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Safflower productivity and oil yield affected by water limitation and nanofertilizers

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Abstract

This research was arranged as split plot experiment based on randomized complete block design with three replications in 2017, to investigate the responses of safflower (*Carthamus tinctorius* L.) to the different levels of irrigation (I_1, I_2, I_3, I_4: Irrigation after 70, 100, 130 and 160mm evaporation, for normal irrigation and mild, moderate and severe water deficits, respectively) and foliar sprays of water (control) and nano-fertilizers (SiO_2 and Mn_2O_3). Means of plant biomass, yield components, oil percentage and grain and oil yields were decreased under moderate and severe water limitations. However, foliar sprays of nano-SiO_2 and nano-Mn_2O_3 increased grain and oil yields via enhancing plant biomass, grains per plant, 1000 grains weight and oil content under different irrigation intervals, especially under stressful conditions. Therefore, foliar application of nano-fertilizers can be used to improve safflower productivity and oil yield under normal and limited irrigation conditions.

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Introduction

Safflower (*Carthamus tinctorius* L.) is originated from southern Asia and is commercially cultivated for oil extracted from the seeds. This plant can produce acceptable yield in the same regions that favor the development of wheat and barley and undoubtedly it is a crop with relatively untapped potential and wide range compatibility (Gilbert *et al.*, 2008).

Drought is the most limiting factor for crop production. In regions with a low annual rainfall with irregular distribution, drought is the most important environmental stress severely decreasing the yield of the crops (Golparvar and Ghasemi, 2007). Decreasing water supply both temporarily or permanently affects morphological traits and yield in plants adversely. Istanbulluoglu (2009) evaluated the effect of water stress at different developmental stages of safflower and found that 1000-grains weight and grain yield per unit area were significantly reduced when plants were subjected to stress at late-vegetative stage.

The oil content of safflower grains ranged between 35 to 50% that consists of about 90% unsaturated fatty acids, placing it as one of the best oils for human consumption (Tahmasebpour *et al.*, 2011). It was found that 60 - 70% of total safflower grain oil was produced at about 22 days after flowering (Sharma *et al.*, 1995). Also, Mohammadi *et al.*, (2018) stated maximum oil percentage of safflower grains was obtained at 1 to 12 days after plant physiological maturity and water stress caused grain oil percentage decline across all cultivars. Safflower is somewhat tolerant to water deficit, but severe drought stress may limit the performance and productivity of this crop (Ghassemi-Golezani *et al.*, 2016). So, any nutrient deficiency or drought stress that occurs at this stage has the most effect on oil content and fatty acid profile of the oil. The oil content of grains could be altered by the filling duration and adverse environmental conditions (Bhardwaj and Hamama, 2003). Balanced plant nutrition is an effective method for improving crop yield and quality. Foliar spray of nutrients is the most effective and environmentally friendly way of nutrient utilization. In the arid and semiarid regions such as Iran, foliar application of nutrients is a more suitable option compared with soil fertilization. Other advantages are quick compensation of nutrient deficiency and less application rates.

Foliar application of beneficial nanoparticles (NPs) on plants is currently an interesting field for research (Karunakaran *et al.*, 2013). The NPs interact with plants causing many morphological and physiological changes, depending on the properties of particles. Among the NPs, nano-silicon has gained greater consideration during recent years. Silicon is plentiful in soils and is the second most common element on earth after oxygen, which has been recognized as a beneficial nutrient for plant growth and yield (Siddiqui *et al.*, 2015). Si may decrease the oxidative damage in plants subjected to environmental stresses (Saqib *et al.*, 2008).

It was shown that a small amount of nutrients, particularly Mn applied by foliar spraying can significantly increase the yield of crops (Sarkar *et al.*, 2007). In the field conditions, where the factors that influencing the uptake of the nutrients are variable, foliar fertilization is a privilege. Among the micronutrients, Si and Mn nutrition may influence the responses of plants to water deficit (Khan *et al.*, 2003). Thus, this research was initiated to generate new information on the efficacy of nanoscale silicon dioxide and manganese dioxide on grain and oil yields of safflower (*Carthamus tinctorius* L.) under normal and limited irrigations.

Materials and methods

A field experiment was conducted at the Research Farm of the University of Tabriz, Iran, located at 38.05° N, 46.17° E with an altitude of 1360m above the sea level, mean annual rainfall of 285 mm, mean annual temperature of 10°C, mean annual maximum temperature of 16.6°C and mean annual minimum temperature of 4.2°C.

The experiment was laid out as split plot based on randomized complete block design in three replicates, with irrigation intervals (I_1, I_2, I_3, I_4 for irrigation after 70, 100, 130, and 160 mm evaporation from class A pan, for normal irrigation and mild, moderate and severe water deficits, respectively) in main plots, and foliar sprays of nanoparticles (water, SiO_2, Mn_2O_3) in sub-plots. Each plot consisted of 6 rows with 4m length, spaced 25cm apart.

Seeds were hand sown in about 3-4cm depth with a density of 80 seeds m^{-2}. Seeds of a spring safflower cultivar (Soffeh) were provided by the Seed and Plant Breeding Research Institute, Karaj, Iran. Nanoparticles of silica (SiO_2) were purchased from the Nanosany, Iran.

According to the manufacturer, the particle sizes of nano-SiO_2 ranged from 20 to 30nm. Specific surface area of nano-sized silica was 180-600 $m^2\ g^{-1}$ and purity was +99%. The particle sizes of nano-Mn_2O_3 were 30 nm. Foliar sprays of safflower plants with nano-SiO_2 (1 g/l) and nano-Mn_2O_3 (0.5 g/l) were carried out at capital formation stage.

Measurements

At maturity, plants in 1 m^2 of the middle part of each plot were harvested and number of grains per plant, 1000-grain/weight, grain yield, oil content and oil yield per unit area were determined. Above ground biomass was oven-dried at 75˚C for 48 hours and then, plant biomass per unit area was recorded.

Statistical analysis

Analysis of variance of the data was performed by SAS 9.1 software. Means were compared by Duncan multiple range test at $p \le 0.05$. Excel software was used to draw Figs.

Results

Plant biomass, grains per plant, 1000 grain weight, grain yield, oil content and yield were significantly affected by irrigation intervals and nano-fertilizers. The interaction of these factors was only significant for grain yield per unit area, oil content and yield (Table 1).

Table 1. Analysis of variance of the effects of irrigation intervals and foliar sprays of nano-SiO_2 and nano-MN_2O_3 on plant biomass, yield components and grain and oil yields.

Source	DF	Plant biomass	Grains per Plant	1000 grain weight	Grain yield	Oil content	Oil yield
Block	2	116.33	11.68	3.43	7.80	0.31	1.16
Irrigation (I)	3	24185.07**	2575.90**	4.73*	2621.44**	7.27**	342.63**
Ea	6	302.71	367.26	1.10	13.90	0.17	0.80
Nano-fertilizer (NF)	2	7458.33**	3577.22**	6.80*	1425.55**	15.48**	262.52**
I × NF	6	410.68	209.23	0.52	51.21*	1.72*	7.17*
Eb	16	370.46	173.93	1.21	13.37	0.41	1.97
c.v.	_	3.86	9.26	4.40	2.42	2.24	3.22

*, **: significant at $p \le 0.05$ and $p \le 0.01$, respectively.

Plant biomass was significantly reduced under moderate (I_3) and severe (I_4) water limitations. Increasing irrigation intervals led to the loss of 3.4% (I_2), 13.7% (I_3), and 20.5% (I_4) safflower plant biomass, compared with normal watering (I_1). However, plant biomass under I_1 and I_2 was statistically similar. Nano-fertilizers increased plant biomass and maximum plant biomass was recorded for nano-SiO_2 treatment (Table 2).

Grains per plant were decreased due to water deficit, with no significant difference between I_1 and I_2 and also between I_3 and I_4. Foliar sprays of nano-fertilizers particularly SiO_2 significantly enhanced number of grains per plant.

The highest 1000 grain weight was obtained under normal irrigation, with no significant decline under mild and moderate stresses. Mean 1000 grain weight was significantly and similarly enhanced by foliar application of nano-fertilizers (Table 2). Grain yield of nano-fertilizer treated and untreated plants significantly reduced under moderate and severe water limitations. Foliar sprays of nano-fertilizers significantly enhanced grain yield per unit area under all irrigation intervals. This superiority was more evident under limited irrigations. Under mild water limitation, silicon improves grain yield, while under moderate and severe water deficit, manganese increases this trait (Fig. 1).

Table 2. Means of plant biomass and yield components of safflower for different irrigation intervals and foliar sprays.

Treatment	Plant biomass (g/m²)	Grains per plant	1000 grain weight (g)
Irrigation			
I1	550.30a	152.48a	26.81a
I2	531.54a	160.76a	26.00a
I3	474.95b	126.28b	25.20ab
I4	437.41c	124.74b	24.55b
spray			
Water	471.40b	123.35b	24.77b
SiO2	520.42a	157.12a	26.94a
Mn2O3	503.82a	146.47a	27.15a

Different letters in each column indicate significant differences at $P \leq 0.05$.

I_1, I_2, I_3, I_4: Irrigation after 70, 100, 130 and 160 mm evaporation, respectively.

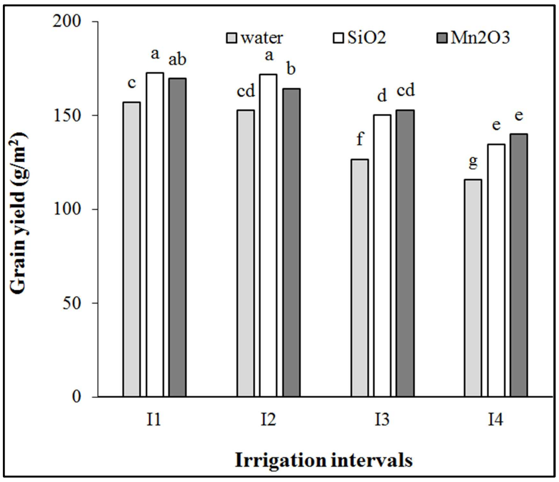

Fig. 1. Means of safflower grain yield for interaction of irrigation intervals × nano-fertilizer

I_1, I_2, I_3, I_4: irrigation after 70, 100, 130 and 160 mm evaporation, respectively. Different letters indicate a significant difference at $p \leq 0.05$.

The oil content of Nano-fertilizers treated plants was higher than that of untreated plants under all irrigation intervals. However, this improvement was greater when plants were subjected to severe water deficit. Oil content of safflower grains in control plants was significantly declined as a result of moderate and severe water limitation, but in nano-SiO_2 and nano-Mn_2O_3 treated plants oil percentage of grains was slightly diminished under these stress levels (Fig. 2).

The oil yield per unit area for nano-fertilizer treated and untreated plants was not significantly affected under mild water stress, but it was significantly reduced under moderate and severe water shortages.

Foliar application of nano-fertilizers significantly increased oil yield under all irrigation intervals, particularly under limited irrigations (Fig. 3).

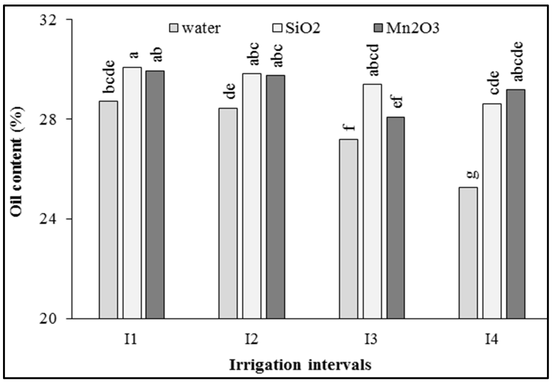

Fig. 2. Means of safflower oil content for interaction of irrigation intervals × nano-fertilizer

I_1, I_2, I_3, I_4: irrigation after 70, 100, 130 and 160 mm evaporation, respectively. Different letters indicate a significant difference at $p \leq 0.05$.

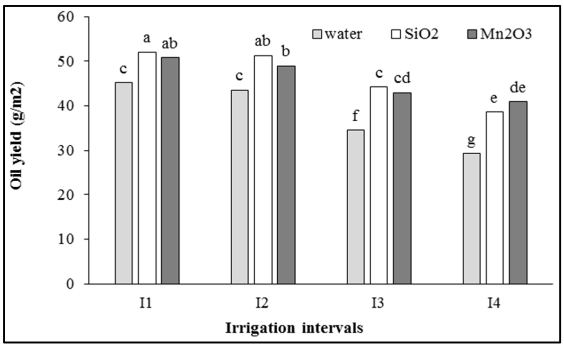

Fig. 3. Means of safflower oil yield for interaction of irrigation intervals × nano-fertilizer

I_1, I_2, I_3, I_4: irrigation after 70, 100, 130 and 160 mm evaporation, respectively. Different letters indicate a significant difference at $p \leq 0.05$.

Discussion

Plant biomass reduction in water stressed-plants is the consequence of decreasing cell growth, leaf area and photosynthesis. Enhancing biomass of nSiO2 and nMn2O3 treated plants (Table 2) is directly related with higher green ground cover of these plants (Ghassemi-Golezani and Afkhami, 2018). Since there is a positive linear relationship between ground cover and light interception (Ghassemi-Golezani *et al.*,2014), the higher values of this trait most likely can increase crop yield per unit area. The expanded canopy can improve light trapping (Soleimanzade and Gooshchi, 2012) for photo assimilate synthesis during crop growth and development, thereby increasing plant biomass. On the other hand, fast canopy closure can reduce soil water losses through evaporation and it can lead to yield improvement.

The reduction in number of grains per plant under water stress was also related with deduction in ground cover and plant biomass (Table 2). This result was supported by previous reports on safflower (Ghassemi-Golezani *et al.*, 2016) and chickpea (Ghassemi-Golezani *et al.*, 2012). This reduction may also be caused by excessive loss of leaves at reproductive stages as reported for sunflower (Rauf, 2008). Increasing number of grains per plant in nano-fertilizers treated plants was also associated with higher green cover and biomass of these plants (Table 2). This could also be attributed to an increase in the initiation of the reproductive organs during plant development (Janmohammadi *et al.*, 2016b).

Decreasing 1000 grains weight due to water deficit (Table 2) was mainly related with a decrease in grain filling duration and photosynthate mobilization to seeds (Ghassemi-Golezani *et al.*, 2009). In contrast, foliar sprays of nano-fertilizers enhanced 1000 grains weight (Table 2) via increasing photosynthetic green area and chlorophyll content of leaves (Ghassemi-Golezani and Afkhami, 2018). Increasing grain weight of nano-fertilizers treated plants can be attributed to the improved supply of photo assimilates resulting from the abundance of essential elements, which are utilized for enlargement of the sink cells (Dordas & Sioulas, 2008) or it can be due to increased assimilates translocation from vegetative tissues to the grains (Xie *et al.*, 2014). Reductions in grains per plant and 1000 grains weight under moderate and severe water limitations (Table 2) were led to significant deductions in grain yield per unit area (Fig. 1). Drought mainly influences yield by limiting grain number by either influencing the amount of assimilates during grain filling or by directly decreasing grain-set (prasad *et al.*, 2008). Increasing grain yield per unit area by foliar sprays of nano-SiO_2 and nano-Mn_2O_3 (Fig. 1) is directly related with an increase in plant biomass, grains per plant and 1000 grain weight (Table 2). This can be also the result of delayed leaf senescence and sustained leaf photosynthesis during grain filling (Janmohammadi *et al.*, 2016a).

A decrease in oil percentage of safflower under moderate and severe water deficits (Fig. 2) may be associated with the reduction in grain capacity for accumulation of oil, or probably is explained by oil oxidation in grains due to exposure to drought and heat stresses and high sunlight radiation after physiological maturity (Mohammadi *et al.*, 2018). The decrement in oil percentage may happen due to oxidation of some polyunsaturated fatty acids (Coşge *et al.*, 2015). This might be also explained by decreased availability of carbohydrates for oil synthesis under drought stress (Ashrafi and Razmju, 2014). Reduction in oil yield under these stress levels (Fig. 3) was the consequence of the decline in grain yield (Fig. 1) and oil percentage (Fig. 2). Enhancing grain yield (Fig. 1) and oil accumulation in safflower grains by foliar sprays of nano-fertilizers (Fig. 2) was led to considerable improvement in oil yield per unit area under different irrigation intervals, particularly under stressful conditions (Fig. 3).

Conclusions

Water limitations, particularly moderate and severe stresses decreased safflower plant biomass, yield components, oil percentage and consequently grain and oil yields per unit area. However, foliar applications of nano-SiO_2 and nano-Mn_2O_3 enhanced plant biomass, grains per plant, 1000 grains weight and oil content, leading to a substantial improvement in grain and oil yields under normal and limited irrigation conditions. These results clearly suggest that foliar application of nano-fertilizers is a very useful method for improving safflower productivity under favorable and unfavorable environmental conditions.

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