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Full Length Research Paper

Yield responses of forage sorghums to salinity and irrigation frequency

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Water stress restricts crop yield in both the arid and semi-arid zones of the world. 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 2008. 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. The irrigation frequency was found to affect growth and yield of the forage sorghums. When irrigation was delayed in leaf water potential of -1.0 to -2.0 MPa, the yield and yield components were found to decrease. The maximum dry forage yields were 45.1, 38.9 and 38.5 g $plant^{-1}$ for frequent, intermediate and infrequent irrigation regimes, respectively. Increased salinity significantly reduced forage dry yield from 44.09 g $plant^{-1}$ in the control to 32.76 g $plant^{-1}$ at salinity of 15 dS m^{-1}. For every one unit increase in salinity, the forage yield decreased by 5.2 units and for every one unit increase in water stress (irrigation frequency), the forage yield decreased by 3.6 units. The variety Speedfeed had higher total dry mass than KFS4 under well-watered conditions but KFS4 performed better than Speedfeed under water stress. For both varieties, infrequent watering reduced dry matter and biomass accumulation, but increased water use efficiency (WUEs) (6.88).

Key words: Salinity, irrigation frequency, dry matter, water use efficiency (WUEs), 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 (Qureshi et al., 2007). Salts in soil and water can reduce water availability and this can lead to stressful conditions. Water stress restricts crop yields, particularly in the arid and semi-arid zones. However, cultivation under salinity and water stress conditions is normally practiced for food supply in developing countries (Munns, 2002). Sorghum has greater salt and drought tolerances than other summer forages. Only warm season annual grasses provide substantial forage yield in a short period of time. There are a number of potential forage sorghum varieties which may be appropriate for various salinity levels of seawater, but the levels of salt tolerance among most of the grown forage sorghum varieties and cultivars have not been adequately characterized (Qadir and Oster, 2004). The general effect of salinity is the reduction in growth (Ghoulam et al., 2002) which resulted from ion toxicity, osmotic stress, mineral deficiencies, physiological and biochemical perturbations, as well as the combinations of these stresses (Munns, 2002; Hasegawa et al., 2000). Due to low availability of soil moisture from osmotic effects associated with salinity, water stress occurs during crop establishment and development. However, where the growing season is long, tillering varieties of forage sorghum are able to recover to a certain extent from water deficits in the early growth periods by forming additional head-bearing tillers. The resulting yield reduction can be partly offset by additional head-bearing tillers (FAO, 2001). Despite significant contributions, earlier investigations on sorghum were focused primarily on grain sorghum. Hence, studies are still needed for forage

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Abbreviations: LWP, Leaf water potential; **FC,** field capacity; **PWP,** permanent wilting point.

sorghum to improve the understanding of the effects of salt and water stresses for different varieties. Many factors are still needed to be considered when addressing the suitability of irrigation water with respect to salinity. Therefore, the objective of this experiment was to determine the growth responses of two forage sorghum varieties to different levels of salinity and irrigation frequency.

MATERIALS AND METHODS

The factorial experiment was conducted under rain shelter at the University Putra Malaysia (02°N 59.476´ 101°E 2.867´, 51 m altitude), from December 2007 to December 2008. The climatic conditions recorded under the rain shelter were 30°C mean temperature, 90% humidity, 4.5 mm evaporation and 72.5% 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 (LWP) reached -1.0 (control), -1.5 and -2.0 MPa. KFS4 is an open pollinated variety from Iran, while Speedfeed is a hybrid variety originally from Australia.

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 soil mixture had a pH of 5.4. During mixing, 60 g of $CaCO_3$, 10 g of 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) were added to each polybag. Soil field capacity (FC) and permanent wilting point (PWP) were measured based on pressure plat and pressure membrane procedures outlined by Richards (1947), before and after the end of the experiment. Soil moisture was determined by gravimetric method (Muhammad et al., 2008).

The plants were irrigated with non-saline water for seedling establishment and with saline water starting from 2 weeks after germination according to the treatments. Plants were harvested at pre flowering stage and washed with deionized water. Leaves, stems and roots were separately weighed and dried at 75°C for 48 h for dry mass determination. Forage weight was calculated based on cumulative shoot dry weight. Irrigation treatments were applied based on leaf water potential (-1, -1.5 and -2 MPa) using the pressure chamber (Santa, Barbara, CA, USA). When leaf water potential reached the considered potential, the soil samples were taken. The amount of water required for the respective irrigation treatment was calculated using the following equation (Muhammad et al., 2008):

$$V=SMD\times A$$

Where, V = volume of water to be applied (litre); A = polybag area = πr^2.

$$SMD = (\theta_{FC} - \theta_I)\ D\ Bd/100$$

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 (1.5 g cm^{-3} in this soil).

Water use efficiency (WUE) was determined by dividing the total dry forage by the volume of irrigation water applied in each treatment during the experimental period. The data were subjected to analysis of variance (ANOVA) using the Statistical Analysis System (SAS) procedure. Treatment means were compared using least significant differences (LSD) at the 5% ($P \leq 0.05$) probability level. Regression analysis was used to determine the relationship among variables and salinity levels.

RESULTS AND DISCUSSION

The irrigation frequency and salinity affect growth and yield of forage sorghums. The above ground part which is important in forage sorghum was highly affected by the main factor, while the total dry weight was significantly ($P < 0.01$) influenced by the interaction of salinity, irrigation and variety (Table 1).

The total dry mass of both varieties declined as salinity level increased and water regime decreased (Figure 1). Salinity may affect the growth by creating an external osmotic potential that prevents water uptake or due to the toxic effects of Na^+ and Cl^- ions on the plant, it affects the uniformity of plant density with negative effect on yield (Okcu et al., 2005). Our result is also in agreement with Munns (2002). Between varieties tested, the interaction effect was more significantly pronounced on the Speedfeed. This was shown by 41.5% decreased in its biomass under normal irrigation with increasing salinity to 15 dS m^{-1} (Figure 1B) as compared to 30.5% for the KFS4 (Figure 1A). At other levels of irrigation (irrigation at -1.5 and -2 Mpa), from 0 to 15 dS m^{-1}, the Speedfeed biomass decreased by 23.8 and 24.1%, respectively. Whereas for the KFS4, the greatest biomass differences between irrigation regimes in respect to salinity, were found only at the highest salinity level. This response would indicate that the KFS4 variety is more tolerant to stress conditions than the Speedfeed. Furthermore, based on varietal characteristic, their total biomass is not significantly different from each other (Table 1).

Although irrigation and salinity had highly significant effects on dry forage yield and root growth, an interaction effect was only found between irrigation and variety. Irrespective of variety, the dry forage decreased linearly with increasing salinity (Figure 2A). A similar result was reported by Hester et al., (2001) who indicated that the crop yield performance decreased markedly with the increase in the concentration of salt. A linear reduction due to salinity was also found on root mass (Figure 2B). Based on varietal responses (Table 2), Speedfeed was more sensitive to water stress as indicated by a significant reduction in its dry root and dry forage. The impact on Speedfeed however was greatly shown only when the irrigation schedule changed from -1 to -1.5 Mpa and as a result, the forage yield decreased by 22.2% and roots declined by 29.4%. However, further delay in irrigation did not show any significant reduction in both parameters. For KFS4, irrigation schedule did not affect its forage yield and root growth. This characteristic may contribute favourably to the persistence of this species in saline soils under natural condition. In irrigated agriculture,

Table 1. Effects of varieties, irrigation and salinity on dry matter yield and root-to-shoot ratio.

Source / Treatment	Dry root (g plant^{-1})	Dry forage (g plant^{-1})	Total dry weight (g plant^{-1})	Root to shoot ratio
Variety				
KFS4	7.47a^{z}	42.25a	49.72a	0.176b
Speedfeed	7.96a	39.41b	47.42a	0.201a
LSD	0.59	2.66	3.23	0.021
Irrigation frequency (MPa)				
at LWP -1.0	8.60a	45.12a	53.729a	0.731a
at LWP -1.5	7.41b	38.88b	46.298b	0.611b
at LWP -2.0	7.13b	38.48b	45.624b	0.631b
LSD	0.76	3.42	4.164	0.024
Salinity (dS m^{-1})				
0	8.93 a	45.73 a	54.669 a	0.657b
5	8.97 a	43.61a	52.592 a	0.736a
10	7.27 b	39.79b	47.073 b	0.653a
15	5.68 c	34.17c	39.867 c	0.591b
LSD	0.91	4.08	4.963	0.029
F value				
V*I	5.91**	4.37*	15.66**	75.29**
V*S	0.07 ^{ns}	0.03 ^{ns}	1.38^{ns}	17.84**
I*S	0.27 ^{ns}	0.29 ^{ns}	0.75 ^{ns}	15.04**
V*I*S	0.75 ^{ns}	0.70 ^{ns}	3.08**	22.42**
Error and CV				
Error (MS)	1.57	31.43	46.43	0.001
CV (%)	16.25	13.73	14.03	6.08

^{z}Means with same letter within a column are not significantly different at 5% level by LSD. V1 = KFS4, V2 = Speedfeed; S1, S2, S3 and S4 = salinity 0, 5, 10 and 15 dS m^{-1}, respectively; I1, I2 and I3 = irrigation frequency when the LWP reach -1, -1.5 and -2MPa, r

salt 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).

Unlike the dry forage yield and roots, root to shoot ratio of both forage varieties responded differently to salinity and irrigation. The root shoot ratio at normal irrigation exhibited by KFS4 (Figure 3A) seems to be opposite to Speedfeed (Figure 3B). The root shoot ratio of KFS4 irrigated at normal frequency was lower than plants under water stress conditions at all levels of salinity. This phenomenon is a normal plant growth reaction towards water stress conditions. On the other hand, the root-to-shoot ratio of well-watered Speedfeed was higher than that under infrequent irrigation. The higher root-to-shoot ratio of KSF4 under water stress would probably explain the better performance of KFS4 under water stress conditions.

Table 3 shows that infrequent irrigations gave higher WUE's when compared to frequently irrigated treatments. In this study, the WUEs obtained for the infrequently watered plants were higher than earlier reports (Gulzar et al., 2003; Mustafa and Abdel Magid, 1982). Although larger volumes of water were used in this investigation as compared to the two previous reports, the higher WUEs obtained here might have been due to the reduction of irrigation by infrequent watering. Irrespective of variety, the frequently watered plants accumulated greater dry matter which eventually had produced high dry forage yield than other irrigation frequencies (Table 3).

The results derived for the irrigation study showed that despite the possibility of greater surface evaporation with the light frequent irrigations, sorghum varieties and other indicators of plant water stress were found to be improved with low frequent irrigation. Pearson correlation matrix reveals that most of the studied characters are significantly and positively correlated, on the other hand, root to shoot ratio is negatively correlated with all the factors. Total dry weight is positively correlated with dry

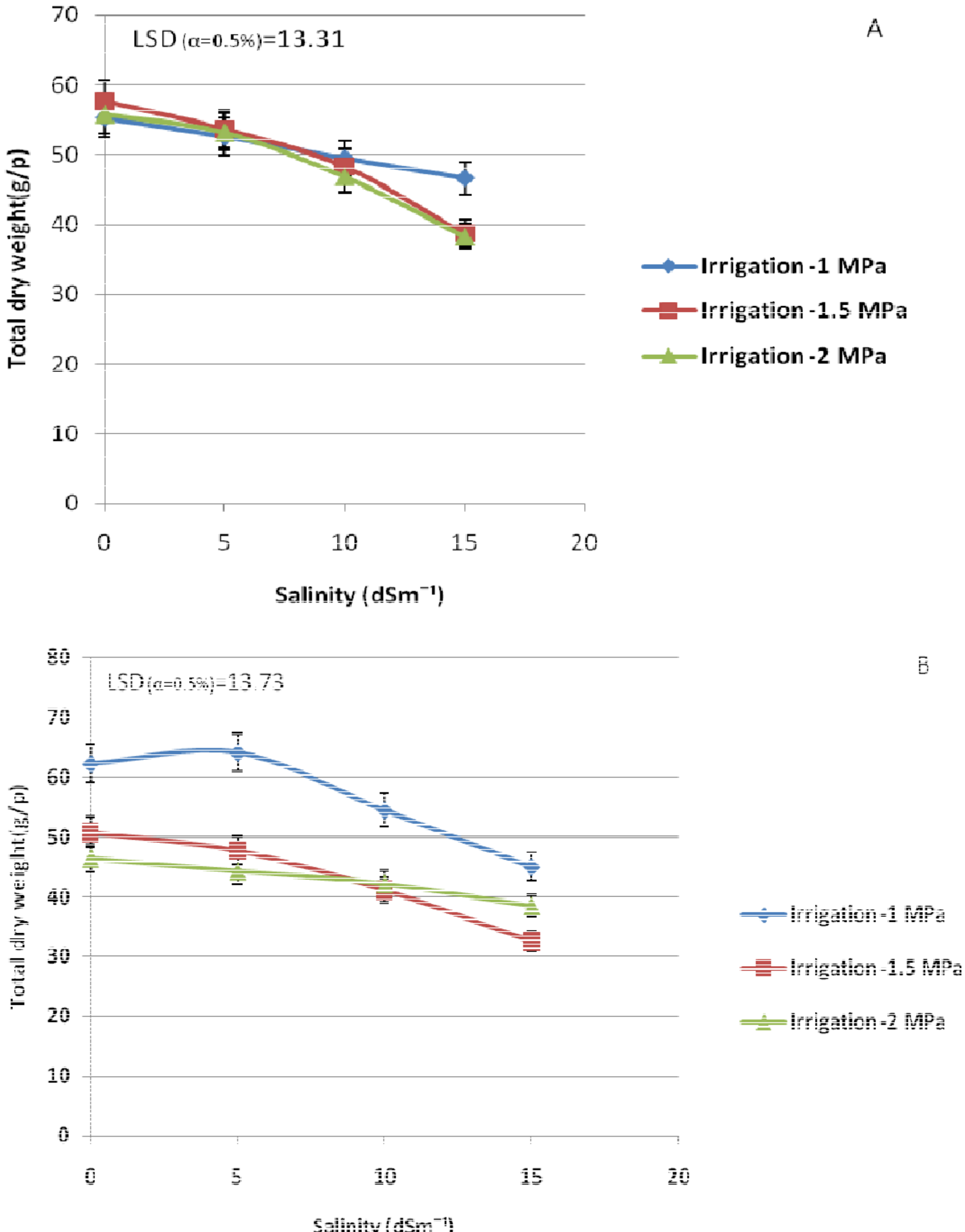

Figure 1. Effect of salinity and irrigation frequency on total dry weight of (A) KFS4 and (B) Speedfeed (average of two years).

forage, dry stem, dry leaf and dry root (Table 4). Similar scenario is observed for the forage dry weight with yield components.

The regression reveals that the forage yield is significantly and negatively correlated with salinity and irrigation frequency ($F < 0.05$). The relationship between yield, salinity and irrigation frequency was studied, and the regression equation was: $Y=-3.277 -5.207X_1-3.586X_2$, where $R^2 = 0.90$ ($n = 72$). For every one unit increase in salinity (X_1), the forage yield would be decreased by 5.2 units and for every one unit increase in water stress (X_2), the forage yield would be decreased by 3.6 units. Ultimately, when irrigation was delayed from -1 to -1.5 and -2MPa, the forage yields were decreased significantly,

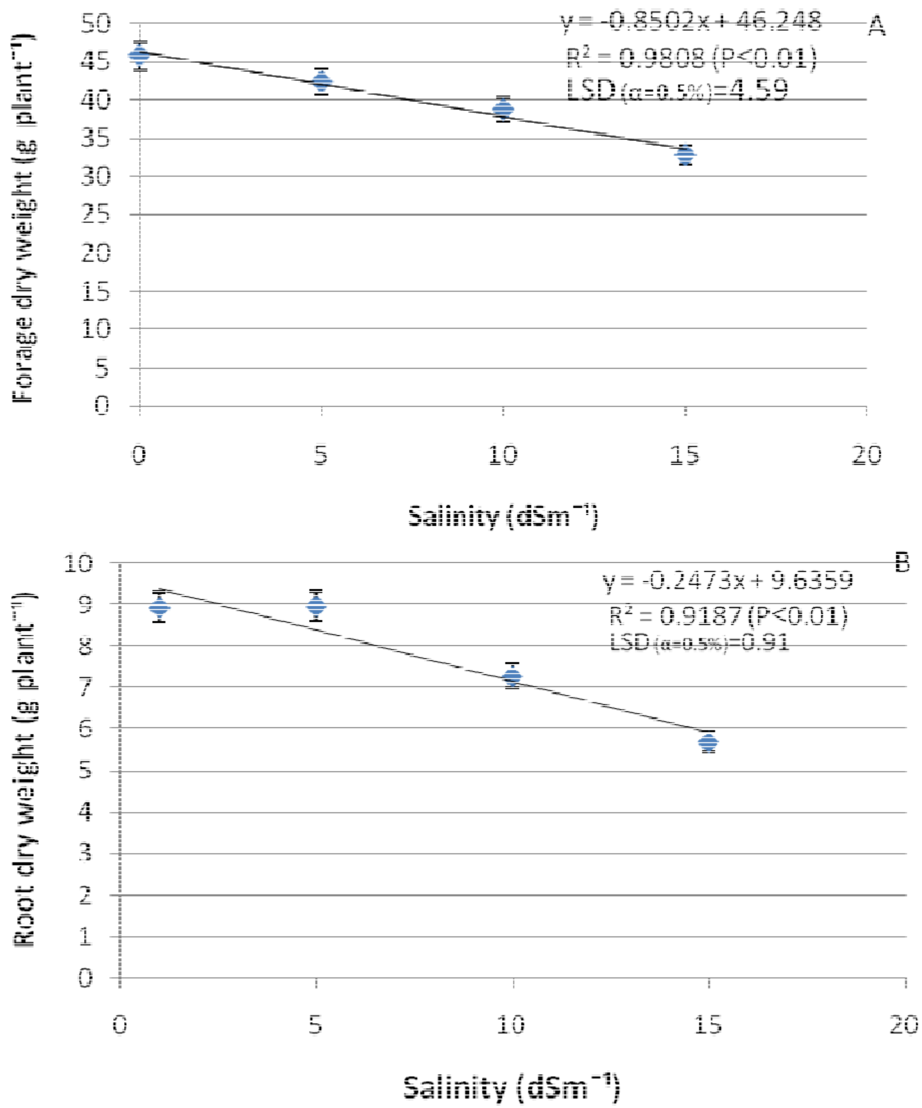

Figure 2. Effects of salinity on forage (A) and root dry weight (B) of forage sorghum.

Table 2. Interaction of variety and irrigation on dry root and dry forage mass.

Irrigation schedule	Dry root (g plant^{-1})		Dry forage (g plant^{-1})	
	V1	V2	V1	V2
I1	7.97 a	9.98 a^z	43.78 a	46.46 a
I2	7.22 a	7.04 b	41.62 a	36.14 b
I3	7.22 a	6.85 b	41.34 a	35.63 b
LSD (%)	1.231	2.131	4.176	7.961

^{z}Means with same letter within a column are not significantly different at 5% level by LSD; V1 = KFS4, V2 = Speedfeed; I1, I2 and I3 = irrigation frequency when the LWP reach -1, -1.5 and -2MPa, respectively.

regardless of variety from 45.1 to 38.9 and 38.5 g plant^{-1} for frequent, intermediate and infrequent irrigation regimes, respectively. The reduction was found to be mostly between the frequently and the less and least frequently watered plants which decreased (Table 3). This finding suggests that in semi-arid environments (where water saving is very important), if the aim is to get high WUE, forage sorghum should be irrigated heavily

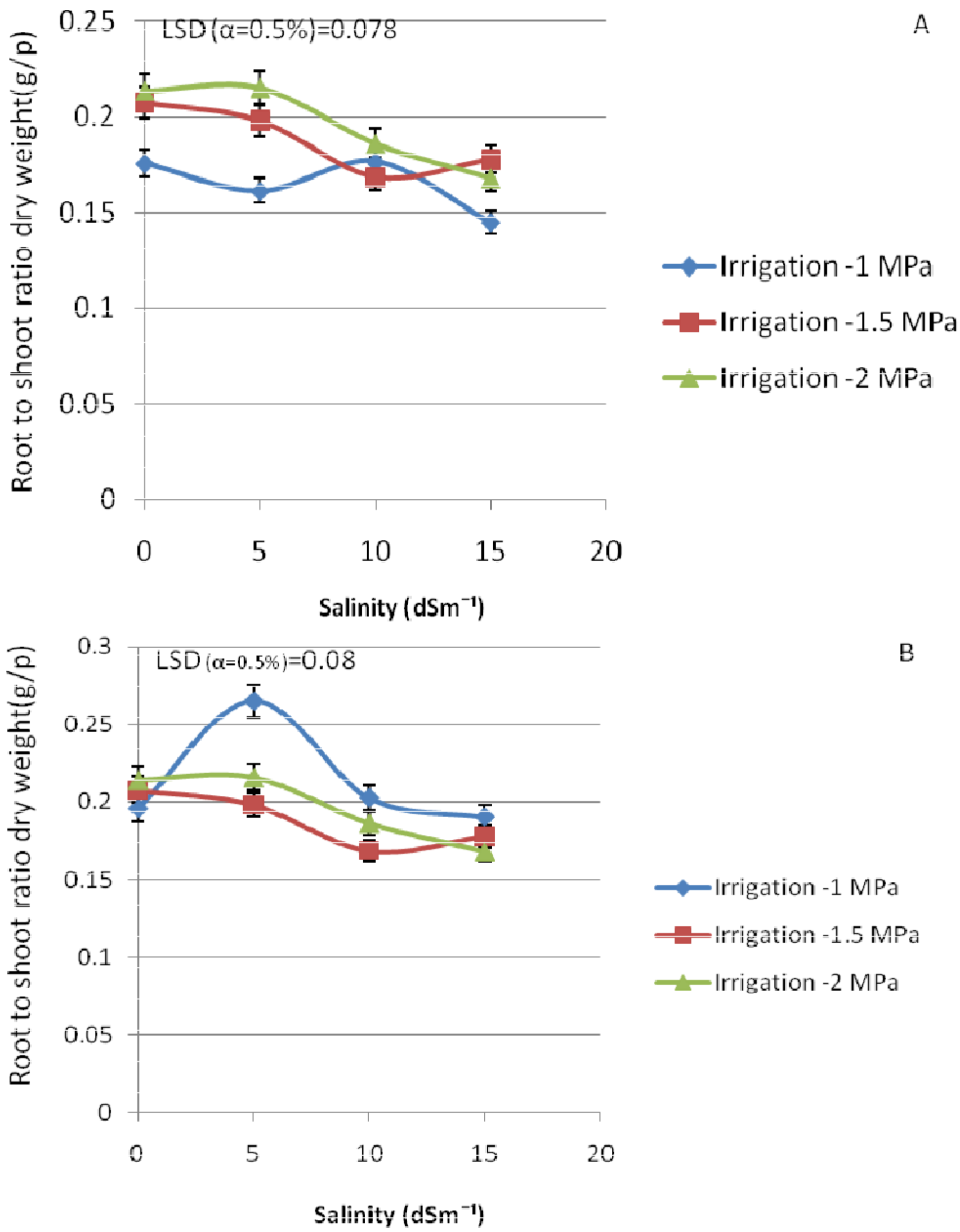

Figure 3. Root to shoot ratio of KFS4 (A) and Speedfeed (B) as affected by salinity and irrigation frequency.

Table 3. Effect of irrigation frequency on yield, total amount of water applied and water use efficiency (WUE).

Irrigation schedule	Days after treatment: 4	14	22	31	36	41	48	56	Dry forage yield (g plant-^{1})	Total water used (liter)	WUE (g plant-^{1} liter-^{1})
	Amount of water applied (liter/plant)										
I1	0.5	1	0.96	0.97	1.14	0.97	0.98	1.13	45.12^{az}	7.65^{a}	5.88^{b}
I2	0.5	1	0	1.19	0	1.42	0	1.98	38.88^{b}	6.10^{b}	6.35^{ab}
I3	0.5	1	0	0	2.02	0	0	2.12	38.48^{b}	5.64^{c}	6.88^{a}
LSD (5%)									3.42	0.61	0.60

I1, I2 and I3 are irrigation frequency when the LWP reaches -1, -1.5 and -2MPa, respectively. ^{z}Means with same letter within a column are not significantly different at 5% level by LSD.

Table 4. Correlation coefficients between plant weight parameters.

Parameter	DR	DL	DS	DF	TDW	R:SH
DR	1	0.74**	0.86**	0.87**	0.92**	-0.28*
DL		1	0.76**	0.87**	0.86**	0.16^ns
DS			1	0.98**	0.97**	-0.48**
DF				1	0.99**	-0.32**
TDW					1	-0.32**
R:SH						1

**Correlation is significant at the 0.01 level (2-tailed test); DR = dry root, DL = dry leaf, DS = dry stem, DF = dry forage, TDW = total dry weight, R:SH = root to shoot ratio.

and infrequently. This contradicted the finding by Saeed and El-Nadi (2004) who recommended using light frequency to get high WUEs.

Conclusion

Under salinity and water stress conditions, the KFS4 variety has a better vegetative growth performance as compared to Speedfeed. Infrequent irrigation had reduced biomass accumulation; the reduction was higher when low irrigation frequency was coupled with salinity. 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}. WUE of forage sorghum could be increased by infrequent irrigation, and new fields could be well irrigated by saving water. The results obtained in this study would serve as a useful guide for managing forage sorghums in saline and water stressed field conditions.

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