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Effects of irrigation regimes and polymer on dry matter yield and several physiological traits of forage sorghum var '*Speedfeed*'

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Drought is the most important limiting factor for crop production; it is becoming an increasingly severe problem in many regions of the world. Sorghum is among the most important forages used in arid and semi-arid regions of southeastern Iran, but its growth and yield is often constrained by water deficit and poor productivity of sandy soil. Irrigation water is becoming scarcer and more costly. The addition of water-saving superabsorbent polymer (SAP) in soil can improve soil physical properties, crop growth and yield and reduce the irrigation requirement of plants. This experiment was conducted on sorghum var 'Speedfeed' grass in Zahedan, Iran during 2009 and 2010 seasons. The experimental design was a split-plot with two factors including four irrigation regime (providing 40, 60, 80 and 100% from consumptive (ET crop) of sorghum) as main plots and four amounts of SAP (0, 75, 150 and 225 kg ha^{-1}) as subplots in a completely randomized block design with three replications. Irrigation level and SAP had significant effects on number of leaves per plant, number of tillers per plant, leaf area index, leaf area duration, relative water content and dry matter. The results indicate that irrigation to meet 80% of the water requirement with 75 kg ha^{-1} SAP may provide a desirable dry matter.

Key words: Dry matter yield, forage sorghum, irrigation level, superabsorbent polymer.

INTRODUCTION

Drought stress is the most important limiting factor of field crops in Iran. Most parts of Iran's cultivation land are placed in arid and semiarid regions. Drought stress limits crop growth and productivity more than any other single environmental factor (Mao et al., 2011; Todorov et al., 1998), specifically for forage production, because the cost of water and energy continues to increase (Maboko, 2006). Superabsorbent polymers are becoming more and more important in regions where water availability is insufficient (Maboko, 2006; Monnig, 2005). Applying superabsorbent polymers in agriculture have a significant role in increase of soil capacity. Polymers are safe and non-toxic and it will finally decompose without any remainder (Mikkelsen, 1994). The application of SAP for stabilizing soil structure resulted in increased infiltration and reduced water use and soil erosion in a furrow irrigated field (Lentz and Sojka, 1994; Lentz et al., 1998). Superab A200 polymer (SAP) works by absorbing and storing water and nutrients in a gel form and undergoing cycles ofhydrating and dehydrating according to for moisture's demand, increasing both water and nutrient use efficiency in crops (Islam et al., 2011; Lentz and Sojka, 1994; Nazarli et al., 2010). Superabsorbent polymer can hold 400-1500 g of water per dry gram of hydrogel (Boman and Evaans, 1991). The SAP also prolonged water available for plant use when irrigation stopped (Huttermann et al.,

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Abbreviations: DM, Dry matter yield; **LAD,** leaf area duration; **LAI,** leaf area index; **NL,** number of leaves per plant; **NT,** number of tillers per plant; **RWC,** relative water content; **SAP,** Superab A200 polymer.

1999). Thus, plant growth could be improved with limited water supply (Yazdani et al., 2007).

Sorghum is the fifth most important cereal crop grown for human consumption in the world being surpassed only by rice, wheat, barley and corn. Most of sorghum grown in Asia and the African tropics is used for human food and also fed to livestock or poultry (Gul et al., 2005). Sorghum is a drought resistant summer annual crop (Aishah et al., 2011). Forage sorghum is an important forage crop in tropical, semi-tropical and even warm-temperate regions and is cultivated over about 30,000 ha, mainly in the southern provinces of Iran such as Sistan and Baluchistan (Muldoon, 1985; Unlu and Steduto, 2000). In spite of its relatively high tolerance to drought, sorghum yields can increase by as much as four-fold if production is under full irrigation (Rai et al., 1999). Sorghum speedfeed is a crop of world-wide importance and is unique in its ability to produce under a wide array of harsh environmental condition (Moghaddam et al., 2007; Sadeghzade et al., 2012).

Relative water content (RWC) is an appropriate measure of plant water status in terms of the physiological consequences of cellular water deficit (Kramer, 1988; Shamsi, 2010). Siddique et al. (2001) reported that decreasing the soil water potential can lead to a decrease in the RWC, decreasing the plant photosynthesis and dry matter. Munamava and Riddoch (2001) reported that leaf area and dry matter yield decreased with water stress. The leaf area index (LAI) of the crop at a particular growth stage indicates its photosynthetic potential or the level of its dry matter accumulation. The higher LAI, increases dry mater accumulation in the plant (Rasheed et al.,_2003). Fischer and Wilson (1966) suggested that dry matter accumulation is closely related to the maximum LAI and sorghum yield increases up to 10 LAI. Reduction in the leaf area in response to water stress occurs either through a decline in the leaf expansion or accelerated leaf senescence (Moseki and Dintwe, 2011). The high leaf area duration (LAD) can produce higher dry matter (Sanjana Reddy, 2012) and the LAI and LAD were posi-tively correlated with dry matter production (Reddi, 2006). LAD is one of the important physiological traits that have an implication on yield potential related to increasing assimilate availability (Brevedan and Egli, 2003).

Sorghum can produce tillers, and the number of productive tillers is influenced by soil water availability (Berenguer and Faci, 2001). Drought stress reduces the number of tillers either by stopping the differentiation process or by the death of growing or grown tillers (Krieg, 1983). Tillering is controlled by hormones and factors such as temperature, photoperiod, soil moisture and plant density (Stoskopt, 1985). Water stress causes the production of abscisic acid in plant, resulting in a decrease of the tillers (Morgan and King, 1984). The tillers are more sensitive to water stress than the main stem (Krieg, 1983). The plant photosynthetic material is consumed when the tillers are generated thus tillers productions and survival depends on photosynthesis and the material stored (McCree, 1983; Krieg, 1983). The advantage of tillering in sorghum forage is the regrowth of plants after harvest. Hart et al. (2001) recognized that leaf number in sorghum was under both genetic and environmental control. Quinby and Karper (1954) pointed out that the floral differentiation of the apical meristem of sorghum terminates the differentiation of leaves and thus effectively regulates the plant size. The number of leaves determines the leaf area index and a high leaf area index with the appropriate structure could result in a high performance (Hart et al., 2001). The objectives of this investigation were to determine the effects of Superab A200 and irrigation regime on the number of leaves per plant, number of tillers per plant, leaf area index, leaf area duration, relative water content and dry matter of sorghum.

MATERIALS AND METHODS

Experimental location, irrigation treatments, SAP treatments and soil properties

The field experiment was conducted in Dashtak that is located near Zahedan, southeastern Iran (25°, 30' N and 58°, 47' E), with a mean annual rainfall of 120 mm with an arid and tropical climate. Before planting, soil samples were taken from the experimental site and were analyzed according to the procedure of Jakson (1973). Some physical and chemical properties of the soil are presented in Table 1.

The present study was conducted as a split plot randomized complete block design with three replications. The treatments included four levels of irrigation assigned to the main plots (providing 100 (I_1), 80 (I_2), 60 (I_3) and 40 (I_4) % from consumptive (ET crop) of sorghum var ‘Speedfeed’) and four SAP levels as a subplot [225 (S_1), 150 (S_2), 75 (S_3) and 0 (S_4), kg SAP ha^{-1}] on sorghum var ‘Speedfeed’ during 2009 and 2010 seasons to evaluate the effects of SAP under the irrigation regime on DM.

SAP material, SAP placement, planting seed and irrigation method

The soil amendment used was a hydrophilic polymer, SAP produced by Rahab Resin Co. Ltd., under license of "Iran Polymer and Petrochemical Institute". The chemical structure of SAP is shown in Table 2 (Abedi-Koupai and Asadkazemi, 2006; Nazarli et al., 2010; Yazdani et al., 2007).

Each plot was 15 m^2 with five planting rows, with an inter-row spacing of 50 cm, an inter-plant spacing of 6 cm and the plant average density was 34 plants per m^2. Before seed planting, SAP was placed by hand where roots were expected to have greater density (15 to 20 cm depth) in the middle of rows along the ridge (Lavy and Eastin, 1969), then the seeds were manually sown at the depths of 2 to 3 cm in the rows in early April. Soil preparation operations included plowing, disking and leveling which were carried out in early March. Thinning was done at 5 to 7 leaf stage and the seedlings distance along rows was set between 8 to 12 cm. Water requirements were determined according to FAO method using the American Class A evaporation pan data (Giovanni et al., 2009; Howell et al., 2008). The sorghum var ‘*Speedfeed*’ evapotranspiration was calculated by Equation 1 and irrigation was assumed 80% application efficiency for the furrow irrigation distributed in the farm. The amount of irrigation in each treatment was determined using flow meters.

Table 1. Some physical and chemical properties of a representative soil samples in the experimental site before sowing (0-30 cm depth) in 2009 and 2010 seasons.

Soil property	2009*	2010*
Silt	24.9	24.8
Sand	65.3	65.9
Clay	9.80	9.30
Texture	sandy - loam	sandy - loam
Organic matter (%)	0.05	0.06
EC (1:1 extract) (ds m^{-1})	6.80	6.70
pH (1:1 suspension)	7.70	7.60
Total nitrogen (%)	0.15	0.16
Total CaCo3 (%)	0.90	1.10
NaHCO3-extractable P (mg L-1)	3.50	3.70
NaOAC-extractable K (mg L-1)	90.0	93.0

*Each value represents the mean of three replications.

$$ET_c = K_C \times ET_0 \qquad (1)$$

$$K_c = \frac{ET_a}{ET_P}$$

Where, K_c, ET_a and ET_c were crop coefficients, evapotranspiration actual and evapotranspiration critical respectively. The K_c was extracted as Dorrenbos and Kassam (1979).

$$ET_0 = K_{pan} \times E_p$$

Where, ET_o, K_{pan} and E_p was evapotranspiration of the reference crop.

K_{pan} was 0.66 (Alizadeh, 2002) and E_p was evaporation of pan.

Calculating growing degree-days (GDD) and plant growth analysis

Growing degree-days were calculated using the Equation 2:

$$GDD = \frac{T\max - T\min}{2} - B \qquad (2)$$

Where, Tmax and Tmin are the daily maximum and minimum temperatures respectively and B represents a base temperature value of 10°C (McMaster and Wilhelm, 1997).

LAI was measured after flowering was at a 10% level by measuring the leaf area of five plants per treatment. The LAI was calculated by Equation 3 as follows (Rasheed et al., 2003):

$$LAI = \frac{Leaf\ \ area(m^2)}{Land\ \ area(m^2)} \qquad (3)$$

LAD was measured after flowering was at a 10% level by Equation 4 as follows (Rasheed et al., 2003):

$$LAD = \frac{(LAI_1 + LAI_2) \times (t_2 - t_1)}{2} \qquad (4)$$

Where, LAI_1 = Leaf area Index at t_1; LAI_2 = Leaf area index at t_2; t_1 = time of first observation; t_2 = time of second observation.

To determine the DM, the harvested plants (stems and leaves) were desiccated at 75°C for two days in a ventilating oven. For calculating dry matter accumulation, five plants.

Measurement RWC, NL, NT and DM

The RWC was determined in the fully expanded topmost leaf one day before irrigation between 8 and 9 a.m. This was accomplished by excising three 1-cm disks of each sample leaf at 282, 444, 600, 766 and 907 GDD. The results were then averaged, resulting in a single value to represent that plot. The fresh weight of the sample leaves was recorded and the leaves were immersed in distilled water in a Petri dish. After 24 h, the leaves were removed, the surface water was blotted-off and the turgid weight recorded. Samples were then dried in an oven at 70°C to constant weight (Munne-Bosch et al., 2007; Schlemmer et al., 2005). The RWC was calculated by Equation 5 as follows:

$$RWC = \frac{Fresh\ Weight - Dry\ Weight}{Turgid\ W - Dry\ Weight} \times 100 \qquad (5)$$

The determination of NL and NT was carried out after flowering was at a 10% level. The NL was counted randomly in one square meter area for each plot and the NT was counted in three plants in each plot, then the results were averaged, resulting in a single value to represent that plot.

Statistical analysis

The data were analyzed with SAS 9.2. The analysis of variance for each physiological variable was performed by the PROC GLM procedure. Comparison the simple effects was also conducted using Duncan's multiple range test and a comparison of the interaction effects was also conducted using the least squares means. The combined analysis of variance over years was performed on the data of two growing seasons after testing the homogeneity of the error according to Bartlett's test.

Table 2. The properties of Superab A200 material.

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

Table 3. Main effects of irrigation regime on some physiological traits of sorghum var 'Speedfeed'.

Irrigation regime	Relative water content			Number of tillers per plant			Number of leaves		
	2009	2010	Average	2009	2010	Average	2009	2010	Average
I_1	81.23^a	80.47^a	80.85^a	2.92^a	2.58^a	2.75^a	13.17^a	13.08^a	13.12^a
I_2	80.20^a	75.04^b	77.62^b	2.00^b	2.08^b	2.04^b	11.33^b	11.75^b	11.54^b
I_3	65.44^b	65.46^c	65.45^c	1.00^c	0.92^c	0.96^c	8.67^c	8.92^c	8.79^c
I_4	60.46^c	59.39^d	59.92^d	0.83^c	0.50^d	0.67^d	6.83^d	6.42^d	6.62^d

Irrigation regime	Leaf area index			Leaf area duration			Dry matter (g m^{-2})		
I_1	8.31^a	8.10^a	8.20^a	92.07^a	87.48^a	89.77^a	2223^a	2174^a	2199^a
I_2	6.93^b	6.54^b	6.73^b	78.48^b	73.39^b	75.93^b	1867^b	1962^b	1915^b
I_3	4.10^c	4.33^c	4.21^c	47.66^c	50.39^c	49.03^c	719^c	650^c	684^c
I_4	2.95^d	3.16^d	3.05^d	34.84^d	38.97^d	36.03^d	379^d	359^d	369^d

Means in each column followed by a similar letter are not significantly different at P<0.05 according to Duncan's multiple range test. I_1=100, I_2=80, I_3=60 and I_4=40% of the water requirement of sorghum var 'Speedfeed' .

RESULT AND DISCUSSION

Number of leaves per plant

NL significantly decreased as irrigation water amount decreased in both seasons and averaged over the years (Table 3). Bennett (1979) reported that when leaf water potential decreased from -4 to -5, caused the number of leaves to decrease. NL increased with increasing level of polymer applied (Table 4). The interaction between the irrigation regime and SAP level were significant at the 5% level for the combined effects of 2009 and 2010 seasons and the NL in I_2S_1 was the same as I_1S_2, I_1S_3 and I_2S_4 (Table 5).

Number of tillers per plant

NT decreased as the amount of irrigation applied decreesed (Table 3). Krieg (1983) suggested that drought stress reduces the number of tillers. NT increased with increasing amount of polymer in the soil (Table 4). The interacttion between the irrigation regime and SAP level was significant at the 5% level for combined effects of 2009 and 2010 seasons (Table 5). There was a positive and significant correlation (Table 6) between NL and NT (0.86).

Relative water content

RWC decreased with decreasing irrigation water amount in both years (Table 3). Girma and Krieg (1992) reported that the RWC in sorghum var 'Speedfeed' decreased with an increase in water stress. RWC increased with increasing amount of polymer in the soil (Table 4). Mao et al. (2011) application of SAP increased RWC significantly by 15.4% when compared with the control. The interaction between the irrigation regime and SAP level was not significant at the 5% level. RWC significantly correlated (Table 6) with NL (0.92) and NT (0.88).

Leaf area index

LAI decreased with decreasing irrigation water amount in both years (Table 3). Moseki and Dintwe (2011) suggested the leaf area decreased with the increase of water stress. LAI increased with increasing amount of polymer in the soil (Table 4). Islam et al. (2011) showed that leaf area did not change under low application of superabsorbent polymer but increased remarkably following SAP application at medium and high rate by 18.9 and 32.5%, respectively. The interaction between the irrigation regime

Table 4. Main effects of Superab A200 polymer (SAP) level on some physiological traits of sorghum var 'Speed feed'.

SAP level	Relative water content			Number of tillers per plant			Number of leaves		
	2009	2010	Average	2009	2010	Average	2009	2010	Average
S_1	76.68^{a}	75.55^{a}	76.12^{a}	2.42^{a}	2.08^{a}	2.25^{a}	11.17^{a}	11.25^{a}	11.21^{a}
S_2	72.37^{b}	71.22^{b}	71.80^{b}	1.67^{b}	1.58^{b}	1.62^{b}	10.25^{b}	10.33^{b}	10.29^{b}
S_3	71.76^{b}	68.63^{c}	70.19^{c}	1.58^{b}	1.33^{bc}	1.46^{b}	9.75^{c}	9.83^{c}	9.79^{c}
S_4	66.51^{c}	64.96^{d}	65.73^{d}	1.08^{c}	1.08^{c}	1.08^{c}	8.83^{d}	8.75^{d}	8.79^{d}

SAP level	Leaf area index			Leaf area duration			Dry matter (gm-^{2})		
S_1	6.46^{a}	6.11^{a}	6.28^{a}	71.19^{a}	68.57^{a}	69.88^{a}	1469^{a}	1460^{a}	1464^{a}
S_2	5.54^{b}	5.93^{a}	5.70^{b}	62.57^{b}	65.37^{ab}	63.78^{b}	1348^{b}	1354^{ab}	1351^{b}
S_3	5.48^{b}	5.33^{b}	5.43^{b}	62.19^{b}	61.59^{b}	62.08^{b}	1267^{b}	1254^{b}	1260^{c}
S_4	4.80^{c}	4.76^{c}	4.78^{c}	57.09^{c}	54.70^{c}	55.89^{c}	1104^{c}	1078^{b}	1091^{d}

Means in each column followed by a similar letter are not significantly different at P<0.05 according to duncan's multiple range test. S_1=225, S_2=150, S_3=75 and S_4=0 kg SAP ha^{-1}.

Table 5. Interaction between irrigation regime and Superab A200 polymer (SAP) on some physiological traits of sorghum var 'Speedfeed' .

Irrigation regime	SAP level	Dry matter (g m^{-2})	Leaf area index	Leaf area duration	Number of leaves	Number of tillers per plant
I_1	S_1	3.33^{a}	14.17^{a}	101.5^{a}	9.50^{a}	2229.33^{ab}
	S_2	3.00^{ab}	13.17^{b}	87.20^{bc}	8.09^{b}	2256.17^{a}
	S_3	2.67^{b}	12.83^{bc}	88.73^{b}	7.93^{b}	2209.00^{b}
	S_4	2.00^{c}	12.33^{cd}	82.11^{cd}	7.29^{cd}	2100.17^{bc}
I_2	S_1	3.00^{ab}	12.67^{bc}	83.25^{bc}	7.56^{c}	2089.17^{bc}
	S_2	2.00^{c}	11.67^{e}	77.26^{d}	6.93^{d}	2011.33^{c}
	S_3	2.00^{c}	11.83^{de}	77.70^{d}	6.86^{d}	1981.60^{c}
	S_4	1.17^{de}	10.00^{f}	65.53^{e}	5.58^{e}	1576.33^{d}
I_3	S_1	1.50^{d}	10.17^{f}	55.34^{f}	4.76^{f}	1122^{e}
	S_2	1.00^{ef}	9.17^{g}	53.74^{f}	4.66^{f}	725.83^{f}
	S_3	0.67^{f}	8.33^{h}	44.56^{g}	3.89^{g}	462.33^{g}
	S_4	0.67^{f}	7.50^{i}	42.48^{gh}	3.54^{gh}	394.17^{gh}
I_4	S_1	0.67^{f}	7.80^{hi}	39.90^{ghi}	3.32^{hi}	417.17^{gh}
	S_2	0.50^{f}	7.17^{i}	36.93^{ij}	3.13^{hij}	376.83^{gh}
	S_3	0.50^{f}	6.17^{j}	37.33^{hij}	3.06^{ij}	388.17^{gh}
	S_4	0.50^{f}	5.33^{k}	33.46^{j}	2.70^{j}	292.83^{h}

I_1=100, I_2=80, I_3=60 and I_4=40% of the water requirement of sorghum var 'Speedfeed' . S_1=225, S_2=150, S_3=75 and S_4=0 kg SAP ha^{-1}. Means in each column followed by a similar letter are not significantly different at P<0.05 according to Duncan's multiple range test.

Table 6. The Pearson correlation coefficient between dry matter and some physiological traits of sorghum var 'Speedfeed' grown in 2009 and 2010 seasons.

Parameter	1	2	3	4	5	6
Dry matter (g m^{-2})						
Leaf area duration	0.93**					
Leaf area index	0.87**	0.99**				
Number of leaves per plant	0.86**	0.92**	0.92**			
Number of tillers per plant	0.84**	0.88**	0.87**	0.86**		
Relative water content	0.88**	0.86**	0.85**	0.92**	0.88**	

**Indicate significant at 0.01.

and SAP level was significant at the 5% level for the combined effects of 2009 and 2010 seasons (Table 5). LAI was significantly correlated (Table 6) with NL (0.92), NT (0.88) and RWC (0.85).

Leaf area duration

LAD decreased with decreasing irrigation water amount in both years (Table 3). Brevedan and Egli (2003) suggested that drought stress reduces the LAD. LAD increased with increasing amount of polymer in the soil (Table 4). The interaction between the irrigation regime and SAP level was significant at the 5% level for the com-bined effects of 2009 and 2010 seasons (Table 5). The LAD was significantly correlated (Table 6) with LAI (0.99), NL (0.92), NT (0.88) and RWC (0.86). In drought condi-tions, the nutrients transfers from leaves increases, accelerating the leaf senescence (Brevedan and Egli, 2003). On the other hand, Islam et al. (2011) showed that SAP could be an effective way to increase both water and nutrient use efficiency in crops and increase LAD. So LAI, LAD and DM increase.

Dry matter

Dry matter decreased with decreasing irrigation water amount in both years (Table 3). Aishah et al. (2011) reported that when the irrigation schedule changed from -1 to -1.5 Mpa, the forage yield ‘Speedfeed’ decreased by 22.2%. Dry matter increased with increasing amount of polymer in the soil (Table 4). The above-ground biomass accumulation in sorghum var ‘Speedfeed’ increased following SAP application but the effect was less for low and medium SAP rate. Islam et al. (2011) showed that the DM increased with increasing rate of superabsorbent polymer and the value increased by only 10.4% with low application of SAP, while it increased significantly by 20.5 and 32.9% with medium and high application, respectively. In sorghum var ‘Speedfeed’, the rate of dry matter production is controlled by leaf area (Peacock and Wilson, 1984). Sorghum var ‘Speedfeed’ leaf area depends on the rate and speed in which primary leaves are formed, their expansion, leaves number, and the leaf senescence rate, all of which depends on the plants water available. So, in this experiment, with an increase in the NL, LAI and LAD, the amount of DM increased (Dale, 1982; Peacock and Wilson, 1984). On the other hand, the use of polymer in soils to improve both the nutritional and water status of plants (Islam et al., 2011). The interaction between irrigation regime and SAP level were significant at a 5% level for the combined effects of 2009 and 2010 seasons and the DM content in I_1S_4 was the same as I_2S_1, I_2S_2 and I_2S_3 (Table 5). Dry matter was significantly correlated with LAD (0.93), LAI (0.87), NL (0.86), NT (0.84) and RWC (0.88).

Conclusion

Water stress decreased number of leaves per plant, number of tillers per plant, leaf area index, leaf area duration, relative water content and dry matter. Our results have shown that the applied SAP had an important effect on forage sorghum var ‘Speed feed’ and increased number of leaves per plant, number of tillers per plant, leaf area index, leaf area duration, relative water content and dry matter. Probably, the application of SAP could be an effective management practice in soils characterized by low water holding capacity where irrigation water and fertilizer often leach below the root zone within a short period of time, leading to poor water and fertilizer use efficiency by crops. Therefore, SAP increases leaf area index through increasing both water and nutrient use efficiency in crops. The higher LAI causes an increase in LAD and results in increasing dry matter accumulation in the plant. The DM yield in treatment I_2S_3 was the same as I_1S_4 that showed by using 75 kg ha^{-1} SAP as much as 20% of irrigation water was saved.

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