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Effect of Superabsorbent Polymer on the Yield and Growth Factors of *Vicia Faba* L. under Water Deficit Stress Conditions

MOHAMMAD REZA KHATERI[1], DAVOUD KHODADADI DEHKORDI[2*], ALI ASAREH[3]

[1]Department of Water Engineering and Sciences, Ahvaz Branch, Islamic Azad University, Ahvaz, Iran

[2]Department of Water Engineering and Sciences, Ahvaz Branch, Islamic Azad University, Ahvaz, Iran

[3]Department of Water Engineering and Sciences, Ahvaz Branch, Islamic Azad University, Ahvaz, Iran

Abstract

Deficit irrigation is an optimum technique for producing products under drought stress conditions. The superabsorbent hydrogel is a hydrophilic polymer with cross-linked 3-D hydrophilic nets that can take up and keep noteworthy values of water and aquatic liquids. This study aimed to investigate the superabsorbent effect on the yield and some of the growth factors of *Vicia faba* L. under the drought stress conditions.The experimental factors included: Irrigation treatments at two levels of 100% and 70% water requirement by the plant. The second factor included the levels of superabsorbent application which included three levels of control treatment, potting soil with a weight percentage of 1, and 2. The third factor was the location of the superabsorbent application.The results showed that plant height, leaf relative water content, leaf proline content, grain protein, number of branches, number of pods per plant,grainyield under different levels of drought stress, and superabsorbent polymer weresignificantly different at 1% level. Besides, S1M treatment (2% of pot soil weight and superabsorbent application along the root zone) with a mean of 4211.6 kg/ha achieved the maximumgrain yield and the control treatmentwith a mean of 3103.20 kg/ha had the minimumgrainyield.Using the superabsorbent could achieve acceptable yield by consuming less water amount. It is recommended to use the superabsorbent along the root zone in the pot.

Keywords:deficit irrigation, grain yield, grain protein, plant height.

1. Introduction

Water shortage is known as the most important limiting factor in agricultural products; especially in the arid and semi-arid regions. As Iran's major areas consist of the arid and semi-arid areas with limited water resources, in case the minimum plant water use is not maintained, the plant would experience drought stress, and the products would suffer irreparable losses [23]. One way for optimal use of the water resources and their preservation is the use of superabsorbent polymers (SAPs) which not only provide conditions for improved products quality but also results in increased water consumption efficiency in the arid and semi-arid areas[11]. Superabsorbent polymers could absorb and retain water up to several times of their weight. Due to the drying up of the environment, the water retained in the superabsorbent is gradually discharged and thus the soil would remain moist for a long time without needing further irrigation. This property is of great importance to confront water shortage and reduce the harmful effects of drought stress in plantations [16,41]. Superabsorbent polymers cause water retention in the soil and reduce the number of irrigation frequency up to 50%[26].The scientific name for the broad bean is*Vicia faba* L. which belongs to the Fabaceae plant family. It is an annual plant in the family of beans which in addition to its effect on the soil fertility, its remains could be well stored in silos. It is also a good source of protein[25].Broad bean is a valuable plant rich in protein, carbohydrate, fat, minerals, and vitamins. It could be used both for human and animals consumption[37].This plant is one of the most popular productions in Behbahan, Iran and cultivated by farmers mostly.Amiri Deh Ahmadi et al.,[7] in his research concluded that the drought stress at the flowering stage of the chickpea plant reduced the grain yield, relative growth rate, plant growth rate, pure photosynthesis rate, and increased the leaf area and the specific leaf area. Allahyari et al.,[6]reported that the superabsorbent polymers had a significant effect on the increase of the biologic yield, number of pods in

*Corresponding author: Davoud Khodadadi Dehkordi; E-mail: davood_kh70@yahoo.com
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chickpea plant and the 100 grains weight concerning the control treatment. Rajabi et al.,[33] reported that the effects of salicylic acid and superabsorbent and their reciprocal effects on the number of pods in the plant, the 1000 grains weight, the grain yield, and the biologic yield of the chickpea plant are significant. Abhari et al.,[8] through investigating the effect of superabsorbent on the yield and the yield components of the chickpea plant in the drought stress conditions,reported that the use of superabsorbent to achieve a desirable economic performance is the best possible way. Timouri et al.,[40] through investigating the effects of drought stress and the superabsorbent on the physiologic properties of the bean plant, reported that the drought stress and superabsorbent both influenced the bean physiologic properties; so that they reported the highest rates of leaf area and the relative water content values belonged to the application of superabsorbent. Also, the use of superabsorbent polymers caused increased biologic yield, number of pods in the plant, and the 100 grains weight for the control treatment. Sio-Seh Mardeh et al.,[38] reported that the drought stress caused a reduced number of pods and grains per the chickpea plant unit area up to 43% and 44% respectively; also, it caused a 43% reduction in the grain yield. Nehbandani et al.,[27] reported that occurrence of the drought at the end of growing season of the chickpea plant, at the flowering stages, and for 10 and 20 days after flowering caused reduced amounts of water consumption up to 36%, 24%, and 14% respectively, and caused 31%, 23% and 10% reduction in the cumulative dry matter with respect to the control treatment plan. Previous studies on superabsorbent polymershave investigated their influences on yield and growth factors of plants; however, few have assessed the effects of the superabsorbent application location in the pot on them. This study aimed to investigate the superabsorbent effect on the yield and some of the growth factors of *Vicia faba* L.under the drought stress conditions.

2. Materials and Methods

This research was conducted in two growing seasons from November01 to April01 (2016-2017& 2017-2018) in a greenhouse located in Behbahan, a township in Khuzestan province, Iran. Behbahan has a hot and relatively arid climate and has a hot summer and a Mediterranean winter. The average annual precipitation is about360 mm and the average temperature is about0℃ in the winter and about50℃ in the summer. Table 1 shows the physical and chemical properties of the irrigation water and Table 2 shows the physical and chemical properties of the tested soil.

Table 1. The physical and chemical properties of the irrigation water

EC ($dS.m^{-1}$)	Na ($meq.l^{-1}$)	Ca ($meq.l^{-1}$)	Mg ($meq.l^{-1}$)
0.66	11.01	5.1	3.1

Table 2. The physical and chemical properties of the soil

Soluble potassium ($mg.kg^{-1}$)	Soluble phosphorus ($mg.kg^{-1}$)	Bulk density ($g.cm^{-3}$)	EC ($dS\ m^{-1}$)	Soil texture	Size of the soil particles (%)		
					Sand	Silt	Clay
375	28.5	1.57	9.66	Loam	36	43	21

The experimental design was factorial in the form of randomized complete blocks. The experimental factors included: Irrigation treatments at two levels of 100% water requirement (I1) and 70% water requirement (I2) by the plant (*Vicia faba* L. [*Barkat* cultivar]). The second factor included the levels of superabsorbent application which included three levels of the control treatment (S0), potting soil with a weight percentage of 2 (S1) and potting soil with a weight percentage of 1 (S2). The third factor was the location of superabsorbent application which included its application at the upper 10 cm of potting soil (O), the area around the root length within the pot (M), and at the 10 cm lower end of the potting soil (U) (in the root area); Therefore, this research had 14 treatment plans (2×2×3+2) and considering 6 replications, totally 84 pots were prepared. Each pot had 40 cm height and 30 cm diameter which contained loam soil. The superabsorbent used in this experiment was Super-AB-A-200. It is a terpolymer of acrylamide, acrylic acid, and acrylate potassium.

Three grains were planted in each pot. After germination, they were thinned out to one plant. From the 4 to 5 leaf stage (after the complete establishment of the seedling) the deficit irrigation treatment was applied.For planning and determining the irrigation interval, by adopting the no water stress treatment as the criterion, the soil moisture index and the soil matric potential were incorporated. The percentage of soil moisture content was measured through sampling to the depth of plant root in the days before irrigation and when the weighted mean of the volumetric soil moisture reached the allowable depletion for the broad beanplant, the next irrigation was performed; Therefore, the irrigation interval was determined for the treatment with no water stress (control) and simultaneously all the treatment plans with equal irrigation intervals and with different water depths were irrigated. For applying different water regimes and applying factors of each treatment, equation (1) was utilized[1]:

$$SMD = (\theta_{fc} - \theta_i).B_d.D_r.f \quad (1)$$

Where SMD is the soil moisture deficit (cm), BD is the bulk density (gr.cm^{-3}), D_r is the plant root development depth (cm), θ_{fc} is the field capacity moisture, θ_i is the weight percentage of available moisture in the farm soil and f is each treatment coefficient (1 and 0.70). In this research, the only limiting factor was water and the plant had no limitations in terms of the fertilizers and other protective measures. After applying deficit irrigation, plant height was measured in different treatmentsof each other for 15 days. The yield and yield components of the broad bean were measured after harvest (physiological processing stage with 15% moisture content). Finally, such parameters as the plant height, leaf relative water content, leaf proline content, grain protein, number of branches, number of pods per plant, and grain yieldwere investigated. To determine the leaf relative water content (RWC), a number offully green leaves were selected from each treatment. After transferring to the laboratory, their surfaces were cleaned usinga damp cloth,then theywere weighed and the read number was recorded as the fresh weight of the plant. The leaves were placed in a water container for 24 hours and re-weighed when their surface water was cleaned. The read number was recorded as the saturated weight of the leaves. To determine the dry weight, the leaves were placed in an oven for 48 hours at 75 °C. Using the following equation, the leaf relative water content (RWC) was calculated [40]:

$$\mathrm{RWC} = \frac{(\text{Fresh weight} - \text{Dry weight})}{(\text{Saturated weight} - \text{Dry weight})} \times 100 \quad (2)$$

To determine the leaf proline, 0.5 g fresh leaves were selected from each treatment. They were washed and their surface water was cleaned. Then, they were dried by an oven at 80 °C for 3 days. Samples were ground in a china mortar and 0.1 g of each sample placed in a glass bottle and were mixed with 10 mg of sulfosalicylic acid. They were filtered after 48 hours using Whatman filter paper No.1. Finally, the filtered solution was used for measuring leaf proline [13]. To determine the grain protein, it was used from automatic Kjeldahl analyzer (Tecator$^{\mathrm{TM}}$ 1030 model).The data analysis was carried out using SPSS 21.0 software. Analysis of variance (ANOVA) was used to check the differences among the treatments. The results presented in the Figures and Tables were the mean values of the two growing seasons.

3. Results and Discussion

3.1. Plant height

The analysis of variance revealed that the effects of drought stress, superabsorbent polymer (SAP), and their interactions on plant height were significant at 1% (Table 3).

Other factors, including superabsorbent location, had no significant effect on plant height. The mean comparison of interaction ofdrought stress (I) and superabsorbent (S) showed that the maximum plant height was related to I1S1 treatment with a mean value of 110.25 cm.The minimum plant height was related to I2S0 treatment with 46.30% reduction compared to the I1S1 treatment (Figure 1).

There was no significant difference between the I2S1 and I2S2 treatments. The superabsorbent application treatments and control treatment (I2S0) were significantly different so that the differences between the I2S1 and I2S2 treatments with I2S0 treatment were greater than 33 and 32% respectively. In general, there was a significant statistical difference between no water stress treatment (I1) and mild water stress treatment (I2) at all levels.

This result also revealed that decreasing water consumption (increasing the drought stress intensity) reduced the average plant height in the broad bean (*Vicia faba* L.).

Table 3. Mean square of some properties evaluated under drought stress, superabsorbent application, and its location in broad bean plant

Mean squares(MS)				Degree of freedom (df)	Variance source
Grain protein	Leaf proline	RWC	Plant height		
**0.001	**14.78	**65.51	ns165.88	5	Replication
**0.008	**21.74	**7768.80	**8782.71	1	Drought stress
**0.002	**37.40	**528.64	**1917.91	2	SAP
*0.0002	*4.52	ns13.56	ns10.53	2	SAP location
**0.0008	**11.27	**67.02	**979.73	2	SAP × Drought stress
ns0.000001	ns1.67	ns0.79	ns18.11	2	SAP location × Drought stress
ns0.00002	ns0.67	ns1.56	ns13.97	4	SAP location × SAP
ns0.000007	ns0.42	ns0.76	ns25.58	4	SAP location × SAP × Drought stress
0.00004	1.28	10.76	83.07	67	Error
2.47	4.06	5.16	9.92	-	Coefficient of variation (%)

* & ** show significant difference at 5 and 1% levels respectively and ns shows an insignificant difference.

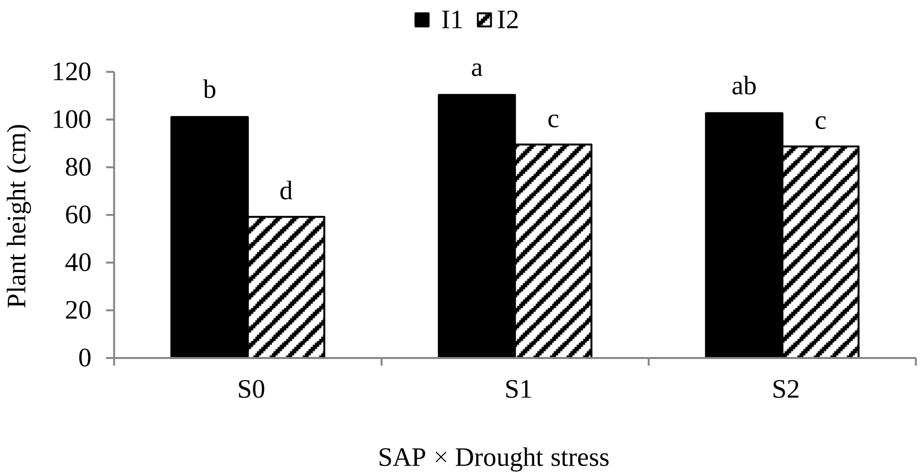

Figure 1. Mean comparison of interaction of drought stress and superabsorbent effects onthe height of a broad bean plant.

Figure 1 shows that superabsorbent well managed to maintain and properly provide soil moisture under the water stress conditions, allowing the more appropriate longitudinal growth of the plant. In other words, under the drought stress conditions, the cellular swelling decreases and the longitudinal growth of the plant ceases due to reduced pressure on the cell wall[2]; however, the presence of superabsorbent in the soil decreases the effect of drought stress on vegetative growth because of the maintenance of moisture and the relative humidity of the soil. The plant height was significantly correlated at 1% level with the RWC (r = 0.79), the number of branches (r = 0.71), number of pods per plant (r = 0.69), and grainyield (r = 0.42) (Table 4).

Ahmadi Nourodinvand et al.,[2] evaluated the effect of superabsorbent polymer on the height of green pea plant and reported that when the irrigation was 75% of plant water requirement and superabsorbent content was 0.5% of the pot soil weight, the longitudinal growth of the green pea was maximum. Fazeli Rostampour et al.,[11] reported that application of superabsorbent polymer increased the yield and height of forage corn. Tohidi-Moghadam et al.,[39] investigated the effect of different levels of superabsorbent polymer and drought stress on plant height, yield, and yield components of six types of rapeseed.

The results of their study showed that the drought stress decreased and the super absorbent application increased significantly in all measured propertiesof treatments compared to the control treatment. Shabani et al.,[35] studied the effect of superabsorbent polymer (0, 2, 4, 6 and 8 g/kg soil in each pot) on vegetative properties of two types of corn (704 and maxima) under drought stress conditions (irrigation intervals of 2, 4 and 6 days) and concluded that the maximum plant height was observed in the treatment of 6 g superabsorbent with 2-day irrigation intervals.

Table 4. Correlation coefficients between evaluated properties of broad bean plant

Evaluated properties	1	2	3	4	5	6	7
1- Plant height	1						
2- Leaf proline	^{ns}0.07	1					
3- Grain protein	^{ns}-0.19	0.58**	1				
4- RWC	0.79**	-0.11^{ns}	-0.38**	1			
5- Number of branches	0.71**	-0.10^{ns}	-0.38**	0.93**	1		
6- Number of pods per plant	0.69**	-0.11^{ns}	-0.24^{ns}	0.93**	0.95**	1	
7- Grain yield	0.42**	0.09^{ns}	0.14^{ns}	0.61**	0.66**	0.80**	1

* & ** show significant difference at 5 and 1% levels respectively and ns shows insignificant difference.

3.2. Leaf relative water content (RWC)

The results of the analysis of variance indicated significant differences between drought stress and superabsorbent polymers treatments as well as their interaction (drought stress × superabsorbent polymerat 1% level; however, the effect of superabsorbent location was insignificant. Insignificant effects were also observed for dual interaction of drought stress × superabsorbent locationand superabsorbent polymer × superabsorbent locationas well as for triple interaction of drought stress × superabsorbent polymer × superabsorbent location (Table 3). According to the mean comparison ofvalues, the maximum and maximum ofRWC with the mean values of 81.32% and 42.69% wereobserved for the I1S1 and I2S0 treatments respectively (Figure 2).

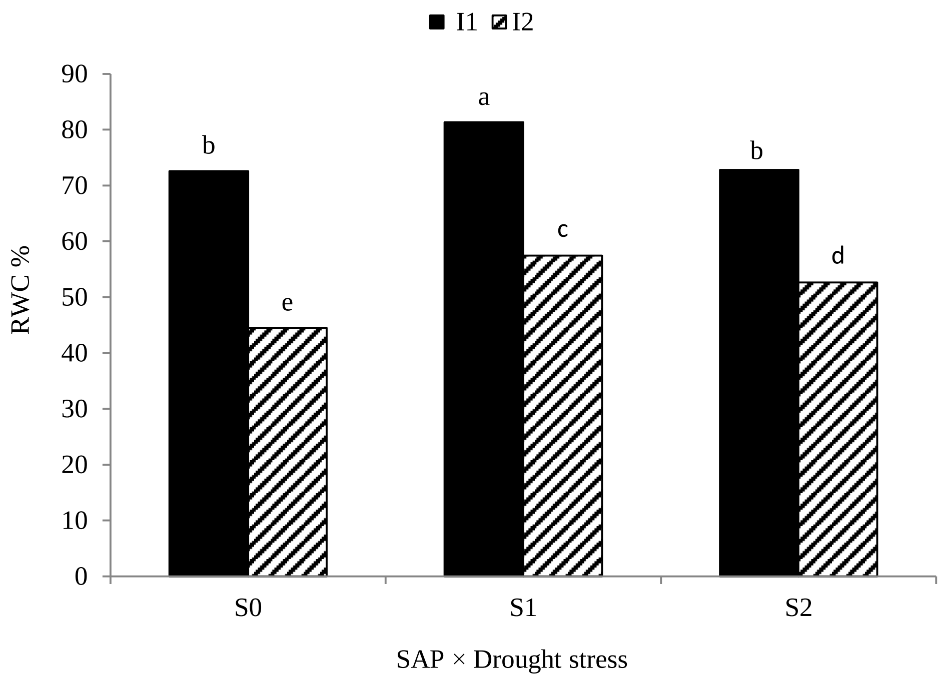

Figure 2. Mean comparison of interaction of drought stress and superabsorbent effects ontheRWCof a broad bean plant.

According to the results, the maximumRWC (81.32%) was related toI1S1 treatment.Besides, no significant difference was observed between the I1S0 and I1S2 treatments. All treatments evaluated under stress conditions (providing 70% of plant water requirement) were statistically significant in terms ofRWC. The differencesbetween I1S1 treatment with the I2S2 and I2S1 treatments were 23.90 and 28.71%. Drought stress reduced RWCwith decreasing thefresh weight and dry weight of leaves in the broad bean plant. RWC was correlated significantly at 1% levelwith number of branches (r = 0.93), number of pods per plant (r = 0.93) and grainyield (r = 0.61) (Table 4). Timouri et al.,[40] researched the effects of drought stress and superabsorbent on the physiological properties of the broad bean and concluded that the maximum RWC(75.94%) was associated with the superabsorbent application treatment that showed a 7% increase compared to the control treatment. Jager and Meyer [17] reported that drought stress reduced the RWC by reducing the fresh and dry weight of *Phaseolus vulgaris* L. leaves. Liptay et al.,[24]reported that the superabsorbent at mild water stresses with providing appropriate water for the plant, prevented from the loss of plant weight and caused non-decrease in RWC.Keshavarz and Farahbakhsh [18]evaluated the effect of superabsorbent (0, 150 and 300 kg/ha) on morphological properties and yield of millet plant under water stress conditions (providing 40, 60, 80 and 100% of plant water requirement) and noticed a significant difference between irrigation and superabsorbent levels regarding plant height, RWC, and protein content. Abedini and Sajadi [5] reported that the effect of superabsorbent treatments on increasing RWC of the rainfedwheat was significant.

3.3. Leaf proline

According to the analysis of variance, the effects of drought stress, superabsorbent and their interaction (drought stress × superabsorbent) at 1% level and the superabsorbent location at 5% level were significant; however, the effects of dual interaction of drought stress × superabsorbent location,and superabsorbent × superabsorbent location, as well as the effects of triple interactions of drought stress × superabsorbent × superabsorbent locationwere not significant (Table 3). The maximum level of leaf proline content with a mean of 29.53µmol per g leaf fresh weight was related to the superabsorbent location (M). The superabsorbent location (O) [The application of superabsorbent at 10 cm above the potting soil] with a mean of 26.95 µmol per g leaf fresh weighthad the minimum level of leaf proline. In other terms, the superabsorbent placement in the root zone (M) couldprovide the plant water requirement better than other locations (O&U). According to the mean comparison of values, the maximum level of leaf proline with a mean value of 30.95µmol per g leaf fresh weight belonged to the I2S1 treatment that had a significant statistical differencewiththe other treatments (Figure 3).

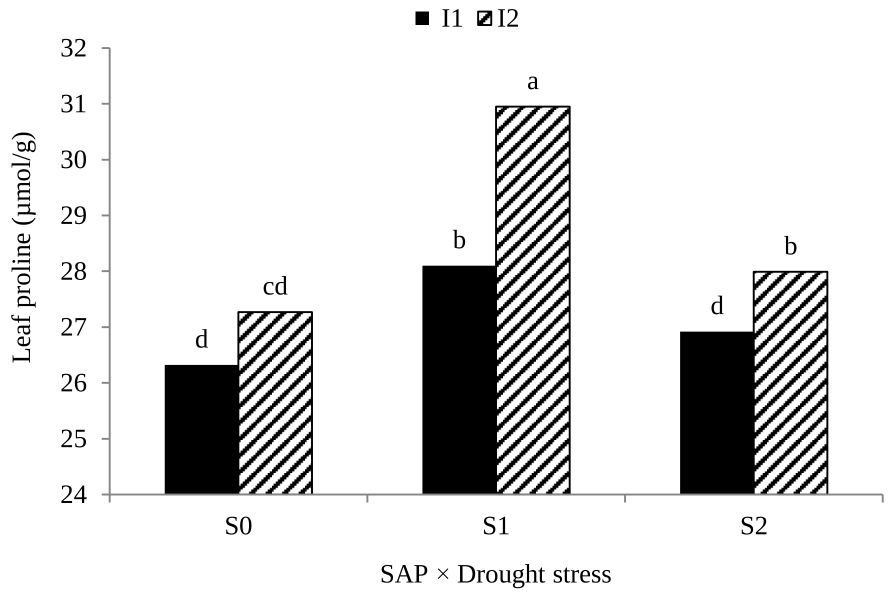

Figure 3. Mean comparison of interaction of drought stress and superabsorbent effects ontheleaf prolineof broad bean plant.

The treatment I1S0 had the minimum level of leaf proline with a mean of 26.32µmol per g leaf fresh weight. In non-drought stress conditions (providing 100% of water requirement), the treatment I1S1 had a significant difference with the other treatments (I1S0 and I1S2). Thelevels of leaf proline content in the I2S1 treatments had a significant difference with the I2S0 and I2S2 treatments. In general, the level of leaf proline in drought stress conditions (providing 70% of water requirement) increased compared to the control treatment. Leaf prolineand grain protein had a significant correlation (r = 0.58) at 1% level (Table 4). Proline accumulation through reducing the osmotic potential is one of the effective methods inconfronting with drought stress in the broad bean plant. The soluble proline can affect the solubility of various proteins and hinder the abnormality of albumin [40]. This is caused by the interrelationship creation between proline and the surface of hydrophobic proteins so that because of the increasingsurface of hydrophilic protein molecules, their stability increasesand prevents from changes in their nature. Enzymes are also affected by such a proline mechanism due to their protein structure and protectedso that plantsprobably because of above-mentioned reason, increase their proline content [40, 32]. The accumulation of proline protectsthe plant from being exposed to the oxidative effects during drought stress, and the plant can ultimately recoverits growth after stress [34]; however, within the prolonged water stress, its efficientimpactnolongerexists, and its accumulation would even harm yield because photosynthetic sources divert the plant toward the processes except forgrain filling [31]. Razban and Pirzad [32] reported that the higher application of superabsorbent could result in decreased drought stress and subsequently reduced proline accumulation. Pandey and Agrawal [28]evaluated the effect of drought stress on the proline content in riceplant and reported that the amino acid proline content in the root and stem was enhanced by drought stress. Barker et al.,[9] reported that when the plant is exposed to drought stress, protein decomposition and thus increase of amino acids (including proline) and amides are accelerated. Lotfi Agha et al.,[22]reported thatdeficit irrigation had a significant effect on proline increase and that the superabsorbent application significantly reduced the proline content in corn leaves. Soheilnejad et al.,[36] reported that the highest level of proline content in the mung bean leaves was estimated to be 0.56 mg/g dry matter in the interaction of 15-day irrigation interval treatment and control treatment; furthermore, the minimum level of leaf proline content was 0.17 mg/g dry matter for 5-day irrigation intervaltreatment and 300 kg/hasuperabsorbent treatment.

3.4. Grain protein

According to the analysis of variance, the effects of drought stress, superabsorbent and their interaction (drought stress × superabsorbent) at 1% level and the superabsorbent location at 5% level were significant; however, the effects of dual interaction of drought stress × superabsorbent location, and superabsorbent × superabsorbent location, as well as the effects of triple interactions of drought stress × superabsorbent × superabsorbent location was not significant (Table 3). According to the mean comparison of values, the maximum level of grain protein (0.29 g dry weight of grain) was related toI1S1 treatment and the minimum level of grain protein (0.24 g dry weight of grain) was related to I2S0 treatment (Figure 4).

All treatments were significantly different in both drought stress conditions and superabsorbent polymer application. The highest level of grainprotein was related to M treatment (superabsorbent placementalong the root zone in the pot) with a mean of 0.274g dry weight of grain and the minimum level was related to O treatment(superabsorbent application in the first 10-cm depth of the potting soil) with a mean of 0.254 g dry weight of grain that their difference wasstatistically significant (Figure 5).

Generally, the differences of grainprotein content in each of three superabsorbent locations; O, M and U were statistically significant. The grain protein had a significant and negative correlation with RWC (r = -.38) and a number ofbranches (r = -0.88) (Table 4). The decreased grainprotein content under drought stress conditions was because reducing soil moisture causes hydrolysis or prevention of some plant proteins synthesis [40, 15]. Kramer and Boyer [19]reported that the decreased protein synthesis under drought stress conditions is as a result of the decreased number of polysomes.

Allahdadi [4]studiedsoybeans and reportedthat adding different amounts of superabsorbent increases the level ofgrainprotein, which is probably due to the provision of sufficient water supply for the plant under drought stress conditions that causedpreparing sufficient water for protein synthesis.

Ghorbani et al.,[14] reported that the reciprocal effect of the superabsorbent and pretreatment of chickpea grainon grain protein yield was significant, whereas the highest grain protein yield (246.67 kg/ha) was related to the pretreatment of grains with humic acid and 30 kg/ha superabsorbent application compared to the other treatments. Roustaie et al.,[30]reported that the combined application of animal manureand superabsorbent polymer under drought stress conditions increased soybean protein content compared to the control treatment.

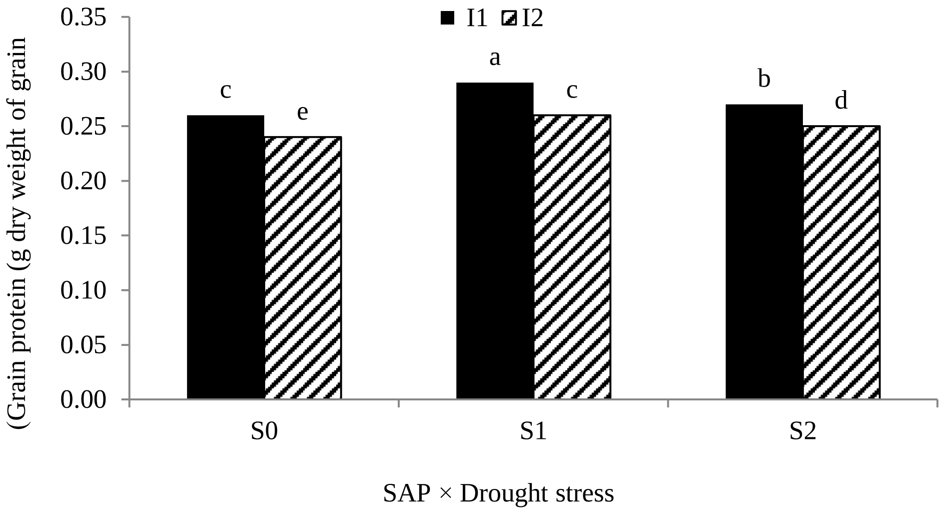

Figure 4. Mean comparison of interaction of drought stress and superabsorbent effects onthegrain proteinof broad bean plant.

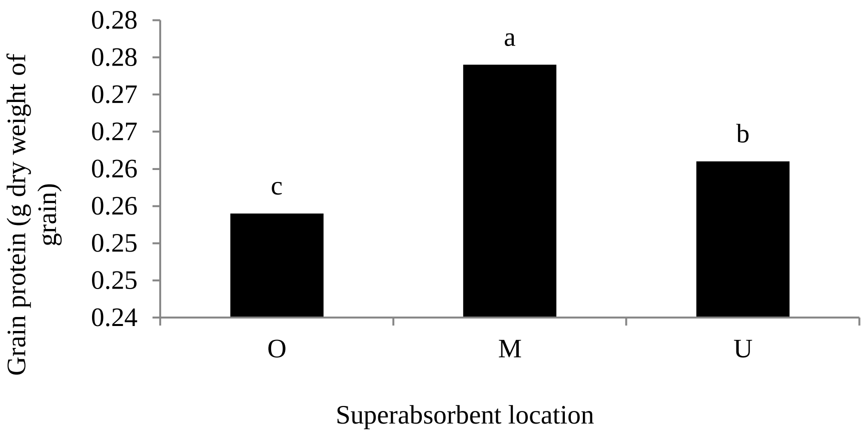

Figure 5. Mean comparison of the superabsorbent location effect onthegrain proteinof broad bean plant.

3.5. Number of branches

According to the analysis of variance (Table 5), the effects of drought stress, superabsorbent polymer and superabsorbent location on the number of broad bean branches were significant at 1% level.

The effects interaction of drought stress × superabsorbent and superabsorbent × superabsorbent location were significant at 1% and 5% levels, respectively; however, the effects of drought stress × superabsorbent location and drought stress × superabsorbent × superabsorbent location were not significant. According to the mean comparison results in Figure 6, the difference between the maximum and the minimum number of the broad bean branches was about 72%.

The maximum number of branches in the broad bean was 7.23 in the I1S1 treatment. No significant difference was observedforthe I1S0, I2S1 and I1S2 treatments. The application of superabsorbent polymer increased the number of branches in the broad bean plant. The superabsorbent application improves soil texture, reduces irrigation intervals and increases soil water retention, which leads to increased germination and rapid plant growth [20]. In general, the number of branches in the broad bean decreased with increasing the drought stress intensity, compared to optimal irrigation (I1) so that the difference between the maximum and the minimum number of branches was about 72%.The addition of superabsorbent polymer increasedthe number of branches in the broad bean significantly, compared to the control treatment. In general, the differences between the evaluatedtreatments (I2S0, I2S1, and I2S2) were statistically significant under drought stress conditions. Figure 7 shows the interaction of superabsorbent × superabsorbent location.

Table 5. Mean square of the number of branches and number of pods per plant under drought stress, superabsorbent application, and its location in broad bean plant

Mean squares(MS)		Degree of freedom (df)	Variance source
Number of pods per plant	Number of branches		
**362.19	**3.43	5	Replication
**5820.27	**137.53	1	Drought stress
**801.46	**11.93	2	SAP
*124.44	**3.11	2	SAP location
**114.69	**5.98	2	SAP × Drought stress
**65.74	^{ns}0.43	2	SAP location × Drought stress
^{ns}6.14	*0.52	4	SAP location × SAP
^{ns}12.92	^{ns}0.25	4	SAP location × SAP × Drought stress
11.02	0.18	67	Error
8.11	10.46	-	Coefficient of variation (%)

* & ** show significant difference at 5 and 1% levels respectively and ns shows an insignificant difference.

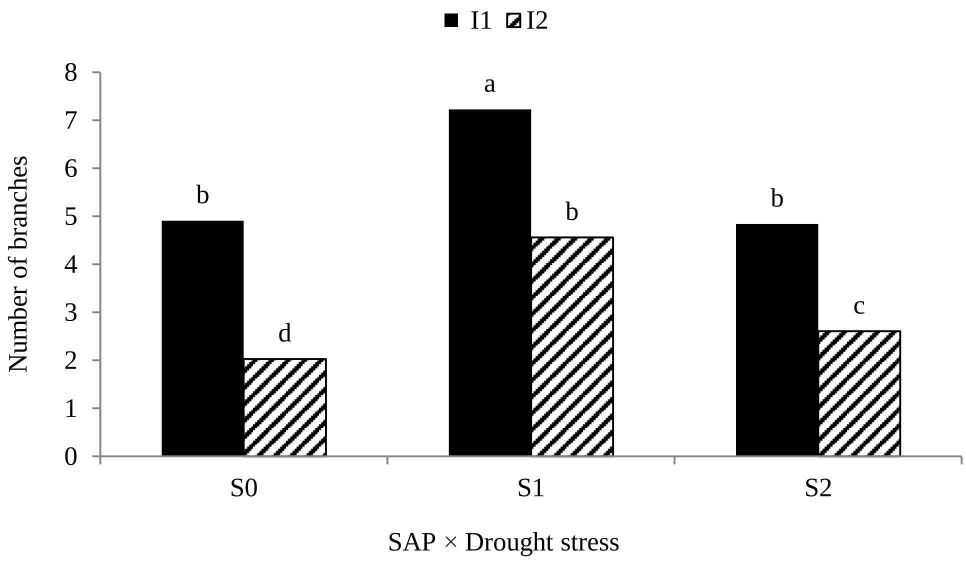

Figure 6. Mean comparison of interaction of drought stress and superabsorbent effects onthenumberof broad bean branches.

The maximum number of broad bean brancheswith a mean of 5.22% was related to the S1M treatment and the minimum number with a mean of 2.80 was related to the S0 treatment (control).The number of branches in the S1M treatment was 49% greater than their number in the S0 treatment. Generally, placing superabsorbent along the root zone (M treatment) in this study provided better results compared to the other two treatments (O and U) because the roots probably could better and more quickly uptake the superabsorbent water storage along the root zone. A number ofbrancheshad a positive and significant correlation at a 1% levelwith a number of pods per plant (r = 0.95) and grain yield (r = 0.66) (Table 4).

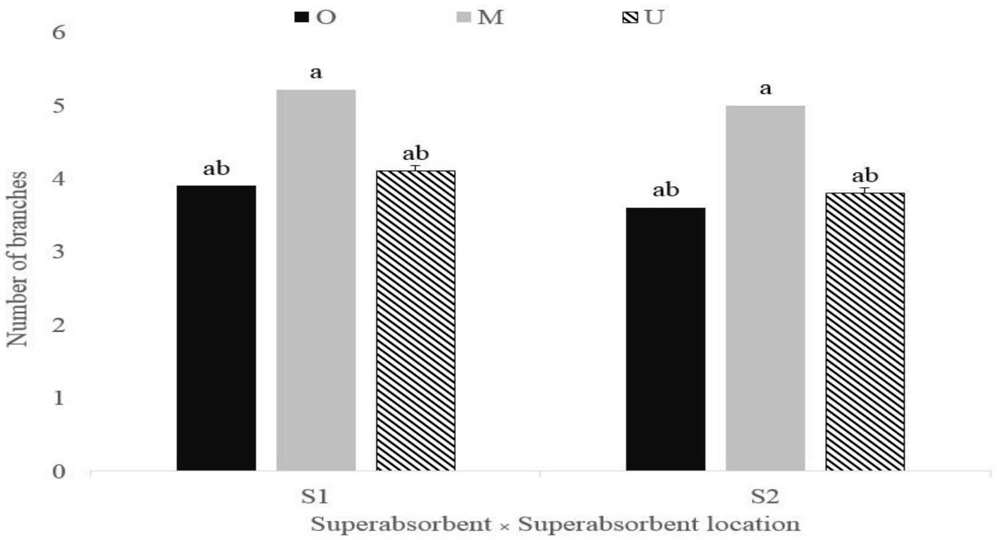

Figure 7. Mean comparison of interaction of superabsorbent and superabsorbent location effects onthenumberof broad bean branches.

Farjamet al.,[12]reported that the effect of the superabsorbent application on the number of rainfed chickpea branches was significant at 1% level. PourIsmaeil et al.,[29] reported that the effect of the superabsorbent application on some Kidney bean branches was significant at 1% level. They also reported that the superabsorbent polymer could reduce many damages caused by water deficit and increase growth factors, grain yield, and water use efficiency through having water absorption and storage. Ghorbani et al.,[14]also observed that the interaction effect of superabsorbent and pretreatment of grains on the number of chickpea branches was significant at 1% level. Kant et al.,[21]also reported that application of superabsorbent polymer significantly reduced the effect of drought stress on growth parameters of the broad bean in saline soils ofarid and semiarid regions.

3.6. Number of pods per plant

According to the analysis of variance (Table 5), the effects of drought stress, superabsorbent polymer and superabsorbent location on the number of pods per plant was significant at 1% level. The effects of the dual interactions of drought stress × superabsorbent location, and superabsorbent × superabsorbent locationwere also significant at 1% level; however, the effects of the triple interactions of superabsorbent × superabsorbent location× drought stress were not significant. As the intensity of drought stress increased, the number of pods per plant decreased (Figure 8).

The maximum number of pods per plant (61.45) belonged to the I1S1 treatment and the minimum number (26.95) was related to the I2S0 treatment, which was significantly different. In treatments under no water stress conditions, the evaluatedtreatments were significantly different. The differences in the number of pods per plant were 29% in the I1S1 and control (I1S0) treatments. The number of pods per plant had a positive and significant correlation at a 1% level with the grain yield (r = 0.80) (Table 4). Drought stress leads to reduced development of photosynthetic organs and with continued growth, the flowering period is reduced and flowers falling and abortion in podsare enhanced[10]. Generally, with the application of superabsorbent polymer, the number of pods per plant was enhanced in comparison to the control treatments, so that the differences between application and non-application of superabsorbent in non-stress and drought stress treatmentswere about 29 and 23%, respectively.

One of the most important reasons for increasing the number of pods per plant in this study was the presence of superabsorbent in the soilconcerning its role in providing better water and nutrients for the plant and increasing the absorption of nutrients by the root, which would lead to a better supplyof water and nutrients in the plantas well as the better vegetative growth of the plant and consequently, an increased number of pods per plant.

Also, due to the more favorable consumption of soil waterby the plants, the number of flowers turning into pods is increased. The presence of sufficient moisture at flowering stage causedthe most of flowers without falling turned into pods, thus enhanced the total number of pods per plant.

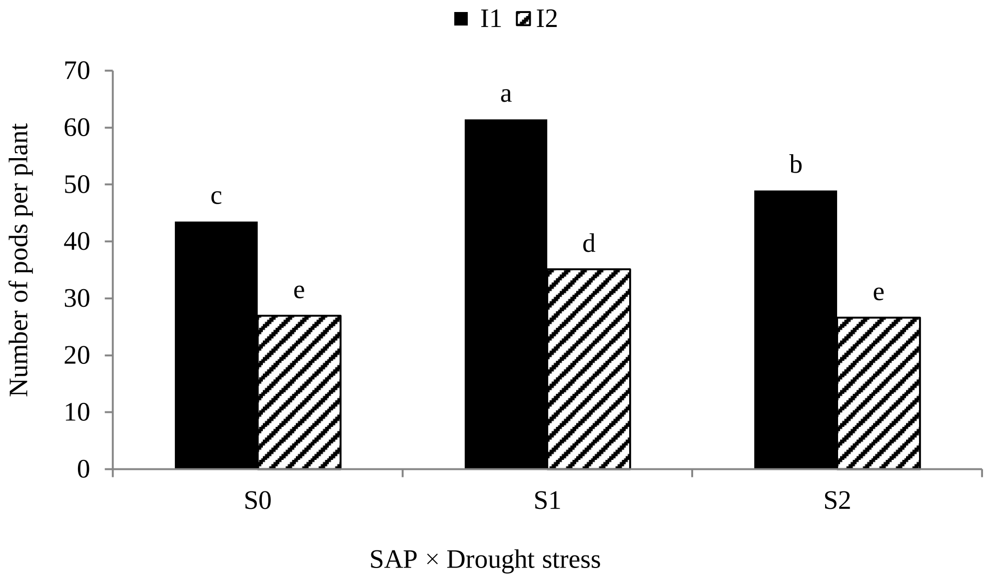

Figure 8. Mean comparison of interaction of drought stress and superabsorbent effects onthenumberof pods per broad bean plant.

Farjamet al.,[12] reported that the effect of superabsorbent on the number of pods per rainfed chickpea was statistically significant, whereas the highest number of pods per plant was obtained in the presence of 9 kg/ha superabsorbentstockosorb. Rajabi et al.,[33] reported that the effect of salicylic acid and superabsorbent and their interaction on the number of pods per rainfed chickpea plant (Hashemi cultivar) was significant, whereas the maximum number of pods per plant (40.73) was obtained from the interaction of 18 kg/ha superabsorbent and spraying 0.4 mM salicylic acid. Allahyari et al.,[6]reported that the effect of superabsorbent on some pods per chickpea plant was significant, compared to the control treatment. According to Figure 9, the maximum number of pods per plant with amean of 55.85 isrelated tothe I1M treatment and the minimumnumber of pods per plant with a mean of 29.34 is related to the I2U treatment, which was significantly different.

There was a significant difference between full irrigation and drought stress treatmentsconcerning superabsorbent location. Totally, under full irrigation conditions, the plant produces the maximum number of pods through the exploitation of all environmental conditions, sufficient development of vegetative organs, and proper production of photosynthetic materials. As a result, the highest number of grains is also produced at these conditions; however, under drought stress conditions and reduced storage of photosynthetic materials, the number of pods and consequently, the number of grains per plant will decrease. Ahmadi Norodinvand and Khodadadi Dehkordi[3] reported that the effect of the superabsorbent application on the number of pods per green pea plant under drought stress conditions was significant at 5%level, whereas the maximum number of pods per plant in the water deficit treatment of providing 75% of the plant water requirement and superabsorbent treatment of 0.5% of pot soil weightwas obtained.

3.7. Grain yield

According to the analysis of variance (Table 6), the drought stress and superabsorbent at 1% level and the superabsorbent location at 5% level had a significant effect on the grain yield.

The effects of the dual interactions of drought stress × superabsorbent location and superabsorbent × superabsorbent location on the grain yield were also significant at 5% level. As shown in Figure 10, the I1M treatmentresulted in the highest grainyield with a mean of 3936.30 kg/ha.

This finding was significantly different (more than 35%) from theI2O treatment.All of the evaluatedtreatments had a significant differencewiththe I1M treatment; however, the I1O treatmenthadno significant difference with the I2M and I2U treatments. According to Figure 11, the mean comparison of the interaction effect ofsuperabsorbent × superabsorbent locationrevealed that the treatment S1M with a mean of 4211.70 kg/ha, had the highest grain yield and the treatment S0 (control) with a mean of 3103.20 kg/ha, had the lowest grain yield, which was significantly different.

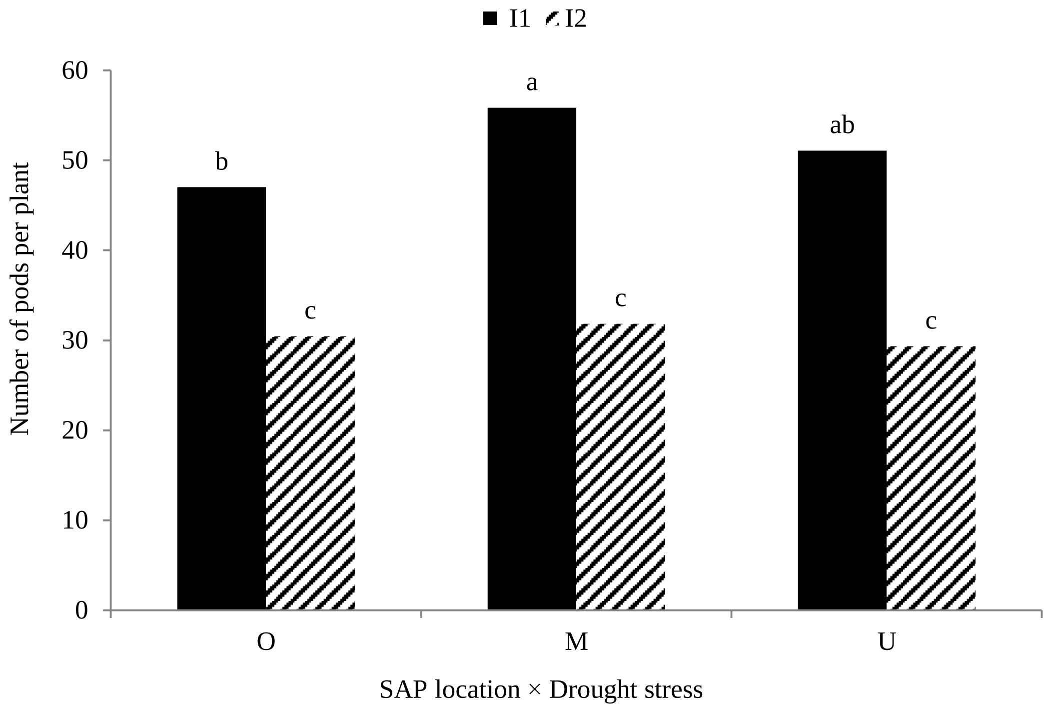

Figure 9. Mean comparison of interaction of drought stress and superabsorbent location effects onthenumberof pods per broad bean plant.

Table 6. Mean square of grain yield under drought stress, superabsorbent application, and its location in broad bean plant

Mean squares(MS)	Degree of freedom (df)	Variance source
Grain yield		
**2619775	5	Replication
**2909791	1	Drought stress
**18448564	2	SAP
*430955	2	SAP location
^{ns}153903	2	SAP × Drought stress
*278739	2	SAP location × Drought stress
*296597	4	SAP location × SAP
^{ns}19328	4	SAP location × SAP × Drought stress
95075	67	Error
9.07	-	Coefficient of variation (%)

* & ** show significant difference at 5 and 1 % levels respectively and ns shows an insignificant difference.

The difference between thegrainyields in the S1M and S0 treatments was about 26%. The reducedgrain yield in the broad bean plant under drought stress conditions was due to the decreased number of pods per plant; and finally, the decreased number of grains per pods. The grainyield was positively correlated at 1% level with the plant height (r = 0.42), RWC (r = 0.61), number of branches (r = 0.66) and number of pods per plant (r = 0.80)(Table 4). To achieve high grain yield, sufficient water is needed as such increasing the available water improves the plant metabolism and consequentlyincreases the grainyield, thus itseems, with supplying sufficient water and nutrients, the superabsorbent has positive effects on vegetative growth of all plant organs and total biomass; moreover, it can reduce the drought stress intensity and increase the grain yield, total biomass and finally harvest index [42].

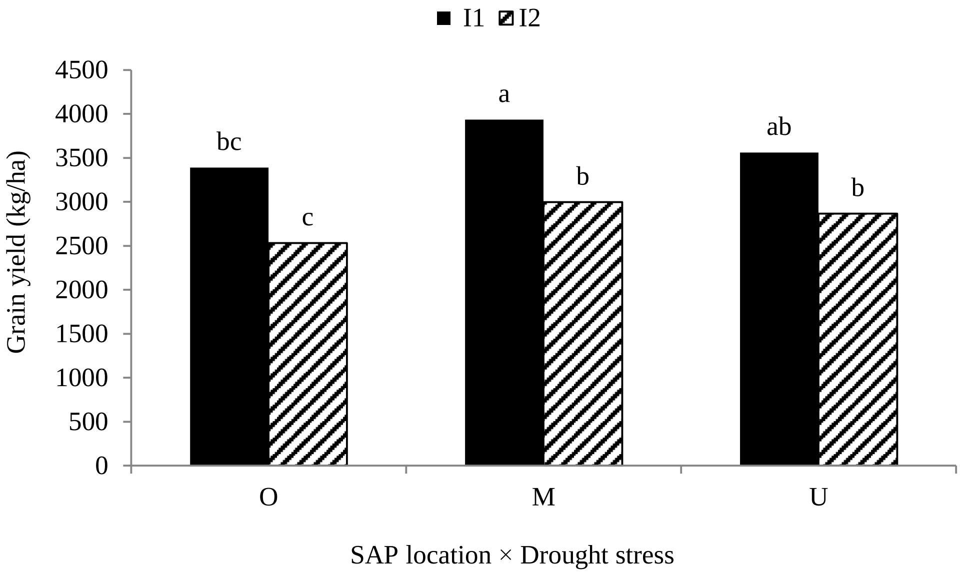

Figure 10. Mean comparison of interaction of drought stress and superabsorbent location effects onthegrain yield of the broad bean plant.

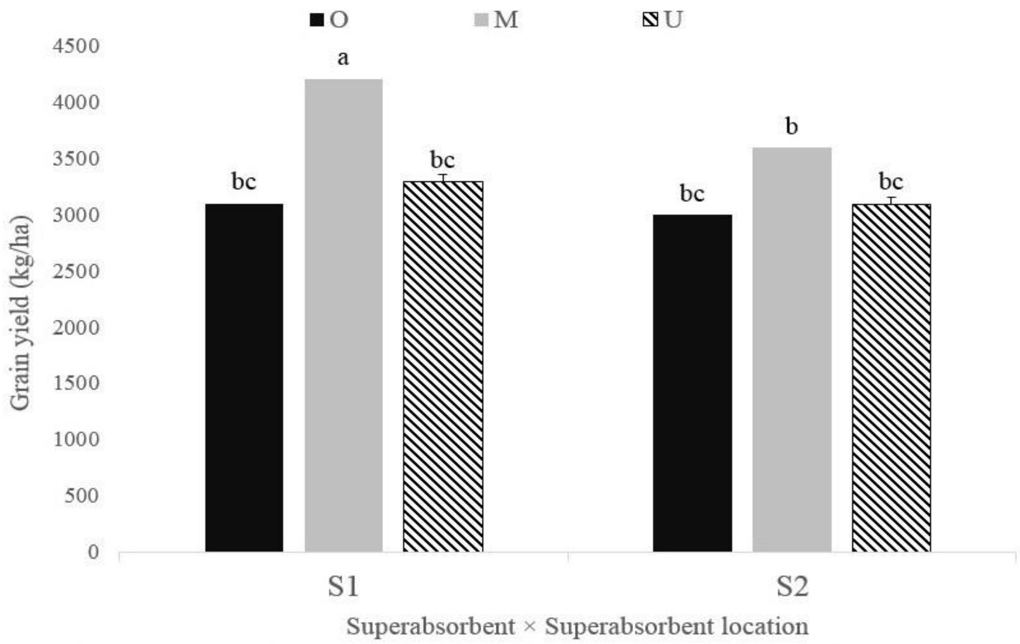

Figure 11. Mean comparison of interaction of superabsorbent and superabsorbent location effects ongrain yieldof the broad bean plant.

Gorbani et al.,[14]reported that thereciprocal effect of superabsorbent and pretreatment of chickpea grain on thegrainyield was significant, whereas the highest grainyield of chickpea (1126.45 kg/ha) was observed in the pretreatment of grain with Humic acid and 30 kg/ha superabsorbent application. Soheilnejad et al.,[26]reported that the effect of the superabsorbent application on grain yield of mung bean plant was significant at 1% level. The results showed that the 200 kg/ha superabsorbent was an optimum amount for mung bean plantand moderated the negative effects of droughtstress and improved its growth and agronomic properties. Rajabi et al.,[33] reported that the effect of salicylic acid and superabsorbent and their interaction on grain yield of rainfed chickpea (Hashemi cultivar) was significant. Grain yield increased by 25% compared to the control treatment after spraying 1.2 mmol/l salicylic acid.

4. Conclusions

According to the results of this study, the presence of superabsorbent at the top and the bottom of the pot hadno significant effect on the provision of water and nutrients for the plant; however, the presence of superabsorbent along the root zone in the pot was effective in providing water and nutrients for the plant root, ultimately leadingto increased vegetative growth and plant yield. The results showed that with the increase in the drought stress, the grain yield was significantly reduced. The reason for it could be attributed to the effect of drought stress, through decreasing the leaf area index and disorder in the process of absorption and transfer of the nutrients. This ultimately resulted in reduced phloem sap and decreased plant yield. Here, the superabsorbent had well performed by storing water and nutrients and releasing them in the drought stress conditions which ultimately had provided enough phloem sap for the plant and prevented significant loss of the plant yield; therefore, by using the superabsorbent, acceptable yield could be achieved by consuming less water amount. Finally, it is recommended to use the superabsorbent along the root zone in the pot.

5. References

1. Alizadeh A:**Planning the irrigation systems**. Imam Reza Publication, 2007, p. 452 (In Persian)
2. Ahmadi Norodinvand F, Khodadadi Dehkordi D, Egdernezhad A:**Evaluation of the Superabsorbent Effect on the Yield and Some Growth Factors of *Pisum sativum* L**. under Drought Stress Conditions. *Recent Patents on Food, Nutrition & Agriculture* 2018,**9**: In Press.
3. Ahmadi Norodinvand F, Khodadadi Dehkordi D:**Impact evaluation of superabsorbent on *Pisum sativum* L. height under drought stress conditions**. 8th *National* Conference on Watershed Management and Soil and Water Resources. Kerman, Iran, February 06, 2018(In Persian)
4. Allahdadi I:**Impact evaluation of applying superabsorbent polymer on drought stress reduction in plants**. Iran Polymer and Petrochemical Institute publication 2002, pp. 33-55 (In Persian)
5. Abedini A, Sajedi NA:**Effect of application of a superabsorbent polymer on physiological traits of dry land wheat cultivars**. *Agronomy Journal (Pajouhesh & Sazandegi)*2014,**27**(103): 140-146 (In Persian)
6. Allahyari S, Golchin A, Vaezi AR:**Study on effect of super absorbent polymer application on yield and yield components of two chickpea cultivars under rainfed conditions**. *Journal of Plant Production* 2013,**20**(1): 125-140 (In Persian)
7. Amiri Deh Ahmadi SR, Parsa M, Nezami A, Ganjeali A:**The effects of drought stress at different phenological stages on growth indices of chickpea (*Cicer arietinum* L.) in greenhouse conditions**. *Iranian Journal of Pulses Research* 2010,**1**(2): 69-84 (In Persian)
8. Abhari A, Azizi A, Hareth Abadi B:**The effect of superabsorbent on pea yield under drought stress of the season end**. *Journal of Crop Production* 2017,**10**(1): 191-202 (In Persian)
9. Barker DJ, Sullivan CY, Moser LE:**Water deficit effects on osmotic potential, cell wall elasticity, and proline in five forage grasses**. *Agronomy Journal* 1993,**85**: 270-275.
10. Daneshian J, Hadi H, Jonoubi P:**Study of quantitative and quality characteristics of soybean genotypes in deficit irrigation conditions**. *Iranian Journal of Crop Sciences* 2009,**11**(4): 393-409 (In Persian)
11. Fazeli Rostampour M, Theghat al-Islami MG, Mousavi SGhR:**Effect of water stress and polymer (super AB A 200) on yield and water use efficiency of corn (*Zea mays* L.) in Birjand region**. *Environmental stresses in crop sciences* 2011, **4**(1): 11-19 (In Persian)
12. Farjam SM, Jafarzadeh V, Toushih V:**Impact evaluation of superabsorbent and density on yield and yield components of rainfed chickpea (*Cicer arietinum* L.) inoculated by *Mesorhizobium* bacteria**. 2nd National Congress of Ecological Agriculture. Gorgan, Iran, October 07, 2007 (In Persian)

13. Farshadfar E, Javadinia J:**Evaluation of chickpea genotypes to drought stress**. *Seed Plant Improv. J* 2011,**4**: 1- 27 (In Persian)
14. Ghorbani A, Jalilian J, Amirnia R:**The Effects of seed priming and superabsorbent on some quantity and quality characteristics of kaboli chickpea (*Cicer arietinum* L.)**. *Research in Field Crops* 2013,**1**(1): 44-53 (In Persian)
15. Heikkila JJ, Papp JET, Schultz GA, Bewley JD:**Introduction of heat shock protein messenger RNA in maize mesocotyls by water stress, abscisic acid, and wounding**. *Plant physiology* 1984,**76**(1): 270-274.
16. Haghighi M, Mozafarian M, Afifi-pour Z:**Impact evaluation of superabsorbent polymer and different levels of deficit irrigation on growth and some qualitative and quantitative properties of *lycopersicum esculentum* L**. *Journal of Horticulture Science* 2014,**28**(1): 125-133 (In Persian)
17. Jager HJ, Meyer HR:**Effect of water stress on growth and proline metabolism of *Phaseolus vulgaris* L**. *Oecologia* 1977,**30**(1): 83-96.
18. Keshavarz L, Farahbakhsh H:**Effect of superabsorbent on physio-morphological traits and forage yield of millet (*Pennisetum amercanum* L.) under different irrigation treatments**. *International Journal of Plant, Animal and Environmental Sciences* 2012,**2**(3): 149-156.
19. Kramer P, Boyer J:**Water relations of plants and soils**. 1st Edition, Academic Press 1995, p. 495.
20. Khodadadi Dehkordi D:**Effect of hydrophilic polymers on seed germination and plant survival for sloping area**. *Journal of Soil and Water Conservation* 2018,**73**(2): 173-178.
21. Kant C, Aydin A, Turan M:**Ameliorative effect of hydrogel substrate on growth, inorganic ions, proline, and nitrate contents of bean under salinity stress**. *Environmental studies, Plant Biology, Journal of Plant Nutrition* 2008,**31**(8): 1420-1439.
22. Lotfi Agha M, Marashi SK, Babainezhad T:**Effect of superabsorbent polymer values and deficit irrigation on yield and some biochemical characteristics of corn (*Zea mays* L)**. *Crop Physiology Journal* 2017,**9**(34): 97-109 (In Persian)
23. Lafitte R:**Relationship between leaf relative water content during reproductive stage water deficit and grain formation in rice**. *Field Crops Research* 2002,**76**(2-3): 165-174.
24. Liptay A, Sikkema P, Fonteno W:**Transplant growth control through water deficit stress**. *Horticultural Technology* 1998,**8**(4): 540-543.
25. Majnoun Hosseini N:**Grain Legume Production**. Jahad Daneshgahi Publication 2015, p. 284 (In Persian)
26. Nazarli H, Zardashti MR, Darvishzadeh R, Najafi S:**The effect of water stress and polymer on water use efficiency, yield and several morphological traits of sunflower under greenhouse conditions**. *Notulae Scientia Biologicae* 2010,**2**(4): 53-58.
27. Nehbandani A, Soltani A, Darvishirad P:**Effect of terminal drought stress on water use, growth and yield of chickpea (*Cicer arietinum* L.)**. *Journal of Plant Ecophysiology* 2015,**7**(23): 17-27 (In Persian)
28. Pandey R, Agrawal RM:**Water stress –induced changes in proline contents and nitrate reductase activity in rice under light and dark conditions**. *Physiology and Molecular Biology of Plants* 1998,**4**:53-57.
29. Pour Ismaeil P, Habibi D, Tavasoli A:**Effect of superabsorbent on yield and water use efficiency of different red bean varieties under drought stress in green house conditions**. *Journal Management System* 2009,**1**(2): 1-16 (In Persian)
30. Roustaie Kh, Movahhedi Dehnavi M, Khadem SA, Owliaie HR:**Effect of different super absorbent polymer and animal manure ratios on the quantitative and qualitative characteristics of soybean under drought stress**. *Journal of Crops Improvement* 2012,**14**(1): 33-42 (In Persian)
31. Roshan B:**Effect of superabsorbent polymer on increasing qualitative and quantitative of agricultural products**. Iran Polymer and Petrochemical Institute publication 2002, pp. 147-157 (In Persian)
32. Razban M, Pirzad A:**Evaluate the Effect of Varying Amounts of Super Absorbent under Different Irrigation Regimes on Growth and Water Deficit Tolerance of German Chamomile (*Matricaria Chamomilla*), as a Second Crop**. *Agricultural Science and Sustainable Production* 2011,**21**(4): 1-15 (In Persian)
33. Rajabi L, Sajedi NV, Roshandel M:**Yield and yield components reaction of rainfed pea to**

salicylic acid and superabsorbent polymer. *Journal of Crop Production Research* 2012,**4**(4): 343-353 (In Persian)

34.Sanchez FJ, Manzanares M, Andres EF, Tenorio JL, Ayerbe, L:**Turgor maintenance, osmotic adjustment and soluble sugar and proline accumulation in 49 pea cultivars in response to water stress**. *Field Crops Research* 1998,**59**(3): 225-235.

35.Shabani Kh, Azimzadeh SM, Tatari M:**Impact evaluation of applying superabsorbent on vegetative characteristics of two types of corn (*Zea mays* L.) under drought stress in greenhouse conditions**. International Conference on Sustainable Development with a Focus on Agriculture, Environment and Tourism. Tabriz, Iran, September 16, 2015 (In Persian)

36.Soheilnejad A, Mahdavi Damghani A, Liaghati S, Pezeshkpour P:**Effect of superabsorbent hydrogel Aquasorb application on mitigating drought stress, grain yield and water use efficiency of mung bean (*Vigna radiate* L.)**. *Iranian Journal of Crop Sciences* 2018,**19**(4): 363-375 (In Persian)

37.Sillero JC, Villegas-Fernandez AM, Thomas J, Rubiales D:**Faba bean breeding for disease resistance**. *Field Crops Research*2010,**115**(3): 297-307.

38.Sio-Se Mardeh A, Sadeghi F, Kanouni H, Bahramnejad B, Gholami S:**Effect of drought stress on physiological traits, grain yield and its components in chickpea (*Cicer arietinum* L.) genotypes**. *Iranian Journal of Crop Sciences* 2014,**16**(2): 91-108 (In Persian)

39.Tohidi-Moghadam HR, Shirani-Rad AH, Nour-Mohammadi G, Habibi D, Modarres-Sanavy SAM, Mashhadi-Akbar-Boojar M, Dolatabadian A:**Response of six oilseed rape genotypes to water stress and Hydrogel application**. *Pesquisa Agropecuaria Tropical* 2009,**39**(3): 243-250.

40.Timouri A, Shiroui H, Mohamadi Babazeidi H:**Evaluation of drought stress and superabsorbent effects on physiologic properties of fava bean varieties**. The first international conference of planning, conservation, environmental protection and sustainable development, Hamedan, Iran, February 20, 2013 (In Persian)

41.Wu L, Liu M, Liang R:**Preparation and properties of a double-coated slow-release NPK compound fertilizer with superabsorbent and water retention**. *Bioresource Technology* 2008,**99**(3): 547-554.

42.Yahyai SGh:**Effect of irrigation regimes on yield and yield components of limited and unlimited growth types of Soybean**. *Journal of Agricultural Sciences and Natural Resources* 2007,**14**(5): 124-134 (In Persian).