 10 m in dimensions. The field was fertilized according to soil test analysis at 250 kg ha^{-1} urea (50% at planting and the rest at 6 leaf stage) and 100 kg ha^{-1} treble super phosphate, which were mixed with the soil. The cultivation rows were 60 cm apart in each plot (at 10 plants m^2 density). Weeds were removed by hand and plots were irrigated as required through the growing season.

Table 1: Soil physical and chemical properties of experimental area

Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Soil texture	PH	E.C (ds/m)	OrganicCarbon (%)	Total N (%)	AvailableP (ppm)	Available K (ppm)
0-30	61	20	19	Sand loam	7.4	3.64	0.49	0.05	7.8	192
Optimum				loam	6.5-7.5	2.0<	>1.0	1.0>	10-15	200-300

In the harvest stage, the two middle rows were used for sampling and measured parameters such as: plant height, number of seeds per head, 1000-grain weight, grain yield, biological yield, harvest index and oil yield were assessed. Grain yield in each plot measured with 10% humidity.

Statistical Analysis: Using SAS, data were subjected to analysis of variance. Mean comparison was conducted using the Duncan's Multiple Range Test (DMRT) at 5% level of probability.

RESULTS AND DISCUSSION

Plant Height: Plant height was significantly affected by drought stress (Table 2). Increasing drought stress resulted in decrease in plant height, so the maximum (141.4 cm) and the minimum (91.2 cm) plant height were obtained in IR_1 and IR_2, respectively (Table 3). It is known that a decrease in plant height is due to a decrease in cell division and assimilate transfer. Riahi nia [20] in his experiment on sunflower, cotton, bean and maize also came to similar results. D´Andria *et al.* [9] in a two-year experiment on sunflower observed that plant height was increased in the first year by increasing the irrigation frequency, whereas no significant difference was observed during the second year among irrigation treatments. Likely, drought stress has led to reduction in stem cells, water potential to a lower level needed for cell elongation and consequently shorter internodes and plant height.

Plant height was not significantly affected by potassium levels (Table 2). But maximum plant height obtained using 100% potassium fertilizer.

Head Diameter: There was a significant difference between irrigation regimes in terms of head diameter (Table 2). Increasing of drought stress resulted in decrease in head diameter. Cut-off irrigation in R_2 and R_5 stages caused 24% and 5% reduction in this parameter as compared to control, respectively (Table 2). In an experiment on influence of drought stress on net photosynthesis and grain yield of sunflower, Human *et al.* [14] observed that head diameter was significantly

Table 2: Analysis of variance for experimental traits

Treatment	d.f	Plant height	Head diameter	Seeds number per head	1000-grain weight	Grain Yield	Biological Yield	Harvest Index	Oil Yield
R	2	86.756^{ns}	1.957^{ns}	10030.027^{ns}	43.210^{ns}	0.430^{ns}	3.161^{ns}	21.0^{ns}	0.086^{*}
Drought levels (D)	2	5816.193^{**}	26.435^{**}	135087.694^{**}	247.924^{**}	12.504^{**}	76.215^{**}	212.25^{**}	3.246^{**}
Error	4	30.587	1.020	2140.152	9.812	0.120	1.754	1.875	0.030
Patassium levels (K)	3	39.572^{ns}	4.573^{ns}	9762.777^{*}	35.242^{ns}	0.421^{ns}	0.501^{ns}	44.851^{*}	0.090^{*}
D*K	6	9.297^{ns}	0.807^{ns}	1593.472^{ns}	1.495^{ns}	0.011^{ns}	0.137^{ns}	8.101^{ns}	0.003^{ns}
Error	18	94.029	1.648	2393.296	14.084	0.156	1.309	9.990	0.024
C.V		8.3	11.7	7.4	7.9	16.5	14.3	10.7	15.1

ns, *: and **: Non significant and significant at the 5 and 1% levels of probability, respectively

Table 3: Effects of irrigation regimes (IR) and potassium levels (K) on yield and yield components of sunflower

Irrigation regimes	Potassium levels	Plant height (cm)	Head diameter (cm)	Seeds number per head	1000-grain weight (gr)	Grain Yield (t. ha^{-1})	Biological Yield (t. ha^{-1})	Harvest Index (%)	Oil Yield (t. ha^{-1})
IR_1	K_1	135.1^{abc}	11.1^{abc}	739.6^{abc}	50.1^{abc}	3.171^{a}	9.562^{a}	33.3^{ab}	1.442^{b}
	K_2	137.7^{ab}	12.6^{a}	725^{abc}	52.2^{ab}	3.460^{a}	10.257^{a}	33.6^{a}	1.579^{ab}
	K_3	136.7^{ab}	11.8^{abc}	759.3^{ab}	53.1^{a}	3.531^{a}	10.159^{a}	34.6^{a}	1.589^{ab}
	K_4	141.4^{a}	12.8^{a}	777^{a}	53.3^{a}	3.747^{a}	10.632^{a}	35.3^{a}	1.741^{a}
IR_5	K_1	116.7^{d}	10.5^{abcd}	672.6^{bcd}	40.9^{e}	1.934^{bcde}	8.411^{a}	23^{e}	0.813^{cd}
	K_2	120^{cd}	11.4^{abc}	661.6^{cd}	43.7^{cde}	2.259^{bcd}	8.567^{a}	26.3^{de}	0.945^{c}
	K_3	118.5^{d}	12.1^{abc}	726.3^{abc}	43.4^{cde}	2.376^{bc}	8.521^{a}	27.6^{cde}	0.998^{c}
	K_4	121.2^{bcd}	12.3^{ab}	699.3^{abcd}	45.9^{bcde}	2.460^{b}	8.922^{a}	28^{bcde}	1.058^{c}
IR_2	K_1	91.6^{e}	8.7^{d}	494.6^{f}	42.2^{de}	1.249^{e}	5.091^{b}	24.6^{de}	0.470^{e}
	K_2	91.2^{e}	8.4^{d}	506.3^{f}	46.2^{bcde}	1.324^{e}	5.375^{b}	25^{de}	0.508^{e}
	K_3	96.9^{e}	9.9^{cd}	562^{ef}	45.5^{bcde}	1.555^{de}	5.225^{b}	30^{abcd}	0.604^{de}
	K_4	95.9^{e}	10.2^{bcd}	612.6^{de}	48.3^{abcd}	1.669^{cde}	5.209^{b}	32.3^{abc}	0.644^{de}

For a given means within each column of each section followed by the same letter are not significantly different ($p<0.05$)

reduced as drought stress increased. Also, Razi and Asad [1] showed that irrigation resulted in greater head and stem diameter, plant height and grain yield in sunflower. Stomatal closure, reduction of leaf area and depression of photosynthesis due to drought stress, caused the lower assimilation and plant growth [21]. Molze and Klepper [22] reported that in field conditions, one of the effects of low water availability is the reduction of head diameter due to lower radius growth of head. Potassium levels did not have significant effect on head diameter (Table 2). This reduction was due to a decrease in yield components such as seed number per head and 1000-grain weight.

Seed Number per Head: The seed number is an important and efficient component in yield. The factor which makes changes in seed number per head is the potential number of flowers which is determined during the plant growth period particularly by leaf distribution. In this study seed number per head was significantly affected by drought stress and potassium treatments (Table 2). Increasing drought stress and decreasing potassium levels resulted in decrease seed number per head. So that maximum and minimum seed number per head were 777 and 494 in IR_1 and IR_2 treatments and consumption of 100% and 25% potassium recommended, respectively. Razi and Asad [1] in their experiment on sunflower also came to similar results. Afkari Bajebaj *et al.* [23] reported that the seed number per head increased with increasing potassium.

1000-grain Weight: Effect of drought stress on 1000-grain weight was significant (Table 2) and there was a decreasing trend in response to increasing stress intensity (Table 3). A decrease in the 1000-grain weight is due to a decline in water and nutrient absorption by plants and decrease assimilation and assimilate transport to grains. Reduction in 1000-grain weight followed by drought stress, also reported by others [9, 1, 24]. Westgate [25] reported that the main reason of grain weight reduction is decrease in grain filling period due to drought stress. Banziger *et al.* [26] demonstrated that delay in leaf aging and availability of foodstuff at grain filling period increase grain weight. On the other hand, it has been specified that stem is counted as a little storage source of mobile non building carbohydrates, which also transports them to grain after flowering. Occurrence of drought stress especially at growth period decreases the quantity of storage of non-building carbohydrates at stem via decreasing leaf area and photosynthesis; as a result for the reason of lack of storage nutrients at secondary source grain weight decreases [27, 28].

Biological Yield: Biological yield was significantly affected by irrigation regimes ($P<0.01$) but potassium had no significant effect on biological yield. Biological yield increased as amount of irrigation increased, the highest biological yield (10.692 t. ha^{-1}) belonging to IR_1 (Table 2). Low water availability caused plant growth inhibitors such as abscisic acid (ABA) to increase and growth regulator hormones to decrease. Reduction of plant regulator hormones is one of the most important factors in plant growth suppression [22]. These results support findings by Radford [29], Kalamian *et al.* [30], Jasso *et al.* [31] in similar experiments. The reason for increase in biological yield production in plants under optimum irrigation was the extension of leaf area and its higher durability that provided enough physiological resource to take advantage of received light and therefore produce more biological yield [31].

Grain Yield: Sunflower yield has a close correlation with the number of flowers in the species, it means that in the high number of flowers the spaces will be thicker and accumulation will be more successful. Consequently grain yield will be higher parallel with that. The factors like non-fertilization of flowers, temperature, relative water content, environment, soil humidity, lack of nutrition and insects for pollination result in grain hollowness. Grain yield was significantly affected by irrigation regimes and potassium levels (Table 2). Grain yield was reduced by 65% in the IR_2 treatment in comparison with IR_1 treatment (control). With increasing drought stress, grain yield decreased. Increasing potassium fertilizer caused grain yield to increase. Application of potassium in full irrigation treatment produced the highest grain yield and applying the same fertilizing treatment at drought stress conditions provided the least damage to sunflower grain production. Afkari Bajebaj *et al.* [23] by applying different potassium levels and irrigation regimes on sunflower concluded that the application of potassium will increase the water use efficiency which lead to a higher grain yield production. The consumption of more quantities of fertilizer at severe drought stress condition caused considerable increase in grain yield in compared with optimum irrigation conditions.

Oil Yield: Oil yield was significantly affected by irrigation regimes and potassium levels (Table 2). Average oil yield was decreased by 65% as irrigation regimes decreased from IR_1 to IR_2 (Table 3). The maximum oil yield was obtained in IR_1 with using 100% potassium fertilizer and the minimum oil yield was gained in IR_2 with using 25%

potassium fertilizer. It means that potassium fertilizer plays an important role in sunflower and therefore to make a significant increase in oil yield, it is recommended to apply in drought stress conditions. The oil yield was decreased by drought stress, most likely because of a reduction in photosynthesis and assimilate remobilization. In addition, drought stress reduces the grain filling period and oil content. Bieloria and Hopmans [32] reported that drought stress via stomatal closure, reduction in leaf area and photosynthesis and also a shortening of the grain filling period limited the carbohydrate supply for grains.

Harvest Index: Harvest index was significantly affected by irrigation regimes and potassium levels (Table 2). In this study drought stress decreased grain yield with a higher degree than biological yield as a result of which harvest index decreased. Harvest index implies the relative distribution of photosynthesis products between economical sinks and other existing sinks in the plant. Setter [33] stated that drought stress is one of the limiting factors of plant growth and development that not only reduces production of biological yield but also causes a disorder to the partitioning of carbohydrates to grains thus reducing the harvest index. Results of this study agree with findings of Cox and Julliff [34] who reported that with reducing water consumption, biological yield production decreased but the reduction of grain yield in response to drought stress was more than the reduction of biological yield. Pandey *et al.* [5] suggested that the reason of harvest index reduction at severe drought stress is the higher sensitivity of reproductive growth to undesirable conditions in comparison with generative growth.

CONCLUSION

Results indicated that reduction of soil water availability to cut-off irrigation in R_2 and R_5 stages decreased plant height, head diameter, seed number per head, 1000-grain weight, biological yield, harvest index as well as grain yield and oil yield as compared to control (full irrigation). In conclusion, this study has shown that application of potassium fertilizer (100% recommended) can increase the survival capacity of sunflower plants under drought stress conditions. The increase in resistance to drought stress is associated with the antioxidant activity. According to these results, it may be suggested that the use of potassium can reduce the harmful effects of reactive oxygen species and improve plant drought resistance.

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