# The effect of superabsorbent and biological fertilizers under water deficit stress on leaf area index, relative water content and yield of sugar beet (*Beta vulgaris*)

Farshad Sorkhi[1]*, Ramin Rostami[2], Mojtaba Fateh[1]

*(1. Department of Agronomy and Plant Breeding, Miandoab Branch, Islamic Azad University, Miandoab, 5971115111, Iran; 2. Department of Irrigation, Miandoab Branch, Islamic Azad University, Miandoab, 5971115111, Iran)*

**Abstract:** To investigate the effect of soil additives in reducing the effect of water deficit stress on sugar beet, an experiment was performed as a combined analysis in two regions based on randomized complete block design with four replications. Experimental treatments were location factor at two levels of Miandoab and Malekan, water deficit stress factor at three levels of 50 mm (lack of stress), 110 mm (moderate stress) and 170 mm (severe stress) evaporation from class A evaporation pan and soil additive factor at four levels of control (no soil additives), superabsorbent, mycorrhiza and livestock manure. In the present study, the use of soil additive treatments in both regions were able to improve the yield of pure sugar compared to control. In irrigation treatment after 170 mm of evaporation, the highest leaf area index (3.28), relative leaf water content (65.96%), shoot dry weight (3.45 t $ha^{-1}$), root yield (49.48 t $ha^{-1}$), gross sugar yield (9.73 t $ha^{-1}$) and pure sugar yield (8.32 t $ha^{-1}$) were obtained by mycorrhiza application and sugar content (20.48%) and pure sugar percent (17.11%) were obtained in control and superabsorbent application, respectively. In water deficit stress, application of mycorrhiza and superabsorbent were able to significantly increase the yield of pure sugar compared to the control. Due to the fact that sugar beet is exposed to different periods of water deficit stress in the tested areas, the use of mycorrhiza and superabsorbent can be a suitable method to reduce the effect of water deficit stress in sugar beet.

**Keywords:** mycorrhiza, sugar beet, superabsorbent, water deficit, yield.

**Citation:** Sorkhi, F., R. Rostami, and M. Fateh. 2024. The effect of superabsorbent and biological fertilizers under water deficit stress on leaf area index, relative water content and yield of sugar beet (*Beta vulgaris*). Agricultural Engineering International: CIGR Journal, 26(1):29-41.

## 1 Introduction

Optimal water consumption in the production of agricultural products as one of the most important environmental factors affecting the growth and development of plants, especially in arid and semi-arid regions such as Iran, is of great importance (Bayat et al., 2009; Sorkhi and Khomari, 2021). Sugar beet (*Beta vulgaris*) is a long-growing plant, so it needs a large amount of irrigation water (Hailay and Haymanot, 2019). So that in different parts of the world, the water requirement of sugar beet has been reported between 350 and 1150 mm (Taleghani and Saremirad., 2023). Sugar beet tolerates drought after emergence (Winter, 1980).

**Received date:** 2022-11-11 **Accepted date:** 2023-05-16

***Corresponding author:** Farshad Sorkhi, Professor, Department of Agronomy and Plant Breeding, Miandoab Branch, Islamic Azad University, Miandoab, Iran. Tel: 45358326. Email: farsorkh@gmail.com.

Superabsorbents are substances that absorb and retain water several times their own weight (Islam et al., 2012). Superabsorbents have many advantages such as increasing water and food storage capacity for a long time, reducing the number of irrigations, rapid and optimal root growth, reducing nutrient leaching in soil, reducing irrigation costs, better soil aeration, increasing activity and multiplication of mycorrhizal fungi and other soil microorganisms, increase the porosity and stability of soil structure (Fazeli Rostampour et al., 2013). Jahan et al. (2012) showed that the application of moisture superabsorbent had a significant effect on leaf area index, gross sugar yield and chlorophyll index compared to the non-use of superabsorbent and the highest values of these traits were 3.4, 11.7 t $ha^{-1}$ and 56.2 spad, respectively.

Glomus fungi by coexisting with the roots of most crops increase the uptake of nutrients such as phosphorus and some micronutrients such as zinc and copper, increase water uptake, reduce the negative impact of environmental stresses such as drought stress and increase resistance to pathogens and improve growth and yield of the crops (Jahan and Nasiri Mahallati, 2012). Abyaneh et al. (2017) reported that the use of biological fertilizers in sugar beet could improve the quantitative and qualitative characteristics of sugar beet and reduce the use of chemical fertilizers. Rezaei Chiyaneh et al. (2017) reported that in safflower, the highest grain yield from irrigation treatment after 60 mm evaporation from the evaporation pan with application mycorrhiza + nano-zinc fertilizer and the lowest grain yield were obtained from irrigation treatment after 150 mm of evaporation from the evaporation pan under no fertilizer application. Due to the importance of sugar beet in West Azerbaijan province in Iran and the occurrence of water deficit stress in different periods of plant growth, the present study was conducted to investigate the effect of water deficit stress on the quantitative and qualitative characteristics of sugar beet and the effect of different soil additive treatments to reduce the effect of water deficit stress on sugar beet.

## 2 Materials and methods

### 2.1 Study site and weather conditions

This experiment was conducted in two regions, including Research Farms of Islamic Azad University of Miandoab (Geographical features including longitude 46 degrees and 6 minutes east and latitude 36 degrees and 58 minutes north and 1314 meters above sea level) and Research Farms of Islamic Azad University of Malekan (Geographical features including longitude 45 degrees and 55 minutes east and latitude 37 degrees and 17 minutes north and 1300 meters above sea level), Iran in 2021. The experiment was performed as a combined analysis based on randomized complete blocks design with four replications. The climatic conditions of the region during the experiment are presented in Table 1. Physicochemical characteristics of soil are presented in Table 2.

**Table 1 The climatic conditions of the region during the experiment.**

| Month | Minimum temperature (℃) | | Maximum temperature (℃) | | Rainfall (mm) | | Relative humidity (%) | |
|---|---|---|---|---|---|---|---|---|
| | Miandoab | Malekan | Miandoab | Malekan | Miandoab | Malekan | Miandoab | Malekan |
| April | 3.6 | 4 | 13.1 | 15.4 | 25.9 | 24.7 | 49 | 46 |
| May | 8.1 | 8.9 | 21.7 | 24.5 | 34.6 | 37.8 | 47 | 51 |
| June | 11.4 | 12.7 | 25.6 | 30.8 | 25.5 | 29.7 | 42 | 47 |
| July | 15.3 | 16.6 | 31.1 | 34.4 | 16.7 | 12.5 | 41 | 37 |
| August | 16.8 | 18.4 | 35.7 | 36.8 | 7.9 | 4.2 | 33 | 30 |
| September | 14.3 | 16.9 | 24.5 | 28.2 | 11.4 | 9.6 | 36 | 32 |

**Table 2 Physicochemical characteristics of soil**

| pH | Electrical conductivity (ds $m^{-1}$) | Organic Carbon (%) | P (mg $kg^{-1}$) | K (mg $kg^{-1}$) | Total N (%) | Soil texture | Region |
|---|---|---|---|---|---|---|---|
| 7.84 | 1.65 | 0.89 | 12.17 | 247.35 | 0.09 | silty loam | Miandoab |
| 7.62 | 1.04 | 0.75 | 11.66 | 215.92 | 0.08 | clay loam | Malekan |

## 2.2 Experimental design

Experimental treatments were region factor at two levels of Miandoab and Malekan, water deficit stress factor at three levels of 50 mm (lack of stress), 110 mm (moderate stress) and 170 mm (severe stress) evaporation from class A evaporation pan and soil additive factor at four levels of control (no soil additives), superabsorbent ($A_{200}$), mycorrhiza and livestock manure. Water deficit stress was applied after full seedling establishment (6-leaf stage). For superabsorbent application in the treatments, furrows were created under the planting rows (below the seed, 10 cm below the soil surface) and mixed with the soil (Mahalleh et al., 2011). The characteristics of superabsorbent are presented in Table 3. Rotten livestock manure at a rate of 50 tons per hectare was added to the soil before planting and mixed with the soil.

**Table 3 Superadsorbent A200 properties**

| Appearance | White granule |
|---|---|
| Grain size (mm) | 0.5-1.5 |
| Water content (%) | 3-5 |
| Density (g $cm^{-3}$) | 1.4-1.5 |
| pH | 6-7 |
| The actual capacity of absorbing the solution of 0.9% NaCl | 45 |
| The actual capacity of absorbing tap water | 190 |
| The actual capacity of absorbing distilled water | 220 |
| Maximum durability (year) | 7 |

Soil containing mycorrhiza (*Glomus intraradices*) is provided by Green Biotechnology Company. At the time of sowing, 40 g was planted in the plant under seed (each gram contained about 300 live spores. Deep plowing was done in the fall to prepare the planting bed. Land preparation operations in the spring included surface plowing, discing and leveling. In each plot, eight planting rows with a length of 10 meters and the distance between planting rows and plant spacing on the row were 50 and 20 cm, respectively. The cultivar used in this experiment was Ekbatan, which was prepared from the Agricultural and Natural Resources Research Center of West Azerbaijan Province, Iran. The seeds were sown on April $10^{th}$. All plots were irrigated simultaneously immediately after planting.

## 2.3 Relative water content

To measure the relative water content (*RWC*) at the 20-leaf stage, after applying water deficit stress treatments, three plates with a diameter of 20 mm from each leaf were separated from the highest mature leaves and weighed immediately (*FW*). The samples were then immersed in distilled water at 5 ℃ and low light for four hours, then the water was taken on a filter paper and weighed (*TW*). Finally, the samples were placed at 80 ℃ for 24 hours and then the samples were weighed (*Dw*). The relative water content of the leaves was calculated from Equation 1 (Shaw et al., 2002).

$$RWC = (FW - DW / TW - DW) \times 100 \quad (1)$$

The units of all parameters is gram.

## 2.4 Leaf area index

To determine the leaf area index (*LAI*) of sugar beet, the whole leaves of the selected plants were placed on graph paper and then photographed. Then the area of each leaf was measured by AutoCAD software. The leaf area index was calculated from the ratio of the leaf area of each plant to the land area occupied by it.

Equation 2 was used to calculate the leaf area index (*LAI*) at the 12-leaf stage (time to maximum leaf area) (Jay et al., 2017).

$$LAI = LA / LG \quad (2)$$

*LA* is the: leaf area ($m^2$) and *LG* is the occupied land area ($m^2$).

**2.5 Root yield**

Irrigation was stopped two weeks before harvest. In November, the yield of each plot was harvested. To remove the margin effect, two side rows were removed and four middle rows were harvested in each experimental plot, then roots counted and weighed to obtain the yield for each plot.

**2.6 Shoot dry weight**

To measure the dry weight of shoots, tissue of plant samples was placed in an oven at 72 ℃ for 48 hours and then the samples were weighed.

**2.7 Sugar content**

To measure the sugar content for each sample, 26 g of root paste was taken with 177 mL of lead acetate (mixture of three parts lead acetate and one-part lead oxide) in a mixer and mixed for three minutes. After transferring the resulting mixture to a filter was obtained clear syrup. Betalyzer device was used to decompose the syrup. The polarimeter, based on the amount of deflection of polarized light, shows the amount of sugar in each sample, which was recorded as the percentage of total sugar for each plot.

**2.8 Pure sugar**

By subtracting the amount of molasses sugar from the total sugar, the amount of pure sugar was obtained.

**2.9 Gross sugar yield**

Equations 3 and 4 were used to measure the gross sugar yield and pure sugar yield, respectively (Fatollah Taleghani et al., 2009).

$$\text{gross sugar yield (t ha}^{-1}\text{)} = \text{root yield (t ha}^{-1}\text{)} \times \text{sugar content (percentage of gross sugar)} \quad (3)$$

**2.10 Pure sugar yield**

Pure sugar yield was calculated as Equation 4.

$$\text{pure sugar yield (t ha}^{-1}\text{)} = \text{root yield (t ha}^{-1}\text{)} \times \text{percentage of pure sugar} \quad (4)$$

**2.11 Statistical analysis**

Data analysis was performed using SAS software and the comparison of the mean of the studied traits was performed using Duncan's test at the level of 5% probability.

## 3 Results

The effect of water deficit stress on all studied traits was significant, however, shoot dry weight and gross sugar yield were significant at 5% probability level and other traits at 1% probability level. The effect of soil additive treatments on the studied traits was significant at the level of 1% probability (except for shoot dry weight at the level of 5% probability). The interaction effect of soil additive treatments in the region on relative water content and sugar content was significant at 1% probability level and on shoot dry weight, root yield, percentage of pure sugar and pure sugar yield at 5% probability level. The interaction effect of water deficit stress in soil additive treatments was significant on the relative water content, shoot dry weight, sugar carat, percentage of pure sugar and yield of pure sugar at the level of 1% probability was significant. While on leaf area index, root yield and gross sugar yield was significant at 5% probability level (Tables 4 and 5).

**3.1 Leaf area index**

The application of mycorrhiza and superabsorbent in the irrigation after 50 mm evaporation with an average of 4.67 and 4.42, respectively, had the highest leaf area index. The lowest amount of leaf area index with an average of 2.66 was assigned to the control treatment in the irrigation after 170 mm evaporation. There was no significant difference between control treatment and livestock manure application treatment in irrigation after 170 mm evaporation. In this study, mycorrhiza and superabsorbent treatments in irrigation after 110 and 170 mm evaporation and the treatment of non-application of soil additive (control) in irrigation after 50 mm evaporation were statistically at the same level (Table 6).

**Table 4 Analysis of variance of leaf area index, relative water content, root yield, shoot dry weight and sugar content**

| Sources of variation | Degrees of freedom | Leaf area index | Relative water content | Root yield | Shoot dry weight | Sugar carat |
|---|---|---|---|---|---|---|
| Region | 1 | $0.15^{ns}$ | $66.31^{ns}$ | $107.19^{ns}$ | $1.45^{ns}$ | $4.10^{ns}$ |
| Error 1 | 6 | 0.37 | 80.76 | 91.62 | 0.56 | 17.46 |
| Water deficit stress | 2 | $2.41^{**}$ | $237.24^{**}$ | $256.23^{**}$ | $10.92^{*}$ | $20.66^{**}$ |
| Soil additive | 3 | $1.68^{**}$ | $170.15^{**}$ | $328.64^{**}$ | $9.77^{*}$ | $18.73^{**}$ |
| Region × Water deficit stress | 2 | $0.61^{ns}$ | $15.04^{ns}$ | $49.92^{ns}$ | $1.73^{ns}$ | $2.82^{ns}$ |
| Region × Soil additive | 3 | $0.29^{ns}$ | $202.88^{**}$ | $138.39^{*}$ | $8.91^{*}$ | $23.97^{**}$ |
| Water deficit stress × Soil additive | 6 | $0.66^{*}$ | $127.34^{**}$ | $105.35^{*}$ | $12.59^{**}$ | $10.03^{**}$ |
| Region × Water deficit stress × Soil additive | 6 | $0.16^{ns}$ | $54.77^{ns}$ | $20.38^{ns}$ | $3.45^{ns}$ | $4.18^{ns}$ |
| Error 2 | 66 | 0.26 | 32.41 | 36.71 | 2.54 | 2.85 |
| Coefficient of variation | 9.31 | 5.82 | 6.78 | 12.13 | 5.93 | |

Note: ns, * and ** are non-significant and significant at the five and one percent probability levels, respectively.

**Table 5 Analysis of variance of gross sugar yield, pure sugar percent, and pure sugar yield**

| Sources of variation | Degrees of freedom | Gross sugar yield | Pure sugar percent | Pure sugar yield |
|---|---|---|---|---|
| Region | 1 | $0.56^{ns}$ | $3.88^{ns}$ | $0.64^{ns}$ |
| Error 1 | 6 | 1.55 | 1.27 | 3.19 |
| Water deficit stress | 2 | $7.49^{*}$ | $16.18^{**}$ | $64.65^{**}$ |
| Soil additive | 3 | $14.97^{**}$ | $26.91^{**}$ | $76.27^{**}$ |
| Region × Water deficit stress | 2 | $1.43^{ns}$ | $3.66^{ns}$ | $22.14^{ns}$ |
| Region × Soil additive | 3 | $19.53^{**}$ | $13.51^{*}$ | $54.28^{*}$ |
| Water deficit stress × Soil additive | 6 | $6.51^{*}$ | $23.77^{**}$ | $53.94^{**}$ |
| Region × Water deficit stress × Soil additive | 6 | $1.30^{ns}$ | $2.48^{ns}$ | $9.07^{ns}$ |
| Error 2 | 66 | 2.16 | 4.52 | 11.84 |
| Coefficient of variation | 8.67 | 6.93 | 4.52 | |

Note: ns, * and ** are non-significant and significant at the five and one percent probability levels, respectively.

**Table 6 Interaction of water deficit stress and soil additive on leaf area index, relative leaf water, shoot dry weight, root yield and sugar content in sugar beet**

| Water deficit stress | Soil additive | Leaf area index | | Relative water content (%) | | Root yield (t $ha^{-1}$) | | Shoot dry weight (t $ha^{-1}$) | | Sugar content (%) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 50 mm evaporation | Control | 3.56 | bc | 76.04 | bc | 67.02 | c | 4.16 | ab | 17.80 | cd |
| | Mycorrhiza | 4.67 | a | 85.32 | a | 77.83 | b | 4.73 | a | 17.01 | de |
| | Superabsorbent | 4.42 | a | 89.41 | a | 88.30 | a | 4.31 | ab | 16.03 | e |
| | Livestock manure | 3.81 | b | 81.03 | b | 75.69 | b | 3.73 | b | 16.26 | e |
| 110 mm evaporation | Control | 3.16 | de | 65.58 | ef | 46.64 | e | 3.18 | c | 18.19 | bc |
| | Mycorrhiza | 3.78 | b | 74.49 | cd | 59.84 | d | 4.60 | a | 18.20 | bc |
| | Superabsorbent | 3.70 | bc | 73.54 | cd | 52.76 | d | 4.47 | ab | 18.66 | bc |
| | Livestock manure | 3.64 | bc | 69.93 | de | 48.83 | e | 3.91 | b | 19.55 | ab |
| 170 mm evaporation | Control | 2.66 | f | 54.92 | g | 37.46 | f | 2.97 | e | 20.48 | a |
| | Mycorrhiza | 3.28 | cd | 65.96 | ef | 49.48 | e | 3.45 | bc | 19.68 | ab |
| | Superabsorbent | 3.20 | cd | 64.8 | f | 46.12 | e | 3.26 | c | 19.14 | ab |
| | Livestock manure | 2.84 | ef | 65.01 | f | 44.15 | ef | 3.39 | bc | 17.97 | cd |

Note: Means in each column with the same letter are no significant difference.

**Table 7 Interaction of water deficit stress and soil additive on gross sugar yield, pure sugar percent, and pure sugar yield**

| Water deficit stress | Soil additive | Gross sugar yield ($t\ ha^{-1}$) | | Pure sugar percent (%) | | Pure sugar yield ($t\ ha^{-1}$) | |
|---|---|---|---|---|---|---|---|
| 50 mm evaporation | Control | 11.92 | bc | 12.98 | c | 8.70 | cd |
| | Mycorrhiza | 13.23 | b | 13.67 | c | 10.64 | b |
| | Superabsorbent | 14.15 | a | 14.54 | b | 12.84 | a |
| | Livestock manure | 12.30 | b | 13.58 | c | 10.28 | b |
| 110 mm evaporation | Control | 8.48 | ef | 13.12 | c | 6.12 | g |
| | Mycorrhiza | 10.34 | cd | 16.5 | a | 9.38 | bc |
| | Superabsorbent | 10.84 | cd | 16.81 | a | 8.87 | cd |
| | Livestock manure | 9.54 | de | 13.25 | c | 6.47 | fg |
| 170 mm evaporation | Control | 7.71 | f | 13.81 | c | 5.17 | h |
| | Mycorrhiza | 9.73 | de | 15.82 | ab | 8.32 | de |
| | Superabsorbent | 8.82 | e | 17.11 | a | 8.09 | ef |
| | Livestock manure | 7.93 | f | 14.38 | b | 6.34 | gh |

Note: Means in each column with the same letter are no significant difference.

**Table 8 Correlation coefficients between traits**

| | Leaf area index | Relative water content | Shoot dry weight | Root yield | Sugar content | Gross sugar yield | Pure sugar percent |
|---|---|---|---|---|---|---|---|
| Relative water content | $0.02^{ns}$ | 1 | | | | | |
| Shoot dry weight | $0.07^{ns}$ | $0.11^{ns}$ | 1 | | | | |
| Root yield | $0.39^{*}$ | $-0.06^{ns}$ | $0.03^{ns}$ | 1 | | | |
| Sugar content | $0.05^{ns}$ | $0.09^{ns}$ | $-0.11^{ns}$ | $0.35^{*}$ | 1 | | |
| Gross sugar yield | $-0.06^{ns}$ | $0.13^{ns}$ | $0.08^{ns}$ | $0.91^{**}$ | $0.17^{ns}$ | 1 | |
| pure sugar percent | $0.01^{ns}$ | $0.04^{ns}$ | $-0.06^{ns}$ | $-0.05^{ns}$ | $0.02^{ns}$ | $-0.14^{ns}$ | 1 |
| Pure sugar yield | $0.04^{ns}$ | $0.08^{ns}$ | $0.27^{*}$ | $0.94^{**}$ | $0.09^{ns}$ | $0.63^{**}$ | $0.87^{**}$ |

Note: ns, * and ** are non-significant and significant at the five and one percent probability levels, respectively.

### 3.2 Relative water content

Application of mycorrhiza in Miandoab with 78% and 83% had the highest relative water content of leaves and there was no significant difference between this treatment and the treatments of application of mycorrhiza, superabsorbent and livestock manure in Malekan. The lowest relative water content with 67.22% and 64.04% was observed in the control treatment in both Miandoab and Malekan (Figure 1a).

The interaction effect of mycorrhiza and superabsorbent in the irrigation after 50 mm evaporation had the highest relative leaf water content with 85.32% and 89.41%, respectively. The lowest value belonged to the interaction of control treatment and irrigation after 170 mm evaporation of evaporation from the evaporation pan with 54.92%. The results showed that water deficit stress reduced the relative water content of the leaves, but the use of mycorrhiza and superabsorbent in the irrigation regime after 110 mm evaporation could have the same relative leaf water content as the control treatment in the irrigation regime after 50 mm evaporation from the evaporation pan (Table 6).

### 3.3 Root yield

The results showed that the application of mycorrhiza in Miandoab with 63.29 tons per hectare had the highest root yield, however, no significant difference was observed between this treatment and the application of superabsorbent application in Malekan and Miandoab. In this study, the lowest root yield with 50.83 tons per hectare was the control treatment in Miandoab (Figure 1b).

Among the interaction of water deficit stress treatments and soil additive treatments, the highest root yield was allocated to irrigation treatment after 50 mm evaporation and use of superabsorbent and with 88.30 tons per hectare. The lowest root yield was allocated to the irrigation treatment after 170 mm evaporation with the treatment of control (non-application of soil additive) with 37.46 tons per hectare, however, no significant difference was observed between this treatment and application of livestock manure in irrigation after 170 mm evaporation of evaporation and (Table 6). The correlation between leaf area index and root yield was significant at the level of 5% probability ($r = 0.39^*$), so increasing leaf area index increases root yield by creating a higher photosynthetic surface (Table 8).

### 3.4 Shoot dry weight

The results showed that mycorrhiza application in Malekan with 4.41 tons per hectare had the highest and control treatment in Miandoab with an average of 3.09 tons per hectare had the lowest shoot dry weight (Figure 1c). The use of mycorrhiza in irrigation after 50 mm evaporation with 4.73 tons per hectare had the highest shoot dry weight, there was no significant difference between this treatment and other soil additive treatments in the irrigation after 50 evaporation mm. The lowest shoot dry weight with 2.97 tons per hectare was assigned to the control treatment in the irrigation after 170 mm evaporation, however, no significant difference was observed between mycorrhiza, superabsorbent and livestock manure treatments in the irrigation after 170 mm evaporation (Table 7).

### 3.5 Sugar content

The interaction of control treatment and irrigation after 170 mm evaporation with 20.48% had the highest sugar content and there was not significant difference between this treatment with the treatments of superabsorbent and mycorrhiza application in the irrigation after 170 mm evaporation (Table 6). The lowest sugar content with 16.03% was assigned to superabsorbent application treatment in irrigation after 50 mm of evaporation. The correlation between sugar content and root yield ($r = -0.35^*$) was negative and significant at the level of 5% probability (Table 8).

### 3.6 Gross sugar yield

Among the interaction effects of region with soil additive, the highest gross sugar yield with 10.79 tons per hectare was allocated to the application of mycorrhiza in Miandoab. There was no significant difference between this treatment and superabsorbent treatment in Miandoab and Malekan. The lowest amount of this trait with 9.13 tons per hectare was allocated to the treatment of livestock manure in Miandoab (Figure 2a).

Use of superabsorbent in irrigation after 50 mm evaporation with 14.15 tons per hectare had the highest gross sugar yield. Application of control in irrigation treatment after 170 mm evaporation with an average of 7.71 tons per hectare had the lowest gross sugar yield, there was no significant difference between this treatment and the application of livestock manure in irrigation treatment after 170 mm evaporation and the control treatment in irrigation after 110 mm evaporation (Table 7). A significant positive correlation was observed between root yield and gross sugar yield ($r = 0.91^{**}$).

### 3.7 Pure sugar percent

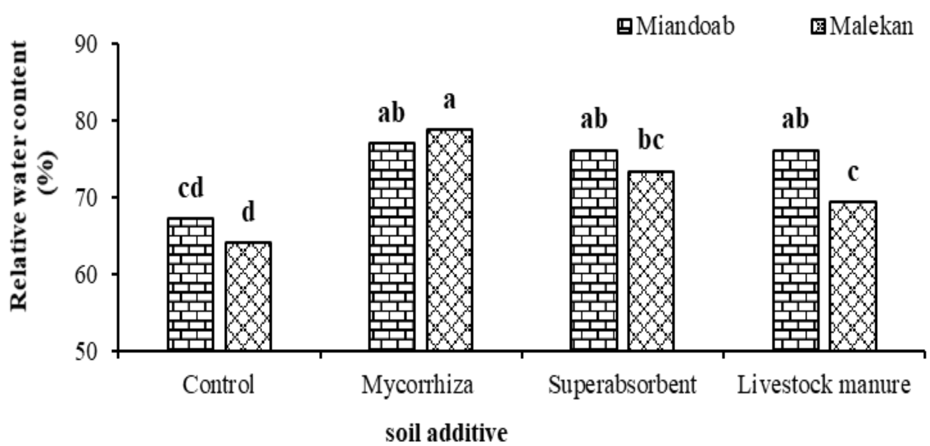
The highest percentage of pure sugar with 15.14% was assigned to the application of superabsorbent in Malekan. However, there was no significant difference between this treatment and superabsorbent application treatments in Miandoab (Figure 2b).

According to the interaction effect of water deficit stress in soil additive, the highest percentage of pure sugar in the irrigation treatment was obtained after 170 mm evaporation and application of superabsorbent with 17.11%. The lowest percentage of pure sugar with 12.98% was allocated to the irrigation treatment after 50 mm evaporation in the control treatment (no additives to soil) but between this treatment with the treatment combination of irrigation after 50 mm evaporation with mycorrhiza, the treatment combination of irrigation after 50 mm evaporation with livestock manure, the treatment combination of irrigation after 110 mm evaporation with control and livestock manure and the treatment composition of irrigation after 170 mm evaporation with control was seen no significant difference (Table 7).

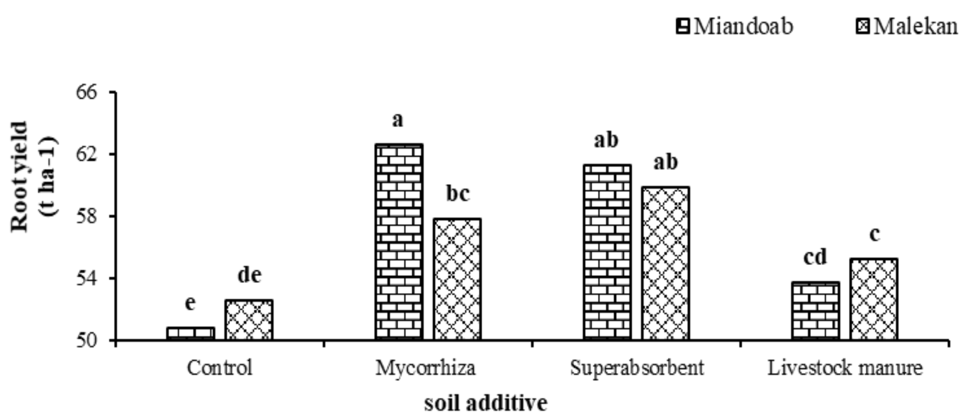
**3.8 Pure sugar yield**

Application of mycorrhiza and superabsorbent with 9.21 and 9.23 tons per hectare, respectively, had the highest yield of pure sugar in Miandoab. The control treatment (no application of soil additives) in Miandoab with 6.35 tons per hectare with had the lowest pure sugar yield (Figure 2c).

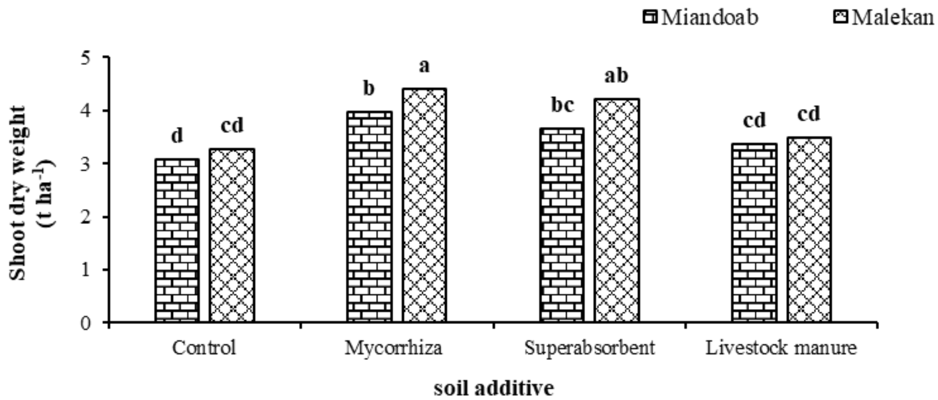
Application of superabsorbent in irrigation treatment after 50 mm evaporation with 12.84 tons per hectare has the highest yield of pure sugar. The combined effect of control in irrigation after 170 mm evaporation with 5.17 tons per hectare had the lowest pure sugar yield (Table 7). However, the use of superabsorbent in irrigation after 50 mm evaporation had the highest yield of pure sugar, but the use of mycorrhiza and livestock manure in irrigation after 50 mm evaporation significantly increased the yield of pure sugar compared to the control. In the irrigation treatment after 110 and 170 mm evaporation, the use of superabsorbent and mycorrhiza significantly increased the yield of pure sugar compared to the control treatment. Correlation between pure sugar yield and root yield ($r = 0.94^{**}$), with gross sugar yield ($r = 0.63^{**}$), with percentage of pure sugar ($r = 0.87^{**}$) was significant at the level of 1% probability and with shoot dry weight ($r = 0.27^{*}$) was positive and significant at the level of 5% probability (Table 8).




(a) relative water content

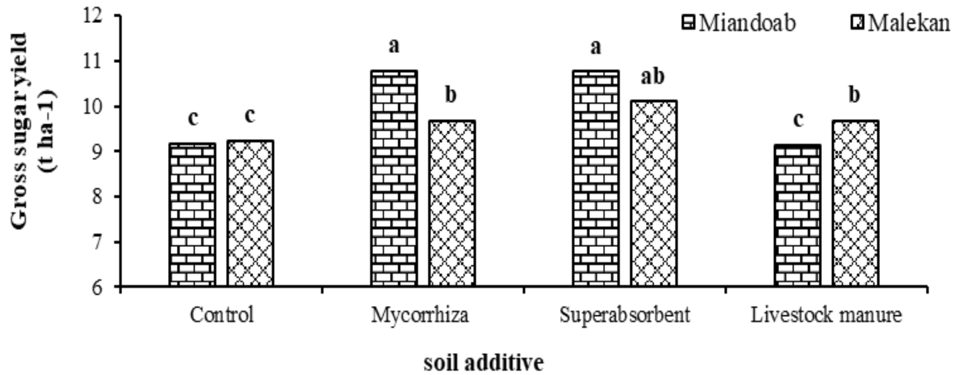



(b) root yield

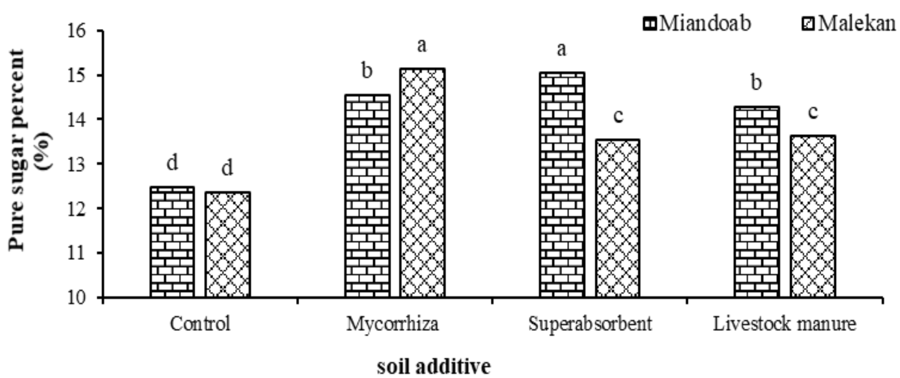



(c) shoot dry weight in sugar beet

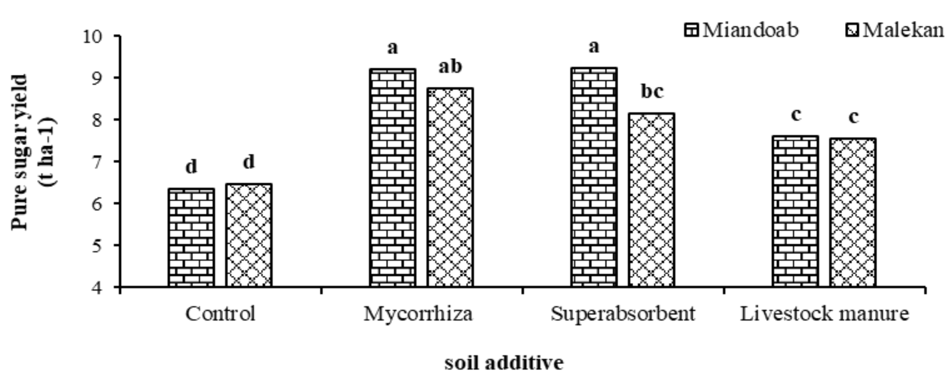
Figure 1 Interaction of region and soil additive




(a) gross sugar yield




(b) pure sugar percent




(c) pure sugar yield in sugar beet

Figure 2 Interaction of region and soil additive

## 4 Discussion

According to the research results, the use of superabsorbent adsorbent and mycorrhiza can significantly reduce the effect of water deficit stress on leaf area index. Jahan et al. (2012) showed that the highest leaf area index in sugar beet was allocated to the application of superabsorbent. Also, Fazeli Rostampour et al. (2013) and Mahalleh et al. (2011) reported that the application of superabsorbent had a significant positive effect on increasing the leaf area index of forage corn and forage sorghum. The researchers report that the reason for the increase in leaf area in plants inoculated with mycorrhiza is due to increased absorption of nutrients, especially phosphorus (Ludwig-Müller, 2000; Millar and Bennett, 2016). Parvizi and Navaei (2019) reported that mycorrhiza in drought stress conditions increased leaf area index in potatoes. Mycorrhizae reduce the osmotic potential of root cells relative to the soil by increasing soluble sugars and proline in the root environment, thereby helping to transfer more water to the roots, especially under driught stress (Bagheri et al., 2012). Islam et al. (2012) and Malik et al. (2023) reported that the consumption of superabsorbent increases the relative water content of the leaves due to the improvement of soil conditions by maintaining moisture and nutrients.

Application of superabsorbent, mycorrhiza and livestock manure in irrigation after 50 evaporation and application of superabsorbent, mycorrhiza in 110 mm evaporation caused a significant increase root yield compared to the control. In irrigation treatment after 170 mm of evaporation, no significant difference was observed between fertilizer treatments and the lowest root yield was recorded in this irrigation. Water deficit stress reduces leaf area and green cover percentage and increases respiration, which ultimately reduces root yield (Zhang et al., 2006). Also, one of the mechanisms of plants for drought resistance is reducing the osmotic potential by increasing the synthesis and accumulation of carbohydrates such as sucrose in the root cell sap, through which the osmotic potential is less than the osmotic potential of soil and water flows into the root. Of course, such a process is associated with high energy use in the plant and consumption of this amount of energy reduces root growth and thus reduces root yield (Waseem et al., 2023; Kaur et al., 2007). Parvizi and Navaei (2019) showed that the highest tuber yield in potatoes was due to mycorrhiza inoculated treatment with water deficit treatment (85% of required water supply), although this treatment with mycorrhiza inoculated treatment with treatment full irrigation (100% of required water supply) did not different significantly. Hasanabadi et al. (2016) reported root yield with 73.34 tons per hectare in water deficit treatment with application of superabsorbent significantly higher than treatment of water deficit with non-application of superabsorbent with 38.2 tons per hectare. Abbas et al. (2018) showed that the highest yield of root yield of sugar beet was obtained by combined application of 100% water requirement of the plant and 12 tons per hectare of compost and nitrogen fertilizer (in the recommended amount). The positive effect of superabsorbent and mycorrhiza on increasing root yield in sugar beet under the water deficit stress has been reported in other studies of researchers (Parvizi and Navaei, 2019).

Drought causes several morphological, physiological and biochemical changes in the plant (Sorkhi, 2020) and stops the expansion of cells, resulting significant decrease in the wet and dry weight of the plant (Shaw et al., 2002; Mahalleh et al., 2011). Drought reduces the transfer of nutrients from the soil to the plant and causes a significant reduction in dry weight (Jozi and Zare Abianeh, 2015). Jahan and Nasiri Mahallati (2012) reported that the shortening of the vegetative and reproductive growth period of the plant under irrigation treatment after 120 mm is due to the reduction of photosynthetic material production and lack of sufficient photosynthetic material for the growing roots. However, under drought stress, coexistence with mycorrhiza fungi increases plant access to water and nutrients by increasing root uptake (infiltration of fungal mycelium and increasing root contact with soil). Mycorrhiza increases plant yield, growth and biochemical activity by increasing the absorption of nutrients, which in cause increases biological yield (Rezaei Chiyaneh et al., 2017). The increase in shoot dry weight in applied superabsorbent treatments is due to the fact that when superabsorbent are added to the soil, they are able to absorb water and nutrients and then release them slowly (Zhao et al., 2015), then this water and nutrients can be used by the plant when it is growing or under water deficit stress (Islam et al., 2012). Keshavarz et al. (2015) showed that drought stress significantly reduced plant dry weight in *Pennisetum glaucum*, but the use of superabsorbent, especially in high amounts, negative effects of drought stress on the plant were significantly reduced, which is consistent with our results. Cazzato et al. (2012) reported the highest shoot dry weight in *Triticosecale wittmack* in application of 200 kg ha$^{-1}$ of superabsorbent was obtained in irrigation treatments after 50 and 110 mm of evaporation from class A evaporation pan.

Water deficit stress in sugar beet reduces fresh root weight, but root sugar content increases due to root water loss (Mohammadian et al., 2009). Fresh weight loss of roots occurs due to water loss in leaves and roots, but sugar production is rarely affected by water deficit stress, even if only 70% of the water required by the plant is provided to sugar beet (Al-Jbawi and Abbas, 2013). The low sugar content in the application of mycorrhiza and superabsorbent is due to the creation of suitable condition to increase root growth and volume, which in turn increases the ratio of root weight to sugar content (Hasanabadi et al., 2016). Rezaei Chiyaneh et al. (2017) showed that with increasing drought stress and application of mycorrhiza, the amount of soluble sugars and proline increased significantly. They also stated that inoculation with mycorrhiza in water deficit conditions can increase the water and nutrient uptake by the plant and increase the plant's resistance to water deficiency by developing the root system and increasing the level of root uptake. Abyaneh et al. (2017) showed that with increasing the level of nitrogen fertilizer and the number of irrigation regimes, the amount of sugar decreases. Abbas et al. (2018) reported that the highest sugar content was obtained in the interaction treatments of 15 tons per hectare of compost with irrigation after 50% of water requirement. The high yield of gross sugar in fertilizer treatments in the irrigation regime after 50 mm evaporation can be attributed to the high root yield in these treatments. Jahan et al. (2012) reported that the highest gross sugar yield with an average of 10.7 tons per hectare belonged to the superabsorbent application treatment of 40 kg ha$^{-1}$. Hashemi et al. (2014) stated that the highest yield of gross sugar and pure sugar was obtained in the combined treatment of complete irrigation and seed inoculation with mycorrhizal organisms. Abbas et al. (2018) reported the highest gross sugar yield in the treatment of 100% of plant water requirement and the use of 12 tons per hectare of compost.

Hasanabadi et al. (2016) reported the highest percentage of pure sugar with 11.88% in low water deficit treatment and superabsorbent application and the lowest value with 7.46% in normal water treatment and no superabsorbent application. When the plant is under water deficit stress, the use of mycorrhiza and superabsorbent is a suitable method to significantly reduce the effect of water deficit stress and achieve proper yield. In the present study, the yield of pure sugar in livestock manure treatment in both irrigations after 110 and 170 mm of evaporation was significantly lower than mycorrhiza and Superabsorbent treatments.

Water deficit stress reduces photosynthesis and consumption of photosynthetic materials in the leaves, because the transfer of sap from the phloem is dependent on the water pressure potential (Abbas et al., 2018). Application of superabsorbents increases the ability to retain water in the soil and thus reduces the negative effect of water deficit stress on the plant (Zahedi and Moghadam, 2011).

## 5 Conclusion

In the present study, the use of mycorrhiza and superabsorbent in both regions of Malekan and Miandoab were able to improve the yield of pure sugar compared to control and livestock manure. The use of mycorrhiza, superabsorbent and livestock manure under normal irrigation conditions could significantly increase the yield of pure sugar compared to the control, but in the condition of water deficit stress, application of mycorrhiza and superabsorbent were able to significantly increase the yield of pure sugar compared to the control. Due to the fact that in the tested areas, sugar beet is faced with several periods of water deficit stress, so the use of mycorrhiza and superabsorbent can be a very good way to significantly reduce the negative effect of water deficit stress on sugar beet.

## References

Abbas, M. S., A. Sh. Soliman, Z. R. Moustafa, and K. M. Abd El-Reheem. 2018. Effect of some soil amendments on yield and quality traits of sugar beet (*Beta vulgaris* L.) under water stress in sandy soil. *Egyptian Journal of Agronomy*, 40(1): 75- 88.

Abyaneh, H. Z., M. Jovzi, and M. Albaji. 2017. Effect of regulated deficit irrigation, partial root drying and N-fertilizer levels on sugar beet crop (*Beta vulgaris* L.). *Agricultural Water Management*, 194: 13-23.

Al-Jbawi, E., and F. Abbas. 2013. The effect of length during drought stress on sugar beet (*Beta vulgaris* L.) yield and quality. *Persian Gulf Crop Protection*, 2(1): 35-43.

Bagheri, V., M. H. Shamshiri, H. Shirani, and H. Roosta. 2012. Effect of arbuscular mycorrhizae and drought stress on growth indexes, water relations and proline as well as soluble carbohydrate content in pistachio (*Pistacia vera* L.) rootstock seedlings. *Iranian Journal of Horticultural Science*, 42(4): 365- 377.

Bayat, M., G. Rostami, and M. Haddadian. 2009. Large amount of water resources and water supply projects in the state. *Academic Journal of Civil Engineering*, 39: 26-37.

Cazzato, E., V. Laudadio, and V. Tufarelli. 2012. Effects of harvest period, nitrogen fertilization and mycorrhizal fungus inoculation on triticale (*Triticosecale wittmack*) forage yield and quality. *Renewable Agriculture and Food Systems*, 27(4): 278-286.

Fatollah Taleghani, D., S. Sadegh Zadeh Hemait, F. Matlobi, and S. Khyamim. 2009. Study of some quantitative and qualitative traits of promising sugar beet genotypes under drought stress conditions. *Journal of Sugar Beet*, 2(25): 123-113.

Fazeli Rostampour, M., M. Yarnia, F. Rahimzadeh Khoee, M. J. Seghatoleslami, and G. R. Moosavi. 2013. Physiological response of forage sorghum to polymer under water deficit conditions. *Agronomy Journal*, 105(4): 951-959.

Hailay, G., and A. Haymanot. 2019. The response of Swiss chard (*Beta vulgaris* L.) to nitrogen levels and intra-row spacing in Debre Berhan Central Ethiopia. *Journal of Horticulture and Postharvest Research*, 2(2): 105-116.

Hasanabadi, T., D. Habibi, and H. Khalaj. 2016. Influence of zeolite and biological fertilizer under different irrigation regime on quantitative and qualitative traits of sugar beet (*Beta vulgaris* L.). *Journal of Crop Nutrition Science*, 2(1): 20-31.

Hashemi, G. H., A. Farnia, M. Rahnamaeian, and M. Shaban. 2014. Changes in carbohydrates and sugar yield in sugar beet (*Beta vulgaris* L.) under different biofertilizers and irrigation closed time. *International Journal of Advanced Biological and Biomedical Research*, 2(8): 2350-2355.

Islam, M. D. Z., M. A. Sattar, M. Ashrafuzzaman, H. M. Saud, and M. K. Uddin. 2012. Improvement of yield potential of rice through combined application of biofertilizer and chemical nitrogen. African *Journal of Microbiology Research*. 6(4): 745-750

Jahan, M., and M. Nasiri Mahallati. 2012. *Soil Fertility and Biofertilizers: An Agroecological Approach*. Postal code: 9177948974, Azadi Square, Mashhad, Iran. Ferdowsi University of Mashhad Press.

Jahan, M., M. Nasiri Mahallati, F. Ranjbar, M. Ariaei, and N. Hamidistani. 2012. The effects of super absorbent polymers on soil moisture content and humic acid spraying on some of the agrophysiological characteristics and quantitative and qualitative yield of sugar beet (*Beta vulgaris* L.) in Mashhad conditions. *Journal of Agroecology*, 6(4): 753-766.

Jay, S., F. Maupas, R. Bendoula, and N. Gorretta. 2017. Retrieving LAI, chlorophyll and nitrogen contents in sugar beet crops from multi-angular optical remote sensing: Comparison of vegetation indices and PROSAIL inversion for field phenotyping. *Field Crops Research*, 210: 33-46.

Jozi, M., and H. Zare Abianeh. 2015. Effect of N-fertilizer levels and deficit irrigation on qualitative and quantitative yield of sugar beet. *Journal of Sugar Beet*, 31(2): 141-156.

Keshavarz, P., F. Moshiri, M. M. Tehrani, and M. R. Balali. 2015. The necessity of integrated soil fertility management for wheat production in Iran. *Iranian Journal of Land Management*. 3: 61-72.

Kaur, K., A. K. Gupta, and N. Kaur. 2007. Effect of water deficit on carbohydrate status and enzymes of carbohydrate metabolism in seedlings of wheat cultivars. *Indian journal of Medical Biochemistry*, 44(4): 223-230.

Ludwig-Müller, J. 2000. Hormonal balance in plants during colonization by mycorrhizal fungi. In *Arbuscular Mycorrhizas: Physiology and Function*, eds. M. Kapulnik, and J. Douds, ch. 12, 263-285. Netherlands: Kluwer Publishers.

Mahalleh, J. K., H. H. S. Abad, G. Nourmohammadi, F. Darvish, I. M. Haravan, and E. Valizadegan. 2011. Effect of superabsorbent polymer (Tarawat A200) on forage yield and qualitative characters in corn under deficit irrigation condition in Khoy Zone (northwest of Iran). *Advances in Environmental Biology*, 5(9): 2579-2587.

Malik, S., K. Chaudhary, A. Malik, H. Punia, M. Sewhag, N. Berkesia, M. Nagora, S. Kalia, K. Malik, D. Kumar, P. Kumar, E. Kamboj, V. Ahlawat, A. Kumar, K. Boora. 2023. Superabsorbent polymers as a soil amendment for increasing agriculture production with reducing water losses under water stress condition. *Journal of Polymers*, 15: 1-18.

Millar, N. S., and A. E. Bennett. 2016. Stressed out symbiotes: hypotheses for the influence of abiotic stress on arbuscular mycorrhizal fungi. *Oecologia*, 182(3): 625-641.

Mohammadian, R., M. Abdollahian-Noghabi, J. Baghani, and A. Haghayeghi. 2009. The relationship of morphological traits at early growth stage of three sugar beet genotypes with final root yield and white sugar yield under different drought stress conditions. *Journal of Sugar Beet*, 25(1): 23- 38.

Parvizi, K., and A. Navaei. 2019. Evaluation of potato growth traits by inoculation of mycorrhiza under drought stress conditions. *Journal of Plant Research*, 32(2): 355-365.

Rezaei Chiyaneh, E., S. Khorramdel, A. Movludi, and A. Rahimi. 2017. Effects of nano chelated zinc and mycorrhizal fungi inoculation on some agronomic and physiological characteristics of safflower (*Carthamus tinctorius* L.) under drought stress conditions. *Iranian Journal of Field Crops Research*, 15(1): 168-184.

Shaw, B., T. H. Thomas, and D. T. Cooke. 2002. Responses of sugar beet (*Beta vulgaris* L.) to drought and nutrient deficiency stress. *Plant Growth Regulation*, 37: 77-83.

Sorkhi, F. 2020. Effect of irrigation intervals and humic acid on physiological and biochemical characteristic on medicinal plant of Thymus vulgaris. *Iranian Journal of Plant Physiology*, 10(4): 3367-3378.

Sorkhi, F., and S. Khomari. 2021. Effect of different levels of water deficit on yield and amount of osmotic regulator in tetraploid and hexaploid wheat genotypes. *CIGR Journal*, 23(1): 12-16.

Taleghani, D., and A. Saremirad. 2023. Drought impacts on the reaction of sugar beet (*Beta vulgaris* L.) pollinator lines in terms of sugar. *Journal of Crop Science Research in Arid Regions*, 4(2):.371-388.

Waseem, M., P. Liu, and M. M. Aslam. 2023. Editorial: Salinity and drought stress in plants: understanding physiological, biochemical and molecular responses. *Journal of Frontiers in plant Science*, 14: 1-3.

Winter, S. R. 1980. Suitability of sugarbeets for limited irrigation in a semi-arid climate. *Agronomy Journal*, 72(1): 118-123.

Zahedi, H., and H. R. T. Moghadam. 2011. Effect of drought stress on antioxidant enzymes activities with zeolite and selenium application in canola cultivars. *Research on Crops Journal*, 12(2): 388-392.

Zhang, Z., W. Zhou, H. Li, G. Zhang, K. Subrhamaniya, and J. Yu. 2006. Effect of jasmonic acid on in vitro explant growth and microtuberization in potato. *Biologia Plantarum*, 50: 453-456.

Zhao, R., W. Guo, N. Bi, J. Guo, L. Wang, and J. Zhang. 2015. Arbuscular mycorrhizal fungi affect the growth, nutrient uptake and water status of maize (*Zea mays* L.) grown in two types of coal mine spoils under drought stress. *Applied Soil Ecology*, 88: 41-49.