

Physiological Effects on Re-Growth of Forage Sorghums Ratoon Crop under Varying Salinity and Irrigation Frequency

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ABSTRACT

The responses of forage sorghum [*Sorghum bicolor* (L.) Moench] varieties to salinity and irrigation frequency were studied from January to December 2009. Two salt tolerant varieties of forage sorghum namely Speedfeed and KFS4 were grown under 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. Salinity and irrigation frequency significantly ($P \leq 0.01$) affected leaf water potential, chlorophyll content, photosynthetic rate, stomatal conductance and stomatal size. Though both varieties were sensitive to salt and water deficit the KFS4 variety had 10.7, 8.2, 6.1 and 4 percent higher leaf water potential, chlorophyll content, photosynthetic rate and stomatal conductance, respectively compared to Speedfeed, hence KFS4 is more tolerant to stress conditions compared to Speedfeed. Combination effect of high salinity and low water availability had an adverse effect on stomatal conductance. When irrigation was delayed from the leaf's water potential of -1 to -2 MPa, the chlorophyll content, photosynthetic rate and stomatal conductance were decreased by 26.8, 10.1 and 28% respectively. The highly significant declined was mostly at -2 MPa irrigation frequencies, it means irrigation of forage sorghum can be delayed till leaf water potential reaches to -1.5 MPa, which takes about two weeks time. The number of stomata and the size of their apertures determine the extent of gaseous exchange and hence the photosynthetic potential. The number and dimension were less in the treated plants.

Key words:

Keywords: salinity, irrigation frequency, physiology, stomatal size, photosynthesis, sorghum

1. 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

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22 effects by a series of morphological, physiological and biochemical processes (Jacoby,
23 1999). Under the variable saline environments, plants have developed different adaptive
24 mechanisms (Rhodes *et al.*, 2002 and Borsani, *et al.*, 2003).

25 A new generation of salt-tolerant forage varieties would allow for landscape development in
26 saline environments and where salt water is a problem, or where limited or no fresh water is
27 available for irrigation. Forage sorghum development in these areas often requires the use of
28 brackish water from affected wells or other secondary sources. Its tillering characteristics
29 enable sorghum to completely regenerate the above-ground portions of the plant. Thus,
30 sorghum plants have been kept alive for as long as 6 to 7 years where the climate is mild
31 enough to avoid winterkill and when disease and insect protection have been provided.

32 Therefore, studies are needed to improve understanding on physiological re-growth of
33 forage sorghum under influence of salt and water stresses. In addition, many factors need to
34 be considered when addressing the suitability of irrigation water with respect to salinity.

35 Hence, the objectives of this experiment were to assess relative salinity tolerance and
36 physiological responses of the first ratoon crops grown under water stress conditions and to
37 compare tolerance levels of the two forage sorghum varieties (KFS4 and Speedfeed) to
38 salinity and water stress.

39 40 **2. MATERIAL AND METHODS**

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42 The factorial experiment was conducted under rain shelter at University Putra Malaysia
43 (02°N 59.476' 101°E 2.867' , 51m altitude), from January 2009 to December 2009. The
44 climatic conditions recorded under rain shelter were 31 °C mean temperature, 88% humidity,
45 4.5 mm evaporation and 71% light at 12 am. Two selected (Fouman *et al.*, 2003) salt tolerant
46 varieties namely Speedfeed and KFS4, of forage sorghum [*Sorghum bicolor* (L.) Moench]
47 were subjected to the salinity levels of 0, 5, 10 and 15 dS m⁻¹ of NaCl concentrations, and
48 irrigated when the leaf water potential reached -1(control), -1.5 and -2MPa.

49 The treatments were arranged in a randomized complete block design with three
50 replications. Polybags (40 cm × 45 cm) were filled with a mixture of top soil, peat moss and
51 sand at the ratio of 3:2:1 (v/v), respectively. The soil mixture had a pH of 5.4. During mixing,
52 60 g of CaCO₃, 10 g complete fertilizer (15% N, P₂O₅, K₂O), 1 g of triple super phosphate
53 (45% P₂O₅) and 2.4 g of urea (46% N) were added to each polybag. Soil field capacity and
54 permanent wilting point were measured before and after the end of the experiment. The
55 plants were irrigated with non-saline water for seedling establishment and with saline water
56 starting from the 2nd week after germination according to the treatments.

57 The amount of water required for the irrigation of each treatment was calculated using the
58 following equation: $V = SMD \times A$ where; V= volume of water to be applied (liter);

59 $A = \text{polybag area} = \pi r^2$; $SMD = (\theta_{FC} - \theta_i) D \text{ Bd} / 100$; SMD = Soil moisture deficit;

60 θ_{FC} = gravimetric soil moisture content at field capacity (%); θ_i = Soil moisture content
61 before irrigation (%); D = rooting depth (cm); Bd = bulk density (in this soil 1.5 g cm⁻³)
62 (Muhammad Aslam *et al.*, 2008).

63 Re-growth plants were harvested at 109 days after planting i.e. 49 days after first cutting. A
64 calibrated portable photosynthesis system (LI-6400; LI-COR, Inc.; Lincoln, NE) was used to
65 measure net CO₂ assimilation rate, stomatal conductance and intercellular CO₂
66 concentration. The leaves used for stomatal conductance measurements were chosen for
67 water potential determination using the pressure chamber (Santa, Barbara, CA, USA).
68 Leaves were analyzed for chlorophyll content (mg cm⁻²) using seaming spectrophotometer
69 (UV-3101pc.chem/eal) at 664 and 647nm. Three discs, one cm² of fresh leaves were
70 sampled by using cork borer. Samples were placed in 20ml of 80% acetone in the dark for
71 seven days to ensure maximum chlorophyll content extracted from the tissues.

72 The stomatal density and stomatal size of the leaf were measured by using scanning
73 electron microscopy (SEM - JEOL JSM-5610LV, Japan) for first ratoon crop applying the
74 protocol of Hawes and Satiat- Jeunemaitre (2001). The newly fully expanded leaves of forty
75 eight-day-old plants from control and treated plants were collected and sampled at two leaf

zones (shoot tips at 0-0.5 cm from the tip, and mature leaves). Leaves were cut to a length of 5 mm with a sharp blade. The excised leaves were put in formalin acetic acid (FAA) (10 mL formaldehyde, 10 mL acetic acid, and 90 mL of 50% ethyl alcohol), and vacuumed for 1 hour at 650 mm Hg. Specimens were post-fixed in 1% osmium tetroxide for 2 h, dehydrated for 30 min in each graded ethanol series at 30, 50, 70, 90, 95 and 100%, and dried in Baltec CPD 030 critical point dryer apparatus. The tissues were mounted on stubs, and then coated with gold using Auto Fine Coater (JEOL JFC-1600, Japan) for 20 min and viewed under a scanning electron microscope, at high vacuum and acceleration voltage of 15 kV with a working distance of 23 mm. Dimensions of the stomatal apparatus and apertures were measured with an ocular micrometer scale in a compound light microscope. Stomatal density per mm² was determined and stomatal index was calculated by the formula of Salisbury (1927). The data was analyzed by means of SAS by the using the proc.GLM. Means test was performed using LSD ($P \leq 0.05$).

3. RESULTS AND DISCUSSION

The leaf water potential was significantly affected ($P \leq 0.01$) by variety, salinity and water stress as well as variety and salinity interaction. Low soil water reduced the leaf water potential. The leaf water potential decreased by 12.2, 22.8 and 32.2% respectively with increasing salinity to 5, 10 and 15 dS m⁻¹, implying that there was a reduction of turgor and that plants suffered from restricted water availability. This could also be attributed to the significant reduction in stomata conductance (Table 1).

The capacity to sustain plant function at low plant water status is a rare occurrence in crops. However, genotypic differences under drought stress can often result in differences in function at low water status. The variety KFS4 had significantly greater leaf water potential (8.25% higher than Speedfeed) which means that the former is more tolerant to stress conditions compared to the latter (Table 1).

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109 **Table 1: Effect of irrigation frequency and salinity on some physiological characters**
 110 **of the forage sorghum varieties in the first ratoon crop**

Source of treatment	Leaf water potential (MPa)	Total chlorophyll content (mg cm ⁻²)	Photosynthetic rate (μmol m ⁻² s ⁻¹)	Stomatal conductance (mmol m ⁻² s ⁻¹)
Variety				
KFS4	-1.12 a ^z	2.18 a ^z	14.65 a	0.075 a
Speedfeed	-1.24 b	2.00 b	13.75 b	0.072 a
LSD	0.032	0.08	0.58	0.0042
Irrigation frequency (MPa)				
at LWP -1	-1.11 a	2.42 a	14.85 a	0.082 a
at LWP -1.5	-1.18 b	2.09 b	14.40 a	0.079 a
at LWP -2	-1.25 c	1.77 c	13.35 b	0.059 b
LSD	0.041	0.10	0.75	0.005
Salinity (dS m⁻¹)				
0	-0.49 a	2.33 a	15.61 a	0.115 a
5	-0.55 b	2.27 a	14.62 b	0.083 b
10	-1.61 c	1.96 b	13.72 c	0.059 c
15	-2.07 d	1.80 c	12.85 c	0.036 d
LSD	0.049	0.12	0.89	0.006
F value				
V*I	2421.21*	1.36 ^{ns}	0.08*	32.81**
V*S	51.65**	0.02 ^{ns}	0.19 ^{ns}	12.27 ^{ns}
I*S	51.65 ^{ns}	1.09 ^{ns}	0.23 ^{ns}	7.70*
V*I*S	0.60 ^{ns}	0.84 ^{ns}	0.39 ^{ns}	13.91 ^{ns}
MS error & CV				
Error	0.004	0.027	0.591	0.00008
CV (%)	-5.70	7.93	8.69	12.12

111 ^zMeans with same letters within treatment sources in a column are not significantly different

112 at 5% level by LSD.

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114 Variety, salinity and water stress had significant effects (P≤0.01) on chlorophyll content.

115 Total chlorophyll content 26.8% decreased under high water stress with varying magnitude

116 of decline depending on forage variety (Table 1). The KFS4 variety had 8.2% higher

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117 amounts of chlorophyll compared to Speedfeed. The leaf chlorophyll content was reduced in
118 response to salinity, and salinity treatment 15 dS m⁻¹ induced 22.7% decrease in total
119 chlorophyll content compared to non saline treatment. The highest water stress effect on
120 chlorophyll content occurred at the lowest leaf water potential of -2 MPa.

121 Although the chlorophyll content did not show significant interaction effect of variety,
122 irrigation frequency and salinity (Table 1), the stomatal movements in the sorghum varieties
123 however, showed variable responses to salinity and irrigation frequency. Variety, salinity and
124 irrigation frequency had significant effects ($P \leq 0.01$) on stomatal conductance. There was a
125 significant variety $\times$ irrigation interaction effect and salinity $\times$ irrigation interaction effect on
126 stomatal conductance (Table 1).

127 The stomatal conductance of Speedfeed variety showed better response at irrigation
128 frequency -1 MPa, while at the -2 MPa irrigation frequency KFS4 variety showed 6.1% better
129 performance (Figure 1B). Stomatal conductance of Speedfeed variety under moderate
130 salinity level was also greater than KFS4 variety, but at the salinity 10 and 15 dS m⁻¹ KFS4
131 had higher values compared to Speedfeed (Figure 1A), which implies that KFS4 is more
132 tolerant to stress conditions compared to Speedfeed variety and this was well correlated with
133 the higher photosynthetic capacity. The irrigation frequency at -2 and -1.5 MPa resulted in 28
134 and 3.6% lower stomatal conductance respectively compared to -1 MPa (Table 1).

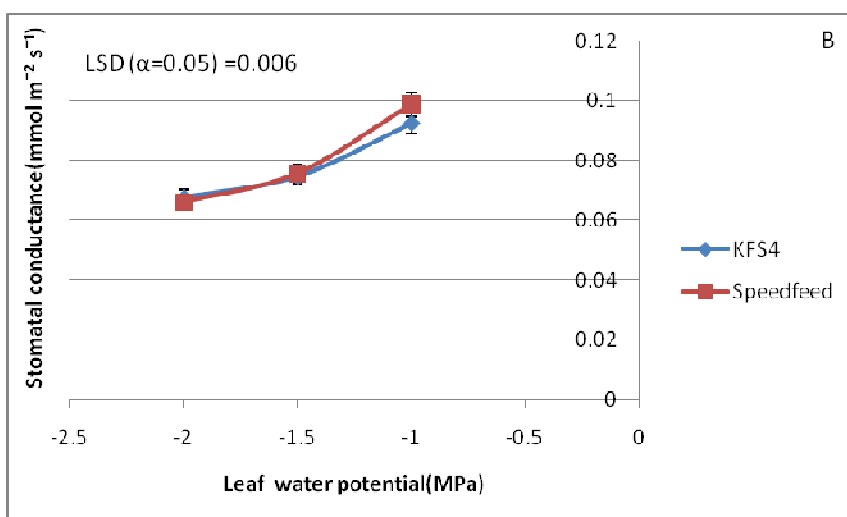
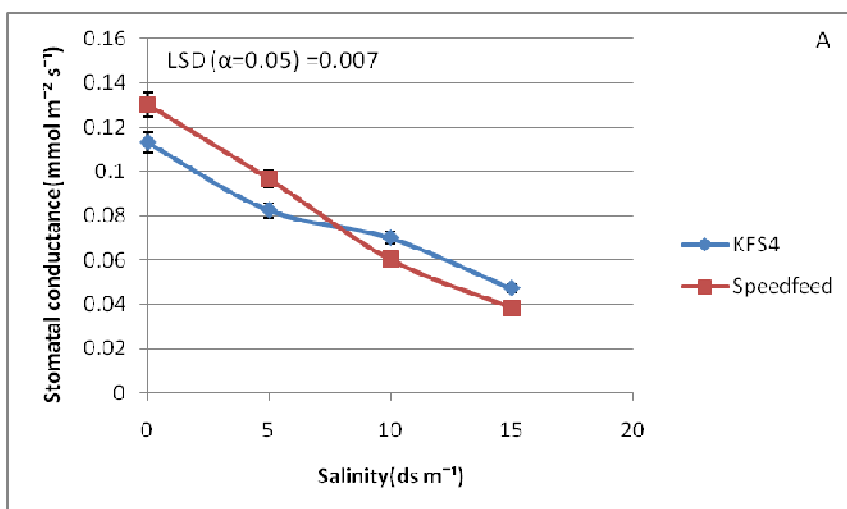


Figure 1: Stomatal conductance of the forage sorghum varieties at different salinity and irrigation frequency.

Photosynthetic rate showed significant ($P < 0.01$) responses to salinity, irrigation frequency and variety (Table 1). Photosynthetic capacity decreased under stress conditions. With increase in salinity to 5 to 10 and 15 dS m^{-1} , photosynthetic rate were evidently decreased to 6.3, 12.1 and 17.6% respectively compared to control. The declined in photosynthetic rate was prominent with irrigation frequency at -2 MPa compared to the other two irrigation frequencies. This implies that irrigation of the forage sorghums can be delayed, for about two weeks, till leaf water potential reaches -1.5 MPa. The photosynthetic rate for KFS4 variety was greater than Speedfeed (Table 1).

There were significant differences in stomata anatomy of first ratoon crop between salinity, irrigation and variety. In addition interaction effects of irrigation and variety on stomata density as well as interaction effect of salinity and variety on stomata width were significant (Table 2). Salt may induce stomata to either open or close, depending on plant species, salt concentration, duration of exposure and environmental conditions at the time of exposure. Scanning electron microscopy showed that stomata size and density of the different forage sorghum varieties had changed in response to salinity and irrigation frequency. At high salinity level stomatal densities in treated plants were lower than in the controls (Figure 2), variations in stomata width to length ratio were also similar to stomatal density (Figures 3, 5 and 6). The difference in stomatal length between treated and control leaves were consistently significant; and the stomata were considerably shorter in treated plants.

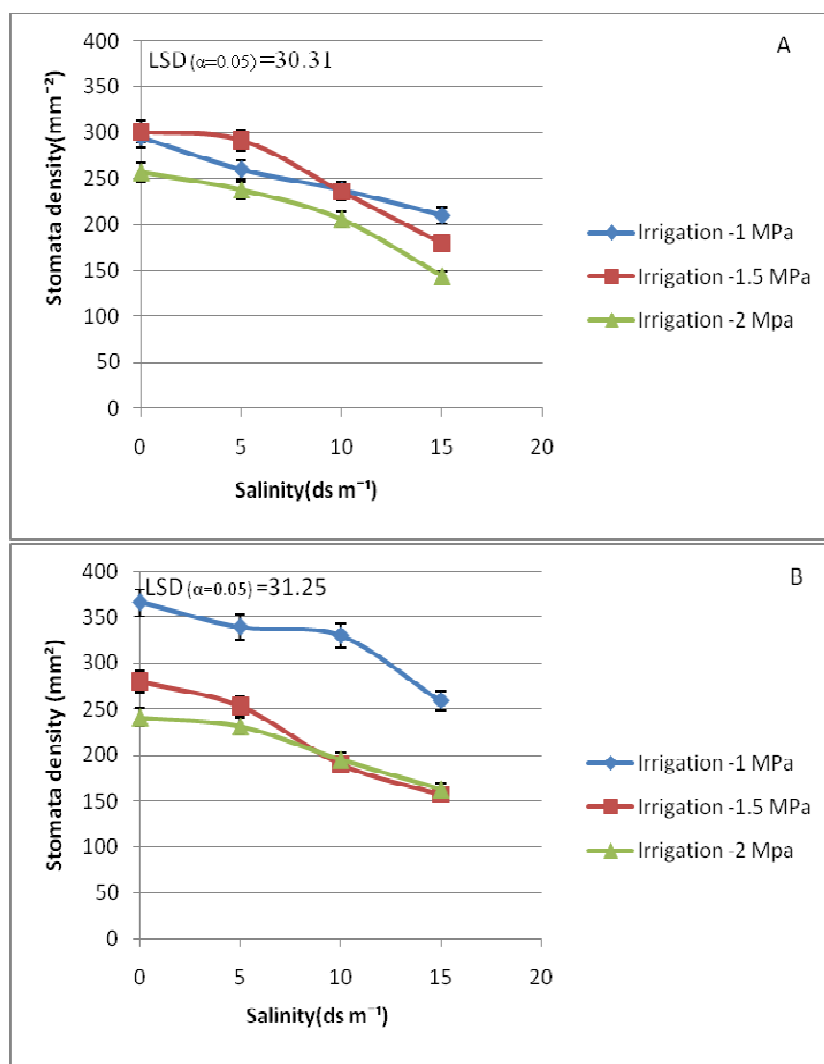
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Table 2: Some stomata characters of forage sorghum varieties at different levels of irrigation frequency and salinity in the first ratoon crop

Source of treatment	Stomata density (mm ²)	Stomata width (mm ²)	Stomata length (mm ²)	Stomata width to length ratio
Variety				
KFS4	250.56 a ^z	1.81 a	14.32 a	0.123 a
Speedfeed	238.08 b	1.64 b	13.48 b	0.115 a
LSD	7.36	0.123	0.405	0.010
Irrigation frequency (MPa)				
at LWP -1	287.2 a	2.07 a	14.90 a	0.136 a
at LWP -1.5	236.2 b	1.83 b	14.08 b	0.126 a
at LWP -2	209.5 c	1.28 c	12.72 c	0.096 b
LSD	9.48	0.15	0.52	0.013
Salinity (dS m⁻¹)				
0	290.1 a	2.61 a	15.70 a	0.166 a
5	269.0 b	2.16 b	14.57 b	0.148 b
10	232.6 c	1.31 c	13.22 c	0.097 c
15	185.5 d	0.83 d	12.10 c	0.067 d
LSD	11.3	0.19	0.62	0.016
F value				
V*I	156.83**	170.43 ^{ns}	60.80 ^{ns}	72.56 ^{ns}
V*S	0.06 ^{ns}	7.73**	0.52 ^{ns}	7.48**

I*S	3.02 [*]	0.33 ^{ns}	0.18 ^{ns}	0.16 [*]
V*I*S	2.22 ^{ns}	0.42 ^{ns}	0.16 ^{ns}	0.36 ^{ns}
MS error & CV				
Error	240.72	0.068	0.730	0.0005
CV (%)	6.35	15.09	6.14	18.95

164 ^zMeans with same letters within treatment sources in a column are not significantly different
165 at 5% level by LSD.
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Figure 2: Effects of salinity and irrigation frequency on stomata density in forage sorghum varieties.

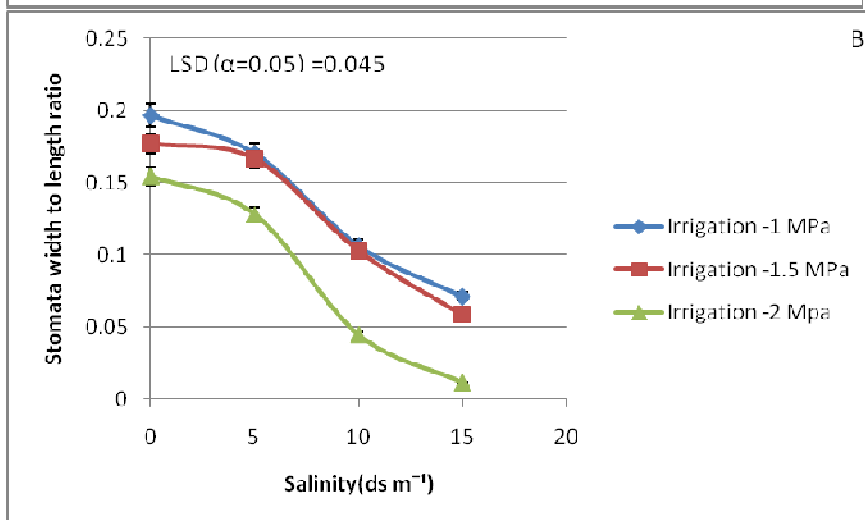
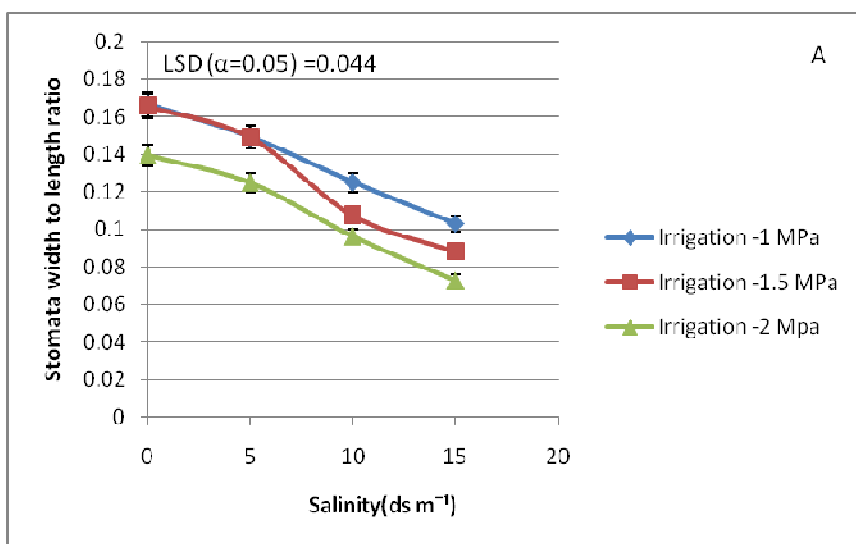


Figure 3: Effects of salinity and irrigation frequency on stomata width to length ratio of the forage sorghum varieties.

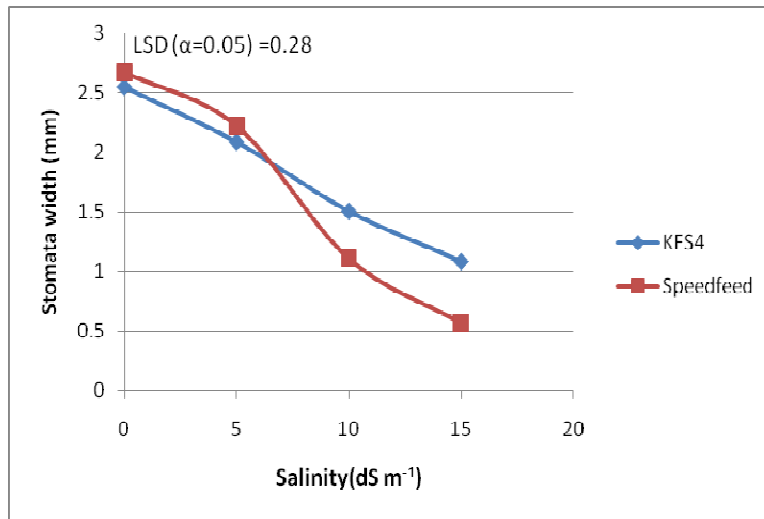


Figure 4: Effect of salinity on stomatal width of the forage sorghum varieties.

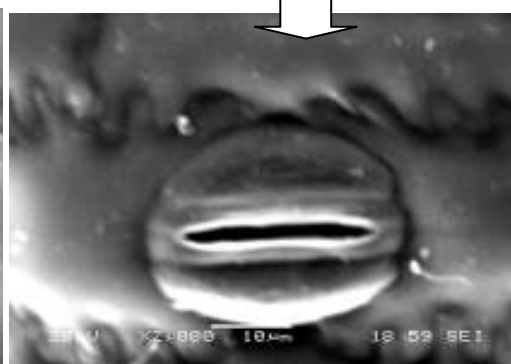
Salinity (dS m⁻¹)

KFS4

Speedfeed

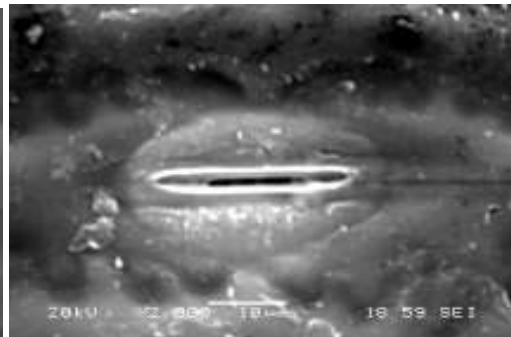
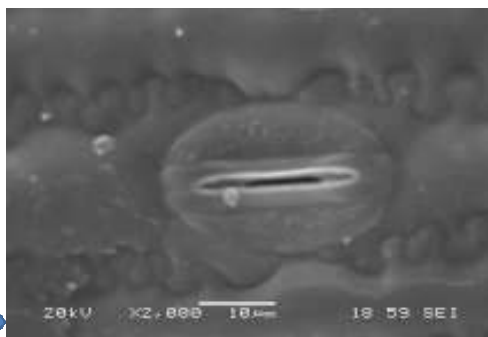
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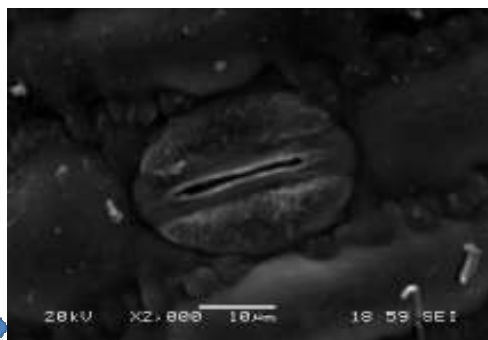
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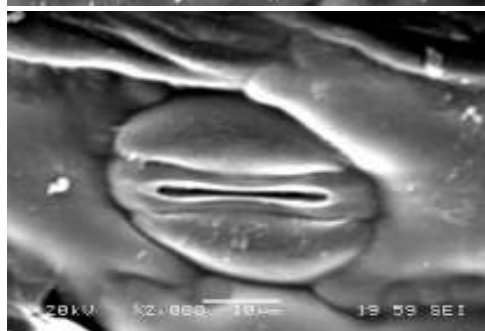
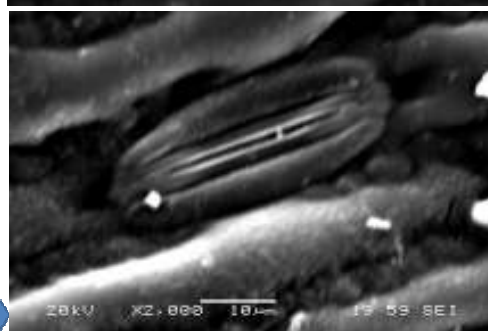
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Figure 5: Scanning electron micrographs showing stomata width and length of the forage sorghum varieties under different salinity levels at leaf water potential of -2 MPa.

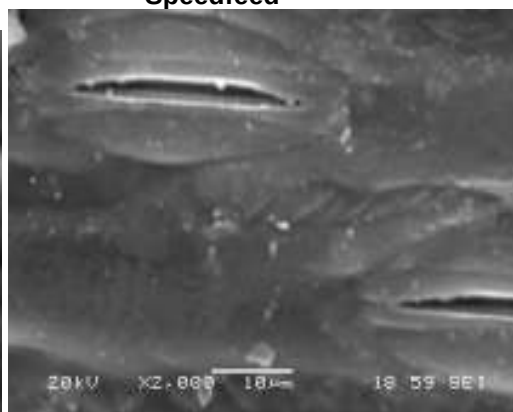
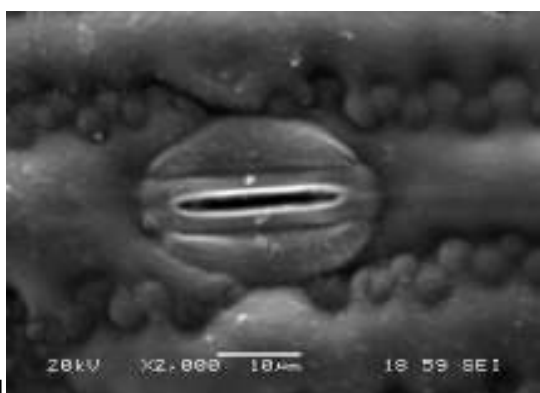
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KFS4

Speedfeed

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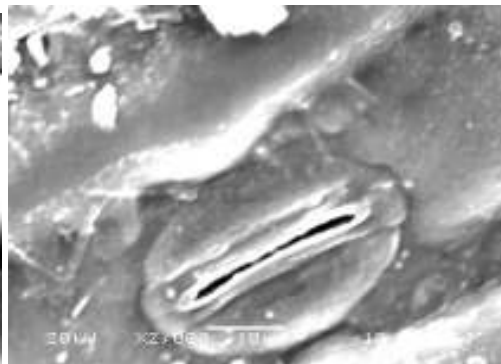
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A

B

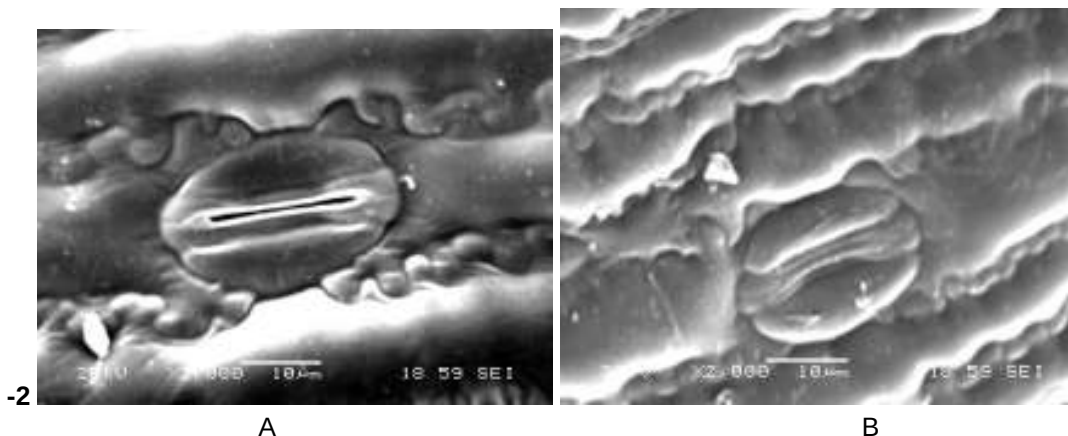


Figure 6: Scanning electron micrographs showing stomata width and length of the forage sorghum varieties (A; KFS4 and B; Speedfeed) under different irrigation frequency at salinity 15 dS m⁻¹.

DISCUSSION

As the saline applications continued into the first ratoon crop, the chlorophyll contents, stomatal conductance and photosynthetic rates were reduced in salt-exposed plants, and the decrease in stomata size and density led to reduced photosynthetic activity. Leaf water potential was lowered with salt stress causing loss of turgosity and available water in the cells (Munns 2002, Neuman 1997). Poljakoff-Mayber and Lerner (1999) also stated that negatively affected cell growth generated smaller leaves, consequently resulting in a reduction in photosynthesis and dry matter yield. Similar effects were reported by Thimmaiah (2002) and Yurtseven *et al.* (2002). The effect of salinity (40 and 80 meq/L NaCl) on stomatal conductance, chlorophyll content, ultrastructural damage and photosynthetic performance of six cultivars of faba beans (*Vicia faba* L.) from different agroclimatic regions showed that the lower salinity (40 meq/L NaCl) increased chlorophyll content in some cultivars but did not lead to simultaneous increase in photosynthesis. However, the higher salinity level (80 meq/L NaCl) decreased chlorophyll content and stomatal conductance. Ultrastructural damage was observed in sensitive cultivars even at low salinity levels. The reduction in CO₂ assimilation rate at the highest salt concentration, especially with KFS4 variety, is attributed to NaCl effects on stomatal closure (Figure 1). The closure of stomata reduces internal CO₂ concentration and CO₂ assimilation rate (Dionisio-Sese and Tobita,

2000); and under saline conditions a positive association between photosynthetic rate and yield has been reported in sorghum (Faville *et al.*, 1999). Anand *et al.*, (2000) found that photosynthesis in two alfalfa genotypes was higher when plants were tap-watered compared to 4 dS m⁻¹ water containing Cl⁻ and SO₄⁻² salts. They reported that certain doses of salts might induce photosynthesis, hence, plant growth. Under drought stress, stomatal closure could induce photorespiration to defend against oxidative and osmotic stress (Heldt, 1999). The results of the current study suggested increased salinity affects photosynthesis not only due to its effect on stomatal closure but also due to other non-stomatal effects such as ultrastructural damage and decrease in chlorophyll content below a threshold level. Chlorophyll degradation is the primary cause of photosynthetic inhabitation and leaf firing and a main biochemical factor for the observed growth reduction (Everard *et al.*, 1994). The NaCl-induced decrease in the chlorophyll level is widely reported both in glycophytes and halophytes (Abdullah *et al.*, 2001; Kaya *et al.*, 2007; Shabala *et al.*, 2005). In the present study, the chlorophyll damage was not recorded until 5 dS m⁻¹ salinity level and thereafter chlorophyll damage increased in severity with increasing salinity (Table 1). Therefore, salinity-induced chlorophyll reduction may be an integral part of salinity stressed conditions (Moradi and Ismail, 2007). This is consistent with reports in other monocots including rice, wheat and maize (Krishna, *et al.*, 1993; Shabala, *et al.*, 1998). Salt sensitive rice cultivars had the lowest chlorophyll content than salt tolerant rice cultivars (Ashraf and Ali 1998; Mohan *et al.*, 2000; Mandal and Singh, 2001).

242 **4. CONCLUSION**

243 The reduction in leaf water potential under stress conditions was found to be associated with
244 decrease in chlorophyll content, photosynthesis and stomatal conductance. At low levels of
245 salinity (5 dS m⁻¹) chlorophyll content neither changed nor led to simultaneous increase in
246 photosynthesis. Increased salinity levels from 5 to 15 dS m⁻¹ decreased chlorophyll content
247 and stomatal conductance 20 and 40% respectively. KFS4 variety maintained comparatively
248 6.1% higher amounts of total chlorophyll under salinity and water stress with only marginal
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250 reductions as compared to Speedfeed. Length and width of stomatal were smaller for leaves
 251 exposed to salinity and water stress. The stomata were longer on the control treatments but
 252 shorter under stress.

253 REFERENCES

- 254
 255 Abdullah, Z., Khan, M. A. and Flowers, T. J. 2001. Causes of sterility in seed set of rice
 256 under salinity stress. *Journal of Agronomy and Crop Science*, 187(1), 25–32.
 257 Anand, A., Baig, M. J., and Mandal, P. K. 2000. Response of alfalfa genotypes to saline
 258 water irrigation. *Biologia Plantarum*, 43(3), 455-457.
 259 Ashraf, M. and Ali, Y. 1998. Effect of salinity on growth, chlorophyll content and flag leaf area
 260 of rice (*Oryza sativa* L.) genotypes. *International Rice Research Institute Notes*. 23(2),
 261 33–35.
 262 Borsani, O., Valpuesta, V. and Botella, M. A. 2003. Developing salt tolerant plants in a new
 263 century: a molecular biology approach. *Plant Cell Tissue and Organ Culture*, 73, 101–
 264 115.
 265 Dionisio-Sese, M. L. and Tobita, S. 2000. Effects of salinity on sodium content and
 266 photosynthetic responses of rice seedlings differing in salt tolerance. *Journal of Plant*
 267 *Physiology*, 157, 54–58.
 268 Everard, J. D., Gucci, R., Kann, S. C., Flore, J. A. and Loescher, W.H. 1994. Gas exchange
 269 and carbon partitioning in the leaves of celery (*Apium graveolens* L.) at various levels of
 270 root zone salinity. *Plant Physiology*, 106, 281–292.
 271 Faville, M.J., W.B. Silvester, T.G.A. Green, and W.A. Jermyn. 1999. Photosynthetic
 272 characteristics of three asparagus cultivars differing in yield. *Crop Science*, 39, 1070–
 273 1077.
 274 Fouman, A., E. Majidi Heravan and Y. Nakano. 2003. Evaluation forage sorghum varieties
 275 for salt tolerance. Prossiding of 7th International Conference on Development of
 276 Drylands. 14-17 September 2003, Tehran ,IRAN.
 277 Harivandi, M.A. Bulter, J.D. and Wu, L. 1992. *Salinity and turfgrass culture*. In Turfgrass
 278 Agronomy, Monograph, No. 32.' (Eds DV Waddington et al.) pp. 207–229. (ASA, CSSA,
 279 and SSSA, Madison, WI).
 280 Heldt, H. W. (Ed.), 1999. *PXanzenbiochemie*, second ed. Spektrum Aka-demischer Verlag
 281 GmbH, Heidelberg, Berlin.
 282 Jacoby, B. 1999. Mechanism involved in salt tolerance of plants. In *Handbook of Plant and*
 283 *Crop Stress*, ed. M. Pessarakli, Marcel Dekker, Inc., New York, pp. 97–124.
 284 Jungklang, J., Usui, K. and Matsumoto, H. 2003. Differences in Physiological Responses to
 285 NaCl Between Salt-Tolerant (*Sesbania rostrata* Brem. and Oberm.) and Non-Tolerant
 286 (*Phaseolus vulgaris* L.). *Weed Biology and Management*, 3, 21–27.
 287 Kaya, C., Tuna, A. L., Ashraf, M. and Altunlu, H. 2007. Improved salt tolerance of melon
 288 (*Cucummis melo* L.) by the addition of proline and potassium nitrate. *Environmental and*
 289 *Experimental Botany*, 60, 397–403.
 290 Krishna, S. Raj, B. T., Mawson, E. C., Yeung, T. and Thorpe, A. 1993. Utilization of induction
 291 and quenching kinetics of chlorophyll a fluorecence for in vivo salinity screening studies
 292 in wheat (*Triticum aestivum* vars. Kharchia-65 and Fielder), *Canadian Journal of Botany*,
 293 71(1), 87– 92.
 294 Mandal, M. P. and Singh, R. A. 2001. Impact of salt stress on chlorophyll content in rice
 295 genotypes. *Journal Research Birsa Agriculture University*, 13(1), 61–63.
 296
 297 McCarty, L. B. and Dudeck, A. E. 1993. Salinity effects on bentgrass germination.
 298 *Horticultural Science*, 28, 15–17.

- 299 Mohan, M. M., Narayanan, S.L. and Ibrahim, S.M. 2000. Chlorophyll stability index (CSI): its
300 impact on salt tolerance in rice. *International Rice Research Notes*, 25(2), 38–39.
- 301 Moradi, F. and Ismail, A. M. 2007. Responses of photosynthesis, chlorophyll fluorescence
302 and ROS-scavenging systems to salt stress during seedling and reproductive stages in
303 rice. *Annals of Botany*, 99(6), 1161–1173.
- 304 Muhammad, A., Haji, Kh., Ahmad, H., Muhammad, A., Ejaz, A. and Muhammad A. 2008.
305 Effect of available soil moisture depletion levels and topping treatments on growth rate
306 total dry biomass in chickpea. *Journal of Agricultural Research*, 46 (3), 229-243.
- 307 Munns, R. 2002. Comparative physiology of salt and water stress. *Plant Cell and*
308 *Environment*, 25, 239–250.[CrossRef][Medline].
- 309 Murdoch, C. L. 1987. Water the limiting factor for golf course development in Hawaii. *USGA:*
310 *Green section record* 25, 11–13.
- 311 Neumann, P. 1997. Salinity resistance and plant growth revisited. *Plant Cell and*
312 *Environment*, 20, 1193-1198.
- 313 Poljakoff-Mayber, A. and Lerner, H. R. 1999. *Plants in saline environments*. In: Handbook of
314 Plant and Crop Stress, (Ed. M.Pessarakli), Marcel Dekker, New York, pp. 125-153.
- 315 Rhodes, D., Nadolska-Orczyk, A. and Rich, P. J. 2002. Salinity, osmolytes and compatible
316 solutes. In: Lauchli, A., Lüttge, U.(Eds.), *Salinity: Environment-Plants-Molecules*. Boston,
317 Kluwer Academic Publ C, 181-204, doi: 10.1007/0-306-48155-3_9.
- 318 Salisbury, E. J. 1927. On the causes and ecological significance of stomatal frequency, with
319 special reference to the woodland flora. *Philosophical Transactions of the Royal Society*
320 *of London*, B: biological sciences 216, 1-65
- 321 Shabala, S. N., Shabala, S. I., Martynenko, A. I., Babourina, O. and Newman, I.A. 1998.
322 Salinity effect on bioelectric activity, growth, Na⁺ accumulation and chlorophyll
323 fluorescence of maize leaves: a comparative survey and prospects for screening,
324 *Australian Journal of Plant Physiology*, 25, 609–616.
- 325 Thimmaiah, S. K. 2002. Effect of salinity on biochemical composition of Sorghum (*Sorghum*
326 *bicolor* L.) seeds. *Indian Journal of Agricultural Biochemistry*, 15, 13-15.
- 327 Yurtseven, E., Kutuk, C., Unlukara, A., Kezmez, G. D. 2002. The effect of salinity and
328 nitrogen fertilization on bean yield and quality. 13th International Semp. of international
329 scientific center of fertilizer (CIEC). 10-13 June 2002, Tokat-Turkey, Proc. Of the 13th
330 international semp. Of CIEC.

331 **Abbreviations:**

- 332 LSD; Least Significantly Different
333 dS m⁻¹; desecemens per meter
334 MPa; Mega Pascal
335 LWP; Leaf Water Potential
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