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Yield and water use efficiency (WUE) responses of forage sorghum ratoon crop under varying salinity and irrigation frequency

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Water stress is associated with low availability of water or with osmotic effects arising from salinity. Besides affecting crop yields, salinity may also influence biochemical composition and nutrient concentration of forage crops. To determine the effect of salinity on biochemical composition and nutrient concentration of forage sorghum [*Sorghum bicolor* (L.) *Moench*], two varieties of sorghum, Speedfeed and KFS4 were grown under rain shelter at salinity levels of 0, 5, 10, 15 dS m^{-1} and irrigated when the leaf water potential reached -1 (control), -1.5 and -2 MPa. The factorial treatment combinations were arranged in a randomized complete block design with three replications. Stem dry matter, leaf dry matter and eventual dry matter yields of ratoon forage sorghum decreased with increasing salinity and irrigation interval. The reduction in plant biomass under stress conditions was found to be associated with increase in water use efficiency (WUE). Since the saline applications continued until the second harvest (first ratoon crop) as soil salinity increased, dry matter yields were reduced dramatically. No viable plants were obtained in the second ratoon crop for KFS4 variety at 15 dS m^{-1} salinity and -2 MPa irrigation frequency treatments. Based on all parameters evaluated in the first ratoon crop, there was no concrete evidence to suggest that Speedfeed was superior in performance, but in the second ratoon, forage yields suggest that this variety can be a good alternative in planning for forage production.

Key words: Salinity, irrigation frequency, ratoon crop, forage sorghum.

INTRODUCTION

The productivity of plants is strongly influenced by environmental stresses. Scientists consider soil salinity as one of the major factors that reduce plant growth in many regions of the world (McCarty and Dudeck, 1993; Murdoch, 1987). Sodium chloride (NaCl) is the predominant component contributing to salinity in soils (Jungklang et al., 2003). To overcome this problem, the search for salt tolerant forage sorghums has increased (Harivandi et al., 1992). Salt tolerant plants have the capability to minimize these detrimental effects by a series of morphological, physiological and biochemical processes (Jacoby, 1999). Under the variable saline

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environments, plants have developed different adaptive mechanisms (Rhodes et al., 2002 and Borsani, et al., 2003).

Sorghum has tillering characteristics that enable it to completely regenerate the above-ground portions of the plant. Individual sorghum plants have been kept alive for as long as 7 years where the climate is mild enough to avoid winterkill and disease and insect protection have been provided. These important features of sorghum have allowed producers to seek a second crop within the same growing season. This decision, however, must be made at or soon after harvest of the main crop, and re-growth should be managed in the same manner as the main crop (Teutsch, 2006). A new generation of salt-tolerant forage varieties would allow for landscape development in saline environments and where salt water usage is a problem, or where fresh water is limited or not available for irrigation. Forage sorghum development in these areas often requires the use of brackish water from affected wells or other secondary sources. The effect of salinity and water deficit on ratoon crops of sorghum is not known. Hence, studies are needed to improve understanding on yield re-growth of forage sorghum under influence of salt and water stresses. In addition, many factors need to be considered when addressing the suitability of irrigation water with respect to salinity. To our knowledge, there are no published studies on drought and salt water tolerance among these forage sorghum varieties. Proper utilization of highly salt tolerant forage sorghum varieties will benefit the growing forage sorghum industry. The specific objectives of this study were: to determine yield, biomass partitioning and water use efficiency (WUE) responses in the first ratoon crop of the two forage sorghum varieties to different levels of salinity and irrigation frequency.

MATERIALS AND METHODS

The factorial experiment was conducted under rain shelter at University Putra Malaysia (02°N 59.476´ 101°ºE 2.867´, 51 m altitude), from January 2009 to December 2009. The climatic conditions recorded under rain shelter were 31°C mean temperature, 88% humidity, 4.5 mm evaporation and 71% light at 12 am. Two selected (Fouman et al., 2003) salt tolerant varieties namely Speedfeed and KFS4, of forage sorghum [*Sorghum bicolor* (L.) Moench] were subjected to the salinity levels of 0, 5, 10 and 15 dS m^{-1} of NaCl concentrations, and irrigated when the leaf water potential reached -1 (control),-1.5 and -2 MPa.

The treatments were arranged in a randomized complete block design with three replications. Polybags (40 × 45 cm) were filled with a mixture of top soil, peat moss and sand at the ratio of 3:2:1 (v/v), respectively. The plants were irrigated with non-saline water for seedling establishment and with saline water starting from the 2^{nd} week after germination according to the treatments. The soil mixture which had a pH of 6.52 was filled into polyethylene bags of size 40 x 45 cm. Each bag of soil was also thoroughly mixed with 62 g of $CaCO_3$, 9 g complete fertilizer (15% N, P_2O_5, K_2O), 1 g of triple super phosphate (45% P_2O_5) and 2.4 g of urea (46% N). Soil field capacity (FC) and permanent wilting point (PWP) were measured before and after completion at the experiment. Soil moisture was determined by gravimetric method (Aslam et al., 2008).

The amount of water required for the irrigation of each treatment was calculated using the following equation: *V = SMD × A* where; V= volume of water to be applied (liter); A= polybag area = πr^2; SMD = (θ_{FC} - θ_i) D Bd /100: SMD = soil moisture deficit; θ_{FC} = gravimetric soil moisture content at field capacity (%); θ_i = Soil moisture content before irrigation (%); D = rooting depth (cm); Bd = bulk density (in this soil 1.5 g cm^{-3}).

Parameters measured

Determination of shoot dry weight in main crop

After harvesting, main crop plants were allowed to re-grow and 49 days after harvest, plants had grown to approximately 170 cm in height. Shoots were harvested at the cutting height of 15 cm from soil surface the same as for the main crop. The plant samples were carefully washed to remove all soil particles. Samples were then dried in an oven at 70°C for 3 days until constant weight was achieved. The dry weight of shoots (g $plant^{-1}$) was recorded for each treatment.

Determination of shoot dry weight in first ratoon crop

After harvesting main crop plants were re-growth and 49 days later than harvest, plants had reached to 170 cm height approximately, shoots were harvested at a cutting height of 15 cm from soil surface, then dried and weighed the same way as main crop.

Determination of shoot dry weight in second ratoon crop

At the end of the experiment (10% flowering stage) when plants had re-growth that reached 150 cm height approximately, fifty-day-old shoots were harvested, then dried and weighed the same as main crop.

The data were analyzed using Procedure ANOVA in the SAS. Treatment means were compared using least significant differences (LSD) at the 95% ($P \leq 0.05$) probability level.

RESULTS

Yield and yield components at harvest in first ratoon crop

Irrigation frequency and salinity, significantly ($P<0.01$) affected; growth, yield and yield components of forage sorghum (Table 1). Under influence of salinity at 15 dS m^{-1} forage mass was reduced, 33.7% as compared to none saline treatment, while the decreases under salinity at 5 and 10 dS m^{-1} were 13.9 and 22.3%, respectively. Comparison between varieties showed no significant differences between KFS4 and Speedfeed.

The highest forage dry mass was obtained with the more frequent irrigation, but decreased 4.3% with moderate irrigation. The impact of irrigation schedule however was strongly evident in plants when irrigation was delayed from -1.5 to -2 Mpa and as a result the forage yield decreased by 18.5 %.

Table 1. Effect of different levels of irrigation frequency and salinity on leaf, stem and forage dry weight of forage sorghum varieties for the first ratoon crop.

Treatment	Leaf dry weight (g $plant^{-1}$)	Stem dry weight (g $plant^{-1}$)	Forage dry weight (g $plant^{-1}$)
Variety			
KFS4	8.74[a]	18.67[a]	27.42[a]
Speedfeed	8.51[a]	18.38[a]	26.85[a]
$LSD_{0.05}$	0.58	1.68	2.26
Irrigation frequency at			
LWP -1.0 (MPa)	9.38[a]	20.07[a]	29.38[a]
LWP -1.5 (MPa)	8.77[a]	19.32[a]	28.09[a]
LWP -2.0 (MPa)	7.73[b]	16.19[b]	23.93[b]
$LSD_{0.05}$	0.75	2.17	2.76
Salinity (dS m^{-1})			
0	10.25[a]	22.75[a]	32.89[a]
5	8.93[b]	19.36[b]	28.30[b]
10	8.13[b]	17.40[b]	25.53[b]
15	7.20[c]	14.60[c]	21.80[c]
$LSD_{0.05}$	0.90	2.58	3.19
F value			
VxI	2.11**	1.53*	0.61**
VxS	0.13 ns	0.15 ns	0.10ns
IxS	0.57 ns	0.67 ns	0.45 ns
VxIxS	0.80 ns	0.60 ns	0.72**
Error and CV			
Error (MS)	216.26	12.62	22.71
CV (%)	14.35	19.17	17.56

**, * and ns are significant at 0.01, 0.05 level and non significant, respectively.

In addition to reduction in yield, stress resulted in changes in composition of leaves and stems of the forage sorghums. The decreases of leaves under leaf water potential of -1.5 to -2 Mpa were 6.5 and 17.5%, respectively, while under salinity treatments the decreases were 12, 20.6 and 29.7%, respectively. Accumulations in dry stem weights under water stress were 3.7 and 19.3%, while under salinity the values were 14.9, 23.5 and 35.8%, respectively. Comparison between yield and yield components of the two varieties showed no significant differences between KFS4 and Speedfeed variety (Table 1).

Water use efficiency at harvest in first ratoon crop

The water use by plants showed very complicated responses; and it was significantly dependent on salinity, variety and interaction of irrigation and variety as well as interaction of salinity and irrigation (Table 2). Unlimited water use lead to higher yields, however this caused some wastage. There was a significant interaction effect of irrigation and salinity levels on water use efficiency (WUE).

WUE in the control treatment was 34.5%, while the WUE with the irrigation frequency at leaf water potential of -2 MPa was 19.3% more than in the control treatment. Irrigation when applied at longer intervals had higher WUE. Irrespective of variety, the more frequently watered plants accumulated greater dry matter to eventually produce higher dry forage yield than other irrigation frequencies (Table 2).

The results derived from the irrigation study showed that despite the possibility of greater surface evaporation with light frequent irrigations, differentials of the sorghum varieties and other indicators of plant water stress were found to be improved with low frequent irrigation. Irrespective of variety, intermediate irrigation regime had

Table 2. Effect of irrigation frequency on yield of first ratoon crop and water use efficiency (WUE)

Irrigation schedule	Days after treatment							Dry forage yield (g plant^{-1})	Total water used (liters)	WUE (g plant^{-1} liter^{-1})
	1	11	19	28	33	38	45			
I1	1	0.98	1.17	1.27	1.09	1.08	1.26	29.38	7.85	3.73
I2	1	0	1.59	0	1.70	0	2.01	28.09	6.30	4.43
I3	1	0	0	2.36	0	0	2.48	23.93	5.84	4.07
LSD $_{0.05}$								2.76	0.61	0.43

I1, I2 and I3 are irrigation frequencies applied when the leaf water potential reached -1, -1.5 and -2 MPa, respectively. * Salinity levels averaged for these data.

Table 3. Mean forage yields in ratoon crops of sorghum varieties at different levels of irrigation frequency and salinity.

Treatment	Main crop (dry forage) (g plant^{-1})	First ratoon crop (dry forage) (g plant^{-1})	Second ratoon crop(dry forage) (g plant^{-1})	Total (dry forage) (g plant^{-1})
Variety				
KFS4	42.25	27.42	2.14	71.81
Speedfeed	39.41	26.85	11.55	78.50
LSD $_{0.05}$	2.66	2.26	0.61	4.52
Irrigation frequency at				
LWP -1.0 (MPa)	45.12	29.38	7.91	81.91
LWP -1.5 (MPa)	38.88	28.09	6.88	74.11
LWP -2.0 (MPa)	38.48	23.93	5.74	69.45
LSD $_{0.05}$	3.25	2.76	0.75	5.54
Salinity (dS m^{-1})				
0	45.73	32.89	8.38	87.23
5	43.61	28.30	7.15	79.46
10	39.79	25.53	6.47	72.36
15	34.17	21.80	5.37	61.57
LSD $_{0.05}$	3.76	3.19	0.87	6.40
F value				
V×I	4.37*	0.61**	16.93**	0.97^{ns}
V×S	0.03^{ns}	0.10^{ns}	8.41**	0.20^{ns}
I×S	0.29^{ns}	0.45^{ns}	1.48^{ns}	0.61^{ns}
V×I×S	0.70^{ns}	0.72**	1.73^{ns}	0.35^{ns}
Error and CV				
Error (MS)	31.43	22.71	2.91	91.05
CV (%)	13.73	17.56	18.94	12.69

**, * and ns are significant at 0.01, 0.05 level and non significant, respectively.

higher WUE than the most frequently irrigated regime. Though, when comparing the two varieties, variety KFS4 significantly produced higher dry forage in the main crop; however, in the second ratoon crop, the total dry weight (submission of three cutting) of Speedfeed was higher than KFS4 (Table 3 and Figure 1).

The results of this study showed that the yield of forage sorghum was significantly increased with more frequent irrigation. More frequent irrigation is usually associated with increase in salt concentrations in the soil as water is extracted by the crop. Typically, salt concentrations are lowest following irrigation and higher just before the next

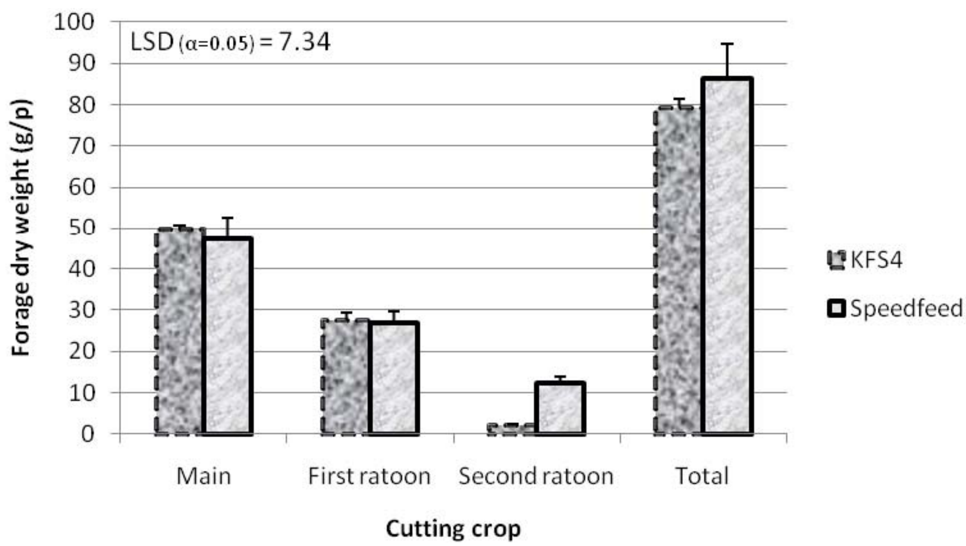

Figure 1. Forage yield in ratoon crops of the two sorghum varieties.

irrigation. Increasing irrigation frequency maintains higher constant moisture content in the soil, and thus more of the salts are kept in solution which aids the leaching process.

DISCUSSION

The effect of salinity and irrigation frequency as reflected by a lower yield may be the result of a combination of osmotic and specific ion effects of Cl and Na. As the salt concentration and water stress increased, dry matter yield diminished the first ratoon with reductions of 13.9, 22.3 and 33.7% as compared to none saline treatment, respectively (Table 1). The highest reduction (33.7%) was from the most salt stressed (15 dS m^{-1}) against 18.6% for the most water stressed plants, and significant decreases were also recorded for other salt levels. This is consistent with reports in other monocots including rice, wheat and maize (Krishna et al., 1993; Shabala, et al., 1998). KFS4 variety which in the main crop study exhibited a higher yield in terms of dry matter production did not show any significant differences with Speedfeed variety in the first ratoon crop. As the saline applications continued into the first ratoon crop, there were significant losses in yield under the stress treatments, however with three cuttings characteristic of Speedfeed led to higher total production of Speedfeed (Figure 1 and Table 3). No viable plants were obtained in the second ratoon crop for KFS4 variety at 15 dS m^{-1} salinity and -2 MPa irrigation frequency treatments, because KFS4 was genetically known to be a one ratoon crop.

Salinity stressed plants certainly faced osmotic challenges. This is in agreement with several previous reports (Munns and Tester, 2008; Lee et al., 2004), which concur that osmotic adjustment is the main response for survival and growth of plants under salinity stress. Also under saline conditions a positive association between photosynthetic rate and yield has been reported in sorghum (Faville et al., 1999).

When plants are under water stress, they firstly reduce and then stop leaf expansion (Hsiao and Jing, 1997). In this study, the WUE obtained for the infrequently watered plants were higher than earlier reports on five forage sorghum cultivars grown on dry land in Texas (Gulzar et al., 2003) or values previously reported for the same crop in the northern part of Sudan (Mustafa and Abdel Magid, 1982). Although larger volumes of water were used in this investigation as compared to the two previous reports, the higher WUE obtained here could be attributed to the reduction in irrigation with the infrequent watering.

Conclusion

There were significant losses in yield in the second ratoon crop under the stress treatments. Irrigation can overcome effect of salinity as increasing irrigation frequency maintains constant moisture content in the soil. Thus, more of the salts are then kept in solution which aids in the leaching process. Irrigation may be intensified in saline soils to mitigate the effect of salinity on plant growth. However, there is a critical level of salinity after which irrigation cannot mitigate the effect of salinity. The critical level of salinity for KFS4 was 15 dS m^{-1}, while for Speedfeed it was 10 dS m^{-1}. The results obtained in this study would serve as a useful guide for managing forage sorghum in saline and water stressed field conditions. On the other hand, WUE in forage sorghums can be increased with reduced irrigation frequency, and this will enable larger field areas to be irrigated with the savings in water used. The present findings suggest that in semiarid environments (where saving water is very important), sorghums should be irrigated infrequently but heavily, if the aim is to get high WUE forage sorghum.

The final concluding remarks describe characteristics, advantages and limitations of the varieties studied: KFS4 variety under stress condition gave better vegetative growth performance especially in main crop dry matter production as compared to Speedfeed. While considering second ratoon crop characteristics, Speedfeed was superior to KFS4 variety.

Conflict of Interests

The author(s) have declared that there is no conflict of interests.

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