Asian Journal of Agriculture and Food Science (ISSN: 2321 - 1571)
Volume 01– Issue 05, December 2013

The Effect of Irrigation Regimes and Polymer on Several Physiological Traits of Forage Sorghum

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ABSTRACT— ***Drought is the most important limiting factor for crop production. Sorghum is among the most important forages used in arid and semi-arid regions of south-eastern Iran, but its growth and yield is often constrained by water deficit and poor productivity of sandy soil. Irrigation water is becoming more scarce and more costly. The addition of water-saving superabsorbent polymer (SAP) in soil can improve soil physical properties, crop growth and yield and reduced the irrigation requirement of plants. The objective of this study was to investigate the effect of different rates of SAP and irrigation regimes on dry matter yield and some physiological and yield-related traits of Speedfeed sorghum. This experiment was conducted on sorghum×sudan grass (Sorghum bicolor (L.) Moench×S. Sudanese (Piper) Stapf, variety 'Speedfeed') in Zahedan, Iran during 2011 and 2012 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 indicated that irrigation to meet 80% of the water requirement with 75 kg ha^{-1} SAP may provide a desirable dry matter.***

Keywords--- Dry matter yield, forage sorghum, irrigation level, Superab A200 polymer.

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1. INTRODUCTION

Drought stress is the most important limiting factor of field crops in Iran. Most parts of Iran's cultivation land is 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 has significant role in increase of soil capacity of 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 to 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 of hydrating 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 availability for plant use when irrigation stopped (Huttermann et al., 1999). Thus, plant growth could be improved with limited water supply (Yazdani et al., 2007).

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., 2009). 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.

Abbreviation: DM, yield dry matter; **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.

The higher LAI, increases dry mater accumulation in the plant (Rasheed et al.,_2003). Fischer and Wilson, 1975 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 positively 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). 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). Advantage of tillering in sorghum forage is 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 floral differentiation of the apical meristem of sorghum terminates the differentiation of leaves and thus effectively regulates 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.

2. MATRIALS AND METHODS

Experimental location, irrigation treatments, SAP treatments and soil properties: The field experiment was conducted in Dashtak, 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.

Table 1: Some physical and chemical properties of a representative soil samples in the experimental site before sowing (0-30 cm depth) in 2011 and 2012 seasons.

Soil properties	2011*	2012*
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.

The present study used 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) and four SAP levels as subplot (225 (S_1), 150 (S_2), 75 (S_3) and 0 (S_4), kg SAP ha^{-1}) on sorghum×sudan grass (S*orghum bicolor* (L.) Moench×S. Sudanese (Piper) Stapf, variety 'Speedfeed') during 2011 and 2012 seasons to evaluate the effects of SAP under 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).

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

Each plot was 15 m^2 with 5 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 greatest density (15-20 cm depth) in the middle of rows along the ridge (Lavy and Eastin, 1969), then the seeds were manually sown at the depths of 2-3 cm on the rows in early April. Soil preparation operations included plowing, disking and leveling which were carried out in early March. Thinning was done at 5-7 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×sudangrass evapotranspiration was calculated by Eq. [1] and irrigation was done assuming 80% application efficiency for the furrow irrigation distributed in the farm. The amount of irrigation in each treatment was determined using flow meters.

$$ET_c = K_C \times ET_0 \qquad [1]$$

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

Where K_c, ET_a and ET_c were crop coefficients, evapotranspiration actual and evapotranspiration critical respectively. The K_c 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 plant growth analysis: 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 Eq. [2] as follows (Rasheed et al., 2003):

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

LAD was measured after flowering was at a 10% level by Eq. [3] as follows (Rasheed et al., 2003):

$$LAD = \frac{(LAI_1 + LAI_2) \times (t_2 - t_1)}{2} \qquad [3]$$

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 2 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 Eq. [4] as follows:

$$RWC = \frac{Fresh\ Weight - Dry\ Weight}{Turgid\ W - Dry\ Weight} \times 100 \qquad [4]$$

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 for 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 with the PROC GLM procedure. Comparing 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.

3. RESULT AND DISCUSSION

Number of leaves per plant: NL significantly decreased as irrigation application amount decreased in both seasons and averaged over 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 irrigation regime and SAP level were significant at 5% level for the combined effects of 2011 and 2012 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 amount of irrigation applied decreased (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 interaction between irrigation regime and SAP level was significant at 5% level for combined effects of 2011 and 2012 seasons (Table 5). That there was a positive and significant correlation (Table 6) between NL and NT (0.86).

Table 3: Main effects of irrigation regime on some physiological traits of sorghum×sudangrass.

Irrigation regime	Relative water content			Number of tillers per plant			Number of leaves		
	2011	2012	Average	2011	2012	Average	2011	2012	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	2174a	2199 a
I_2	6.93 b	6.54 b	6.73 b	78.48 b	73.39 b	75.93 b	1867 b	1962b	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% providing of the water requirement of sorghum.

Table 4: Main effects of Superab A200 polymer (SAP) level on some physiological traits of sorghum×sudangrass.

SAP level	Relative water content			Number of tillers per plant			Number of leaves		
	2011	2012	Average	2011	2012	Average	2011	2012	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** (g m-^{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.
S1=225, S2=150, S3=75 and S4=0 kg SAP ha-1.

Table 5: Interaction between irrigation regime and Superab A200 polymer (SAP) on some physiological traits of sorghum×sudangrass.

Irrigation regime	SAP level	Number of tillers per plant	Number of leaves	Leaf area duration	Leaf area index	Dry matter (g m^{-2})
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% providing of the water requirement of sorghum. S_1=225, S_2=150, S_3=75 and S_4=0 kg SAP ha^{-1}.

Table 6: The Pearson correlation coefficient between dry matter and some physiological traits of sorghum×sudangrass grown in 2011 and 2012 seasons.

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

** indicate significant at 0.01.

Relative water content: RWC decreased with decreasing irrigation application in both years (Table 3). Girma and Krieg (1992) reported that the RWC in sorghum 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 control. The interaction between irrigation regime and SAP level was not significant at 5% level. RWC significantly correlated (Table 6) with NL (0.92) and NT (0.88).

Leaf area index: LAI decreased with decreasing irrigation application in both years (Table 3). Moseki and Dintwe, 2011 suggested the leaf area decreased with the increased 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 changed 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 irrigation regime and SAP level was significant at 5% level for the combined effects of 2011 and 2012 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 application 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 irrigation regime and SAP level was significant at 5% level for the combined effects of 2011 and 2012 seasons (Table 5). LAD was significantly correlated (Table 6) with LAI (0.99), NL (0.92), NT (0.88) and RWC (0.87). Drought in drought conditions 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 an increase in LAD. So LAI, LAD and DM increase.

Dry matter: Dry matter decreased with decreasing irrigation application in both years (Table 3). Aishah et al. (2011) and 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 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 the rate of dry matter production is controlled by leaf area (Peacock and Wilson, 1984). Sorghum 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 increases (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 2011 and 2012 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 (0.926), LAI (0.87), NL (0.86), NT (0.84) and RWC (0.88).

4. 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 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 mater accumulation in the plant. The DM yield in treatment I_2S_3 was the same as that is using 75 kg ha^{-1} SAP as much as 20% of water irrigation was saved.

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