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Effect of irrigation regimes and application of barley residue, zeolite and superabsorbent polymer on forage yield, cadmium, nitrogen and some physiological traits of corn and sorghum

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Abstract

In water deficit conditions, planting the proper crop, utilizing efficient cropping methods and using soil amendments can reduce the harmful effects of drought stress. Therefore to investigate some agronomic and physiological characteristics of corn and sorghum under various irrigation regimes and combination treatments of barley residue, zeolite, and superabsorbent polymer (RZS), two separate experiments (each plant, one experiment) were conducted over two years in Iran. A randomized complete block design arranged in a split plot was used with three replications. Two irrigation regimes of normal irrigation and water deficit stress based on 70 mm and 140 mm cumulative pan evaporation, respectively, were compared in main plots. Five RZS treatments, (I) -10 t ha^{-1} zeolite + 4.5 t ha^{-1} residue (ZR), (II) - 60 kg ha^{-1} superabsorbent + 4.5 t ha^{-1} residue (SR), (III) - 5 t ha^{-1} zeolite + 30 kg ha^{-1} superabsorbent +4.5 t ha^{-1} residue (ZSR), (IV) - 4.5 t ha^{-1} residue (R), and (V) – control (C), were compared in subplots. Under water deficit stress, Malondialdehyde and proline content in leaf increased, but the forage yield decreased significantly. In both plants, zeolite application (ZR and ZSR treatments) had the highest forage yields and the lowest cadmium concentrations for forage. Using 4.5 t ha^{-1} residues (R), significantly affected increasing RWC and decreasing leaf Malondialdehyde and proline. The forage fresh yield of corn and sorghum (first cutting) were 62.6 and 48.5 t ha^{-1}, respectively. We recommend planting corn using 5 t ha^{-1} zeolite and 4.5 t ha^{-1} residues in a double-cropping system.

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Introduction

In Iran, drought stress due to water deficit is the most important environmental stress limiting plant growth and production. Planting the proper crop, utilizing efficient cropping methods, and using soil amendments can reduce the harmful effects of drought stress. In arid and semi-arid environments, materials such as zeolite, superabsorbent polymer, and crop residue can increase a soil's water holding capacity as well as its nutrient absorption and release to avoid damage caused by stress to the photosynthetic apparatus (Wicks *et al.,*1994; Polat *et al.,* 2004; Mao *et al.,* 2011). To assess the impact of management factors on moderating drought stress, we can usefully measure some physiological and agronomic parameters such as proline, MDA, soluble protein, relative water content, and yield. Proline, as an active amino acid in the osmoregulation process, is the most stable amino acid which resists oxidative stress and has minimal inhibitory effects on cell growth (Kumur, 1992). Lipid peroxidation indicates oxidative stress in plants, and MDA, the product of lipid oxidation of cell membranes, is put as a good marker for determining the amount of oxidative damage to lipids under stress conditions (Davey *et al.,* 2005). Reduced soluble protein content in leaf is a sign of reduced Rubisco concentration, which can be followed to reduce the current photosynthetic activity (Saeidi *et al.,* 2011). Relative water content is closely related to plant water potential. As plant water potential decreases, relative water content also decreases. Consequently, with a decrease in stomata conductance and a plant's inaccessibility to CO_2, photosynthesis decreases (Lafitte, 2002). Zeolites added to the soil can improve the condition of the soil for maintaining moisture and nutrients, which results in a significant reduction of agricultural costs of water and fertilizer (Ploat *et al.,* 2004). Moreover, numerous laboratory and field studies have been conducted to demonstrate the effectiveness of natural and synthetic zeolites in reducing heavy metal content in plants (Leggo *et al.,* 2006). Eskandari *et al.*, (2012) stated that the relative water content and soluble protean of leaf in medicinal pumpkin (*Cucurbita pepo* L.) were reduced under water deficit stress, but the application of 12 t ha^{-1} zeolite increased relative water content and soluble protean and simultaneously decreased proline in leaf. Falkon *et al.* (2009) reported a 54% yield reduction in triticale under water stress in soil lacking zeolite, whereas in the same soil with an adequate intake of zeolite, only a 16% yield reduction was obtained. Naseri *et al.* (2012) observed a maximum grain yield of 4287.6 kg ha^{-1} in sorghum with normal irrigation and the application of 12 t ha^{-1} zeolite. In their study, the percentage of grain protein increase under water stress and maximum grain protein were obtained in the water stress treatment without the use of zeolite. Another batch of additives for soil is the superabsorbent polymers which are currently a focus in the arid and semiarid regions of the world for reducing the use of water and fertilizer on plants. Johnson (1984) reported a 171% to 402% increase in the soil's water holding capacity by applying superabsorbent polymer to sandy soil. In another experiment, using 60 kg ha^{-1} superabsorbent polymer increased the soluble protein of corn leaf 15.3% and decreased the MDA content of leaf 13.1% (Mao *et al.,* 2011).

In Iran, 25000 and 395000 ha of sorghum and corn, respectively, were cultivated in 2012. Corn plays an important role in providing the required forage of the country due to its high yield and compatibility with environmental conditions, but a water deficit limits production and promotion of corn cropping. In water deficit conditions, sorghum may be a good alternative to corn because of its high drought resistance. Therefore, based on the mentioned characteristics, the objectives of this study were: (1) to investigate yield and physiological changes in corn and sorghum under two irrigation regimes (normal irrigation and water deficit stress) and the application of barley residue, zeolite, and superabsorbent polymer; (2) to compare the yield of corn and sorghum under minimum tillage in a double-cropping system.

Materials and methods

This study was carried out at the Jupar Research Station of Agricultural and Natural Resources

Research Center in Kerman, Iran (57°14´E longitude, 31°7´N latitude, and altitude of 1749 m) over two years, 2012-2013. Air temperatures changes over two growing seasons are presented in fig.1. The randomized complete block design (RCBD) arranged in a split plot was used with three replications to study each plant species separately (each plant, one experiment). Two irrigation regimes of normal irrigation and water deficit stress based on 70 mm and 140 mm cumulative pan evaporation, respectively, were compared in main plots. Five combination treatments of barley residue, zeolite, and superabsorbent polymer (RZS), (I) -10 t ha^{-1} zeolite + 4.5 t ha^{-1} residue (ZR), (II) - 60 kg ha^{-1} superabsorbent + 4.5 t ha^{-1} residue (SR), (III) - 5 t ha^{-1} zeolite + 30 kg ha^{-1} superabsorbent +4.5 t ha^{-1} residue (ZSR), (IV) - 4.5 t ha^{-1} residue (R), and (V) – control (C) without adding soil amendments were compared in subplots. In this study, sorghum (Peghah cultivar) and corn (SC704 hybrid) were planted on June 11th and 12th of the first and second year, respectively. The zeolite and superabsorbent polymer used in this research were obtained from the Afrazand Company (Zeolite mines of Mianeh – Iran) and the Petrochemical Institute of Iran, respectively. Physical and chemical analyses of soil, zeolite, and superabsorbent polymer are presented in Table 1. This research was conducted under minimum tillage in a former crop bed (barley) which was planted in two rows on either side of the furrow. Each subplot had 5 lines spaced 70 cm apart and measuring 7 meters long. Superabsorbent polymer and zeolite were placed 18 cm under the soil surface in the middle of the furrow, and barley residue was spread on the soil surface. Chemical fertilizers used were184 kg ha^{-1} N, 40 kg ha^{-1} P2O5, and 55 kg ha^{-1} K2O in the first year and 184 kg ha^{-1} nitrogen, 25 kg ha^{-1} P2O5, and 30 kg ha^{-1} K2O in the second year in the form of urea, triple super phosphate, and potassium sulphate, respectively. Corn and sorghum were planted with a density of 102040 and 178570 plants ha^{-1}, respectively. Water deficit stress was applied 17 days after planting, and irrigation timing was determined based on 70 mm (normal irrigation) and 140 mm (water deficit) cumulative pan evaporation. In this study, the furrow irrigation method was used. At irrigation time, volumetric soil moisture content at a depth of highly active root zone was measured using a Time-Domain Reflectometry (TDR), model Trime-FM (TDR device was calibrated before using). The depth of root zone varied from 14 cm in the early stage (3-4 leaf stage) to 41 cm in the late stage, according to plant growth. In each plot the amount of required water was calculated using the following equations (Fotouhi *et al.*, 2007).

$I_n = (\theta_{fc} - \theta_i) \times d$, $V = I_n \times A$

θ_{fc}: volumetric soil moisture at field capacity, θi: volumetric soil moisture at irrigation time, d: depth of root zone (mm), I_n: irrigation depth (mm), A: area of the plot (m^2), V: volume of required water for the plot. Soil moisture content in field capacity was determined using a pressure plate apparatus in the central laboratory of the Soil and Water Department. The volume of water which entered the plots was measured with 2-inch flow meters installed in the delivering pipes.

Leaf relative water content (RWC) was determined in five leaves (highest, fully developed leaves) from five randomly selected plants ten weeks after planting. In all treatments, the leaf samples were taken between 9.30 - 10.30 am. The following equation was used to calculate RWC (Malta and Lamattina, 2001):

%RWC= (Fw-Dw)/ (Tw-Dw) ×100.

Fw: Leaf fresh weight, Dw: Leaf dry weight, Tw: Saturated leaf weight (Leaves were kept in distilled water and darkness at 5°C for 24 hours.), RWC: relative water content. To measure free proline, total soluble protein, and malondialdehyde (MDA), leaf sampling (ear leaf in corn and fourth fully-developed leaf from top in sorghum) was performed ten weeks after planting. Samples were collected, immediately placed into a liquid nitrogen tank, and stored at -80°C. Free proline content was measured according to Bates *et al.* (1973). Total soluble protein was determined using Bradford's method (1976) with bovine serum albumin as a standard. MDA concentration was estimated using the method of

Hodges *et al.* (1999). Total nitrogen content was determined using Kjeldahl's method automated with the Kjeltec. Cd concentration in the dry matter of forage was determined using a Shimadzo AA-670 atomic absorption spectophotometer (Sparks, 1996).

The following equation was used to measure soil moisture content at a depth of 0-25 cm (Fotouhi *et al.,* 2007):

%Sm = (Ww-Dw)/Dw

Sm: Soil moisture, Ww: Wet weight, Dw: Weight of dry soil.

The forage fresh yield of sorghum (89 days after planting in 14 leaves stage) and corn (90 days after planting in grain dough stage) were harvested from an area of 7 m^2. After weighing and measuring water content, forage fresh yield was calculated based on 79% moisture.

Data analysis

Split-plot analysis was performed to study each plant species separately by two-way ANOVA using Proc GLM of SAS 9.2. To compare means, Duncan's test and LSMEANS statement was used for each plant. Since interaction between the two growing seasons was not significant, the mean of two years for the treatments was used. The two plant species were compared with each other using the t-test.

Results and discussion

Forage fresh yield

Based on the results, the forage fresh yields of corn and sorghum (1st cutting) were 62.6 t ha^{-1} and 48.5 t ha^{-1}, respectively (Table 2). In the period of 90 days after planting, the growth rate of corn (CGR) and its dry matter production per area unit were much greater than those of sorghum (data not shown). The higher forage dry matter yield of corn compared to sorghum has been previously reported (Khalesro *et al.,* 2009). In water deficit stress, the yield of fresh forage of both plants was significantly reduced (Table 3). Reduced soil moisture leads to a range of morphological and biochemical changes in plants. The consequential increase of abscisic acid in plant shoots changes the hormonal balance, decreases photosynthesis enzymes activity, and finally reduces the plant biomass (Levitt, 1980). In this research, the reduction of forage yield under water deficit stress can be attributed to the low moisture content of the soil (Table 3). Other researchers have also reported the reduction of corn and sorghum yield under drought stress (Kamara *et al.,* 2003; Tanguillig *et al.,* 1987).

Table 1. Result of physico- chemical properties of soil (0-30 cm depth), Zeolite and Superabsorbent polymer.

	Soil analysis		Zeolite		Superabsorbent polymer (A200)	
Year	2012	2013				
Soil texture	S.L	S.L	SiO2 (%)	68	Appearance	White granule
F.C (%)	19.2	19.2	Al2O3 (%)	11.5	Particle size (mm)	1-5
P.W.P (%)	7.8	7.8	Zn (mg/kg)	0.46	Moisture content (%)	2-3
BD (g/cm3)	1.41	1.41	Cu (mg/kg)	0.45	Density (g/cm3)	1.3-1.5
O.C (%)	0.48	0.5	Mn (mg/kg)	1.64	PH	6-7
P (mg/kg)	8	9.7	Fe (mg/kg)	1.15	Absorbency in %9 NaCl (g/g)	45
K (mg/kg)	208	224	Cd (mg/kg)	0.03	Absorbency in distilled water	220
PH	7.9	7.9	P (mg/kg)	16	Stability in soil (year)	7
EC (ds/m)	1.2	1.3	K (mg/kg)	7400	-	-
-	-	-	C.E.C (meq/100g)	260	-	-

F.C: Field Capacity, P.W.P: Permanent Wilting Point, BD: Bulk Density, O.C: Organic Carbon, S.L: Sandy loam, EC: Electrical Conductivity.

Combination treatments of barley residue, zeolite, and superabsorbent polymer (RZS) significantly affected the Forage fresh yield of corn and sorghum. In both plants, ZR and ZSR treatments produced maximum forage yields, while the lowest forage yield was harvested from the control treatment (Table 3). The results prove the positive role of residue and zeolite in increasing forage yield. In many studies where crop residues were preserved on the soil surface, the increased yield was attributed to the maintenance of soil moisture and reduction of evaporation (Wicks *et al.,* 1994). In our research, the increased forage yield caused by applying barley residues to the soil surface is attributed to the role of residues in maintaining soil moisture (Table 3). Some studies have also reported increased corn and sorghum yields achieved by applying zeolite (Naseri *et al.,* 2012; Bernardi *et al.,* 2011). Because it absorbs and maintains water and nutrients in the soil for a long time, zeolite can keep water and elements such as nitrogen, potassium, calcium, magnesium, and micronutrients in the root environment and then release them according to the plant's needs, ultimately improving plant growth (Mumpton, 1999). In the present study, neither plant showed significant differences in forage yields between R and SR treatments, indicating the ineffectiveness of superabsorbent polymer in the presence of residue (Table 2). The interaction effect of irrigation regimes and RZS treatments on forage yield was not significant, which represents the same reaction of RZS treatments in different irrigation regimes (data not shown).

Table 2. Comparison of forage fresh yield, nitrogen, cadmium, soil moisture and physiological parameters between corn and sorghum.

Plant species	Forage fresh yield (kg ha-1)	Nitrogen (%)	Cadmium (mg/kg)	Soil moisture (%)	RWC (%)	Proline cotent (μmol/g. F.W)	MDA content (μmol/g. F.W)	Soluble protein content (mg/g.F.W)
Maize	62605 a	1.05 b	1.296 a	9.82 a	87.7 b	4.74 a	7.56 a	7.78 a
Sorghum	48506 b	1.22 a	1.162 a	9.5 a	89.79 a	4.93 a	5.81 b	8.63 a

In each column, means with the same letter are not significant differences according to t-test.

Forage Nitrogen (N)

As previously reported (Naseri *et al.,* 2012), the nitrogen content of forage sorghum increased significantly under water deficit stress (Table 3). Interpreting water deficit effects on absorbing and cumulating elements in plants is rather difficult. Researchers have reported the different effects of absorbing nutrients on various species and different genotypes of one species under stress conditions (Tanguilig *et al.,* 1987). In this study, based on the significant reduction of forage yield under water deficit stress (Table 3), we can state that the nitrogen concentration in plant tissue increases with a decrease in dry matter production in area unit; subsequently, the dilution of the nutrient element in plant tissue is reduced. The results of some studies have shown that a reduction in dry matter production results in reduced dilution of the nutrient element and ultimately increased nitrogen concentration in plant issue (Tanguiling *et al.,* 1987; Singh *et al.,* 1973). In comparing the two plants, we found that the forage nitrogen content in sorghum was 13.12% higher than that of corn (Table 2). Sorghum can absorb more nitrogen from the soil because of its root system and its power to 'suck' more moisture. This result is in agreement with the findings of Khalesro *et al.* (2010), who reported the superior nitrogen concentration of sorghum forage in comparison with corn forage. In sorghum, the effects of RZS treatments on the nitrogen percentage of forage show that treatments of zeolite with residue (ZR and ZSR) have the lowest nitrogen percentage, and the control treatment has the highest nitrogen percentage. For corn, however, the control treatment has the lowest nitrogen percentage, and no significant difference was observed among the other treatments (Table 3). We have also observed the negative correlation between forage yield and nitrogen percentage for forage, r= -0.82 (correlation table not shown). At harvest, total percentage of soil nitrogen was more in depths of 0-30 cm and less in depths of 30-60 cm in the ZR and ZSR treatments than in the other treatments (data not shown). Therefore, the lower concentration of nitrogen in zeolite treatments (ZR and ZSR) can be attributed to two factors: a) the blocking of nitrogen in the soil by zeolite, and b) the reduction of nitrogen dilution in plant tissue caused by increased forage yield. One study reported a reduction in the nitrogen concentration of sorghum due to the use of zeolite (Naseri *et al.,* 2012). Another research reported that zeolite in the soil blocking nitrogen caused a reduction in nitrogen in forage (Rahakova *et al.,* 2004).

Table 3. Effect of irrigation regimes and combination treatments of barley residue, zeolite and super absorbent polymer (RZS treatments) on soil moisture, forage fresh yield, forage nitrogen and forage cadmium of corn and sorghum .

	Corn				Sorghum			
Experimental factors	Forage fresh yield (kg ha-1)	Nitrogen (%)	Cadmium (mg/kg)	Soil moisture (%)	Forage fresh yield (kg ha-1)	Nitrogen (%)	Cadmium (mg/kg)	Soil moisture (%)
Irrigation Regimes								
Normal irrigation	67843 a	0.96 a	1.01 b	11.4 a	55593 a	1.04 b	0.87 b	11.07 a
Water deficit	57368 b	1.15 a	1.58 a	8.24 b	41420 b	1.39 a	1.45 a	7.94 b
RZS treatments								
ZR	68158 a	0.980 b	1.01 b	10.07 a	53902 a	1.12 b	0.94 b	9.79 a
SR	64314 ab	1.03 b	1.47 a	9.78 a	47175 b	1.23 ab	1.32 a	9.33 ab
ZSR	66446 ab	1.02 b	0.94 b	10.17 a	52148 a	1.16 b	0.95 b	9.67 a
R	61884 b	1.03 b	1.45 a	10.15 a	46897 b	1.24 ab	1.34 a	9.68 a
C	52225 c	1.21 a	1.6 a	8.95 b	42410 c	1.31 a	1.24 a	9.04 b

Means with the same letters in each column are not significantly different (Duncan's, P≤0.05).

ZR: 10 t ha^{-1} Zeolite + 4.5 t ha^{-1} barely residue, SR: 60 kg ha^{-1} Superabsorbent polymer + 4.5 t ha^{-1} barely residue, ZSR: 5 t ha^{-1} Zeolite + 60 kg ha^{-1} Superabsorbent polymer + 4.5 t ha^{-1} barely residue, R: 4.5 t ha^{-1} barely residue, C: Control.

Forage Cadmium (Cd)

Cadmium is a nonessential, toxic element and environmental pollutant that has inhibitory effects on plant growth and chlorophyll synthesis (Ernst *et al.,* 1992). Under water deficit stress, Cd concentrations increased 36.05% and 39.50% in corn and sorghum forage, respectively (Table 3), but no significant difference was seen in a comparison of the two plants (Table 2). In water deficit stress, the increase in Cd concentration of forage can be attributed to the lower forage yield which is caused by the reduction in dilution in plant tissue (Table 3). Some studies have shown that as the dry matter production decreases under stress conditions, the dilution of nutrient elements decreases in plant tissue, and consequently the element's concentration increases in plant tissue (Singh *et al.,* 1973; Tanguiling *et al.,* 1987). ZR and ZSR treatments for both plants had the lowest amount of Cd concentration in forage (Table 3). Various studies have documented the positive role of zeolites in stabilizing and reducing the adsorption of heavy metals by roots (Gworeke, 1992; Rehakova *et al.,* 2004). Zeolites are mostly used for removing heavy metals because of their high capacity for cation exchange and ion absorption in wide ranges. This leads to a reduction in the Cd concentration of soil soluble containing zeolite, and the plant will have little absorption (Ponizovsky and Tsadilas, 2003). In several experiments, the use of zeolites in soils contaminated with heavy metals caused significant decreases in these elements in plant tissue (Koelliker *et al.,* 1980). Eshghi *et al.* (2010) have stated that zeolite can decrease the Cd accumulation in soybean shoots.

Leaf Proline

In both corn and sorghum, the amount of proline in leaf was significantly increased under water deficit stress. The leaf proline content was 41.3% and 48.6% higher under water deficit stress than normal irrigation in corn and sorghum respectively (Table 4). In sorghum, no significant differences were seen among RZS treatments under normal irrigation conditions regarding the amount of proline, but under water deficit stress, the control treatment had the highest leaf proline. Other treatments(ZR, SR, ZSR and R) showed no significant differences (Fig. 2). In corn, the control treatment had the highest proline content under conditions of both normal irrigation and water deficit stress, but there were no significant differences among the treatments of ZR, SR, ZSR, and R (Fig. 2). No significant differences were seen in either plant with regard to leaf proline (Table 4). Some studies have documented and reported the accumulation of proline as a free amino acid with a high degree of water solubility in the shoots of various plants under different stresses (Thomas *et al.,* 1992; Jones *et al.,* 1980). The accumulation of this amino acid in leaf can provide cells the possibility of water absorption by means of reducing the osmoregulation potential and cell water potential. In one study, the amount of accumulated proline under drought stress in tobacco plant was more than 80% of the total amino acids in this plant.

Table 4. Effect of irrigation regimes on leaf relative water content (RWC), leaf proline, malondialdehyde(MDA) and soluble protein of corn and sorghum.

	Maize				Sorghum			
Experimental factors	RWC (%)	Proline cotent (μmol/g. F.W)	MDA content (μmol/g. F.W)	Soluble protein content (mg/g.F.W)	RWC (%)	Proline cotent (μmol/g. F.W)	MDA content (μmol/g. F.W)	Soluble protein content (mg/g.F.W)
Irrigation regimes								
Normal irrigation	88.5 a	3.51 b	6.52 b	8.24 a	90.3 a	3.349 b	4.94 b	10.28 a
Water deficit	86.2 b	5.98 a	8.60 a	7.31 a	89.2 a	6.52 a	6.68 a	6.98 b

Means with the same letters in each column are not significantly different (Duncan, P≤0.05).

This indicates the role of proline in the osmoregulation process under stress conditions (Binzel *et al.,* 1987). Soil amendments such as zeolite, superabsorbent polymer, and residues, due to their positive influence in keeping moisture in soil, can prevent stress from affecting a plant by providing it with much usable water. The lack of a significant difference between barley residue treatment (R) and the ZR, SR, and ZSR treatments indicates that residues play a main role in moderating water deficit stress. In this research, no significant difference was observed in the amount of soil moisture in the residue treatment (R) and the ZSR, SR, and ZR treatments (Table 3). Crop residues on the soil surface retain more moisture in the soil by making a shadow, reducing evaporation, and reducing the temperature of the soil surface layer (Wicks *et al.,* 1994; Lal, 1995).

Leaf Malondialdehyde (MDA)

MDA contents in the leaves of both corn and sorghum plants were significantly higher under conditions of water deficit stress than under normal irrigation (Table 4). In the sorghum experiment, the control treatment (C) had the highest amount of MDA, but the ZR treatment under normal irrigation and the SR treatment under water deficit stress had the lowest MDA contents (Fig. 3). In the corn experiment, there was no significant difference between the RZS treatments under normal irrigation, but under water deficit stress, the control treatment had the highest MDA content. No significant differences were observed among the ZR, SR, ZSR, and R treatments (Fig. 3). MDA, the product of lipid oxidation of cell membrane, is put as a good marker for determining the amount of oxidative damage to lipids under stress conditions (Davey *et al.,* 2005). An increase in MDA content indicates that water deficit stress can lead to cell membrane lipid oxidation by producing oxygen free radicals (Sairam *et al.,* 2000). Soil amendments due to their positive influence in retaining moisture in soil, can reduce the accumulation of MDA by providing much available water for the plant. Therefore, a small amount of MDA indicates the suitability of conditions and the balancing of oxidative stress caused by the application of zeolite and superabsorbent polymer. Some researchers have also reported an increase in leaf MDA content under water stress conditions and its reduction caused by the application of zeolite and superabsorbent polymer under stress conditions (Islam *et al.,* 2010; Mao *et al.,* 2011; Eskandari Zanjani *et al.,* 2012). In comparing the two plants, corn had a higher MDA content than sorghum (Table 2). The lower amount of MDA in sorghum can be attributed to its extensive root system, the waxy coating on the leaves, and the lower transpiration rate in contrast to corn, which accordingly can reduce water loss (Francis *et al.,* 1984).

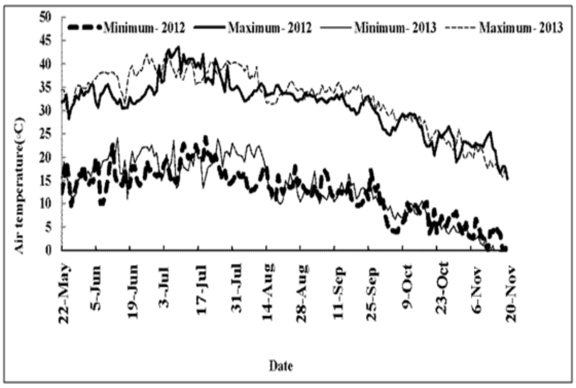

Fig. 1. Daily air temperature from 22 May to 20 November over two years (2012-2013).

Total Soluble Protein of Leaf

In sorghum, the soluble protein content significantly decreased under water deficit stress, but this reduction was not significant in corn (Table 4). In both plants in terms of water deficit stress, the highest soluble protein contents were related to the ZR and ZSR treatments, and the lowest content was related to the control treatment (Fig. 4). For corn under normal irrigation conditions, the SR and control(C) treatments had the highest and lowest soluble protein content, respectively (Fig. 4). For sorghum in normal irrigation conditions, the control(C) and residue(R) treatments had the least amount of soluble protein content (Fig. 4). Rubisco is the most important and most abundant soluble protein in a leaf. Every kind of reduction in the soluble protein content of leaf is a sign of reduced Rubisco concentrations, which can be followed to reduce the current photosynthetic activity (Saeidi *et al.,* 2011). A reduction in soluble protein content under stress can be the results of protein reactions with free radicals, the increase of the activity of protein-degrading enzymes, the reduction of protein synthesis, or the accumulation of free amino acids such as proline (Ranjan *et al.,* 2001). The reduction of the amount of soluble protein in drought conditions has also been reported by other researchers (Ranjan *et al.,* 2001; Islam *et al.,* 2010). The increased rate of soluble protein caused by the application of zeolite, residue, and superabsorbent polymer could be due to improved photosynthesis and moderating stress conditions caused by the beneficial effects of amendments on soil properties. Increased rate of soluble protein due to the application of zeolites and superabsorbent polymer under stress conditions have also been reported (Eskandari Zanjani *et al.,* 2012; Islam *et al.,* 2010).

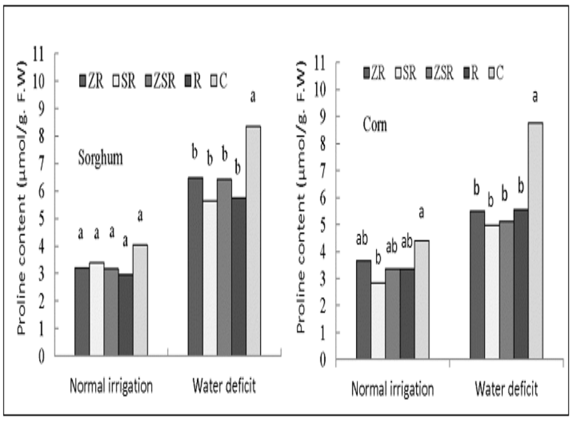

Fig. 2. Proline content of normal irrigation and water deficit stress under RZS treatments in sorghum (left) and corn (right). Different letters indicate significant differences among mean values within each irrigation treatment (LSMEANS, P≤0.05).

Relative Water Content (RWC)

Under water deficit stress, the RWC in corn was significantly decreased, but the RWC in sorghum was not significantly affected (Table 4). RWC is directly related to a plant's water potential; as water potential decreases, the RWC decreases, and subsequently, due to the reduction in plant stomata conductance and access to CO_2, photosynthesis is reduced (Lafitte, 2002). Reduced RWC under drought stress has been reported in a range of crops, including corn and sorghum (Singh and Singh, 1995). Sorghum had a greater RWC than corn (Table 2), which can be attributed to its extensive root system, waxy coating on the leaves, and lower transpiration rate (Francis *et* *al.,* 1984). Therefore, the high RWC in sorghum may be due to mechanisms that reduce water loss through stomata closure or due to the greater absorption of water through the roots and the power of sucking more moisture from soil (Jiang *et al.,* 2001). For corn, ZR and ZSR treatments had the highest RWC, and the control treatment had the lowest RWC (Fig. 5). For sorghum under normal irrigation conditions, the ZR and control(C) treatments had the highest and lowest RWC, respectively. In this plant under stress conditions, the lowest RWC was observed in the control treatment. No differences were seen among other treatments (Fig. 5). The reduction in RWC in the control treatment can be attributed to the lack of available moisture to the plant due to much evaporation and the lack of residue in the soil surface. Crop residues on the soil surface tend to retain moisture by making a shadow, reducing evaporation, and moderating the temperature of the surface layer of soil (Wicks *et al.,* 1994; Lal, 1995). In this study, the soil moisture was significantly lower in the control treatment than in other treatments (Table 3). Therefore, the existence of residue on the soil surface provides much accessibility to moisture by retaining the soil moisture for a long time. Zeolite can help improve plant growth by maintaining moisture in channels and cavities and by supplying the needed moisture to the plant (Mumpton, 1999; Polat *et al.,* 2004). Eskandari Zanjani *et al.* (2012) reported similar results in increasing RWC by applying zeolite.

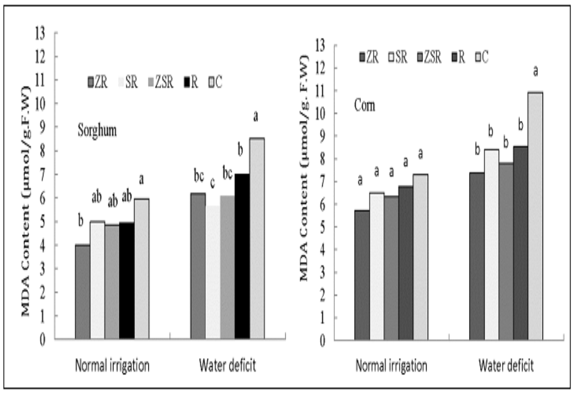

Fig. 3. Malondialdehyde (MDA) content of normal irrigation and water deficit stress under RZS treatments in sorghum (left) and corn (right). Different letters indicate significant differences among mean values within each irrigation treatment (LSMEANS, P≤0.05).

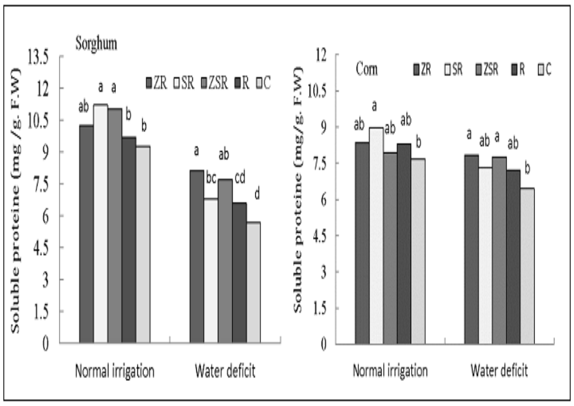

Fig. 4. Soluble protein content of normal irrigation and water deficit stress under RZS treatments in sorghum (top) and corn (bottom). Different letters indicate significant differences among mean values within each irrigation treatment (LSMEANS, P≤0.05).

Conclusions

Under water deficit, free proline and MDA content in leaf were increased but RWC, and total soluble protein and forage fresh yield were decreased. Therefore, these parameters can be used to assess the severity of drought stress in plants. Considering the trends in growth reduction due to water stress and the progressive influence of crop residue and zeolite on the growth parameters of corn and sorghum, it was clear that the application of these materials would be more appropriate for growth and productivity of these crops in the double cropping system in Kerman, Iran. Maintaining crop residue on the soil surface can reduce the effects of water deficit by improving soil properties. The application of zeolite at our recommendation (5 t ha^{-1}) will cost an additional 100 USD ha^{-1} (5 t × 20 USD), whereas, the price of forage produced (average of 4.87 t ha^{-1}) due to the application of 5 t ha^{-1} zeolite for one growing season was equal to 243.5 USD (4.87 t × 50 USD). Moreover, zeolite can maintain soil moisture and nutrients for several years after its application. At the same time, it can also increase crop yield. Nevertheless, there are many zeolite mines in Iran with agricultural applications, most of which remain unused. Zeolite prices in Iran range from 18 - 20 USD per ton. Therefore, using this material would be advantageous to Iran's agricultural, because it is inexpensive and abundant. The results also showed that forage corn cannot be replaced by forage sorghum because of the short growing season after harvesting winter cereals in the double cropping system.

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References

Ahmed OH, Sumalatha G, Nik Mohamad AM. 2010. Use of zeolite in maize (*Zea mays* L.) cultivation on nitrogen, potassium and phosphorus uptake and use efficiency. International Journal of the Physical Sciences **15,** 2393-2401.

Bates IS, Waldren RP, Teare ID. 1973. Rapid determination of free proline for water-stress studies. Plant Soil **39,** 205-207.
http://dx.doi.org/10.1007/BF00018060

Bernardi AC, Souza GBD, Polidoro JC, Paiva PR, Mello MBD. 2011. Yield, quality components and nitrogen levels of silage corn fertilized with urea and zeolite. Communications in soil science and plant analysis **42,** 1-10.
http://dx.doi.org/10.1080/00103624.2011.571980

Binzel ML, Hasegawa PM, Rhodes D, Handa S, Handa AK, Bressan RA. 1987. Solute accumulation in tobacco cells adapted to NaCl. Plant Physiology **84,** 1408-1415.

Bradford M. 1976. A rapid and sensitive method for the quantitation of microgram quantities of protein utilizing the principle of protein-dye binding. Analytical Biochemistry **72,** 248-254.
http://dx.doi.org/101016/0003-2697(76)90527-3

Davey MW, Stals E, Panis B, Keulemans J, Swennen RI. 2005. High-throughput determination of malondialdehyde in plant tissues. Analytical Biochemistry **347,** 201-207.
http://dx.doi.org/10.1016/j.ab.2005.09.041

Ernst WJ, Verkley J, Schat H. 1992. Metal tolerance in plants. Acta botanica neerlandica **41,** 229-248.

Eshghi S, Mahmoodabadi MR, Abdi GR, Jamali B. 2010. Zeolite ameliorates the adverse effect of cadmium contamination on growth and nodulation of soybean plant (*Glycine max* L.). Journal of Biological and Environmental Sciences **4(10),** 43- 50.

Eskandari Zanjani K, Shirani Rad AH, Naeemi M, Aghdam M, Taherkhani T. 2012. Effects of zeolite and selenium application on some physiological traits and oil yield of medicinal pumpkin (*Cucurbita pepo* L.) under drought stress. Current Research Journal of Biological Sciences **4 (4),** 462- 470.

Falkon P, Diatta JB, Grzebisz W. 2009. Spring triticale reaction to simulated water deficit and zeolite. In: Proc.of the 14th Int. Symposium on Tropentage, September 13-14, Bern, Swaziland 205-209.

Fotouhi K, Ahmdaly J, Noorjo A, Pedram A, Khorshid A. 2008. Irrigation management under water discharge permit at the different stages of sugar beet grown in Miandoab region. Journal of Sugar Beet **24(1),** 43-60.

Francois LE, Donova T, Mass E V. 1984. Salinity effect on seed yield, growth and germination of grain sorghum. Agronomy Journal **76,** 741-744.
http://dx.doi.org/10.2134/agronj1984.00021962007600050008x

Gworek B. 1992. Inactivation of cadmium in contamined soils using synthetic zeolites. Environmental pollution **75,** 269-271.
http://dx.doi.org/10.1016/0269-7491(92)90126-U

Hodges DM, Delong JM, Forney CF, Prange RK. 1999. Improving the thiobarbituric acid-reactive-substances assay for estimating lipid peroxidation in plant tissues containing anthocyanin and other interfering compounds. Planta 207, 604–611.
http://dx.doi.org/10.1007/s004250050524

Islam MR, Ren C, Zeng Z, Jia P, Eneji E, Hu Y. 2011. Fertilizer use efficiency of drought-stressed oat (*Avena sativa* L.) Following soil amendment with a water saving superabsorbent polymer. Acta agriculture Scandinavia Section B- Soil and plant Science **61,** 721-729.
http://dx.doi.org/10.1080/09064710.2011.553197

Jiang Y, Huang B. 2001. Osmotic adjustment and root growth associated with drought pre-conditioning enhanced heat tolerance in Kentucky bluegrass. Crop Science **41,** 1168-1173.

Johnson MS. 1984. The effect of gel-forming polyacrylamides on moisture storage in sandy soils. Journal of the Science of Food and Agriculture **35,** 1196-1200.
http://dx.doi.org/10.1002/jsfa.2740351110

Kamara AY, Menkir A, Badu-apraku B, Ibikunle O. 2003. The influence of drought stress on growth, yield and yield components of selected maize genotypes. Journal of Agricultural Science **141,** 43-50.
http://dx.doi.org/10.1017/S0021859603003423

Khalesroo S, Aghaalikhani M, Moddares Sanavy SAM. 2010. Effect of nitrogen fertilizer on yield and quality of forage maize, pearl millet and sorghum in double-cropping system. Iranian Journal of Field Crops Research **7(6),** 930-938.

Lafitte R. 2002. Relationship between leaf relative water content during reproductive stage water deficit and grain formation in rice. Field Crops Research **76,** 165-174.
http://dx.doi.org/10.1016/S0378-4290(02)00037-0

Leggo PJ, Ledesert B, Christie G. 2006. The role of clinoptilolite in organo-zeolitic-soil system used for phytoremediation. Science of the Total Environment **363,** 1-10.
http://dx.doi.org/10.1016/j.scitotenv.2005.09.055

Levitt J. 1980. Responses of plants to environmental stresses. Academic Press London, 607 p.

Mao S, Islam MR, HU Y, Qian X, Chen F, Xue X. 2011. Antioxidant enzyme activities and lipid peroxidation in Maize (*Zea mays* L.) following soil application of super absorbent polymer at different fertilizer regimes. African Journal of Biotechnology **10(49),** 1000-1008.
http://dx.doi.org/10.5897/AJB11.1348

Mata CG, Lamattina L. 2001 Nitric oxide induces stomata closure and enhances the adaptive plant responses against drought stress. Plant Physiology **126,** 1196 – 1204.
http://dx.doi.org/10.1104/pp.126.3.1196

Mumpton FA. 1999. Uses of natural zeolites in agriculture and industry. Proceeding of the National Academy of Sciences USA **96,** 3463-3470.
http://dx.doi.org/10.1073/pnas.96.7.3463

Naseri M, Khalatbari M, Paknejad F. 2012. Evaluate the effect of different ranges zeolite consuming on yield and yield component and physiological characteristics of grain Sorghum (*Sorghum bicolor* L. Moench) Var. Kimiya under water deficit stress. Annals of Biological Research **3 (7),** 3547-3550.

Polat E, Karaca M, Demir H, Naci Onus A. 2004 Use of natural zeolite (Clinoptilolite) in agriculture. Fruit and Ornamental Plant Research **12,** 183-189.

Ponizovsky AA, Tsadilas CD. 2003. Lead (II) retention by Alfisol and clinoptilolite: cation balance and pH effect. Geoderma **115,** 303–312.
http://dx.doi.org/10.1016/S0016-7061(03)00069-7

Rahakova M, Cuvanova S, Dzivak M, Rimar J, Gavalova Z. 2004. Agricultural and agro chemical uses of natural zeolite of the clinoptilolite type. Current Opinion In solid state and Materials Science **8,** 397-404.
http://dx.doi.org/10.1016/j.cossms.2005.04.004

Ranjan R, Bohra S P, Jeet A M. 2001. Book of plant senescence. Jodhpur, Agrobios New York *Pp*. 18-42.

Saeidi M, Moradi F, Ahmadi E, Sepehri R, Najafian G, Shaabani A. 2011. The effect of terminal drought stress on physiological characteristics and source-sink relationship in two cultivar of wheat (*Triticum aestivum* L.). Iranian Journal of Agricultural Science **12 (4),** 392-408.

Sairam RK, Siravastava GC. 2002. Changes in antioxidant activity in sub cellular fractions of tolerant and susceptible wheat genotypes in response to long term salt stress. Journal of Plant Science 162: 897-907
http://dx.doi.org/101016/s0168-9452(02)00037-7

Singh BR, Singh DP. 1995. Agronomic and physiological responses of sorghum, maize and pearl millet to irrigation. Field Crops Research **42,** 57- 67.
http://dx.doi.org/10.1016/0378-4290(95)00025-L

Singh TN, Paleg LG, Aspinall D. 1973. Stress metabolism. 1. Nitrogen metabolism and growth in barley plant during water stress. Australian Journal of Biological Science **26,** 45-56.
http://dx.doi.org/10.1071/BI9730045

Sparks DL. 1996. Methods of soil analysis. Part 3 – Chemical methods. SSSA Book Series No. 5. SSSA and ASA, Madison WI.

Tanguilig VC, Yambao EB, Toole JCO, DeDatta SK. 1987. Water stress effects on leaf elongation, leaf water potential, transpiration and nutrient uptake of rice, maize, and soybean. Plant and Soil **103,** 155-168.
http://dx.doi.org/10.1007/BF02370385

Thomas JC, Armond RL, Bohnert HJ. 1992 Influence of NaCl on growth, proline and phosphoenolpyruvate carboxylase levels in Mesembryanthemum crystallinum suspension cultures. Plant Physiology **98,** 626-631.
http://dx.doi.org/10.1104/pp.98.2.626

Wicks GA, Crutchfield, DA, Burnside OC. 1994. Influence of wheat (Triticum aestivum L.) straw mulch and metolachlor on corn (*Zea mays* L.) growth and yield. Weed Science **42,** 141-147.

Xiubin H, Zhanbin H. 2001. Zeolite application for enhancing water infiltration and retention in loess soil. Resources, Conservation and Recycling **34,** 45-52.
http://dx.doi.org/10.1016/S0921-3449(01)00094-5

Zhang S, Lovdahl L, Grip H, Tong Y, Yang X, Wang Q. 2009. Effects of mulching and catch cropping on soil temperature, soil moisture and wheat yield on the Loess Plateau of China. Soil Tillage Research **102,** 76-86.
http://dx.doi.org/10.1016/j.still.2010.11.006