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Effects of Water Stress and Zinc Fertilizer on Yield Components, Seed and Oil Yields of a Sunflower Hybrid, Alstar

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Abstract: To investigate the effects of water stress and zinc fertilizer on yield components and seed and oil yields of sunflower (Alstar hybrid), an experiment was conducted at The Isfahan Agricultural Research Center, Isfahan, Iran, during 2008 and 2009 using a randomized complete block design within a split plot layout with 18 treatments replicated three. Six irrigation treatments (irrigation after 70 mm (no-stress) or 120 mm cumulative evaporation from class A evaporation pan at all growth stages, irrigation after 70 mm cumulative evaporation from class A evaporation pan except withholding irrigation at R2, R5.1, R5.7-8 and R7 growth stages) were allocated to main plots and three zinc fertilizer levels (0, 30 and 60 kg ha^{-1} of zinc sulfate) to sub plots. The highest amount of all measured traits, except harvest index (HI), was obtained with no-stress treatment. Irrigation after 120 mm evaporation significantly reduced number of seeds per head (SH), 1000 seed weight (SW), seed yield (SY), biological yield (BY), seed oil content (SO) and oil yield (OY). The lowest BY and the highest HI were obtained by withholding irrigation at R2. As compared to no-stress irrigation treatment, withholding irrigation at R5.1 only reduced SW. Withholding irrigation at R5.7-8 significantly reduced SH, SW, SY, BY, SO and OY and produced the lowest HI. Withholding irrigation at R7 significantly reduced SW, SY, HI, SO and OY. BY was the only trait was significantly affected by zinc fertilization. The results of this experiment indicates that sunflower should be irrigated after 70 mm cumulative evaporation from class A evaporation pan and duration of grain filling is very sensitive to water stress under conditions similar to this experiment. Sunflower may not respond to Zn fertilization when zinc content of the soil is close to 0.3 mg kg^{-1} of soil or higher.

Key words: Water stress · Zinc fertilizer · Sunflower · Yield

INTRODUCTION

Adequate water and nutrient supply are important factors affecting optimal plant growth and successful crop production. Water stress is one of the most limiting factors affecting crop growth, especially in arid and semi-arid regions of the world because it has a vital role in plant growth and development at all growth stages. The effects of water stress depend on timing, duration and magnitude of water stress [1]. Identification of the critical plant growth stages and scheduling irrigation according to plant's demand is the key factor for conserving water and improving irrigation efficiency and sustainability of irrigated agriculture [2, 3]. Manivannan *et al.* [4] found that fresh and dry weight of sunflower, reduced under water stress. Chimenti *et al.* [5] and Erdem *et al.* [6] reported that seed yield and 1000 seed weight of sunflower decreased as drought stress increased.

Zinc is a cofactor of over 300 enzymes and constituent of many proteins that are involved in cell division, nucleic acid metabolism and protein synthesis. Crops yield are often limited by low level content of Zn in soils of arid and semi-arid regions [7]. Antioxidant enzymes activity increases in plant cell as a response to environmental stresses [8, 9, 10]. Cakmak [8] stated that Zn deficiency may inhibit the activities of a number of antioxidant enzymes. Khan *et al.* [11] showed that zinc-deficiency reduced water use and water use efficiency in

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chickpea. Khurana and Chatterjee [12] reported that the numbers of seeds per head and 1000-seed weight of sunflower were highest when zinc was sufficient. Mirzapour and Khoshgoftar [13] stated that addition of 20 kg Zn ha $^{-1}$ increased seed production and shoot dry matter yield of sunflower, while plant height and head diameter did not change. Effects of soil application of zinc fertilizer for sunflower has been studied rarely, but the effects of this method of using zinc fertilizer to reduce the deleterious effects of temporary water stress in reproductive stage of sunflower under arid climatic conditions similar central of Iran has not been studied yet. Thus this study was conducted to evaluate this response in a sunflower hybrid, Alstar.

MATERIALS AND METHODS

The experiment was carried out at the Kabutar Abad Agricultural Research Station, Isfahan, Iran (45°32′N, 47°51′E) during 2008 and 2009 using a randomized complete block design within a split plot layout with 18 treatments, replicated three times. Six irrigation treatments (irrigation after 70 (no-stress, irrigation treatment, R1) or 120 mm cumulative evaporation from class A evaporation pan at all growth stages (irrigation treatment, R2), irrigation after 70 mm cumulative evaporation from class A evaporation pan except withholding irrigation at R2 (irrigation treatment, R3), at R5.1 (irrigation treatment, R4), at R5.7-8 (irrigation treatment, R5) and at R7 (irrigation treatment, R6), growth stages, as described by Schneiter and Miller [14] were used. Irrigation treatments were allocated to main plots and thee zinc fertilizer levels (0 (Zn_0), 30 (Zn_{30}) and 60 (Zn_{60}) kg ha $^{-1}$ of zinc sulfate) to sub plots. Daily evaporation data were obtained from the nearby weather station. For determining the volume of water to be applied per irrigation, soil was sampled at the desired developmental stages by auger from root growing depth in each treatment about 24 hours before the anticipated irrigation time and soil moisture content was determined. The required volume of water to bring soil to field capacity was calculated on the bases of water distribution efficiency of 90 percent and was applied using parshall flume and chronometer. Zinc fertilizers were incorporated in soil before planting. The row and plant distances on beds were 60 and 16.6 cm, respectively.

The soil was clay loam. Soil was sampled from 0 to 60 cm depth before fertilizer application and was analyzed for various constituents (Table 1). Split application of 115 kg ha $^{-1}$nitrogen as urea (50% at planting and the rest at 7-8 leaf stage) and 45 kg ha $^{-1}$ P_2O_5 as triple superphosphate was mixed with soil before Planting. The Alstar hybrid was planted on July 5th in both years. Weeds were controlled by hand at 20 and 40 days after planting. Moisture of seed when seed yield measured was about 14%. Fifteen plants were cut at the soil level at harvest maturity from two middle rows of each plot for head diameter (HD), seeds per head (SH), 1000 seed weight (SW), seed yield (SY), biological yield (BY), seed oil content (SO), oil yield (OY) and harvest index = SY / BY (HI) determination. Seed oil content (SO) was determined by NMR oil analysis [15]. OY was calculated by OY= GY× SO equation. Data were statistically analyzed using ANOVA procedure of SAS and the means were compared using LSD at 5 present level of probability.

RESULTS AND DISCUSSION

As the trend of changes in evaluated traits in respond to experimental factors was similar in both years, the pooled data over the two years are presented here to save time and space.

Head Diameter: The effect of irrigation regimes on HD was not significant (Table 2) and the differences between treatments were less than 1 cm (Table 3). It appears that the sunflower hybrid under study is well tolerant to the water stress (irrigation after 140 mm cumulative evaporation from class A evaporation pan) during head growth stage (R2). This is in contrast to the results of Soleimanzade *et al.* [16] where head diameter was significantly reduced when irrigations were cut off at R2 and R5 growth stages of sunflower. The contradiction could be due to differences in environmental conditions and genotypes used in their study. HD was not significantly affected by zinc fertilization (Table 2) and the differences between treatments were very small (Table 3). Similar results were found by Mirzapour and Khoshgoftar [13] with sunflower. The interaction of irrigation with Zn on HD was not significant (Table 2).

Table 1: Chemical and physical properties of soil at 0-60 cm depth.

		Clay	Silt	Sand	OC	Total N	P	K	Zn	Cu	Fe	Mn
EC ds m $^{-1}$	pH	%					mg kg $^{-1}$					
4.9	7.6	39.8	45.8	14.4	0.64	0.06	11	269	0.3	1.3	4.6	4.3

Table 2:Combined analysis of variance for traits[1] of sunflower in different drought stress and zinc fertilization.

Source of variation	df	F value HD	SH	SW	SY	BY	HI	SO	OY
Block	2	0.03ns	0.41ns	1.20ns	1.01ns	1.95ns	2.75ns	0.50ns	4.34ns
Block (year)	2	1.82ns	1.29ns	2.12ns	3.20ns	0.5ns	2.66ns	7.36*	2.22ns
Year	1	52.43**	586.52**	24.57**	65.93**	20.21**	13.01**	69.55**	84.00**
Irrigation	5	2.16 ns	20.74**	7.80**	18.54**	31.74**	21.79**	41.86**	21.82**
Year× Irrigation	5	9.10**	2.50*	4.39**	2.13 ns	0.05 ns	1.09 ns	0.48 ns	3.16*
Zinc	2	0.30 ns	0.64 ns	0.98 ns	1.25 ns	3.78*	0.87 ns	1.36 ns	1.07 ns
Year× Zinc	2	0.57 ns	0.27 ns	0.86 ns	0.09 ns	5.00*	1.04 ns	0.22 ns	0.23 ns
Zinc× Irrigation	10	0.51 ns	1.87 ns	0.27 ns	1.35 ns	1.21 ns	0.98 ns	0.48 ns	1.19 ns
Zinc× Irrigation×year	10	1.16 ns	1.24 ns	0.69 ns	1.36 ns	2.53 ns	0.92 ns	1.09 ns	1.17 ns
C.V(%)		5.44	8.48	7.28	11.48	9.45	14.85	2.32	11.85

1- HD= head diameter, SH= seed per head, SW= 1000-seed weight, SY= seed yield, BY= biological yield, HI= harvest index, SO= seed oil content and OY= oil yield.

2-**, * and ns significant at the 1%, 5% probability levels and non significant respectively

Table 3: Mean comparison for traits of sunflower in different drought stress and zinc

Treatments	HD (cm)	SH	SW (g)	SY (kg ha $^{-1}$)	BY (kg ha $^{-1}$)	HI (%)	SO (%)	OY (kg ha $^{-1}$)
Irrigation								
IR_1	13.6^{a}	616^{a}	72.5^{a}	4339^{a}	14567^{a}	30.0^{c}	43.6^{a}	1889^{a}
IR_2	13.1^{a}	521^{bc}	67.7^{b}	3435^{cd}	11342^{c}	30.5^{c}	42.9^{b}	1474^{bc}
IR_3	13.4^{a}	601^{a}	72.2^{a}	4233^{a}	10747^{c}	39.4^{a}	43.5^{a}	1840^{a}
IR_4	13.3^{a}	615^{a}	64.7^{b}	3909^{ab}	11061^{c}	34.4^{b}	43.2^{ab}	1689^{a}
IR_5	12.9^{a}	493^{c}	65.6^{b}	3192^{d}	12932^{b}	24.8^{d}	41.0^{c}	1320^{c}
IR_6	13.4^{a}	573^{ab}	67.5^{b}	3802^{bc}	13610^{ab}	28.1^{cd}	39.6^{d}	1510^{b}
Zinc								
Zn_0	13.3^{a}	563^{a}	67.9^{a}	3740^{a}	11944^{b}	32.7^{a}	42.0^{a}	1575^{a}
Zn_{30}	13.2^{a}	571^{a}	69.3^{a}	3902^{a}	12533^{a}	31.8^{a}	41.9^{a}	1640^{a}
Zn_{60}	13.3^{a}	575^{a}	67.9^{a}	3813^{a}	12652^{a}	32.9^{a}	42.3^{a}	1618^{a}

1- Within each column and for each factor, means followed by same letter are not significantly different at the 5% level of probability according to LSD Test.

2- HD= head diameter, SH= seed per head, SW= 1000-seed weight, SY= seed yield, BY= biological yield, HI= harvest index, SO= seed oil content and OY= oil yield.

Numbers of Seeds per Head: SH was significantly ($p<0.01$) affected by irrigation treatments (Table 2). The lowest number of seeds per head was obtained by withholding irrigation during late fertilization stage and irrigation after 120 mm cumulative evaporation from class A evaporation pan (Table 3). This may indicate that the central flowers, which are naturally weak, are very sensitive to water stress during fertilization. Roshdi *et al.* [17] revealed that maximum number of seeds in each head of sunflower belonged to the irrigation after 90 mm in comparison with the irrigation after 60 or 120 mm cumulative evaporation from class A evaporation pan. Flenet *et al.* [18] demonstrated that delaying irrigation decreased the numbers seeds per head in sunflower. Similar results are reported for sunflower by Razi and Asad [19]. The effect of zinc fertilization and the interaction of irrigation by zinc were not significant (Table 2). This may indicate that zinc fertilization does not increase flower vigor or reduce the deleterious effect of water stress when soil zinc content is around or higher than 0.3 mg kg^{-1} of soil.

1000-Seed Weight: Irrigation treatments showed significant ($p<0.01$) effects on 1000-seed weight (Table 2). Irrigation after 120 mm cumulative evaporation from class A evaporation pan or withholding irrigation during pollination and later seed developmental stages reduced seed weight (Table 3). This may indicate that seed vigor could be reduced by water stress during flowering and latter seed growth stages. In addition, water stress may reduce photosyntethates available for seed filling.

In other words, both sink and sources for seed weight could be adversely affected by water stress during flowering and later growth stages. These results are in agreement with others [19, 20]. Transfer of non-structural carbohydrates from stem to seeds may not be significant in sunflower under water stress conditions. Because water stress also decreases non-structural carbohydrate accumulation in stem via decreasing leaf area and photosynthesis [21]. Effect of zinc treatments and interaction effects of zinc by irrigation were not significant (Table 2), indicating that zinc fertilization apparently does not increase seed vigor or reduce the deleterious effect of water stress when soil zinc content is around or higher than 0.3 mg kg^{-1} of soil. No data is available regarding the deficiency level of Zn in soils. In the experiments of Khurana and Chaterjee [12] the highest 1000-seed weight of sunflower was obtained when 0.65 mg L^{-1} of zinc sulfate was applied to pots.

Seed Yield: Irrigation regime significantly ($p<0.01$) affected seed yield (Table 2). The seed yield obtained by imposing water stress at late flowering stage was lower than seed yield obtained by irrigating after 120 mm cumulative evaporation from class A evaporation pan (Table 3). This is consistent with the least number of seeds per head obtained with this treatment. The inability of 1000-seed weight to compensate for this shortcoming (Table 3) may indicate that growth potential of all seeds was also adversely affected. It appears that sunflower yield is very sensitive to water stress imposed by delayed irrigation and/or probably by high transpiration demand during late flowering when flowers with low vigor are pollinating and the growth potential of pollinated ovaries are determined. In the experiments of Pejic *et al.* [22], water stress at flowering stage resulted in poor pollination and reduced number of fertile florets in the central portion of the head, which leaded to a decline in total seed weight per head and 1000-seed weight, brought about major yield losses. Effects of zinc treatments and interaction effect of irrigation by zinc were not significant (Table 2), indicating that the intense deleterious effect of water stress may not be compensated by zinc fertilization when soil zinc content is around or higher than 0.3 mg kg^{-1} of soil. In contrast our results, Shanmugasundaram and Savithri [23] found that application of 37.5 kg ha^{-1} $ZnSO_4$ was sufficient to obtain maximum seed yield of sunflower when soil Zn content was 1.01 mg kg^{-1}. This level of soil Zn content is much higher than 0.3 mg kg^{-1} of soil in our experiment. The contraversy could be due to differences is soil type. Zare *et al.* [24] studied Zn-critical deficiency levels for corn and finally resulted that relative corn yield varied from 0.59 to 1.64 mg kg^{-1} of soil. persist

Biological Yield: BY was significantly ($p<0.01$) affected by irrigation regimes (Table 2). Considerable reductions in BY as the result of withholding irrigation at R2 (26.2%) and at R5.1 (24.06%) growth stages are not consistent with changes in SY (Table 3). It appears that withholding irrigation at these stages have had more deleterious effect on stem and/or leaves growth than on SY. Reduction in BY as the result of water stress is also reported by Kamalian *et al.* [25] and Jasso *et al.* [26]. Effect of zinc fertilizer was significant on biological yield (Table 2). However, the increase in BY as the result of 30 kg ha^{-1} zinc sulfate application was less than 5% (Table 3) and there was no significant differences between Zn30 and Zn60 treatments. Khoshgoftar *et al.* [27], showed that application of 15 mg Zn kg^{-1} dry soil increased shoot dry-matter yield of wheat where soil Zn content was 31.5 mg kg^{-1} of soil. Reduction in BY as a result of low plant zinc content might be attributed to impeded protein synthesis, or due to lower carbonic anhydrase activity [28].The interaction effects of irrigation regimes by zinc fertilization on BY was not significant (Table 2).

Harvest Index: Effect of irrigation on HI was significant ($p<0.01$) (Table 2). The highest HI was obtained by withholding irrigation at R2 through sever decrease in vegetative growth without significant decrease in SY (Table 3). The lowest HI was obtained by withholding irrigation at R5.7-8 due to sever decrease in SY with apparently no affect on vegetative growth. Irrigation after 70 mm cumulative evaporation from class A evaporation pan at all growth stages increased both vegetative growth and SY resulting in low HI (Table 3). Soleimanzade *et al.* [16] reported that harvest index was significantly affected by cutting off irrigation at R2 and R5 growth stages of sunflower. It appears that reduction in HI under water stress is more due to changes in reproductive growth than to changes in vegetative growth of sunflower [29] and of corn [30]. Effects of zinc treatments and interaction effect of irrigation by zinc were not significant (Table2).

Oil Content: The effect of irrigation treatments on SO was significant ($p<0.01$) (Table 2). Withholding Irrigation during R5.7-8 and R.7 considerably reduced seed oil content (Table 3). This is consistent with the results of others [31, 32], that water stress reduced seed oil percent of sunflower. Khan et al [33] stated that seed oil content of sunflower is very sensitive to even mild water stress. Effect of Zinc treatments and interaction effect of irrigation by zinc were not significant (Table 2), indicating that the harmful effect of water stress at this growth stage may not be compensated by zinc fertilization when soil zinc content is around or higher than 0.3 mg kg^{-1} of soil. In the experiments of Khurana and Chaterjee [12] with sunflower, watering polyethylene containers with up to 0.65 mg l^{-1} zinc sulfate increased SO, while higher zinc sulfate concentrations reduced SO. Mirzapour and Khoshgoftar [13] showed that, the maximum content of seed oil was achieved under the 10 kg Zn ha^{-1}, then decreased at higher rates of soil-applied Zn such that oil content of seed under the 30 kg Zn ha^{-1} and 60 kg Zn ha $^{-1}$, was significantly lower than that of the control.

Oil Yield: OY was significantly ($p<0.01$) affected by irrigation regimes (Table 2). Although the lowest OY was obtained by withholding irrigation at R5.7-8, but this treatment had higher SO than when water stress was imposed during later stages of seed development (Table 3). In general, the deleterious effects of water stress on SO were much smaller than on SY (Table 3). Consequently OY was mainly the function of SY. Reduction in OY of sunflower by water stress is shown in other researches [34, 35]. Apparently water stress decreases SY and SO through reduction in photosynthesis and assimilate remobilization and thus OY [16]. Zinc fertilization and the interaction effect of irrigation by zinc were not significant (Table 2) indicating that soil zinc content in this experiment has been sufficient for oil production and zinc fertilization can not help the plant to recover from water stress. Movahedi Dehnavi and Moddares Sanavi [36] showed that foliar application of Zn (3000 mg l^{-1}) zinc sulfate does not significantly increase SO and OY of safflower under withholding irrigation conditions at flowering and seed filling stages. Ravi *et al.* [37] showed that foliar application of 5% zinc sulfate increased SO and SY of safflower where zinc content of soil was 0.63 mg kg^{-1}

CONCLUSIONS

Although maximum seed yield was obtained when sunflower was irrigated after 70 mm cumulative evaporation from class A evaporation pan, but Alstar hybrid seems to be tolerant to water stress during vegetative growth period and might be irrigated during this stage after 120 mm cumulative evaporation from class A evaporation pan without significant reduction in yield under conditions similar to this experiment. Sunflower is most sensitive to water stress during late flowering when weak vigor flowers located around center of the head are pollinating. Zinc application to sunflower may not increase yield when soil zinc content is about 0.3 mg kg^{-1} of soils similar or soil. In addition Zn fertilization may not help sunflower to recover from harmful effects of water stress when soil Zn content is sufficient.

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