African Journal of Biotechnology Vol. 11(48), pp. 10834-10840, 14 June, 2012
Available online at http://www.academicjournals.org/AJB
DOI: 10.5897/AJB11.3963
ISSN 1684-5315 ©2012 Academic Journals

Full Length Research Paper

Effect of polymer and irrigation regimes on dry matter yield and several physiological traits of forage sorghum

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Accepted 4 July, 2012

Drought stress is one of the most serious problems in crops production in the arid and semi-arid regions. Application of some materials such as superab A200 polymers (SAP) in soil can improve soil water reservation. They can also decrease water losses, fertilizer leaching in soils, effects of water deficiency in plants and so can improve the yield in the arid and semi-arid regions. This experiment was conducted on forage sorghum (S*orghum bicolor* (L.) variety 'Speedfeed') in Zahedan, Iran during 2010 season. The experimental design was a split-plot with two factors including four irrigation regimes (providing 40, 60, 80 and 100% of the water requirement of sorghum calculated from pan evaporation) 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 chlorophyll index, leaf area index, leaf area duration, crop growth rate, relative water content and dry matter. The results indicate that irrigation to meet 80% of the water requirement with 75 kg ha-1 SAP which may provide a desirable dry matter.

Key words: Dry matter yield, forage sorghum, growth analysis, irrigation regime, superab A200 polymer.

INTRODUCTION

Forage sorghum-Sudangrass hybrid is grown widely for summer forage production (Bullock et al., 1988). Sorghum is adapted to the climate of Iran, particularly in tropical and arid areas such as Sistan and Baluchistan and south-eastern provinces of Iran (Muldoon, 1985; Unlu and Steduto, 2000). Sorghum is a drought resistant summer annual crop (Aishah et al., 2011). According to the research findings, it requires 330 L water to produce 1 kg of dry matter. This amount is 368 kg for corn, 434 kg for Barley and 514 kg for wheat (House, 1985). Water is one of the fundamental resources for the vital processes of vegetation. Plants need to maintain adequate levels of water in their tissues to assure growth and survival and to perform physiological processes, such as photosynthesis and nutrient uptake (Nobel, 1999). In conditions of water deficit, plant cell turgor is reduced, and a series of harmful effects on plant physiology for example, reduction of cell growth, cell wall synthesis, protein synthesis, respiration, and sugar accumulation occur, generating a state of increasing suffering in plants, usually named 'water stress' (Lauenroth and Coffin, 1992). Most parts of Iran's cultivation land is placed in arid and semiarid regions and because of water deficiency, plant stress appears and plant performance reduces severely in these regions (Shamsi, 2010). 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; the increase of soil capacity. Polymers are safe and non-toxic and it will finally decompose without any remainder (Mikkelsen, 1994). The application of superab A200 polymers (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). SAP works by absorbing and storing water and

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Abbreviations: CGR, Crop growth rate; **CI,** chlorophyll index; **DM,** yield dry matter; **LAD,** leaf area duration; **LAI,** leaf area index; **RWC,** relative water content; **SAP,** Superab A200 polymer; **SNK,** Student-Newman-Keuls.

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

Soil property	2010*
Silt	24.8
Sand	65.9
Clay	9.30
Texture	Sandy – loam
Organic matter (%)	0.06
EC (1:1 extract) (ds m^{-1})	6.70
pH (1:1 suspension)	7.60
Total nitrogen (%)	0.16
Total $CaCo_3$ (%)	1.10
$NaHCO_3$-extractable P (mg L^{-1})	3.70
NaOAC-extractable K (mg L^{-1})	93.0

*Each value represents the mean of three replications.

nutrients in a gel form, and undergoing cycles of hydrating and dehydrating according to 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 to 1500 g of water per dry gram of hydrogel (Boman and Evans, 1991). The SAP also prolonged water availability for plant use when irrigation stopped (Huttermann et al., 1990). Thus, plant growth could be improved with limited water supply (Yazdani et al., 2007).

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. (2003) reported that decreasing the soil water potential can lead to a decrease in the RWC, decreasing the plant photosynthesis and dry matter (DM). Drought stress directly affects the leaf chlorophyll index (CI) and consequently the yield (Schlemmer et al., 2005). Earl and Davis (2003) reported that active oxygen causes damages to the cellular membranes under water stress conditions because of lipids peroxidization. It finally leads to decrease of the plant chlorophyll content and results in reduced dry matter and leaf area duration (LAD). Munamava and Riddoch (2001) reported that leaf area and dry matter yield decreased with water stress. Crop growth rate (CGR) expresses the rate of dry matter accumulation. Higher CGR and leaf area index (LAI), increase dry mater accumulation in plant (Akram et al., 2010). The CGR is positively correlated with leaf area index (Bullock et al., 1988). The LAI of the crop at a particular growth stage indicates its photosynthetic potential or the level of its DM accumulation. LAI is the component of crop growth analysis that accounts for the ability of the crop to capture light energy and is critical to understand the function of many crop management practices (Almodares et al., 2007). Higher LAI increases DM accumulation in plant (Rasheed et al., 2003). Fischer and Wilson (1966) suggested that DM 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 LAD can produce higher dry matter (Sanjana, 2012) and the LAI and LAD were positively correlated with DM 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).

The aim of this investigation was to study the effects of the various levels of water stress and superab A200 polymer on the RWC, CI, LAI, LAD, CGR and DM, in order to achieve an effective solution for optimizing the limited water sources in the arid and semi-arid areas.

MATERIALS 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.

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) percent water requirement of sorghum calculated based on pan evaporation) 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-Sudangrass (S*orghum bicolor* (L.) Moench-S. Sudanese (Piper) Stapf, variety 'Speedfeed') during 2010 season to evaluate the effects of SAP under irrigation regime on DM and several physiological traits.

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 the 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).

Before seed planting, SAP was placed by hand where roots were expected to have the greatest density (15 to 20 cm depth) in the middle of rows along the ridge (Lavy and Eastin, 1969), and then the seeds were manually sown at the depths of 2 to 3 cm on the rows in early April. Plant density was at an average density of 34 plants m^{-2} (inter-row spacing and inter-plant spacing were 0.5 m and 0.06 m, respectively). 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.,

Table 2. The properties of Superab A200 Polymer.

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

2009; Howell et al., 2008). The sorghum×sudangrass crop evapotranspiration (ET_c) was calculated by Equation [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:

$$ET_c = K_c \times ET_0$$

$$K_c = \frac{ET_a}{ET_P} \quad [1]$$

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

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

Where, ET_o 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 was calculated using Equation [2]:

$$GDD = \frac{T\max - T\min}{2} - B \quad [2]$$

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] (Akram et al., 2010):

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

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

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

Where, LAI_1 = Leaf area Index at t_1; LAI_2 = Leaf area index at t_2; t_1 = time of first observation and t_2 = time of second observation Crop growth rate (CGR) was calculated by Equation [5] (Akram et al., 2010):

$$CGR = \frac{(w_2 - w_1)}{(t_2 - t_1)} \quad [5]$$

Where, W_2 = dry weight per unit land area (g m^{-2}) at second harvest, W_1 = dry weight per unit land area (g m^{-2}) at first harvest, t_2 = time corresponding to second harvest and t_1 = time corresponding to first harvest.

Measurement relative water content (RWC) and yield dry matter (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 [6] as follows:

$$RWC = \frac{Fresh\ \ Weight - Dry\ \ Weight}{Turgid\ \ Weight - Dry\ \ Weight} \times 100 \quad [6]$$

The forages were grown until pre-flowering, and then the shoots were cut 2 cm above the soil surface. To determine the DM, the harvested plants (stems and leaves) were desiccated at 75°C for two days in a ventilating oven.

Statistical analysis

The data were analyzed with SAS 9.2. The analysis of variance for each variable was performed with the PROC GLM procedure. Comparison of the simple effects was also conducted using

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

Irrigation regime	Relative water content	Chlorophyll index	Leaf area index	Leaf area duration (m^{-2} day^{-1})	Crop growth rate (g m^{-2} day^{-1})	Dry matter (g m^{-2})
I_1	80.47^a	38.01^a	8.10^a	87.48^a	40.30^a	2174^a
I_2	75.04^b	36.23^b	6.54^b	73.39^b	37.10^a	1962^b
I_3	65.46^c	29.11^c	4.33^c	50.39^c	14.67^b	650^c
I_4	59.39^d	24.96^d	3.16^d	38.97^d	10.09^b	359^d

Means in each column followed by a similar letter are not significantly different at P<0.05 according to SNK's multiple range test. I_1=100; I_2=80; I_3=60; 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	Chlorophyll index	Leaf area index	Leaf area duration (m^{-2} day^{-1})	Crop growth rate (g m^{-2} day^{-1})	Dry matter (g m^{-2})
S_1	75.55^a	33.78^a	6.11^a	68.57^a	26.98^b	1460^a
S_2	71.22^b	32.66^b	5.93^a	65.37^{ab}	25.22^b	1354^{ab}
S_3	68.63^c	31.59^c	5.33^b	61.59^b	23.37^b	1254^b
S_4	64.96^d	30.30^d	4.76^c	54.70^c	21.94^b	1078^c

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

Student-Newman-Keuls (SNK) multiple range test and a comparison of the interaction effects was also conducted using the least squares means.

RESULTS

Relative water content

RWC decreased with decreasing irrigation application (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). Our results are confirmed by Islam et al. (2011). The interaction between irrigation regime and SAP level was not significant at 5% level.

Chlorophyll index

CI decreased with decreasing irrigation application (Table 3). Hayatu and Mukhtar (2010) suggested that at both moderate and severe water stress, there was 100% reduction in the chlorophyll content (SPAD). CI increased with increasing amount of SAP in the soil (Table 4). Khadem et al. (2010) reported that SPAD value in the leaves significantly increased with the application of SAP. The interaction between irrigation regime and SAP level was significant at 5% level and the CI content in I_1S_4 was the same as I_2S_1 and I_2S_2 (Table 5). Chlorophyll Index was significantly correlated (Table 6) with RWC (0.82). The RWC to maintain the maximum amount of chlorophyll should be high (Bohrani and Habili, 1992). The water stress resulted in significant decreases in chlorophyll content and the RWC and total chlorophyll content in high water stress was reduced by 55% compared to the control (Kirnak et al., 2001).

Leaf area index

LAI decreased with decreasing irrigation application (Table 3). Bullock et al. (1988) suggested that the leaf area decreased with increase in water stress in sorghum-Sudangrass. The 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 SAP 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 (Table 5). LAI was significantly correlated (Table 6) with RWC (0.84) and CI (0.90).

Leaf area duration

LAD decreased with decreasing irrigation application (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

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

Irrigation regime	SAP level	Chlorophyll Index	Leaf area duration (m^{-2} day^{-1})	Leaf area index	Crop growth rate (g m^{-2} day^{-1})	Dry matter (g m^{-2})
I_1	S_1	38.69^{a}	97.35^{a}	9.11^{a}	39.93^{a}	97.35^{a}
	S_2	37.92^{a}	85.80^{b}	8.09^{b}	42.11^{a}	85.80^{b}
	S_3	37.84^{a}	87.12^{b}	7.89^{bc}	40.51^{a}	87.12^{b}
	S_4	37.59^{ab}	79.64^{b}	7.29^{bcd}	41.09^{a}	79.64^{b}
I_2	S_1	37.68^{a}	81.08^{b}	7.47^{bc}	40.91^{a}	81.08^{b}
	S_2	37.17^{ab}	75.26^{c}	6.86^{cd}	39.41^{a}	75.26^{c}
	S_3	35.64^{bc}	75.10^{c}	6.46^{de}	37.74^{a}	75.10^{c}
	S_4	34.43^{cd}	62.12^{d}	5.36^{fg}	32.36^{b}	62.12^{d}
I_3	S_1	32.47^{de}	53.28^{d}	4.44^{gh}	27.55^{c}	53.28^{d}
	S_2	30.50^{e}	61.62^{d}	5.53^{ef}	20.87^{d}	61.62^{d}
	S_3	27.71^{f}	44.10^{e}	3.76^{hi}	17.05^{e}	44.10^{e}
	S_4	25.77^{g}	42.58^{ef}	3.58^{hij}	16.60^{e}	42.58^{ef}
I_4	S_1	26.27^{g}	42.58^{e}f	3.41^{ij}	17.19^{e}	42.58^{ef}
	S_2	25.02^{gh}	38.80^{ef}	3.23^{ij}	16.60^{e}	38.80^{e}f
	S_3	25.17^{gh}	40.04^{ef}	3.21^{ij}	15.60^{e}	40.04^{ef}
	S_4	23.39^{h}	34.46^{f}	2.78^{j}	15.29^{e}	34.46^{f}

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

Parameter	1	2	3	4	5	6
1	1					
2	0.91**	1				
3	0.91**	0.99**	1			
4	0.98**	0.91**	0.91**	1		
5	0.91**	0.91**	0.90**	0.93**	1	
6	0.81**	0.86**	0.84**	0.83**	0.82**	1

** indicate significant at 0.01. 1, Dry matter; 2, leaf area duration; 3, leaf area index; 4, crop growth rate; 5, chlorophyll index; 6, relative water content.

interaction between irrigation regime and SAP level was significant at 5% level (Table 5). LAD was significantly correlated (Table 6) with RWC (0.86), CI (0.91) and LAI (0.99). 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 LAD. So, LAI, LAD and DM increased.

Crop growth rate

CGR decreased with decreasing irrigation application (Table 3). Bullock et al. (1988) suggested that CGR decreased with the increased of water stress in sorghum-Sudangrass. The CGR increased with increasing amount of polymer in the soil (Table 4). The interaction between irrigation regime and SAP level was significant at 5% level (Table 5). CGR was significantly correlated (Table 6) with RWC (0.83), CI (0.93), LAI (0.91) and LAD (0.91).

Dry matter

DM decreased with decreasing irrigation application (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%. DM increased with increasing amount of polymer in the soil (Table 4). 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. Therefore, in this experiment with an increase in the RWC, CI, LAI, LAD and CGR, the amount of DM increased. Our result is also in agreement with the results of Bullock et al. (1988) and Peacock and Wilson (1984). On the other hand, the use of polymer in soils improved 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 and the DM content in I_1S_4 was the same as I_2S_1, I_2S_2 and I_2S_3 (Table 5). DM was significantly correlated (Table 6) with RWC (0.81), CI (0.91), LAI (0.91), LAD (0.91) and CGR (0.98).

DISCUSSION

Water stress decreased CI, LAI, LAD, CGR, RWC and DM. Our results have shown that the applied SAP had an important effect on forage sorghum and increased CI, LAI, LAD, CGR, RWC and DM. CGR expresses the rate of dry matter accumulation. Water stress reduced the LAI that resulted in a reduced photosynthesis and hence a low dry biomass accumulation. It is a common adverse effect of water stress on crop plants in the reduction of dry biomass production. The application of SAP significantly improved the periodic CGR and leaves area under irrigation regimes. 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 LAI and CGR and then LAD through increasing both water and nutrient use efficiency in crops. The DM yield in treatment I_2S_3 was the same as that using 75 kg ha^{-1} SAP; as much as 20% of water irrigation was saved.

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