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Research paper

Effects of zeolite, vermiculite, and superabsorbent application on agronomic and physiological traits of safflower in response to water-deficit stress

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Abstract
Drought is the most important stress factor that reduces plant growth and yield. However, the application of moisture absorbents may decrease the negative effects of drought. This study aims to investigate the effect of irrigation levels (irrigation after 140, 100, and 70 mm evaporation from pan evaporation) and moisture absorbents (without moisture absorbent, superabsorbent, vermiculite, zeolite, and the combined use of all three moisture absorbents) on yield components and physiological characteristics of safflower (*Carthamus tinctorius* L. cv. Goldasht). This experiment was performed in 1397 and 1398 as the split-plot design using the randomized complete block design with three replications. Results showed that under 140 mm evaporation due to the severe drought, seed yield and oil yield declined by 36.3% and 46.6%, respectively, as compared to the 70 mm evaporation. As usual, drought increased the malondialdehyde content significantly. Water absorbent treatments increased the grain yield as compared to the control. However, there were no significant differences in the effect of water absorbents on the grain yield but the most effective moisture absorbent to increase the oil yield was zeolite. Oleic and palmitic acids percent increased due to drought, while the amount of linoleic acid decreased with increasing the irrigation intervals. In conclusion, the results showed that the use of moisture absorbents alleviated the adverse effects of drought stress on the safflower yield and some yield components.

Keywords: drought; oil quality; safflower; water absorbent

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Introduction

Safflower (*Carthamus tinctorius*) is one of the most economical oil plants for arid and semi-arid regions such as Iran (Khounani *et al*. 2019). Drought is one of the most important environmental factors which limits plant growth and yield. Drought has negative effects on plants by disrupting the ionic and osmotic balance of the cells. The stress signal switches on the stress-responsive genes (Hussain *et al.* 2016).

Drought tolerance is an important feature in plants to increase the plant yield. To improve drought resistance, management of some factors may reduce the harmful effects of drought (Wijewardene *et al*. 2020). Hydrogels can make 95% of their moisture available to the plant (Johnson and Veltkamp 1985). Several compounds, such as absorbent polymers, can absorb different amounts of water and increase water retention in the soil. Absorbents can store 400 to 1,500 grams of water per gram of hydrogel (Tolstikh *et al.* 1992). The absorbed water is slowly released during the water stress period, and roots in plants can use it (Verma *et al.* 2019), therefore, these compounds can be used to strive against drought and improve plant growth. Farsaraei *et al*. (2020) found that super-absorbents increased the weight and seed yield of the basil. These researchers reported that in addition to maintaining soil moisture during the period of vegetative growth, the superabsorbent reduced soil nitrogen loss as well. Cao *et al*. (2017) investigated the effect of drought and A200 superabsorbent on the corn growth indices. The drought had a negative effect on the leaf area index, plant growth rate, and net assimilation rate due to the reduced leaf area, reduced sunlight absorption, and disruption in the process of nutrient uptake and transport in plants. In their study, the application of superabsorbent reduced the effect of drought on corn and the crop showed a higher leaf area index, growth rate, and net assimilation rate.

Vermiculite is the geological name for a group of sheet minerals composed of magnesium, iron, and aluminum silicates that look like mica. For the use of vermiculite, it is exposed to high temperatures which results in the particles similar to accordion granules, which have numerous plate-like layers. Horticultural vermiculite has many interesting properties, including improving soil aeration and maintaining water and nutrients for root nutrition, and improving seed germination and root growth. Maintaining high water levels in its structure is the most important feature of this vermiculite (Addison *et al*. 1995).

Zeolite can absorb water in the soil and keep it for a long time due to its porous structure. The absorbed water gradually is released and taken up by the plant. The use of zeolite in agriculture for countries that are facing water shortages can solve some of the problems (Ghassemi Sahebi *et al*. 2020). Zeolites can absorb calcium, magnesium nitrogen, micronutrients, and potassium for a long time and gradually provides it to the plant (Mumpton 1999). The use of zeolite also controls the soil acidity (Ghassemi Sahebi *et al*. 2020).

In Iran, drought is one of the most serious yield decreasing factors. Superabsorbent, vermiculite, and zeolite application may alleviate its effect and may improve the growth and yield of safflower under drought conditions. So, this study was performed to investigate this hypothesis.

Materials and Methods

The experiment was conducted for two years (2018-2019) in the research field of the Faculty of Agriculture, Malekan Azad University, Malekan, East Azarbaijan province, Iran. The average annual temperature is 10 ºC, the maximum annual temperature is 16 ºC, and the minimum annual temperature is 2.2 ºC. The average annual rainfall in this area is 271.3 mm. The pH of the soil in the region ranges from alkaline to moderate alkaline.

The experiment was performed as a split-plot design based on the randomized complete blocks with three replications. The studied factors included irrigation levels (irrigation after 70, 100, and 140 mm evaporation from the pan) and application of superabsorbent, zeolite, and vermiculite (control, application of 400 kg/ha superabsorbent, 300 kg/ha vermiculite, 300 kg/ha zeolite, the combined application of superabsorbent, zeolite, and vermiculite) before planting by mixing with the soil. Irrigation levels were allocated in the main plots.

Before planting, a soil sample from six points of the field was prepared from a depth of 0-30 cm in the experimental site. The physical and chemical characteristics of the soil are given in Table 1.

After field preparation and planting, an amount of 50 kg/ha of phosphorus was applied as a strip in the rows. The length of each plot was 2.5 meters and the distance between the rows was 60 cm. The distance between the plants on the row was 30 cm. In each plot, 4 planting rows were considered. About 24 hours before planting irrigation was performed. Then the seeds were planted on 4 and 9th of June in the first and second year, respectively. The initial irrigation was carried out immediately after planting and continued until the seedlings were established. Irrigation treatments were applied after plants were fully established. The urea fertilizer at the rate of 100 kg/ha was applied uniformly during the growing season. Weeds were removed by hand when needed.

To measure various traits, 6 plants were selected from each plot. The chlorophyll index was measured on 10 random leaf samples per plant at the full flowering stage by using the chlorophyll meter device (Opti-Science, Australia). Harvesting was done on the 17th of June in both years from an area of 2.7 m^2. Arial parts were chopped and put in paper bags, and placed in an oven at 75 °C for 48 hr to obtain the biomass without roots. To determine the oil percentage, 5 grams of safflower seeds (*Carthamus tinctorius* L. cv. Goldasht) were weighed and put on the filter paper; then the filter paper was folded and placed inside the extractor.

Diethyl ether, as a solvent, was added until to be emptied from the extracted part. Then the water flow was turned on and heated for at least three hours to complete the extraction operation. In the end, the filter paper containing the sample in the oven was dried and weighed (Santos *et al.* 2017). Consequently, the oil percentage was determined by the following formula:

Percentage of oil = (weight of the filter paper and sample at the beginning - weight of the filter paper and sample at the end)/weight of filter paper and sample at the beginning

To calculate the oil yield per plot, the oil percentage was multiplied by the grain yield in each plot.

Fatty acid methyl esters were prepared by gas chromatography (GC) according to De Jong and Badings (1990). The mixture was stirred vigorously at room temperature for one minute, then centrifuged (1500 rpm). The top layer was separated by a clean microsyringe and stored in a micro-tube by a filter (micropore, 0.22 μm). The injection to GC was performed smoothly according to the normalization and external standard method. The HP 6890 GC device was used to measure the composition of fatty acids.

Lipid peroxidation in the leaf tissues was determined in terms of the malondialdehyde (MDA) content
by the thiobarbituric acid (TBA) method as described by Popham and Novacky (1990). Briefly, 0.2 g of the leaf tissue was homogenized in 5 ml of

Table 1. Soil analysis results of the experimental site in 2018 and 2019

Year	Organic carbon (%)	Organic matter (%)	Sand (%)	Silt (%)	Clay (%)	EC (ds/m)	pH	P (ppm)	K (ppm)
2018	1.7	2.9	76	13	11	1.56	7.53	25.7	7.7
2019	1.9	2.3	71	16	14	1.41	7.73	19.3	8.1

1% (w: v) trichloroacetic acid (TCA) and then centrifuged at 8000 g for 10 min. One ml of the supernatant was added to 4 ml of 20 % TCA that contained 0.5 % TBA, and the solution was heated for 30 min at 95 °C in the water bath. The samples were cooled on ice for 5 min and re-centrifuged for 5 min at 8000 g. Absorbance was measured at 532 nm. MDA was calculated according to the following formula and the extinction coefficient of 155 $mM^{-1}cm^{-1}$:

$$\text{MDA } (\mu\text{mol/g FW}) = [A532\text{-}A600/155] \times 1000$$

At first, the data normality was tested and then statistical analysis of data was performed using the Mstat-C software. Mean comparison was done by Duncan's Multiple Range Test at the 5% probability level.

Results and Discussion

Results of this study showed that the use of absorbents and irrigation levels had a significant effect on all studied traits, except the effect of absorbents on the oil yield. However, the interaction of these factors was only significant for plant height, chlorophyll index, 100-grain weight, oil percent, and the percentage of oleic acid (Table 2).

Plant height

The height of safflower plants was affected by the interaction of irrigation level × type of absorbent (Table 2). The highest height of the safflower plants (78.08 cm) was obtained under irrigation after 70 mm evaporation from the pan + superabsorbent, and the lowest height (51.63 cm) belonged to the irrigation after 140 mm evaporation without the application of moisture absorbent (Table 3). Severe drought at all levels of absorbents significantly reduced the height of safflower plants. Across all levels of absorbents, by reducing irrigation water from 70 mm to 140 mm evaporation, plant height decreased between 27.7 to 35.2%. Under irrigation after 70 mm evaporation from the pan, only superabsorbent, and under irrigation after 140 mm evaporation from the pan, only vermiculite caused a significant increase in the plant height over the control (Table 3). Hu *et al*. (2007) reported that drought reduces the absorption of nutrients, which in turn can reduce the growth of aerial parts of the plant. In general, drought reduces cell division and lengthening in all dimensions. This is because of the reduction in the hydraulic force of the water, which is effective on the cell growth, and also the thickening of the cell walls (Luković *et al*. 2009). However, studies have shown that absorbents retain water in the soil and

Table 2. Analysis of variance of safflower traits as affected by irrigation level and biological fertilizer in two years

Source of variation	df	Chlorophyll Index	100-grain weight	Grain yield	Dry weight (total)	Harvest index	Oil percent	Oil yield	Protein percent
Year (Y)	1	10.88	41.88*	707.84**	120.18*	15.29**	49.88**	153.14**	3.10
Replication/Year	4	43.83	1.93	47.43	9.10	1.40	13.20	6.77	3.55
Irrigation level (I)	2	461**	83.88**	4072.83**	1261.33**	42.41**	202.86**	714.82**	63.82**
I × Y	2	20.56	5.77	41.05	0.87	2.85	10.28	21.08	1.93
Error a	8	24.02	6.30	25.50	16.64	0.42	5.60	6.43	3.18
Biological fertilizer (F)	4	23.05**	7.36	352.8**	83.99*	7.64*	50.37**	66.50	6.01
F × Y	4	7.61	7.05	113.56	30.00	1.33	6.27	20.84**	0.99
I × F	8	20.44**	14.22**	89.30	24.06	4.01	11.67**	12.47	3.55
I × F × Y	8	9.76	3.61	49.12	3.64	3.59	4.17	7.53	1.95
Error b	48	6.40	3.03	60.97	28.21	2.77	3.73	6.12	2.80
CV (%)		9.60	5.91	15.68	12.70	11.27	6.36	16.13	8.88

Table 2 continued

Source of variation	df	MDA	Palmitic acid	Stearic acid	Oleic acid	Linoleic acid	Number of seeds per head	Number of seeds per plant	Plant height
Year (Y)	1	13.07*	0.06	1.55	1.13	3.44	30.51	4184.75	7.74
Replication/Year	4	3.26	1.55	1.66	0.34	25.03	3.38	622.16	26.29
Irrigation level (I)	2	177.15**	44.10**	117.34**	88.31**	1638.0**	786.28**	116534**	2027.34**
I × Y	2	7.90	1.15	7.01	4.75	33.37	16.33	1538.36	48.09
Error a	8	2.13	1.33	3.00	4.06	28.50	13.82	972.49	48.91
Biological fertilizer (F)	4	13.23	4.23*	10.61*	23.02**	72.85**	51.13**	7643.11**	101.83*
F × Y	4	19.27**	0.12	1.42	4.35	9.40	7.86	1968.99	15.39
I × F	8	8.31	2.22	6.64	8.79**	56.58	12.24	1002.66	93.89*
I × F × Y	8	7.89	0.72	3.77	5.90	34.31*	4.83	962.42	50.79
Error b	48	5.44	1.81	3.30	2.91	14.62	8.58	1109.36	39.66
CV (%)		15.06	17.66	30.95	11.70	6.40	10.80	16.24	9.86

* and **significant at 5% and 1% probability levels, respectively; MDA: malondialdehyde

Table 3. Means of the combination of irrigation levels and water absorbents for the measured traits in safflower

Irrigation level	Absorbent	Chlorophyll index	100-grain weight	Oil %	Oleic acid	Plant height
70	Control	29.17bc	27.40fg	31.70b-d	14.48c-e	69.90bc
70	Serabsorbent	28.67bc	22.67h	31.63b-d	12.70d-f	78.08a
70	Vermiculite	31.62ab	27.05g	32.07bc	11.65f	71.67a-c
70	Zeolite	33.77a	27.18g	36.52a	11.82f	69.52b-d
70	Combination	29.37bc	28.17d-g	32.77bc	12.37ef	76.08ab
100	Control	24.00d-f	30.08b-d	28.13e-g	15.70bc	59.97ef
100	Serabsorbent	26.73cd	29.53c-f	30.97b-d	14.13c-e	60.07ef
100	Vermiculite	25.02de	29.55c-f	29.45d-f	16.97ab	55.80fg
100	Zeolite	26.13cd	32.02b	33.18b	15.00bc	66.50c-e
100	Combination	26.95cd	29.80b-e	30.37c-e	14.93b-d	64.55c-e
140	Control	20.88f	34.05a	25.53h	17.97a	51.63g
140	Serabsorbent	22.53ef	30.90bc	30.92b-d	14.02c-e	58.73e-g
140	Vermiculite	22.20ef	30.22b-d	26.08gh	17.87a	61.67d-f
140	Zeolite	21.70f	28.58c-g	28.45e-g	15.42bc	54.75fg
140	Combination	26.38cd	29.00c-g	27.70f-h	13.53c-f	59.15e-g

Means with the similar letters in each column are not significantly different based on Duncan's Multiple Range Test;
+Combination of the three absorbents

plant cells, and reduce the negative effects of drought on plant growth (Li and Chen 2019).

Biomass

The reduction of irrigation water from irrigation after 70 mm evaporation to irrigation after 140 mm evaporation caused a 26.5% decrease in biomass (Table 4). Plant growth depends on the availability of water. Drought not only directly affects cell growth but also reduces plant growth by reducing photosynthesis (Talbi *et al*. 2020). Both superabsorbent and vermiculite increased the biomass as compared to the control over the mean of irrigation levels (Table 5). The use of hydrogels improves water retention in the soil and thus increases water use efficiency by plants (Galeş *et al*. 2016). Verma *et al*. (2019) examined the effect of vermiculite and superabsorbent application on the growth of gerbera. The results of their study showed that both compounds caused a significant increase in the dry weight of the shoots. Also, the plants that grew in the hydrogel environment had much higher root growth. As a result, the turgor pressure inside the cell is maintained at a desirable level that can increase plant growth. In another study, the application of zeolite and superabsorbent caused better growth of the sunflower plants under water-deficit stress conditions (Moradi-Ghahderijan *et al*. 2017).

100-grain weight

In this study, the treatments had contradictory effects on 100-grain weight. Under the influence of the drought stress, the application of superabsorbent and vermiculite, and also the use of no absorbent (control) had positive effects on 100-grain weight as compared to the 70 mm evaporation. In the absence of moisture absorbents, the reduction of irrigation water from 70 mm evaporation from the pan to 140 mm increased the weight of 100 grains by 24% (Table 3). Drought reduces the number of plant reproductive components, thus more assimilates may have been allocated to each grain and eventually may have increased the grain weight (Prathap *et al*. 2019). In this study, under 70 mm and 100 mm evaporation from the pan, the absorbents treatments did not affect the weight of 100 seeds, except for the superabsorbent after 70 mm evaporation, while under the irrigation after 140 mm evaporation from the pan, the use of superabsorbent, vermiculite, zeolite, and the combined application of all three moisture absorbers, and under 70 mm evaporation, the superabsorbent caused a significant reduction in the grain weight (Table 3).

Number of seeds per plant and head

Drought in the present study significantly reduced the number of safflower seeds. Intensified drought caused a further reduction in the number of seeds per plant (Table 5). Mehrpouyan *et al*. (2010) reported that drought reduced the number of seeds per plant and number of heads per plant and consequently lowered the grain yield in sunflowers. All absorbents caused a significant increase in the number of seeds per plant and head as compared to the control (Table 5). Absorbents increase growth and yield by increasing water access.

Grain yield

Drought significantly reduced the grain yield of

Table 4. Comparison of the mean of the studied traits under the influence of irrigation levels

Irrigation level	Grain yield	Shoot dry weight	Oil yield	Malondialdehyde	Protein %
70	62.62a	49.16a	20.65a	12.70b	17.29c
100	46.87b	39.42b	14.37b	16.58a	19.03b
140	39.87c	36.87c	11.03c	17.18a	20.18a

Irrigation level	Stearic acid	Palmitic acid	Seed number per head	Seed number per plant	Harvest index
70	3.64b	6.25b	32.75a	275.0a	15.92a
100	6.53a	8.02a	25.88b	184.7b	14.80b
140	7.43a	8.58a	22.74c	155.5c	13.55c

Means with the similar letters in each column are not significantly different based on Duncan's Multiple Range Test

Table 5. Comparison of the mean of the studied traits under the influence of moisture absorbers

Absorbent	Grain yield	Shoot weight	Harvest index	Superoxide dismutase	Stearic acid	Palmitic acid	Seed number per head	Seed number per plant
Control	42.20b	38.27b	13.76b	90.94b	6.52a	8.45a	24.42b	169.3b
Superabsorbent	51.31a	43.21a	14.67ab	105.3a	5.11b	7.27b	27.18a	211.8a
Vermiculite	50.82a	43.01a	14.69ab	99.91ab	5.97ab	7.49b	27.11a	211.7a
Zeolite	50.73a	41.24ab	15.16a	93.25ab	6.69a	7.58b	27.90a	210.0a
All	53.86a	43.36a	15.49a	105.2a	5.04b	7.29b	28.98a	222.6a

Means with the similar letters in each column are not significantly different based on Duncan's Multiple Range Test

safflower. Reduction of irrigation water after 140 mm evaporation from the pan as compared to irrigation after 70 mm evaporation decreased grain yield by 36.4% (Table 4). Grain production may be halted due to the lack of nitrogen and carbon compounds because of drought, leading to a reduction in the number of grains per head. Meiosis, pollination, and fertilization of the flowers are very sensitive to drought. Drought reduces the amount of soluble carbohydrates in plants and thus reduces the survival of flowers before and after pollination. This is because drought during these stages reduces photosynthesis (Rajala *et al*. 2009). Other studies have stated that pre-pollination drought reduces grain yield by reducing the grain number in *Fagus sylvatica* (Aranda *et al*. 2018).

All absorbents caused a statistically significant increase in grain yield as compared to the control (Table 5). Zheng *et al*. (2018) also showed that the application of zeolite significantly increased the yield of rice seeds.

Oil percentage

In this study, drought reduced the percentage of safflower seed oil (Table 3). Mohammadi *et al.* (2018) showed that by reducing irrigation water from 70 mm evaporation from the pan to 130 mm, the percentage of oil declined by 19.1%. In our study, the superabsorbent application under irrigation after 100 and 140 mm evaporation from the pan and application of zeolite at all irrigation levels significantly increased the percentage of oil in the safflower plants (Table 3). Moradi-Ghahderijan *et al*. (2017) examined the effect of zeolite on sunflower and observed that the application of this compound causes a significant increase in the percentage of oil.

Oil yield

By reducing the irrigation water after 70 mm evaporation from the pan to irrigation after 140 mm evaporation, the yield of safflower oil decreased by 46.4% (Table 4). Mohammadi *et al*. (2018) showed that by reducing the irrigation water from the 70 to 130 mm evaporation from the pan, oil yield declined by 22.1%. They associated this decline to with the reduced grain yield and oil percentage.

In this study, oil yield also significantly increased due to the application of moisture absorbents. In both years, all moisture-absorbent treatments caused a significant increase in the oil yield. The highest increase in the oil yield was achieved due to the use of the zeolite treatment in the second year with an increase of 53% (Table 6). Moradi-Ghahderijani *et al*. (2017) also found a significant increase in the yield of rapeseed oil using the superabsorbent.

Harvest index

The reduction of irrigation water caused a significant decrease in the safflower harvest index (Table 4). Moser *et al*. (2006) reported that drought significantly reduced the maize harvest index. The zeolite treatment and the combined use of all three moisture absorbents caused a significant increase in the harvest index, while superabsorbent and vermiculite did not have a significant effect on this trait as compared to the control (Table 5).

Chlorophyll index

The highest chlorophyll index was obtained in the irrigation treatment after 70 mm evaporation from the pan + zeolite (Table 3). The chlorophyll index decreased significantly due to drought. Ghassemi-Golezani *et al.* (2016) also reported similar results as drought reduced the chlorophyll index in the milk thistle. Under severe drought, the combination of all moisture absorbents significantly increased the chlorophyll index as compared to the control. Tohidi Moghadam (2017) reported that the application of superabsorbent increased the chlorophyll index and alleviated the negative effect of arsenic in wheat.

MDA content

In this study, the MDA level was significantly increased under the influence of drought. Irrigation after 140 mm evaporation increased MDA by 29.6% as compared to the irrigation after 70 mm evaporation (Table 4). The highest MDA was obtained in the first year without the application of moisture absorbents but the application of vermiculite, zeolite, and the combination of all three moisture absorbents reduced the MDA level significantly (Table 6). The moisture absorbents did not affect MDA in the second year.

Protein percentage

The percentage of protein was not affected by the absorbent treatments, but drought caused a significant increase in the percentage of protein (Table 4). However, Talbi *et al*. (2020) obtained a significant increase in the protein content of seeds in *Oudeneya africana* under the influence of drought.

Table 6. Comparison of the mean of the studied traits under the influence of moisture absorbers in two years

Year	Superabsorbent	Oil yield	Malondialdehyde
1	Control	11.12e	18.28a
1	Superabsorbent	15.01b-d	16.93ab
1	Vermiculite	14.04cd	13.86c
1	Zeolite	13.94cd	14.69bc
1	All	16.10bc	15.59bc
2	Control	13.24de	14.51bc
2	Superabsorbent	16.98b	15.97a-c
2	Vermiculite	16.02bc	15.61bc
2	Zeolite	20.26a	15.13bc
2	All	16.77b	14.31c

Means with the similar letters in each column are not significantly different based on Duncan's Multiple Range Test

Composition of fatty acids

The composition of the predominant fatty acids in the safflower oil was significantly affected by the studied factors and the percentage of palmitic acid and stearic acid increased under the influence of drought conditions (Table 4). The oleic acid content only significantly increased under the severe-drought stress as compared to 70 mm evaporation from the pan (Table 3), while linoleic acid was significantly reduced at 100 and 140 mm evaporation in the first year and at 140 mm in the second year (Table 7).

In this study, all moisture-absorbent treatments significantly reduced the palmitic acid content in the safflower oil as compared to the control. Also, superabsorbent and the combined use of all three moisture absorbents caused a significant reduction in the percentage of stearic acid (Table 5). In the irrigation after 70 mm evaporation from the pan, vermiculite and zeolite, and in the irrigation after 140 mm evaporation from the pan, superabsorbent, zeolite, and the combination of all three moisture absorbents reduced the percentage of the oleic acid in safflower (Table 3). The response of linoleic acid to the moisture absorbents was not consistent and depended on the year, irrigation level, and type of the moisture absorbent. At the 70 mm evaporation, application of zeolite in the first year, significantly reduced the linoleic acid content, while application of vermiculite in the second year significantly increased the content of this acid in the safflower oil. Also, the superabsorbent at the 70 mm evaporation and the combination of all moisture absorbents at the 140 mm evaporation significantly increased the linoleic acid content in the first year.

Conclusions

The number of seeds per plant and the number of seeds per head decreased significantly under the influence of drought levels and ultimately reduced grain and oil yield. However, the application of moisture absorbents improved the growth and functional properties of the safflower. The use of zeolite caused the highest percentage of oil yield, however, grain yield, number of seeds per plant, and number of seeds per head were similarly affected by the moisture-absorbent treatments. Overall, the results showed that the use of moisture absorbents under conditions of normal irrigation and drought increased the safflower yield and some yield components and increased the safflower tolerance to drought.

Table 7. Comparison of means of linoleic acid under the influence of irrigation levels and moisture absorbers in two years

Year	Irrigation	Superabsorbent	Linoleic acid
1	70	Control	68.40a-c
1	70	Superabsorbent	61.83c-f
1	70	Vermiculite	70.47ab
1	70	Zeolite	61.20d-g
1	70	All	71.63ab
1	100	Control	56.23f-j
1	100	Superabsorbent	67.20a-d
1	100	Vermiculite	53.93g-j
1	100	Zeolite	55.40f-j
1	100	All	55.30f-j
1	140	Control	50.97j
1	140	Superabsorbent	55.07f-j
1	140	Vermiculite	53.30h-j
1	140	Zeolite	52.83h-j
1	140	All	60.10e-h
2	70	Control	64.43b-e
2	70	Superabsorbent	70.87ab
2	70	Vermiculite	72.63a
2	70	Zeolite	68.17a-c
2	70	All	71.57ab
2	100	Control	57.57e-j
2	100	Superabsorbent	58.17e-j
2	100	Vermiculite	53.87g-j
2	100	Zeolite	55.77f-j
2	100	All	58.63e-i
2	140	Control	50.90j
2	140	Superabsorbent	52.83h-j
2	140	Vermiculite	52.37ij
2	140	Zeolite	53.63h-j
2	140	All	58.33e-j

Means with the similar letters in each column are not significantly different based on Duncan’s Multiple Range Test

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Conflict of interest

The authors declare that they have no conflict of interest with any organization concerning the subject of the manuscript.

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اثرات کاربرد زئولیت، ورمیکولیت و سوپرجاذب روی پاسخ‌های زراعی و فیزیولوژیکی گیاه گلرنگ در شرایط کم‌آبی تحت رژیم‌های آبیاری مختلف

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چکیده

خشکی مهم‌ترین عامل تنش‌زایی است که رشد و عملکرد گیاهان را کاهش می‌دهد ولی کاربرد جاذب‌های رطوبتی ممکن است اثرات منفی خشکی را تا حدودی برطرف نماید. این مطالعه با هدف بررسی تأثیر سطوح آبیاری (آبیاری پس از ۱۴۰ میلی‌متر تبخیر از تشتک، آبیاری پس از ۱۰۰ میلی‌متر تبخیر از تشتک و آبیاری پس از ۷۰ میلی‌متر تبخیر از تشتک) و کاربرد جاذب‌های رطوبتی (عدم کاربرد جاذب رطوبتی، سوپرجاذب، ورمیکولیت، زئولیت و کاربرد توأم هر سه جاذب رطوبتی) بر عملکرد و اجزای عملکرد و خصوصیات فیزیولوژیک گلرنگ (رقم گلدشت) بود. این آزمایش در دو سال ۱۳۹۷ و ۱۳۹۸ و در هر سال به صورت طرح اسپیلت پلات در قالب طرح بلوک‌های کامل در سه تکرار اجرا گردید. بر اساس نتایج به دست آمده از این مطالعه، عملکرد دانه و روغن گلرنگ تحت تأثیر تیمار تنش شدید کم‌آبی پس از ۱۴۰ میلی متر تبخیر از تشتک به ترتیب به میزان ۳۶/۴ و ۴۶/۶ درصد کاهش یافت. طبق معمول، خشکسالی محتوای مالون دی آلدئید را به طور قابل توجهی افزایش داد. تیمارهای جاذب رطوبتی عملکرد دانه را نسبت به شاهد افزایش دادند. با این حال، تفاوت معنی‌داری بین اثر تیمارهای جاذب رطوبتی بر عملکرد دانه وجود نداشت؛ اما مؤثرترین تیمار جاذب رطوبتی در افزایش عملکرد روغن، زئولیت بود. در این مطالعه درصد اسید اولئیک و اسید پالمیتیک تحت تأثیر کم‌آبی افزایش نشان داد در حالی که میزان اسید لینولنیک با کاهش آب آبیاری کاهش یافت. به طور کلی نتایج نشان داد که استفاده از جاذب‌های رطوبتی اثرات نامطلوب تنش خشکی بر عملکرد گلرنگ و برخی اجزای عملکرد را کاهش می‌دهد.

واژه‌های کلیدی: جاذب رطوبتی؛ خشکی؛ کیفیت روغن؛ گلرنگ