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Effects of deficit and normal irrigation with the use of superabsorbents and soil amendments in desert lands of semnan province

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Abstract

This research was aimed to compare normal and deficit irrigation methods and its impact on *Atriplex canescens* in a desert region of Semnan Province in Iran. In addition, the effect of Stockosorb and Zeolite superabsorbents on water holding capacity in a sandy soil was investigated. According to the obtained results, maximum seedling height (76.33 cm) was obtained in the treatment of 15 weight% zeolite+ 70% sand with normal irrigation, having significant difference with other treatments including the control treatment. However, maximum large and small diameters were recorded in the treatment of 0.3% Stockosorb by volume+ 80% sand and normal irrigation method, showing significant difference with control and all treatments of deficit irrigation method. Results showed that significant differences existed in the soil physical, chemical and hydraulic properties between normal and deficit irrigation methods. Therefore, if the sole goal of *Atriplex canescens* cultivation in rangelands is to improve range condition and plant species diversity, deficit irrigation method and superabsorbents could be recommended in arid regions similar in the study area. On the other hand, normal irrigation could be recommended when livestock grazing and producing excellent seedlings with maximum length and diameter growth are the goals of *Atriplex canescens* cultivation.

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Introduction

More than 90% of the country's area have an arid and semi-arid climate (Shooshtarian *et al*., 2011) and the annual average precipitation of Iran is 240 mm, so that in addition to low annual precipitation, its distribution is not favorable (Sharifan *et al*., 2013). As a result, one of the consequences is water scarcity and drought stress, considered as one of the factors limiting agricultural crops production and in many parts of the world is a problem growing increasingly (Passioura, 2007). Studies show that water scarcity in agriculture affects the growth and physiological cycles of plants (Singh *et al*., 2014), affecting agriculture sector in future periods through changing the evapotranspiration of plants, crop yield and water productivity (Thomas, 2008, Oritz *et al*., 2008).

Easily absorption, storage and release of water are one of the main functions of soil for growing plants. This feature differs in different soils, depending on the fine or coarse size of soil particle and its minerals (Banedjschafie *et al*., 2006). For instance, in sandy soils, soil water holding capacity is limited, and irrigation must be inevitably done more frequently at smaller amounts, increasing the costs (Rahbar and Banedjschafie, 2009). Therefore, different technologies, compatible with the soil in each region, are required for soil moisture conservation (Six *et al*., 2002). One of the existing technologies is the use of hydrophilic superabsorbents (Dorraji *et al*., 2010). The use of superabsorbent polymers is one of the solutions to increase the water use efficiency in agriculture, leading to increased quality of crop yield (Sharifan *et al*., 2013). Superabsorbents polymers are hydrophilic networks absorbing a large volume of water (200-500 ml per gram dry weight) (Zohurian-Mehr and Kabiri, 2008). For instance, zeolite is one of the mineral soil amendments, which could be used in order to improve soil physical and chemical conditions and increase soil water holding capacity (Abedi- Koupai *et al*., 2008). Stockosorb is a polyacrylamide polymer which, because of its cross-linked structure, has a large water absorption capability (Chirino *et al*., 2011), so that one kilogram of this superabsorbent can absorb 250 liter of water (EVONIK Industries, 2014). Several studies have been performed on the application of superabsorbents (Li *et al*., 2004), physical and chemical properties (Bai *et al*., 2010), and their impacts on soil and plants (Islam *et al*., 2011, Wu *et al*., 2012). Researchers reported that hydrophilic polymers caused increased water holding capacity in sandy soils and reduced water losses through leaching (Ekebafe *et al*., 2011, Taban and Movahedi Naeini, 2006). Nazarli *et al*. (2010) showed that superabsorbent polymers led to the increased water retention in the soil, reducing the irrigation to 50%. Bal *et al*. (2010) applied different types of superabsorbents in a sandy soil and found that it increased soil moisture content, while soil bulk density and EC decreased. Zangooei Nasab *et al*. (2013) reported the positive and significant effect of using Stockosorb superabsorbent on the growth indices of *Haloxylon persicum* including height, shoot fresh and dry weight, root fresh and dry weight and root length.

According to the joint project of FAO and Forests, Range and Watershed Organization of Iran, Atriplex species have been introduced for range improvement in arid regions, so that the cultivation of this species in desert regions of Iran has been recommended (Rahimzadeh *et al*., 2011). On the other hand, water resources are the most important limiting factor in arid and desert regions (Chen *et al*., 2014). Given limited water resources in Iran and the dominant share of agriculture in the use of these resources, conservation and the use of management techniques to enhance water use efficiency is of utmost importance (Sharifan *et al*., 2013). The aim of the current research was to compare normal and deficit irrigation methods and investigation of the effects of Stockosorb and Zeolite superabsorbents on water holding capacity of sandy soils as well as its impact on *Atriplex canescens*.

Materials and methods

The study area

This research was conducted in a desert region of Semnan province in Iran, located between longitude 53° 23' E and latitude 35° 34 N'. The study area has an average annual precipitation of 140 mm and an altitude of 1130 m above sea level.

Research methodology

A split factorial based on a randomized complete block design with four replications was used. The cultivation of 320 seedlings of *Atriplex canescens* was performed in April 2013, so that there were four seedlings for each treatment. According to the suggestions provided by Baghestani Maybodi and Sanadgol (2007), the seedlings were transferred to the field when they were 7months old with a height of 30 cm, cultivated at a distance of two meters from each other. The first irrigation was done after cultivation. In the current research, Stockosorb as superabsorbent, and zeolite as soil amendment, were applied and mixed with a sandy soil (soil particle diameters= 2 mm).

First factor included normal irrigation at two levels (every 30 days in spring and summer and for six times in the first year) as well as deficit irrigation (every 45 days for four times in the first year). Sandy soil texture at two levels (70% and 80% weight%) and superabsorbents at five levels (0, 0.1, and 0.3 % Stockosorb by volume and 10 weight% and 15 weight% zeolite) were considered as the second and third factors. Superabsorbents were prepared according to the specified levels separately, and then were mixed with soil, taken from a depth of 45 cm. Since at high concentrations of superabsorbents like Stockosorb water is hardly available to the plants and at lower concentrations (Sivapalan, 2001, Abdul-Qados, 2015) it does not prevent the evaporation from the soil surface (Olszewski *et al.*, 2012), therefore, the lower and higher levels of superabsorbents were not applied. Then, after six months of experiment, attributes such as plant height, basal area, large diameter of canopy, and small diameter of canopy were evaluated. As well, soil moisture condition was determined during the periods of deficit irrigation, normal irrigation, with and without superabsorbents and soil amendments and without these materials. Soil sampling was done to study the effect of studied treatments on some physical and chemical properties of soil. The concentration of nitrogen, phosphorus and potassium (soluble + exchangeable) were measured by the Kjeldahl, Olsen, and flame photometry methods, respectively (Faithfull, 2002). To measure field capacity (FC) and wilting point (P.W.P), air-dried soil samples were put on the plastic rings of pressure plate. The plate was saturated with water one day before the experiment and after placing the samples on the plate, water was added until the samples became saturated. After 24 hours, saturated samples were at the pressures of 0.33 bar and 15 bar for the measurement of field capacity wilting point, respectively. After the release of water from the samples, they were weighed and after drying at 105 °C, soil moisture was measured (Mehrabi Gohari *et al.*, 2013). To measure soil porosity, after determining the soil bulk density (Bd) and practical density (Pd), the following equation was used (Miriti *et al.*, 2013):

Soil porosity (%) = $(1- Bd/Pd)\times 100$.

Statistical analysis

Data analysis was performed using SPSSv.16 and MSTAT-C.

Results and discussion

Morphological traits of Atriplex canescens

According to the obtained results, maximum seedling height (76.33 cm) was obtained in the treatment of 15 weight% zeolite+ 70% sand with normal irrigation, having significant difference with other treatments including the control treatment. Minimum seedling height (54.33 cm) was obtained from the combination of control treatment+ 80% sand and deficit irrigation method. However, maximum large and small canopy diameters were recorded in the treatment of 0.3% Stockosorb by volume+ 80% sand and normal irrigation method, showing significant difference with control and all treatments of deficit irrigation method. The lowest values of these traits like seedling height were recorded for control treatment and deficit irrigation method. Generally, all treatments of normal irrigation method showed significant difference as compared to the treatments of deficit irrigation method.

No significant difference was recorded in basal area and all treatments were in one statistical group (Table 1). Similar results have been reported on seedling height and canopy diameter by Davarpanah (2005). It seems that under the proper ventilation conditions and plant available water in the soil, water-soluble compounds, with low molecular weight (eg, nutrients), can be absorbed by polymers and cause plant growth by the gradual release (Gagi, 1999). Superabsorbents not only provide elements such as potassium and phosphorus, but also are effective in providing cations like calcium, magnesium and micronutrients (Polite *et al.*, 2004). In other words, it can be stated that these compounds, with increasing soil aeration, lead to better performance of some types of chemical fertilizers as well as a better soil microbial activity or due to the negative charge of hydrated state provide the absorption possibility of some positive ions in the soil (Abedi Koupai and Mesforoush, 2009).

Table 2. Mean comparisons of interaction effects of treatments for EC, pH and some studied hydrological traits by LSD method (α=0.05).

Combination of treatment			EC (dS/m)	pH	FC (%)	AW (%)	PWP (%)
Irrigation	Sand (%)	Superabsorbents					
Deficit irrigation	70% sand	control	4.100 a-c	7.767 b-e	18.93 f	10.70 h	8.233 a-e
		0.1% Stockosorb by volume	3.867 a-e	7.967 a-e	23.10 e	15.57 b-f	7.533 e
		0.3% Stockosorb by volume	3.533 e	8.100 a	24.37 a-d	16.60 ab	7.767 c-e
		10 wt% zeolite	3.933 a-e	7.967 a-e	23.07 d	15.03 e-g	8.033 b-e
		15 wt% zeolite	3.733 b-e	8.000 a-d	24.40 a-d	15.30 c-g	9.100 a-e
	80% sand	control	4.000 a-d	7.767 b-e	21.10 e	11.43 h	9.667 ab
		0.1% Stockosorb by volume	3.800 a-e	7.933 a-e	24.10 b-d	15.80 b-e	8.300 a-e
		0.3% Stockosorb by volume	3.767 a-e	8.100 a	25.03 ab	16.73 ab	8.300 a-e
		10 wt% zeolite	4.000 a-d	8.000 a-d	23.97 b-d	14.50 fg	9.467 a-c
		15 wt% zeolite	4.133 ab	7.933 a-e	24.27 a-d	15.10 d-g	9.167 a-e
Normal irrigation	70% sand	control	4.167 a	7.700 de	20.00 ef	11.27 h	8.733 a-e
		0.1% Stockosorb by volume	3.933 a-e	7.967 a-e	24.03 b-d	14.13 g	9.900 a
		0.3% Stockosorb by volume	3.633 de	8.133 a	25.03 ab	17.20 a	7.833 c-e
		10 wt% zeolite	3.833 a-e	7.833 a-e	24.60 a-c	15.57 b-f	9.033 a-e
		15 wt% zeolite	3.900 a-e	8.033 a-c	24.07 b-d	16.40 a-c	7.667 de
	80% sand	control	4.100 a-c	7.667 e	21.13 e	11.73 h	9.400 a-d
		0.1% Stockosorb by volume	3.900 a-e	7.733 c-e	24.60 abc	15.73 b-e	8.867 a-e
		0.3% Stockosorb by volume	3.700 c-e	8.067 ab	25.60 a	17.07 a	8.533 a-e
		10 wt% zeolite	3.967 a-d	8.100 a	23.57 cd	16.10 a-e	7.467 e
		15 wt% zeolite	3.767 a-e	8.100 a	24.73 a-c	16.30 a-d	8.433 a-e

Similar letters in each column indicate that the means are not significantly different.

Table 3. Mean comparisons of interaction effects of treatments for available elements and the studied some soil physical traits by LSD method (α=0.05).

Combination of treatment			Bd	Pd	Porosity	K	P	N
Irrigation	Sand (%)	Superabsorbents	(gr/cm3)	(gr/cm3)	(%)	(mg/kg)	(mg/kg)	(mg/kg)
Deficit irrigation	70% sand	Control	1.61 a	2.48 ab	34.90 d	157.0 d	60.33 ef	0.040 b
		0.1% Stockosorb by volume	1.43 b	2.44 ab	41.13 bc	192.7 ab	63.33 c-f	0.043 b
		0.3% Stockosorb by volume	1.37 b-e	2.43 ab	43.50 a-c	204.0 a	65.00 b-f	0.026 b
		10 wt% zeolite	1.42 bc	2.48 ab	42.67 a-c	186.3 ab	64.67 b-f	0.046 b
		15 wt% zeolite	1.36 b-e	2.45 ab	44.33 a-c	193.0 ab	57.67 b-f	0.046 b
	80% sand	Control	1.64 a	2.51 a	34.60 d	166.7 b-d	59.00 ef	0.033 b
		0.1% Stockosorb by volume	1.45 b	2.44 ab	40.17 c	193.3 a	66.00 a-f	0.066 a
		0.3% Stockosorb by volume	1.38 b-e	2.41 ab	42.53 a-c	194.0 a	64.33 b-f	0.030 b
		10 wt% zeolite	1.39 b-e	2.48 ab	43.73 a-c	193.0 ab	60.33 ef	0.030 b
		15 wt% zeolite	1.40 b-e	2.48 ab	43.50 a-c	200.3 a	73.33 a-c	0.023 b
Normal irrigation	70% sand	Control	1.65 a	2.51 a	34.40 d	156.0 d	61.33 d-f	0.023 b
		0.1% Stockosorb by volume	1.37 b-e	2.46 ab	44.20 a-c	189.0 ab	75.67 ab	0.036 b
		0.3% Stockosorb by volume	1.33 c-e	2.45 ab	45.47 a-b	200.3 a	77.00 a	0.023 b
		10 wt% zeolite	1.40 b-e	2.43 ab	42.37 a-c	183.7 a-c	64.33 b-f	0.043 b
		15 wt% zeolite	1.38 b-e	2.42 ab	43.13 a-c	197.3 a	77.33 a	0.050 b
	80% sand	Control	1.66 a	2.43 ab	31.60 d	158.0 cd	55.00 f	0.030 b
		0.1% Stockosorb by volume	1.41 b-d	2.38 b	40.57 c	188.0 ab	63.67 c-f	0.030 b
		0.3% Stockosorb by volume	1.32 e	2.47 ab	46.73 a	202.3 a	62.33 c-f	0.033 b
		10 wt% zeolite	1.43 b	2.43 ab	41.23 bc	187.7 ab	72.67 a-d	0.036 b
		15 wt% zeolite	1.33 de	2.44 ab	45.57 ab	192.3 ab	67.00 a-e	0.023 b

Similar letters in each column indicate that the means are not significantly different.

Soil physical, chemical and hydraulic properties

According to the results, the use of superabsorbent compounds caused reduced EC and increased pH as compared with control treatment, so that maximum EC (4-4.167 ds/m) and minimum pH (7-7.7) were recorded in the control treatment at both levels of irrigation and sand percentage (Table 2). This result is in agreement with the findings reported by Bal *et al.* (2010). They reported that the decrease of EC was due to the absorption of a large volume of water and physiological solutions of polymers. The high content of water in the soil leads to the dilution of solutes and low electrical conductivity (Bal *et al.*, 2010). Wang *et al.* (1987) investigated the water from soil leaching containing superabsorbent polymer and showed that this water was of low electrical conductivity. They related the reason for this decline to the absorption of fertilizers and salts added to the soil matrix by superabsorbent polymers. The increase of pH had been already reported by Ekaterina and Christos (2002). Mean comparisons of the interaction effects showed that permanent wilting point followed no clear trend at different levels of treatments. It seems that the mentioned treatments had no impact on the moisture content at wilting point. In contrast, the use of superabsorbents polymers (Stockosorb and zeolite) increased the field capacity and available moisture to plants. The maximum values of the mentioned traits were obtained from the combined treatment of 3% Stockosorb by volume+ 80% sand in the normal irrigation method, showing significant difference with a control treatment.

Maximum moisture content at field capacity and available moisture were calculated to be 25.6% and 17.2% and the lowest was 18.93% and 10.7%, respectively. With the deficit irrigation method, the maximum percentage of the studied traits were obtained from this combined treatment, showing no significant difference with normal irrigation method (Table 2). These results indicate that the use of stockosorb and zeolite polymers of the deficit irrigation method could partially improve soil moisture status as compared with normal irrigation methods. Therefore, water losses occurring to the plants in natural conditions are removed (Huttermann *et al.*, 1999) and consequently available soil moisture shows good results as compared with control. According to Abedi Koupai and Asadkazemi (2006), with the use of superabsorbents in the farm, soil reached to the permanent wilting point later which is inconsistent with our results. The reason may be attributed to the difference in soil texture. However, these results are consistent with the findings reported by other researchers, stating an increased soil water holding capacity due to the application of superabsorbents (Goebel *et al.*, 2005, Orikiriza *et al.*, 2013). As well, increased plant available water with the use of Stockosorb has been reported (Abdul-Qados, 2015).

Table 4. Regression coefficients of relationship between field capacity and soil porosity percentage.

Cubic Equation	df	Mean Square	R Square	Constant	b1	b2	b3
Regression	2	23.909 **	0.821 **	5.045	0.488	0.000	-2.384 E-5
Residual	17	0.789					

The increase of plant available water in treatments containing superabsorbents could be attributed to the structure of polymer and its hydrophilic properties (Chirino *et al.*, 2011). It seems that the network structure of Superabsorbents polymer causes higher water retention as compared with control. Superabsorbents significantly increase the amount of plant available water through water retention in the soil, changing soil pore size distribution, and reducing physical evaporation (Naderi and Vasheghani Farahani, 2006).

Table 5. Regression coefficients for the relationship between available moisture and soil porosity percentage.

Cubic Equation	df	Mean Square	R Square	Constant	b1	b2	b3
Regression	2	29.365 **	0.776 **	-17.998	1.028	0.000	0.000
Residual	17	1.111					

In other research, the reason of this increase was related to the effect of superabsorbents on increasing soil aggregates stability and prevent from crust formation and runoff in the farm (Behbahani *et al.*, 2009). According to other researchers, the reason of increased available soil moisture with the use of polymers was attributed to the reduced resistance to water penetration (Lino *et al.*, 2011, Li *et al.*, 2011), prevent water leakage and evaporation from the soil (Han *et al.*, 2013). Behbahani *et al.* (2009) with the application of different levels of Stockosorb, recommended a value of 0.3% weight% to increase soil moisture saturation. They stated that this increase was attributed to the improved soil structure (due to increased adhesion between soil aggregates) and capillary porosity. The lowest available phosphorus content (156 and 166.7 mg/kg soil) was recorded in the control treatment, showing significant difference with other treatments, which indicates the effect of superabsorbent polymers on increasing this trait. Available phosphorus showed no significant difference between the treatments of normal and deficit irrigation methods. Available phosphorus content in the treatments of the normal irrigation method was more than that of the same treatments in deficit irrigation method; however this difference was not statistically significant. However, the maximum value for this trait was obtained from the treatment of 70% sand with normal irrigation and application of 0.3% Stockosorb by volume and 15 weight% zeolite. In addition, total nitrogen was not influenced by different treatments and did not follow a clear trend (Table 3). Increased levels of exchangeable potassium with the use of superabsorbent compounds were reported by Ekaterina and Christos (2002).

Table 6. Correlation coefficients of the studied traits (n=20).

	Available moisture	Soil porosity (%)	Seedling height (cm)	Large canopy diameters (cm)	Small canopy diameters (cm)	Basal area (mm)
Available moisture	1					
Soil porosity (%)	0.862 **	1				
Seedling height	0.499 *	0.504 *	1			
Large canopy diameters	0.726 **	0.660 **	0.833 **	1		
Small canopy diameters	0.811 **	0.742 **	0.781 **	0.974 **	1	
Basal area	0.569**	0.464 *	0.208 ns	0.380 ns	0.419 ns	1

*, ** and ns indicate significant differences from control (P<0.05 and P<0.01 and no significant differences respectively).

In other research, it was shown that, with the use of zeolite, soil quality was improved through the availability of elements such as potassium and phosphorus (Polite *et al.*, 2004), which is in agreement with our results. It was also reported that an amount of potassium present in the formulation of superabsorbent compounds might have entered the soil (El-Hady *et al.*, 2006). According to the results of mean comparisons, similar treatments in normal and deficit irrigation methods showed no significant difference in bulk density, practical density and soil porosity. However, bulk density and soil porosity showed significant difference between control treatment and the treatments of Stockosorb and zeolite application. Maximum soil bulk density was obtained from the control treatment at different levels of sand percentage and irrigation methods (1.61 gcm^{-3} to 1.66 gcm^{-3}), showing significant difference with all treatments. Actually, the value of this trait was decreased by using superabsorbent polymers, as compared with control treatment. Maximum soil bulk density was obtained from 0.3 % Stockosorb by volume (gcm^{-3}). However, different treatments had no significant effect on soil practical density and all treatments were in one statistical group. Maximum soil porosity was recorded in the treatment of Stockosorb and zeolite application at both treatments of sand percentage and irrigation method, showing significant difference with control treatment (Table 3). Given the importance of soil porosity in water retention, the relationship between soil porosity and field capacity was investigated. The results of regression analysis showed a significant relationship between soil porosity and the mentioned traits ($p<0.01$), so that the coefficient of determination of the relationship between soil porosity and field capacity was calculated to be 82% as a third degree equation (Table 4 and Fig. 1). A third degree equation with a coefficient of determination of 77% was obtained for soil porosity and available moisture (Table 5 and Fig. 2). According to the results, changes in soil porosity are due to the swelling of the polymer in the presence of water, leading to an increase in the volume of soil, reduced bulk density and increased total porosity. Increased soil porosity and reduced bulk density with the higher use of superabsorbent polymers was already reported in literature (Behbahani *et al*., 2009, Han *et al*., 2013, Zangooei Nasab *et al*., 2013). In a study on the use of zeolite in the soil, it was reported that this compound could increase the capillary porosity of the soil and through absorption of water could increase the moisture retention in sandy soils (Shaddox, 2004). Zangooei Nasab *et al*. (2013) stated that reduced soil bulk density with the use of superabsorbent polymers was resulted from soil expansion and low bulk density of water in comparison with soil bulk density. There was a significant positive correlation between soil porosity and available moisture with all morphological traits (Table 6). This result can explain the cause of the improved plant morphological characteristics after the application of different treatments (compared with control). It seems that nutritional effects (such as increased potassium and phosphorus in the soil), improved physical properties and increased available water due to the use of superabsorbents increased plant growth parameters. Although, Islam *et al*. (2011) reported that these compounds have no direct role in nutrition, in any case, the application of superabsorbents is one of the most effective methods to help the plants grow through increasing water storage in sandy soils (Akhter *et al*., 2004).

Conclusion

The results clearly showed that there were significant differences between two irrigation methods in terms of morphological characteristics of *Atriplex canescens*. However, this difference in terms of physical, chemical and hydraulic characteristics of soil was not significant. Therefore, it can be concluded that the use of Stockosorb and zeolite polymers of the deficit irrigation method could delay the time to reach the permanent wilting point, through increasing the plant available water, field capacity and soil porosity in arid regions. Therefore, if the sole goal of *Atriplex canescens* cultivation in rangelands is to improve range condition and plant species diversity, deficit irrigation method and superabsorbents could be recommended in arid regions similar in the study area. According to the results, the polymers with the increase of available water to the plants prevent critical drying (wilting point) and have a great impact in rehabilitation of the regions in which timing and amount of irrigation for plants is limited. The importance of this issue in Iran, which is in the category of arid countries with average annual rainfall of 210 mm, is very high. On the other hand, normal irrigation could be recommended when livestock grazing and producing excellent seedlings with maximum length and diameter growth are the goals of *Atriplex canescens* cultivation.

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