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Relationship between Some Growth Indexes and Tillering of Forage Sorghum under Irrigation Regimes and Polymer

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Abstract: 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 scarcer 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 irriga¬tion requirement of plants. This experiment was conducted on sorghum variety 'Speedfeed' in Zahedan, Iran during 2012 and 2013 seasons. The experimental design was a split-plot with two factors including four irrigation regime (providing 55, 70, 85 and 100% from consumptive (ET crop) of sorghum) as main plots and four amounts of SAP (0, 40, 80 and 120 kg ha-1) as subplots in a completely randomized block design with three replications. Irrigation level and SAP had significant effects on leaf area index, crop growth rate, leaf area duration and number of tillers per plant. Water stress decreased leaf area index, leaf area duration, crop growth rate and tillers per plant. Our results have shown that the applied SAP had an important effect on forage sorghum and increased leaf area index, leaf area duration, crop growth rate and tillers per plant. The results indicated with an increase in the LAI, LAD and CGR the number of tillers per plant increases.

Keywords: Forage sorghum; Growth indexes; Irrigation regimes; Number of tillers per plant; Superab A200 polymer.

1. Introduction

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 [1, 2]. Superabsorbent polymers are becoming more and more important in regions where water availability is insufficient [3, 4]. 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 [5, 6]. The application of SAP for stabilizing soil structure resulted to increased infiltration and reduced water use and soil erosion in a furrow irrigated field [7-9]. 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 [8, 10, 11]. Superabsorbent polymer can hold 400-1500 g of water per dry gram of hydrogel [12]. The SAP also prolonged water availability for plant use when irrigation stopped [13, 14]. Thus, plant growth could be improved with limited water supply [15].

Sorghum (*Sorghum bicolor* L. Moench) is one of the 5 major cultivated species in the world. It can out produce most other cereals under marginal environmental conditions, especially dry and hot climate conditions which prevails the most parts of the country [16]. Sorghum tolerates drought relatively well, and it responds to adequate fertility and soil moisture with faster growth [17]. Sorghum is a drought resistant summer annual crop [18]. 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 [19, 20]. 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 [21]. 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 [22]. 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 [23] . The high leaf area duration (LAD) can produce higher dry matter [24] and the LAI and LAD were positively correlated with dry matter_production [25]. LAD is one of the important physiological traits that have an implication on yield potential related to increasing assimilate availability [26]. Pedersen and Lauer [27] reported that seasonal CGR patterns, total dry matter (DM) and leaf area index (LAI) were highly associated with each other. CGR is a prime dynamic growth factor to study since it reflects canopy assimilatory capacity, and affects total DM levels and equilibrates through adjustments of LAI and/or net assimilation rate [28]. Shibles and Weber [29] demonstrated that optimal CGR and yield resulted when LAI was sufficient (3 to 3.5) to achieve an optimal light interception of 95% by R5. However, subsequent studies showed that the relationship between LAI and optimal CGR varied with environmental conditions [30]. Sorghum can produce tillers, and the number of productive tillers is influenced by soil water availability [31]. Drought stress reduces the number of tillers either by stopping the differentiation process or by the death of growing or grown tillers [32]. Tillering is controlled by hormones and factors such as temperature, photoperiod, soil moisture, plant density and CGR [33]. Water stress causes the production of abscisic acid in plant, resulting in a decrease of the tillers [34]. The tillers are more sensitive to water stress than the main stem because in this condition the available assimilate decrease [32]. Plant photosynthetic material is consumed when the tillers are generated thus tillers productions and survival depends on photosynthesis and the material stored [32, 35]. The objectives of this investigation were to determine the effects of Superab A200 and irrigation regime on the leaf area index, crop growth rate, leaf area duration and number of tillers per plant of sorghum.

2. Materials and Methods

2.1. 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. 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, 85, 70 and 55 % from consumptive (ET crop) of sorghum) and four SAP levels as subplot (0, 40, 80 and 120 kg ha^{-1}) on S*orghum bicolor* (L.) variety 'Speedfeed' during 2012 and 2013 seasons to evaluate the effects of SAP under irrigation regime on DM.

2.2. 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 1 [15, 36].

Table-1. 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 [37], 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 [38, 39]. The forage sorghum evapotranspiration was calculated by Eq. [1, 2 and 3] 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.

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

$$K_c=ET_a/ET_p \qquad [2]$$

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 [40].

$$ET_0=K_{pan}\times E_p \qquad [3]$$

Where ET_o, K_{pan} and E_p was evapotranspiration of the reference crop.
K_{pan} was 0.66 [41] and E_p was Evaporation of pan.

2.3. 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. [4] as follows [22]:

$$LAI=Leaf\ area\ (m^2)/Leaf\ area\ (m^2) \qquad [4]$$

LAD was measured after flowering was at a 10% level by Eq. [5] as follows [22]:

$$LAD = [(LAI_{1+}LAI_2) \times (T2-T1)]/2 \qquad [5]$$

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

CGR was measured after flowering was at a 10% level by Eq. [6] as follows [42]:

$$CGR = W2\text{-}W1/\ (T2\text{-}T1)\ GA \qquad [6]$$

Where
W_1 = Initial weight
W_2 = Final weight
GA = Ground area

T_1 and T_2 are the time interval between initial and final dry matter determination.

The determination of 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 number of tillers per plant (NT) was counted in three plants for each plot, then the results were averaged, resulting in a single value to represent that plot.

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.

2.4. Statistical Analysis

Statistical analysis was performed using SAS software for a split plot arranged in a randomized complete block design. Year was considered as a random effect in the statistical analysis. Irrigation regime and SAP were considered fixed effects. The analysis of variance for each physiological variable was performed with the PROC MIXED procedure in SAS [43]. The Linear, quadratic, and cubic models were tested for irrigation regime and SAP level. The regression equations were fitted by PROC REG. The linear, quadratic, and cubic regression models were tested for each irrigation level, with SAP level entered in the model as an independent variable. All the estimated parameters in the regression models were significant at $P \leq 0.01$. The graphs were designed using Sigma Plot software.

3. Result and Discussion

3.1. Leaf Area Index

The LAI was also significantly affected by the irrigation regime, SAP level, and their interactions at $P < 0.01$ (data not shown).

Table-2. Parameters estimate for regression models for LAI (leaf area index), LAD (leaf area duration m2 day-1), CGR (crop growth rate g g-1 m-2 day-1), NT (number of tillers per plant) under irrigation regime (I) and superabsorbent polymer (SAP) in forage sorghum.

Parameter estimates for regression models								
Dependent variable	treatments		Model	$\hat{\beta}_0$	$\hat{\beta}_1$	X_0	R^2	Model significance
	I	SAP (kg ha^{-1})						
LAI	100	all levels	-	-	-	-	-	n.s
	85		Q	0.03	0.0002	5.4	0.89	<0.01
	70		Q	0.01	0.0003	3.5	0.96	<0.01
	55		Q	0.0006	0.00008	2.7	0.86	<0.01
LAD	100	all levels	-	-	-	-	-	n.s
	85		Q	0.3	0.003	67.7	0.97	<0.01
	70		Q	0.2	0.003	42.6	0.98	<0.01
	55		Q	0.12	0.001	33.9	0.94	<0.01
CGR	100	all levels	-	-	-	-	-	n.s
	85		Q	0.06	0.0001	31.6	0.88	<0.01
	70		Q	-	0.00074	14.16	0.91	<0.01
	55		L	0.098	-	7.6	0.87	<0.01
NT	100	all levels	-	-	-	-	-	n.s
	85		Q	0.02	0.0008	2.8	0.94	<0.01
	70		Q	-	0.0009	2.5	0.91	<0.01
	55		L	0.0004	-	1.8	0.92	<0.01

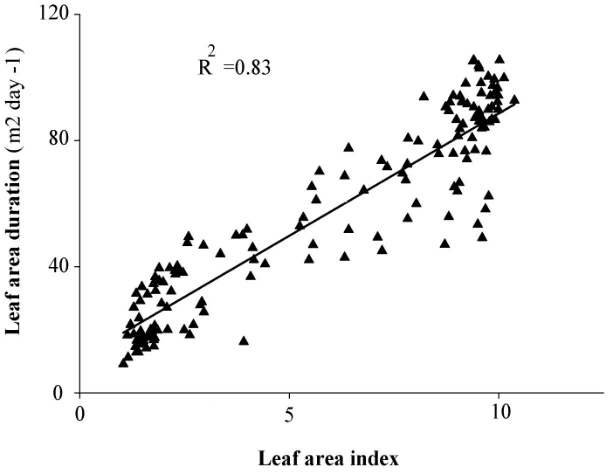
L, linear regression model; Q, quadratic regression model.

The LAI means for the 55, 70 and 85% ETc treatments were 3.02, 5.18 and 7.92, respectively. [23] suggested that the leaf area decreases with increasing water stress. The LAI increased with increasing evapotranspiration, well-irrigated conditions stimulated vegetative growth for sorghum *var* speedfeed under semiarid conditions [5]. Responses of the LAI to SAP levels for 55, 70, and 85% ETc were quadratic, while the response of LAI to SAP levels for 100% ETc was not significant (Table 2). Means of LAI for 0, 40, 80 and 120 kg SAP ha^{-1} were 4.6, 5.1, 5.4 and 5.8, respectively. Islam et al. (2011) showed that the leaf area did not change under limited application of a SAP but increased by 18.9 and 32.5% following the application of SAP at medium and high rates, respectively.

3.2. Leaf Area Duration

The LAD was also significantly affected by the irrigation regime, SAP level, and their interactions at $P < 0.01$ (data not shown). The LAD means for the 55, 70 and 85% ETc treatments were 44.7, 65.4 and 96.5 m^2 day^{-1}, respectively. Brevedan and Egli [26] suggested that drought stress reduces the LAD. LAD increased with increasing amount of polymer in the soil. Responses of the LAD to SAP levels for 55, 70 and 85% ETc were quadratic, while the response of LAI to SAP levels for 100% ETc was not significant (Table 2). Means of LAD for 0, 40, 80, and 120 kg SAP ha^{-1} were 55.6, 63.1, 68.4 and 75.8 m^2 day^{-2}, respectively. There was a positive linear relationship between LAI and LAD (Fig. 1). In drought conditions the nutrients transfers from leaves increases, accelerating the leaf senescence [26]. On the other hand, Islam, *et al.* [11] showed that SAP could be an effective way to increase both water and nutrient use efficiency in crops and an increase in LAD.

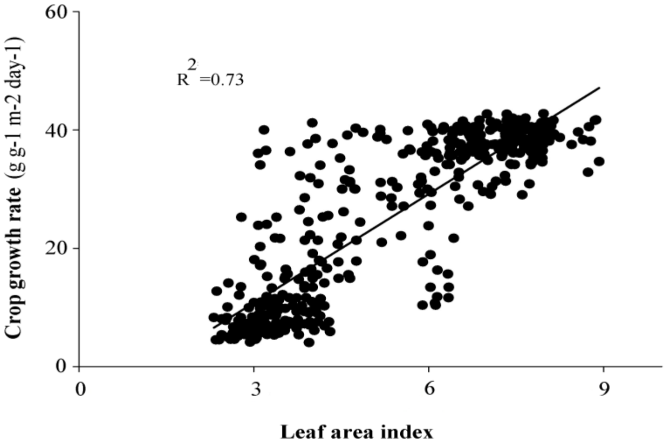
Fig-1. Relationship between leaf area index and leaf area duration.



3.3. Crop Growth Rate

The CGR was also significantly affected by the irrigation regime, SAP level, and their interactions at $P < 0.01$ (data not shown). The CGR means for the 55, 70 and 85% ETc treatments were 13.48, 16.82 and 35.56 g g^{-1} m^{-1} day^{-1}, respectively. Bullock, *et al.* [44] suggested that the CGR decreases with increasing water stress. Responses of the CGR to SAP levels for 70, and 85% ETc were quadratic, while the response of CGR to SAP levels for 55 and 100% ETc were linear and not significant, respectively (Table 2). Means of CGR for 0, 40, 80 and 120 kg SAP ha^{-1} were 21.5, 23.7, 25.9 and 31.2 g g^{-1} m^{-1} day^{-1}, respectively. The substantial increase in LAI and LAD with increasing irrigation was reflected in a large increase in the CGR [44]. There was a positive linear relationship between LAI and CGR (Fig. 2).

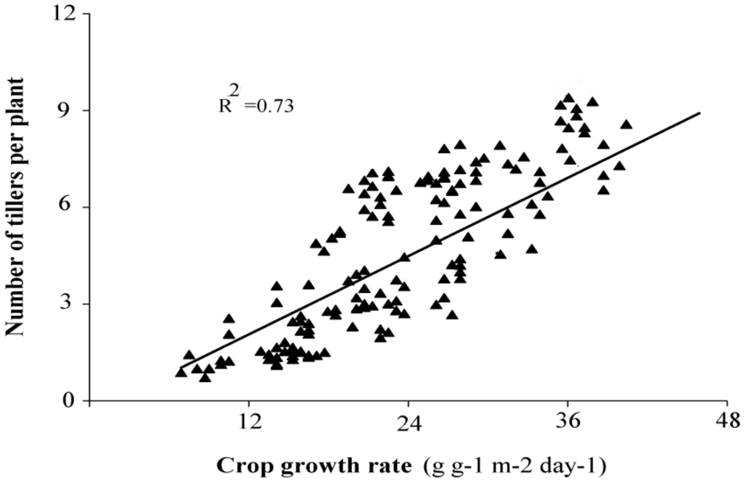
Fig-2. Relationship between leaf area index and crop growth rate.



3.4. Number of Tillers per Plant

The NT was also significantly affected by the irrigation regime, SAP level, and their interactions at $P < 0.01$ (data not shown). The NT means for the 55, 70 and 85% ETc treatments were 1.82, 5.74 and 6.88, respectively. Krieg (1983) suggested that drought stress reduces the number of tillers. Responses of the CGR to SAP levels for 70, and 85% ETc were quadratic, while the response of CGR to SAP levels for 55 and 100% ETc were linear and not significant, respectively (Table 2). Means of CGR for 0, 40, 80 and 120 kg SAP ha^{-1} were 2.84, 3.46, 3.79 and 4.16, respectively. Fazeli [5] suggested that NT increased with increasing amount of polymer in the soil. There was a positive linear relationship between CGR and NT (Fig. 3). The tillers are more sensitive to water stress than the main stem because in this condition the available assimilate decrease [32]. Plant photosynthetic material is consumed when the tillers are generated thus tillers productions and survival depends on photosynthesis and the material stored [35].

Fig-3. Relationship between crop growth rate and number of tillers per plant.



4. Conclusion

Water stress decreased leaf area index, leaf area duration, crop growth rate and tillers per plant. Our results have shown that the applied SAP had an important effect on forage sorghum and increased leaf area index, leaf area duration, crop growth rate and tillers per plant. 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 available assimilate in the plant. The increasing available assimilate caused increasing in crop growth rate. On the other hand, Plant photosynthetic material is consumed when the tillers are generated thus tillers productions and survival depends on photosynthesis and the material stored. So, in this experiment with an increase in the LAI, LAD and CGR the number of increases.

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