Yield and Water Use Efficiency of Sunflower as Affected by nano ZnO and Water Stress

Mohammadjavad Seghatoleslami and Reza Forutani
Birjand branch, Islamic Azad University, Birjand, Iran
Email: {mjseghat, rezaforutani}@yahoo.com, mjseghat@iaubir.ac.ir

***Abstract*—Zinc has an important role in plants survival under environmental stress conditions. Nano technology can be used in crop production to increase yield. In order to evaluate sunflower responses to Zno nanoparticle, an experiment was conducted in Agricultural Research Center of Islamic Azad University, Birjand branch, Iran. The experimental design was a split plot based on randomized complete block with three replications. Two irrigation treatments (full irrigation and 50% water requirement) were as main plots and 7 ZnO fertilizer levels (control, three bulk ZnO treatments and three nano ZnO treatments) were as sub plot. Water stress reduced significantly seed and biomass yield. All ZnO application treatments increased significantly seed yield mainly through increasing seed number per head. Harvest index was not significantly affected by irrigation and ZnO treatments. Deficit irrigation significantly increased seed and biomass WUE 43.6 and 40.2 percent, respectively. In full irrigation treatment the highest seed and biomass WUE were related to bulk ZnO treatments, but in water stress condition the highest biomass WUE was related to NZnO treatment. Totally the result indicated that application of nano ZnO increased seed yield and water use efficiency.**

***Index Terms*—biomass, harvest index, nano fertilizer, seed number**

I. Introduction

Water stress is the most important factor affecting crop yield in arid and semi arid regions. These regions are generally noted for their low primary productivity. Improvement of plant nutrition can contribute to increased resistance and production when the crop is submitted to water stress [1]. Zinc has an important role in plants survival under environmental stress conditions. Considering Zn role in stomatal regulation due to its role in maintaining membrane integrity and retaining the potassium content of protective cells, fertilizer containing zinc may affect plant water relations [2]. In an experiment on chickpea Khan *et al.* (2004) indicated that Zn deficiency reduced the plant ability to adjust osmotically in water shortage condition [2]. Zinc influence auxin production [3]. This micro-element is a co-enzyme for production of tryptophane, a precursor to the formation of auxin. Auxin enhances the root growth and drought tolerance in plants [4].

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Zinc deficiency can cause imbalance in plant nutrients and decrease crop yield and quality. In an experiment Zn application increased the growth of maize [5]. Also in another experiment on pearl millet [6] it has been concluded that non stress treatment accompanied by foliar applications of zinc and manganese increased percentages of ash, raw protein and nitrogen of forage.

To use chemical fertilizers in agriculture has harmful effects on the environment and the quality of the produced food. Sustainable agricultural systems rely on environmentally friendly technologies based on physical and biological treatments in crop production [7]. Nanotechnology offers an important role in improving the existing crop management techniques [8]. Using nano fertilizer is a way to release nutrients in to the soil gradually and in a controlled way, thus preventing autrification and pollution of water resources [9]. Treatment with TiO_2 nano particles on maize had a considerable effect on growth, whereas the effect of TiO_2 bulk treatment was negligible [10].

This experiment was conducted to evaluate sunflower responses to nano Zno application under water stress conditions.

II. Material and Methods

This experiment was done in the growing season of 2012 at the Agricultural Research Center of Islamic Azad University, Birjand branch, Iran. Longitude, latitude and altitude of Birjand are 59° 13’, 32° 53’ and 1480 m, respectively. Birjand has a dry, warm climate and rainfall mainly occurs between the months of November to April. Annual average rainfall is 167 mm.

Maximum and minimum temperature averages are 27.5◦ and 4.6◦C, respectively**.** Soil texture and pH were sandy loam and 8.07, respectively. Soil nitrogen, phosphorus, potassium and zinc content were 0.019%, 3.17 ppm, 185 ppm and 0.51 ppm.

The experimental design was a split plot based on a randomized complete block with three replications. Two irrigation treatments (full irrigation and 50% water requirement) were as main plots and 7 Zn fertilizer levels (control- C, ZnO nanoparticles spraying with 250 ppm concentration- NZn1, ZnO nanoparticles spraying with 500 ppm concentration- NZn2, ZnO nanoparticles spraying with 1000 ppm concentration- NZn3, ZnO spraying with 3000 ppm concentration-Zn1, ZnO spraying with 6000 ppm concentration- Zn2 and ZnO

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spraying with 12000 ppm concentration- Zn3) were as sub plot. Fig. 1 shows the size of ZnO nanoparticles by electron microscope.

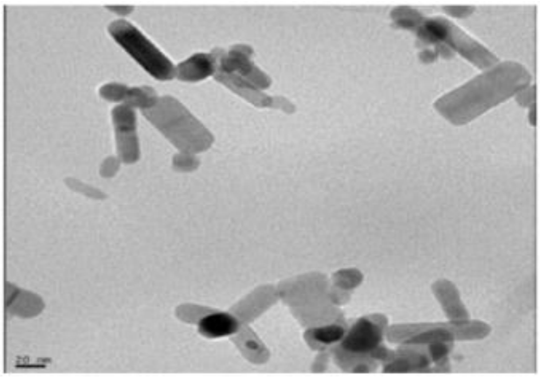

Figure 1. The size of ZnO nanoparticles by electron microscope (TEM)

Plant water requirement were determined by the FAO method using evaporation statistics of A class pan.

$$ET0= ET\ pan \times 0.75,\ ET\ plant= ET0 \times Kc$$

Each sub plot had four ridges. The length of the ridges and distance between them were 5 and 0.7 m, respectively. Sowing was conducted on the ridges in 30th May. Distance between plants after thinning was 20 cm. Weed control was done by hand as and when required. The irrigation was carried out by a pressurized system using hose and contour in each plot. Foliar application of ZnO treatments was conducted at two stages (65 and 85 days after sowing). Seed and biomass yield was determined by harvesting 2 m^2, with regard to border effects. Harvest index of seed per head ($HI_{s/h}$), seed per plant ($HI_{s/p}$) and head per plant ($HI_{h/p}$) were determined through seed yield/head dry weight, seed yield/biomass and head dry weight/biomass, respectively. Water use efficiency (WUE) for biomass and seed were also determined through yield/irrigation volumes. Data analysis was done by sas software and means were compared by Duncan's multiple range tests at 5% probability level.

III. Result and Discussion

A. Seed Yield and Components

Water stress reduced seed and biomass yield 14.4 and 19.8 percent, respectively (Table I). References [11] and [12] also have reported seed yield reduction in sunflower under water stress conditions.

Drought stress at different growth stages, especially during reproductive stage, decline seed yield through reducing mobilization of assimilates to seeds, duration of photosynthesis period and contribution of remobilization of stem reserves to seeds [13].

To study seed yield components in two irrigation treatments indicated that seed number per head and 1000 seed weight declined 21.2 and 11.1 percent, respectively under water scarcity conditions (Table I). Seed number per plant is a very important yield components that mainly affected by floret number. Normally water stress at the start of reproductive stage, cause a reduction in floret number. On the other hand, in sever water stress condition; continuation of stress at the seed filling stage can reduce photoassimilates production and translocation to the sink.

TABLE I. Simple Effect of Irrigation and ZnO Application on Yield and Yield Components of Sunflower

Treatments	Seed yield ($g.m^{-2}$)	Biomass yield ($g.m^{-2}$)	seed number per head	1000 seed weight (g)
Irrigation				
water stress	282.20 b	777.44 b	290.88 b	51.75 b
Control	329.82 a	931.46 a	369.19 a	58.19 a
ZnO				
Control	256.08 b	763.25 c	274.13 d	52.90 a
NZn1	291.05 ab	774.23 c	307.82 cd	54.63 a
NZn2	310.95 a	881.18 ab	312.83 bcd	54.51 a
NZn3	332.20 a	899.93 ab	380.57 a	55.11 a
Zn1	335.85 a	961.20 a	337.13 abc	54.88 a
Zn2	304.03 a	875.75 ab	327.62 abcd	57.03 a
Zn3	311.95 a	825.60 bc	370.19 ab	55.73 a

Interaction of irrigation and ZnO treatments on seed and biomass yield was significant. In full irrigation condition, treatment Zn3 had the highest seed yield (377.93 $g.m^{-2}$), but this treatment had low seed yield under water stress conditions (Table II). Nano ZnO application especially in full irrigation treatment had a positive effect on the plant growth and yield (Table III). Because we used, too low concentration ZnO in the nano treatments, this is very important as a view of environmental pollution. Reference [14] also has reported seed yield enhancement with Zn application. Zinc application reduces the activity of membrane-bound NADPH oxidase which in turn decreases the generation of reactive oxygen species (ROS) and protects cells against ROS attack under water stress [4]. On the other hand Zinc has an important role in protecting plant cells against reactive oxygen species [15].

The effect of ZnO treatments on seed number per head was significant. Treatment NZn3 had the highest seed number per head (380.6) that was not significantly different with three normal ZnO treatments (Table I).

Although 1000 seed weight was not significantly affected by Zno treatment (Table I) but interaction of irrigation and ZnO treatment on this trait was significant

(Table II). Zno application in full irrigation treatment had not any significant effect on 1000 seed weight, but in water stress condition foliar application of ZnO increased the weight (Table II). Reference [14] also indicated that in water stress condition, foliar application of Zn containing had a positive effect on 1000 seed weight. Because this micro-element is a co-enzyme for production of tryptophane, a precursor to the formation of auxin [2], it is suggested that ZnO has increased cell division in the growing seeds.

TABLE II. INTERACTION OF IRRIGATION AND ZNO TREATMENTS ON YIELD AND YIELD COMPONENTS OF SUNFLOWER

Treatments		Seed yield ($g.m^{-2}$)	Biomass yield ($g.m^{-2}$)	seed number per head	1000 seed weight (g)
Irrigation	ZnO				
Water stress	Control	256.8 cd	755.8 g	225.9 f	47.6 d
	NZn1	235.1 d	739.7 fg	281.0 def	53.6 bcd
	NZn2	289.1 bcd	855.2 cdef	276.7 def	48.0 d
	NZn3	314.9 abc	820.6 defg	337.8 bcd	52.4 cd
	Zn1	328.0 ab	829.3 defg	348.2 abcd	53.7 bcd
	Zn2	311.7 abc	738.1 fg	244.8 ef	54.8 abc
	Zn3	245.9 cd	703.5 g	321.9 de	52.1 cd
Control	Control	255.4 cd	770.7 efg	322.4 de	58.2 abc
	NZn1	346.9 ab	808.8 defg	334.7 cd	55.6 abc
	NZn2	339.0 ab	907.2 bcde	349.0 abcd	61.0 a
	NZn3	349.5 ab	979.3 abc	423.4 a	57.8 abc
	Zn1	343.7 ab	1093.1 a	326.1 de	56.1 abc
	Zn2	296.4 bcd	1013.4 ab	410.4 abc	59.2 ab
	Zn3	377.9 a	947.7 bcd	418.5 ab	59.4 ab

NZn1, NZn2 and NZn3 are ZnO nanoparticles spraying respectively with 250, 500 and 1000 ppm concentration- Zn1, Zn2 and Zn3 are bulk ZnO spraying respectively with 3000, 6000 and 12000 ppm concentration

B. *Harvest Index*

Harvest index was not significantly affected by water stress (Table III). This means that vegetative and reproductive organs of plant were equally affected by the stress. This is evidently, considering the stress applied at the whole growing stage. Interaction of irrigation and ZnO treatments on $HI_{S/H}$ and $HI_{S/P}$ was significant (Table IV). Under full irrigation conditions, treatment Zn2 had the lowest HI's, but in water stress condition this treatment had the highest HI's (Table IV). High $HI_{S/H}$ means that photoassimilate translocation inside the head (from head to seed) had a good efficiency.

C. *Water Use Efficiency*

Deficit irrigation significantly increased seed and biomass WUE 43.6 and 40.2 percent, respectively (Table III). Deficit irrigation is a technique to conserve water and improve WUE. Increasing WUE under drought stress has been reported by Egilla *et al*. [16] and Cheruth et al. [17] in *Hibiscus rosa-sinensis* and *Catharanthus roseus*, respectively.

TABLE III. SIMPLE EFFECT OF IRRIGATION AND ZNO APPLICATION ON HARVEST INDEX AND WATER USE EFFICIENCY OF SUNFLOWER

treatments	HI (seed/ head)	HI (seed/plant)	HI (head/plant)	Seed WUE ($g.l^{-1}$)	Biomass WUE($g.l^{-1}$)
Irrigation					
water stress	55.00 a	36.42 a	66.55 a	0.391 a	1.071 a
Control	57.24 a	35.94 a	63.66 a	0.224 b	0.642 b
ZnO					
Control	52.62 a	33.60 a	64.07 ab	0.266 c	0.791 c
NZn1	61.48 a	37.32 a	61.63 b	0.283 bc	0.793 c
NZn2	55.38 a	35.85 a	65.74 ab	0.313 abc	0.907 ab
NZn3	54.43 a	37.05 a	68.07 a	0.339 a	0.908 ab
Zn1	53.00 a	35.51 a	67.14 ab	0.346 a	0.953 a
Zn2	57.38 a	36.35 a	64.47 ab	0.318 ab	0.863 bc
Zn3	58.57 a	37.58 a	64.59 ab	0.301 abc	0.816 c

Interaction of irrigation and ZnO treatment on seed and biomass WUE were significant (Table IV). The highest seed and biomass WUE were respectively related to Zn3 (0.26 $g.l^{-1}$) and Zn1 (0.75 $g.l^{-1}$) in full irrigation treatment and Zn1 (0.45 $g.l^{-1}$) and NZn2 (1.18 $g.l^{-1}$) in water stress condition (Table IV). Appropriate nutrition of plant caused effective use of water and other resource in the environment. In a fertile soil, plants produce an extensive and deep root system that can be uptake water more effectively [18].

Totally the result indicated that application of nano ZnO increased seed yield and water use efficiency.

TABLE IV. INTERACTION OF IRRIGATION AND ZNO TREATMENTS ON HARVEST INDEX AND WATER USE EFFICIENCY OF SUNFLOWER

Treatments		HI (seed/ head)	HI (seed/plant)	HI (head/plant)	Seed WUE ($g.l^{-1}$)	Biomass WUE ($g.l^{-1}$)
Irrigation	ZnO					
Water stress	Control	50.21 bc	33.95 abc	67.65 ab	0.35 bc	1.04 bc
	NZn1	48.29 c	31.90 bc	65.78 abc	0.32 c	1.02 c
	NZn2	48.64 c	33.11 abc	68.31 ab	0.39 ab	1.18 a
	NZn3	54.52 abc	38.43 abc	70.44 a	0.43 a	1.13 ab
	Zn1	59.85 abc	39.57 abc	66.11 abc	0.45 a	1.14 ab
	Zn2	69.71 ab	43.03 a	61.95 abc	0.43 a	1.02 c
	Zn3	53.77 bc	34.94 abc	65.57 abc	0.34 bc	0.97 c
Control	Control	55.03 abc	33.25 abc	60.49 bc	0.17 e	0.53 g
	NZn1	74.66 a	42.74 ab	57.47 c	0.24 d	0.56 fg
	NZn2	62.12 abc	38.59 abc	63.17 abc	0.23 de	0.62 efg
	NZn3	54.33 abc	35.68 abc	65.71 abc	0.24 d	0.67 def
	Zn1	46.14 c	31.45 c	68.17 ab	0.23 de	0.75 d
	Zn2	45.05 c	29.66 c	66.99 ab	0.20 de	0.70 de
	Zn3	63.36 abc	40.22 abc	63.60 abc	0.26 d	0.65 def

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Mohammadjavad A. Seghatoleslami was born in Birjand, Iran in 1973. His educational background is listed below:

BA: Crop Production and Plant Breeding, University of Shahid Bahonar, Kerman, Iran-1996

MA: Agronomy, University of Shiraz, Iran-1999

PhD: Crop Physiology, Tehran Science and Research branch, Islamic Azad University, Tehran, Iran- 2004.

Now he is a FACULTY MEMBER at Birjand branch, Islamic Azad University, Birjand, Iran for about 15 years. He is head of Agriculture faculty from three years ago. Before that, he was head of department for about 10 years. His M.Sc. and Ph.D. thesis were respectively about corn defoliation and millet resistance to water stress. Now he works on medicinal plant cultivation under drought conditions.

Dr. Seghatoleslami is membership of Iranian Society of Medicinal Plants. Also he is managing editor of a scientific journal.