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Full Length Research Paper

Morphological responses of forage sorghums to salinity and irrigation frequency

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Water stress occurs when the demand for water exceeds the available amount during a certain period or when poor quality water restricts its use. In particular, water stress is associated with low availability of water, as well as osmotic effects associated with salinity. The response of forage sorghum [*Sorghum bicolor* (L.) Moench] varieties to salinity and irrigation frequency were studied from December 2007 to December 2009. Two forage sorghum varieties (Speedfeed and KFS4) were grown under salinity levels of 0, 5, 10 and 15 dS m^{-1} and irrigated when the leaf water potential reached -1.0 (control), -1.5 and -2.0 MPa. Irrigation frequency and salinity were found to affect the morphology and growth of the forage sorghum. Maximum number of leaves was produced in non-saline soil (13.5 leaves $plant^{-1}$) with normal irrigation (12.4 leaves $plant^{-1}$). Low soil water and high salinity reduced the number of leaves as well as the number of tillers produced. Leaf area of plants were also reduced in response to salinity and decreasing soil water availability, while the suppressive effect was magnified under the combined effect of the two factors. Significant differences in stem diameter were found between the frequently and the least frequently watered plants, and stem diameter decreased with increasing salinity. Leaf firing increased with increasing salinity reaching 59.9% in the extreme salinity treatment of 15 dS m^{-1}, and it increased with increasing water stress reaching 48.6% in the extreme water stress treatment of -2 MPa. Under stress condition, the KFS4 variety had a better performance in terms of morphological and growth parameters compared to Speedfeed variety. The threshold concentration was found to vary with variety. However, in control treatment, Speedfeed variety had greater leaf area, plant heights, number of leaf and number of tiller.

Key words: Salinity, irrigation frequency, morphologic parameters, forage sorghum.

INTRODUCTION

Salinity is one of the most important environmental factors limiting crop production of marginal agricultural soils in many parts of the world. Salinity hazard may exist when the salt levels are too high. In soil, salts can reduce water availability to the plant to such an extent that yields can be affected (Munns, 2002). Salinity includes imposition of ion toxicities (example Na and Cl), ionic imbalances, osmotic stress and soil permeability problems (Ashraf et al., 2008). Water stress which resulted from salinity restricts crop yields in both the arid and semi-arid zones of the world (Misra and Dwivedi, 2004). However, cultivation under salinity and water stress conditions is normally practiced for food supply in the developing countries (Macon, 2002).

In general, salt tolerance in plants is associated with low uptake and accumulation of Na (Jacoby, 1999). The plants are able to minimize detrimental effects by producing a series of anatomical, morphological and physiological adaptations (Poljak-off-Mayber, 1988), such as growing an extensive root system (Marcum and Murdoch, 1990; Marcum et al., 1998; Sinha et al., 1986), and through mechanisms restricting the uptake of toxic ions (Ashraf, 2004). A large proportion of the biomass shows a negative parabolic relationship with the amount of irrigation. This suggests that when water supply is

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Table 1. Rating scale used for leaf firing and forage quality assessment.

Leaf firing (%)	Forage quality
0	9
1-10	8
11-20	7
21-30	6
31-50	5
51-70	4
71-90	3
91-99	2
100	1

sufficient, excessive vegetative growth may cause less root activity and an unhealthy canopy structure (Zhang and Yang, 2004). Irrigation is practiced to alleviate drought due to salinity impacts on crop yield (Macon, 2002). Forage sorghum which is a major summer forage crop for feed production, has greater reliability salt and drought tolerance than other summer forages. There are a number of potential forage sorghum varieties which may be appropriate at various salinity levels of seawater (Qudir and Oster, 2004). Despite significant reports on salinity, earlier investigations on sorghum were focused primarily on grain sorghums. Hence, studies are needed to improve understanding on the effects of salt and water stresses on different forage sorghum varieties. In addition, many factors need to be considered when addressing the suitability and management of irrigation water with respect to salinity. Therefore, producers should pay more attention in selecting the appropriate species to meet their needs. The objective of this study was to determine morphological responses of two forage sorghum varieties (Speedfeed and KFS4) to different levels of salinity and irrigation frequency.

MATERIALS AND METHOD

The two years experiment was conducted under a rain shelter at the University Putra Malaysia (02ºN 59.476´ 101ºE 2.867´, 51 m altitude) from December 2007 to December 2009. The mean climatic conditions recorded under the rain shelter were 30°C temperature, 90% humidity, 4.5 mm evaporation, and 72.5% light at 12 am. The temperature was measured using a thermometer and light intensity was measured with a heavy duty light meter (Extech® Model 407026).

Two selected (Fouman, 2003) salt tolerant varieties (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 to -1(control),-1.5 and -2 MPa.

The soil media was prepared by thoroughly mixing top soil, peat moss (KOSASR) and sand in the ratio of 3:2:1 (v/v), respectively. The 25 kg of soil mixture was filled into polyethylene bags of size 40 × 45 cm and each bag of soil was also mixed with 60 g of $CaCO_3$, 10 g of complete fertilizer (15% N, 15% P_2O_5 and 15% 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 of the experiment. Soil moisture was determined by gravimetric method (Muhammad et al., 2008).

Factorial combinations of treatment were laid out in a randomized complete block design and replicated three times. One plant was established in each bag. Each bag was considered as an experimental unit.

Irrigation treatments were applied based on leaf water potential (-1, -1.5 and -2 MPa) which was measured using the pressure chamber (Santa, Barbara, CA, USA). When the leaf water potential reached the required potential level, the soil samples were taken. The amount of water applied for the respective irrigation treatment was calculated using the following equation (Muhammad et al., 2008):

$$V = SMD \times A$$

Where, V is the volume of water to be applied (liter); A is the polybag area = πr^2; SMD is the soil moisture deficit; SMD is (θ_{FC} - θ_t) D Bd / 100; θ_{FC} = the gravimetric soil moisture content at field capacity (%); θ_t is the gravimetric soil moisture content before irrigation (%); D is the rooting depth (cm) and Bd is the soil bulk density (1.5 g cm^{-3})

At the final sampling time (at 60 days after planting and before flowering stage) morphological parameters were measured. Plant height was measured from the soil surface to the highest tip of plant; the average of three tillers was recorded. Stem diameter, total leaf area, leaf numbers, root length, and number of tillers were also measured. Leaf length (from the point of insertion of petiole to the tip of the leaflet) and leaf width (middle of the leaf) of the mature leaf were measured. The total leaf area per plant was measured with a leaf area meter (AM-200, ADC Bio Scientific Ltd., England). Treatment effects on leaf firing were estimated as the total percentage of chlorotic leaf area, with 0% corresponding to no leaf firing, and 100% as totally brown leaves. At the end of the experiment, visual forage quality was estimated on a 1 to 9 scale, where 1 is the brown, thin, dead forage; 9 is the dense, uniform, green, non-stressed forage; and 6 is the acceptable quality (Alshammary et al., 2004). The rating scale of 1 to 9 is illustrated in Table 1.

The data were analyzed by analysis of variance followed by comparison of treatment means using least significant differences (LSD) at the 5% ($P \leq 0.05$) probability level.

RESULTS

Plant height

Plant height was highly ($P \leq 0.01$) affected by irrigation frequency and varieties. Average plant height for the three irrigation intervals was 172.72, 151.54 and 142.97 cm, for irrigation regimes at leaf water potential -1, -1.5 and -2 MPa, respectively (Table 2). Lower irrigation frequency (-2 and -1.5 MPa) reduced plant height by 17.22 and 5.65% of control, respectively; whereas in the highest saline treatment, there was a 10.24% reduction in plant height relative to the control. However, the reductions in plant height at lower salinity levels were not significant. There was a significant interaction between variety and irrigation frequency where Speedfeed showed a marked decline in plant height with increasing water stress while in KFS4 plant height was unaffected by

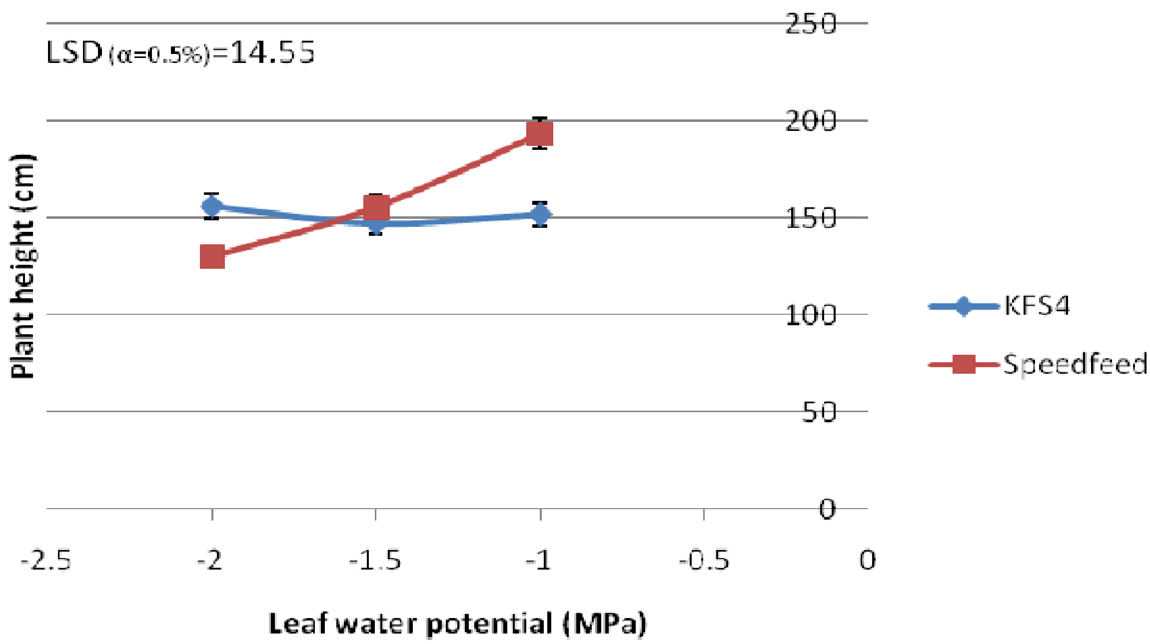

Figure 1. Varietal differences in plant height due to irrigation frequency (Average of two years).

irrigation frequency (Figure 1).

Number of tillers

Salinity and water stress significantly (P≤0.01) affected the number of tillers. The response in tiller numbers varied with salinity, irrigation level and variety. Maximum number of tillers was produced in non-saline treatments and at normal irrigation (Table 2). The number of tillers declined 35, 24 and 13% with salinity of 5, 10 and 15 dS m^{-1}, respectively, while 40 and 26% reductions in tillers were observed with less and least frequent irrigation. Speedfeed variety recorded a higher number of tillers than KFS4. The significant (P<0.01) interaction effect of salinity × variety and irrigation frequency × variety showed, reduction of tillers under these stresses, and the slope of decline for Speedfeed was higher than KFS4 (Figure 2).

Root lengths

Although, root length was significantly different due to salinity and water stress but root growth of forage varieties responded more pronouncedly to salinity. The interaction effects of salinity and variety indicated the existence of differences in root length for both varieties at salinity level of 0 and 5 dS m^{-1}, while no variation was observed at salinity level of 10 and 15 dS m^{-1} (Figure 3). Root length in Speedfeed variety was greater than KFS dS m^{-1} root length in Speedfeed variety decreased dramatically. In general, irrespective of variety, root length was reduced by 6, 19 and 29% with increasing salinity to 5, 10 and 15 dS m^{-1} respectively, and the percentage reduction under irrigation at -1.5 and -2 MPa were similar to reductions at salinity 10 and 15 dS m^{-1} (Table 2).

Stem diameter

Salinity and water stress as well as their interaction significantly (P≤0.01) affected stem diameter of forage sorghums (Table 2), mean stem thickness decreased 6% at the highest salinity level of 15 dS m^{-1}. Overall Speedfeed variety had stems with a smaller diameter than KFS4. Under all salinity levels, infrequent irrigation had smallest stem diameter in both variety, but frequent irrigation and moderate irrigation could mitigate effect of salinity and produced greater stem diameter compared to infrequent irrigation (Figure 4).

Number of leaves

Salinity, irrigation frequency, variety and the interaction effects of variety and year (V×Y) as well as irrigation frequency and year (I×Y) were found to significantly (P<0.01) affect the number of leaves. The number of leaves decreased significantly with increasing salinity (Table 3). The number of leaves decreased 24% at the highest salinity 15 dS m^{-1} while the reduction in number of leaves at salinity 10 and 5 dS m^{-1} were 15 and 6% compared to the control (Table 3). Figure 5 shows reduction in the number of leaves under water stress

Table 2. Effect of irrigation frequency and salinity on morphological characters of forage sorghum varieties (Average of two years).

Source of treatment	Plant height (cm)	Number of tiller	Root length (cm)	Stem diameter (mm)
Variety				
KFS4	151.91^{az}	0.642^{b}	32.98^{a}	15.13^{a}
Speedfeed	159.58^{a}	2.273^{a}	26.98^{b}	14.40^{b}
LSD	8.48	0.080	1.37	0.209
Irrigation frequency(MPa) at				
LWP -1	172.72^{a}	1.87^{a}	35.84^{a}	15.16^{a}
LWP -1.5	151.54^{b}	1.38^{b}	28.71^{b}	14.84^{b}
LWP -2	142.97^{b}	1.11^{c}	25.38^{c}	14.29^{b}
LSD	10.387	0.098	1.688	0.256
Salinity (dS m^{-1})				
0	160.77^{a}	1.78^{a}	34.73^{a}	15.14^{a}
5	161.02^{a}	1.54^{b}	32.71^{b}	14.82^{b}
10	156.88^{a}	1.35^{c}	27.92^{c}	14.96^{ab}
15	144.30^{b}	1.14^{d}	24.54^{d}	14.14^{c}
LSD	11.994	0.113	1.949	0.296
F value				
V×I	20.87**	102.72**	1.58^{ns}	4.46*
V×S	1.78 ^{ns}	9.97 **	0.46*	1.74^{ns}
I×S	1.25 ^{ns}	1.86 ^{ns}	2.27 ^{ns}	4.76 **
V×Y	0.41^{ns}	1.25 ^{ns}	89.20**	0.94 ^{ns}
I×Y	0.26 ^{ns}	0.09 ^{ns}	0.46 ^{ns}	5.36**
S×Y	0.16 ^{ns}	0.05 ^{ns}	4.36**	11.12**
V×I×S	0.90 ^{ns}	0.67 ^{ns}	0.45 ^{ns}	6.92**
V×I×Y	0.02 ^{ns}	1.26 ^{ns}	4.14*	16.76**
V×S×Y	0.12 ^{ns}	0.35 ^{ns}	0.12^{ns}	0.77 ^{ns}
I×S×Y	0.08 ^{ns}	1.53 ^{ns}	1.37^{ns}	3.45**
V×I×S×Y	0.17 ^{ns}	0.23 ^{ns}	1.21^{ns}	5.99**
Error (MS)	656.46	0.058	17.35	0.39
CV (%)	16.45	16.59	13.89	4.28

**, * and ^{ns} are significant at 0.01, 0.05 level and non significant, respectively

conditions and superiority of Speedfeed variety in number of leaves compared to KFS4.

Leaf length

Salinity, irrigation frequency and variety affected the leaf length. Leaves length declined in response to the less frequent irrigation (Table 3).

However, leaf length at salinity of 5 dS m^{-1} was not different from the control, but salinity level of 10 dS m^{-1} caused 1.7% reduction in leaf length and 3.9 % reduction at salinity of 15 dS m^{-1}.

Leaf width

Irrigation frequency and variety had highly significant (P≤0.01) effects on leaf width. When irrigation was delayed from -1 to -1.5 and -2 MPa, leaf width was found to decrease by 2.4 and 3.6%, respectively with the increase in water stress (Table 3). Salinity did not cause significant variation in leaf width.

Total leaf area

The total leaf area of both forage sorghums was

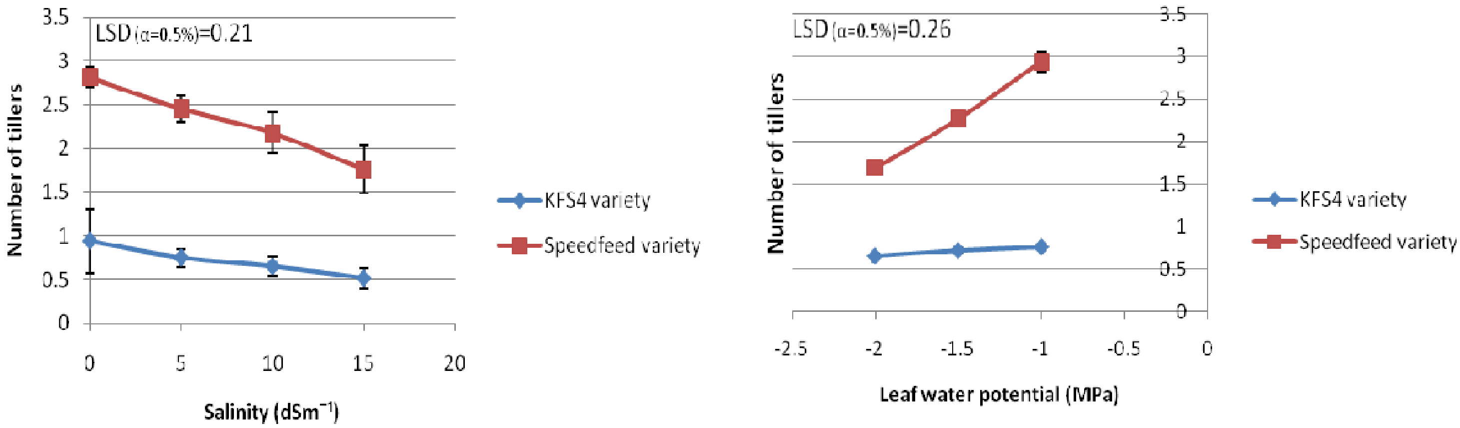

Figure 2. Varietal differences in tiller production due to salinity and irrigation frequency (Average of two years).

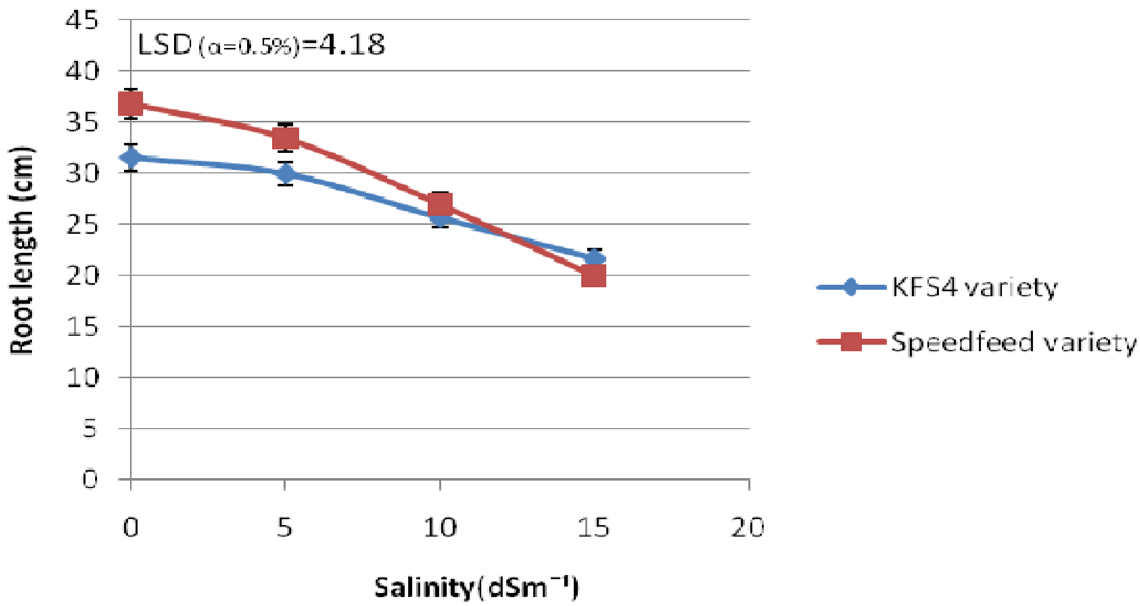

Figure 3. Varietal differences in root lengths due to salinity (Average of two years).

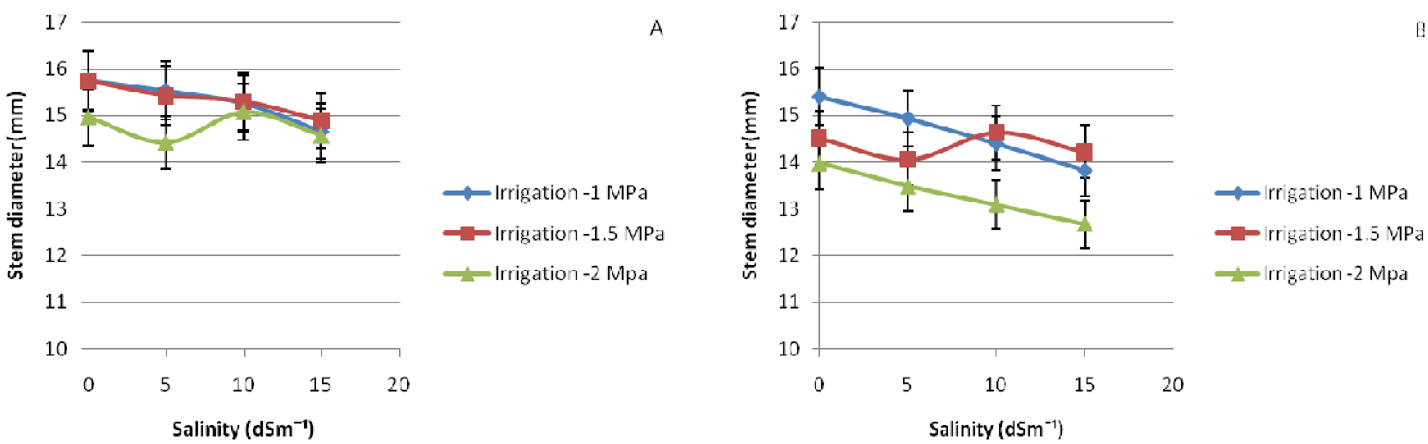

Figure 4. Effects of salinity and irrigation frequency on stem diameter (mm) of forage sorghum varieties (A) KFS4, and (B) Speedfeed (Average of two years).

Table 3. Effect of irrigation frequency and salinity on some morphological characters of forage sorghum varieties (Average of two years).

Treatment	Total leaf area plant^{-1} (mm^2)	Leaf length (mm)	Leaf width (mm)	Number of leaves
Variety				
KFS4	1857.70^{az}	11.18^a	4.13^a	10.15^b
Speedfeed	1907.55^a	10.33^b	3.83^b	13.85^a
LSD $_{0.05}$	56.41	0.132	0.054	0.539
Irrigation frequency at				
LWP -1.0 (MPa)	2030.72^a	10.99^a	4.06 ^{a}	12.46^a
LWP -1.5 (MPa)	1863.06^b	10.74^b	3.96 ^{b}	12.29 5^a
LWP -2.0 (MPa)	1673.69^c	10.54^c	3.91 ^{b}	11.25^b
LSD $_{0.05}$	69.097	0.16	0.06	0.66
Salinity (dS m^{-1})				
0	2076.43^a	10.91^a	4.01^a	13.55^a
5	1991.40^b	10.89^a	4.01^a	12.72^b
10	1804.27^c	10.72^b	3.97^a	11.47^c
15	1551.19^d	10.48^c	3.92^a	10.25^d
LSD $_{0.05}$	79.78	0.18	0.077	0.761
F value				
V×I	5.88**	1.11^{ns}	0.11 ^{ns}	0.31 ^{ns}
V×S	0.73^{ns}	0.44^{ns}	0.09^{ns}	2.77*
I×S	1.91^{ns}	0.10^{ns}	0.15^{ns}	0.17 ^{ns}
V×Y	3.07 ^{ns}	11.96**	3.18^{ns}	35.23**
I×Y	0.23^{ns}	2.96 ^{ns}	1.32^{ns}	4.67*
S×Y	0.54^{ns}	1.25^{ns}	0.34^{ns}	0.06 ^{ns}
V×I×S	2.31*	0.14^{ns}	0.27^{ns}	0.47^{ns}
V×I×Y	4.46*	1.44^{ns}	2.44^{ns}	2.09^{ns}
V×S×Y	0.32^{ns}	0.04^{ns}	0.20^{ns}	0.42^{ns}
I×S×Y	0.75^{ns}	0.16^{ns}	0.14^{ns}	0.14^{ns}
V×I×S×Y	2.97*	0.28^{ns}	0.14^{ns}	0.58^{ns}
Error (MS)	1.57	0.159	0.027	2.65
CV (%)	16.25	3.71	4.13	13.56

**, * and ^{ns} are significant at 0.01, 0.05 level and non significant, respectively

significantly (P≤0.01) affected by salinity and irrigation frequency. Interaction of variety, irrigation and year (V×I×Y), significantly (P≤0.01) affected the total leaf area. Leaf area, irrespective of variety was reduced by 4, 13 and 25% with salinity levels of 5, 10 and 15 dS m^{-1} and by 17 and 8% with least and less frequent irrigation respectively (Table 3). The interaction effects elucidated frequent irrigation could maintained maximum leaf area of Speedfeed variety at all salinity levels, the same trend observed for KFS4 variety except salinity 5 dSm^{-1} which stimulated leaf area. Overall with increasing salinity and infrequent irrigation, leaf area was found to decrease, the leaf area in Speedfeed was reduced to 1391 mm^2/plant, while the reduction was lower in KFS4 (Table 4). In both experimental years, KFS4 under water stress treatment responded with lower decline in leaf area while the slope of curve for Speedfeed variety was dramatic (Figure 6).

Leaf firing (%)

Salinity, water stress, variety and their interaction significantly (P≤0.01) affected leaf firing. Leaf firing increased with increasing salinity reaching 59.9% in the extreme salinity treatment of 15 dS m^{-1}, and it increased with increasing water stress reaching 48.6% in the extreme

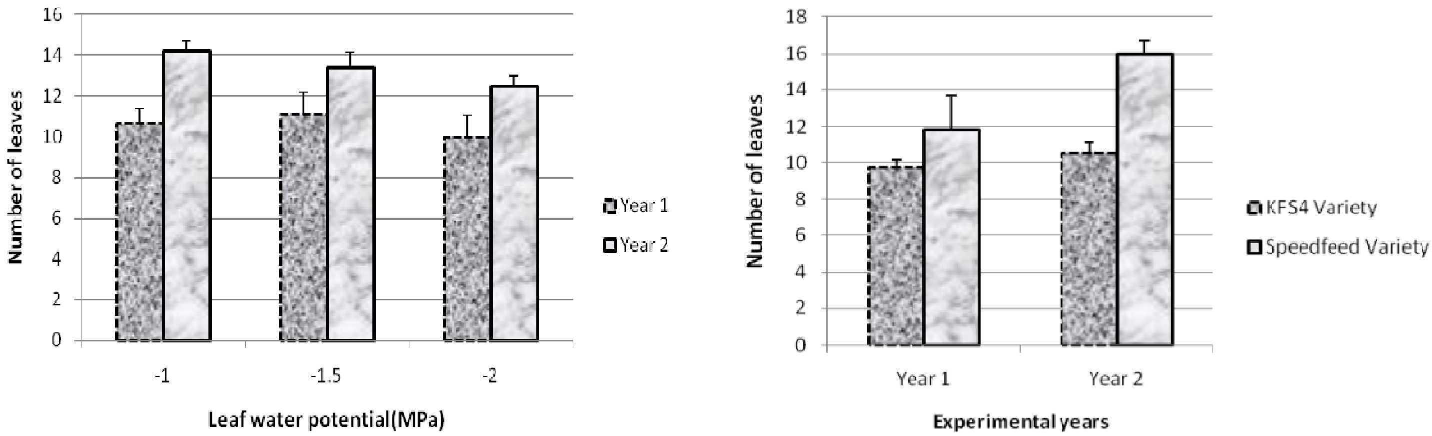

Figure 5. Varietal differences in leaf production due to irrigation frequency and years.

Table 4. Effect of salinity and irrigation frequency on total leaf area of the two forage sorghum varieties.

Parameter	Total leaf area ($mm^2/plant^{-1}$)					
	KFS4			Speedfeed		
	I1	I2	I3	I1	I2	I3
S1	2115.1^{abz}	2079.5^{ab}	2009.4^{abc}	2606.9^{a}	2170^{bc}	1577.8^{efg}
S2	2272.9^{a}	1994.4^{abc}	1958.5^{abc}	2254.4^{b}	2048.3^{bcd}	1750.4^{def}
S3	2031.9^{bcd}	1954.8^{abc}	1746^{def}	1922.7^{abc}	1899.7^{de}	1605.9^{cd}
S4	1930^{bcd}	1775.6^{bcd}	1483.4^{g}	1531.7^{e}	1391.7^{g}	1391.9^{g}
LSD (5%)		411.9			351.56	

^{z} Means with same letters within a variety are not significantly different at 5% level (LSD test). I1, I2 and I3, Irrigation frequency when the leaf water potential reach to -1, -1.5 and -2 MPa, respectively (days alternative). S1, S2, S3 and S4 = Salinity 0, 5, 10 and 15 dS m^{-1}, respectively.

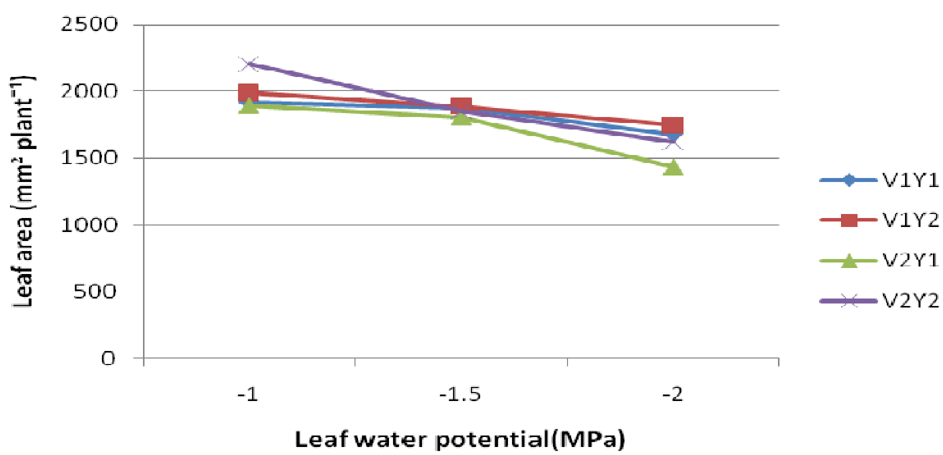

Figure 6. Varietal differences in total leaf area between varieties (V1 = KFS4 and V2 = Speedfeed) due to irrigation frequency in experimental years (Y1 = First year and Y2 = Second year).

water stress treatment of -2 MPa (Table 5). Frequent irrigation could protect plants at low salinity level of 5 dS m^{-1} and alleviate effect of salinity at the highest dose of salinity (15 dS m^{-1}) for KFS4 variety and at moderate salinity level (10 dS m^{-1}) for Speedfeed. However, there was less water deficit and salinity injury noticeable in

Table 5. Effect of irrigation frequency and salinity on leaf firing of forage sorghum varieties (Average of two years).

Treatment	Leaf firing (%)
Variety	
KFS4	33.40[bz]
Speedfeed	46.05[a]
LSD $_{0.05}$	1.785
Irrigation frequency at	
LWP -1.0 (MPa)	27.80[c]
LWP -1.5 (MPa)	42.75[b]
LWP -2.0 (MPa)	48.63[a]
LSD $_{0.05}$	2.18
Salinity (dS m^{-1})	
0	16.57 [d]
5	30.71 [c]
10	51.70 [b]
15	59.93[a]
LSD $_{0.05}$	2.52
F value	
V×I	5.92**
V×S	7.08**
I×S	31.57**
V×Y	1.21 [ns]
I×Y	0.01 [ns]
S×Y	0.01 [ns]
V×I×S	2.95*
V×I×Y	0.02 [ns]
V×S×Y	0.04 [ns]
I×S×Y	0.00 [ns]
V×I×S×Y	0.00 [ns]
Error (MS)	29.08
CV (%)	13.57

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

KFS4 variety compared to Speedfeed (Figure 7).

DISCUSSION

Optimum use of agricultural water requires consideration with respect to water use patterns in each region. The root lengths are important traits for salt stress evaluation because roots are in direct contact with the soil and responsible to absorb the water needed for plant growth. While the shoot length indicated the reaction to supplying of sink. For this reason, root and shoot lengths provide an important clue to the response of plants to salt stress (Jamil and Rha, 2004).

Salinity reduced root length and plant height as the level of salt increased, however, the decrease in the length of the roots was more prominent as compared to the shoots because of pot experiment. The reason for the reduction in the roots and subsequently the shoots may be due to the toxic effect of NaCl as well as to an imbalance of nutrients in the plant. Some studies indicated that plant growth reductions were proportional to the increase in Na. Demir and Arif (2003) observed that root growth was more adversely affected by salinity as compared to shoot growth. In irrigated agriculture, salts would normally be leached from the surface at sowing, and in dry-land agriculture, the crop is normally planted after rain (Serraj and Sinclair, 2002). Thus, in

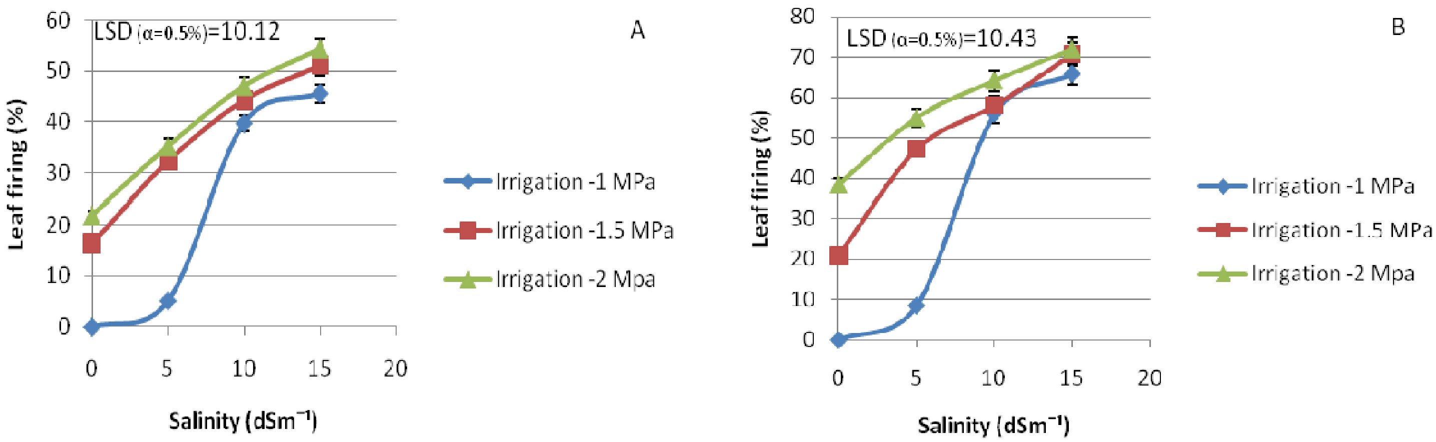

Figure 7. Effect of salinity and irrigation frequency on leaf firing in (A) KFS4, and (B) Speedfeed (Average of two years).

irrigated and rain-fed agriculture, salinity effects may be overcome especially at the early growth stages when plants were more sensitive.

Under irrigation at -1 MPa, root length and stem diameter were maintained in salinities up to 15 dS m^{-1} for KFS4 variety, while with Speedfeed, the threshold salinity was 10 dS $m^{-1.}$ Overall KFS4 was found to be more tolerant than Speedfeed to salt and water stress as indicated by important morphological parameters (greater plant height, root length and stem diameter). The increased salt concentration in soil solution reduces osmotic potential of the soil water solution (it becomes more negative), and hence the plant must expend more metabolic energy to absorb water. The consumption of energy caused plant to have short stature (Ghoulam and Fares, 2001; Munns, 2002).

Salinity may also affect the leaf by creating an external osmotic potential that prevents water uptake or due to the toxic effects of Na^+ and Cl^- ions on the plant, affecting the uniformity of plant density with negative effect on yield (Okcu et al., 2005). Our result is also in agreement with Munns (2002).

It can be concluded that increased salt concentration and delayed irrigation caused forage sorghum plants to have shorter stature, smaller stems and decrease in size of morphological characters. At high salinity levels, plant height and main stem thickness were decreased from 160.7 to 144.3 cm and 15.1 to 14.1 mm, respectively. Under saline and water stress conditions, plant height, root length and stem diameter of KFS4 variety was greater than Speedfeed, while variety Speedfeed had considerably higher number of leaves and number of tillers. With increase in salinity and irrigation interval, plant height, leaf length, leaf area, stem diameter, number of leaves and number of tillers decreased. Plants grown under water stress and saline conditions resulted in decreased leaf area which subsequently resulted in reduced growth of plants. Highest leaf injury was observed at the highest dose of salinity and water stress.

The growth of both sorghum varieties were found to be sensitive to salt, as indicated by the morphologic and growth parameters although, KFS4 variety showed more tolerant to salinity and water stress conditions. The results obtained in this study would guide procedures both in use of saline water without damaging plants and in the field experiments.

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