Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 7 (7): 1061-1066, 2007
ISSN 1812-5654

Response of Drip Irrigated Sorghum Varieties Growing in Dune Sand to Salinity Levels in Irrigation Water

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Abstract: Saline-water drip irrigated sorghum varietal response to limited available soil water in dune sand was assessed using salinity response function. In a randomized complete block design three sorghum varieties (Local sorghum, BK 16 and EC 90) were grown with drip irrigated saline-water, at four salinity levels (5.47, 7.32, 9.38 and 12.50 dS m^{-1}) and with quality water of 0.11 dS m^{-1} serving as the control. Four salinity response models were used to assess their ability to discriminate salinity-induced grain yield differences under limited available soil water. Response analysis indicated the four models were equally good in fitting that the grain yield data, but the modified discount model produced the consistently the best fit. Analysis of the data indicated that the impact of salinity stress on varieties was best discriminated by the parameters salinity threshold (Ct), Salinity Tolerance index (ST-index) and the salinity at which 50 % grain reduction (C_{50}) occurred. The analysis indicated that the variety BK 16 was the most tolerance to salinity stress.

Key words: Drip irrigation, crop response model, saline water, salt tolerance, sorghum varieties

INTRODUCTION

Fresh water resources in the arid and semi-arid regions are becoming increasingly scarce; therefore farmers are resorting to unconventional water sources, particularly those high in salinity. Irrigated agriculture using saline water in the arid and semi-arid region can lead to salt accumulation in the profile, reduction in yield and deterioration in soil resource sustainability, if proper management practices are not adapted. The management practices would include appropriate irrigation system use, scheduling and water input, system of irrigation and crops/varieties. However, sufficient information on the impact of the aforementioned practices when saline water is used for irrigation is lacking.

In the semi-arid regions in Mauritania, irrigated rice production has led to rising groundwater levels and development of saline conditions (2.20 dS m^{-1}) in the root zone even when quality water (0.10 – 0.25 dS m^{-1}) has been used for irrigation (FAO, 2002a; van Asten *et al*., 2003). Sorghum, which occupies 60 % of the total area, was for grain production in Mauritania is mostly cultivated in the arid to semi-arid regions. Sorghum is widely used for human consumption and as feed and fodder (Ministère du Développement Rural, 1998). The FAO (2002) reported that sorghum accounts for 25% of the total grain production in Mauritania. Farmers frequently face sorghum crop failure due to drought, however supplementary or full irrigation for this crop has never been tried out. This is partially because of insufficient water resources in these regions as the available scarce groundwater resources are used mostly for human consumption and for livestock. The wells are usually 5 to 20 m deep and they dry out after couple of consecutive dry years. The groundwater tends to become saline after years of water extraction. Under such circumstances, people abandon the saline wells and move to construct new wells. Soil and water salinization places substantial constraints on crop productivity in the arid and semi-arid regions (Royo *et al*., 2000). Ayers and Westcot (1985) defined salinity problem as a condition whereby the salt in soil solution within the crop root-zone accumulates in concentrations that will have an impact on crop yield. There is however, tolerance A limit characteristic of crop/variety. Several workers have highlighted the importance of the selection of crops/varieties that can tolerate water and salinity stress to a certain degree (Fisher, 1980; DeMalach and Pasternak, 1993; Mastrorilli *et al*., 1995; Andrew *et al*., 2000a, b; Yuan *et al*., 2001; Graeme and Ian, 2003; Yuan *et al*., 2003; Calaudivan *et al*., 2005). There is a need for assessment of the varietal response to salinity, particularly under conditions of limited available soil water in sandy soils that are common in arid to

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semi-rid regions and under very efficient irrigation systems, such as the drip system that irrigate water only to the crop root-zone in very limited quantities to maximize water resource use efficiency for irrigation purpose.

Several response functions have been used during the last two decade to water crop yield for salinity (van Genuchten, 1983; Steppuhn *et al*., 2005a, b). Very few attempts have been made to conduct variety-functional sensitivity analysis for sorghum grown in sandy soil, with Drip Irrigation System (DIS).

The objectives of this study were to assess different response models to discriminate sorghum varietal response to level of salinity in irrigation water applied using DIS; to select the best model that could fit sorghum yield response to salinity and to select the sorghum verities to most tolerant salinity.

MATERIALS AND METHODS

Experiment: The experiment was conducted at the Arid Land Research Center, Tottori University Tottori-Japan, from April to August 2005 and from May to September 2006 in a greenhouse. The response of three sorghum varieties (Local, BK 16 and EC 90) was tested, in a randomized complete block experiment with three replication, to 4 levels of salinity of the irrigation water; 5.47 (S1), 7.32 (S2), 9.38 (S3) and 12.50 (S4) dS m^{-1} along with quality water (0.11 dS m^{-1}) as control. Sorghum plant was irrigated daily at rates equivalent to daily open-pan evaporation using a DIS. The experimental plots received 180 kg N ha^{-1}, 45 kg P_2O_5 ha^{-1} and 80 kg K_2O ha^{-1} just before seeding. The total irrigation input during the growing season was 770 mm in 2005 and 850 mm in 2006. Soil water electrical conductivity (ECsw) was measured during the experiment period using TDR sensors up to 30 cm depth. The ECsw was converted to saturated paste extract conductivity (ECe) using the followed equation:

$$ECe = \frac{ECsw}{2} \text{ (FAO, 2002)} \quad (1)$$

The maximum and minimum average temperature was 45 and 24°C, respectively in 2005 and 50 and 26°C, respectively in 2006. The relative humidity ranged between 40 and 90% in 2005 and between 44 and 100% in 2006. Grain yield at harvesting was measured after oven drying at 75°C for 48 h.

Response functions models: Four models were used to assess sorghum grain yield response to salinity. To compare the tolerance of different crops to root-salinity, yields are usually standardized and expressed on a relative basis (Steppuhn *et al*., 2005a, b). Various equations have been applied for describing relative yield (Yr) as a function of variable, which reflects the average of root zone salinity (C).

Bi-exponential function model: Bi-Exponential function model, suggested by van Genuchten (1983) is giving by following equation:

$$Yr = \exp[(aC - b(C^2)] \quad (2)$$

where a and b are empirical constants and can be evaluated by nonlinear regression, C (dS m^{-1}) is average salinity in the root-zone.

Modified Gompertz function model: This function proposed by Gompertz (1925) to predict human mortality, has been used to estimate salinity response function (Baker *et al*., 1975; Tipton, 1984; Gan *et al*., 1992; Steppuhn *et al*., 1998) and is given below:

$$Yr = 1 - \exp[(a\exp(bC)] \quad (3)$$

where a and b are empirical constants and always negative and they can be evaluated by nonlinear regression.

Modified discount function model: According to Steppuhn *et al*. (2005a, b), the compound discount equation can be modified into a sigmoidal-shaped response function as shown below:

$$Yr = \frac{1}{1 + (\frac{C}{C_{50}})^{EXP(sC50)}} \quad (4)$$

where C_{50} is salinity level at Yr = 0.5 and *s* represents the response curve steepness.

Steppuhn *et al*. (2005a, b) suggested to use salinity tolerance index (ST-Index). ST-Index is expressed as follow:

$$\text{ST-Index} = C_{50}\,(1 + s) \quad (5)$$

where C_{50} and s can be computed as regression constants, or approximated by a visual inspection of the response data. The shape of the function for salinity levels greater than C_{50} in not included in this index.

Alternative S-shaped salinity response function model: van Genuchten and Gupta (1993) proposed the use of alternative S-shape model for salinity response function:

$$Y = \frac{Ym}{1+(\frac{C}{C_{50}})^p} \qquad (6)$$

This model has three unknown parameter, Y is yield obtain under different salinity levels, Ym is the maximum yield under nonsaline water irrigation, C_{50} and p is constant equal 3, where p = is shape parameter without biophysical identity.

In this study, various procedures to convert the linear parameter of threshold salinity (Ct) into the nonlinear parameters of the salinity C_{50}, were used as described by Steppuhn *et al.* (2005a, b).

Statistic analysis: The nonlinear regression analysis function and sum of squares were conducted using the SAS/Statg (1991) software package. Three indicators of agreement between simulated and observed values were calculated: Root Mean Square Error (RMSE) and the index of agreement (I_d) (Willmot, 1982), which are defined as follows:

$$RMSE = \sqrt{\frac{\sum(Si-Oi)^2}{N}} \qquad (7)$$

where Si and Oi are simulated and observed values, respectively and N is the number of data points included in the comparison:

$$I_d = \left[\frac{\sum_{i=1}^{n}(Si-Oi)^2}{\sum_{i=1}^{n}(|Si'|+|Oi'|)^2}\right] \qquad (8)$$

where $S' = Si - \bar{O}, O' = Oi - \bar{O}$. The value of I_d varies from 0 to 1 where 1 indicates prefect agreement between the simulated and observed values.

RESULTS AND DISCUSSION

Sorghum grain yield decreased with increasing salinity of the irrigation water, which is in agreement with report of (Maas and Grattan, 1999). There were differences between different varieties in response to saline irrigation. The highest yield obtained under quality irrigation water for the varieties EC 90, local and BK 16 was, respectively 0.30, 0.35 and 0.35 kg m^{-2} in 2005 and was 0.19, 0.22 and 0.25 kg m^{-2} in 2006 these values served as control for com puting relative yield of each variety. The grain yield was less during 2006 than 2005 probably because of higher temperatures during 2006. The lowest yield obtained under the highest salinity level was 0.01, 0.02 and 0.04 kg m^{-2} during 2005 and 0.00, 0.01 and 0.02 kg m^{-2} during 2006 for EC 90, bicolor and BK 16, respectively. In general, the EC 90 had the lowest yields compared to the others two varieties which might reflect its low adaptation to salinity. The BK 16 had the highest yield, indicating that it was most tolerant to salinity. Relative yield data shown in Fig. 1 indicate that visual discrimination of varietal response to salinity is difficult. The data were fitted to 4 models to mathematically discriminate the responses. Figure 2 shows the relationships between grain yield and ECe (C) for the three sorghum varieties and as described by the four functions. Table 1 presents the statistical parameters of RMSE, correlation coefficient (r) and I_d obtained using the different models. The highest of RMSE were observed in Model (4) for EC 90, local and BK 16, the values were 3.69×10^{-2}, 0.63×10^{-2} and 11.62×10^{-2}, respectively in 2005 and 1.15×10^{-2}, $^{0.65}\times10^{-2}$ and 0.62×10^{-2}, respectively in 2006. The lowest RMSE was observed in Model (3) the values are 0.01×10^{-2}, 0.01×10^{-2} and 0.003×10^{-2}, respectively in 2005 and 0.17×10^{-2}, 0.03×10^{-2} and 0.06×10^{-2}, respectively in 2006 for EC 90, bicolor and

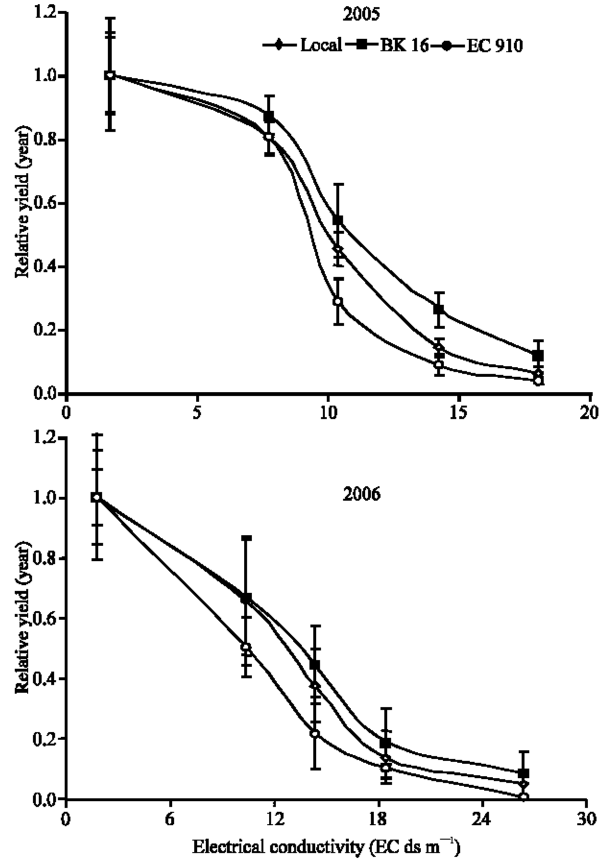

Fig. 1: Sorghum relative yield under different sorghum varieties using saline drip irrigation in sandy soil. (a) is bicolor, (b) is BK 16 and (c) is EC 90

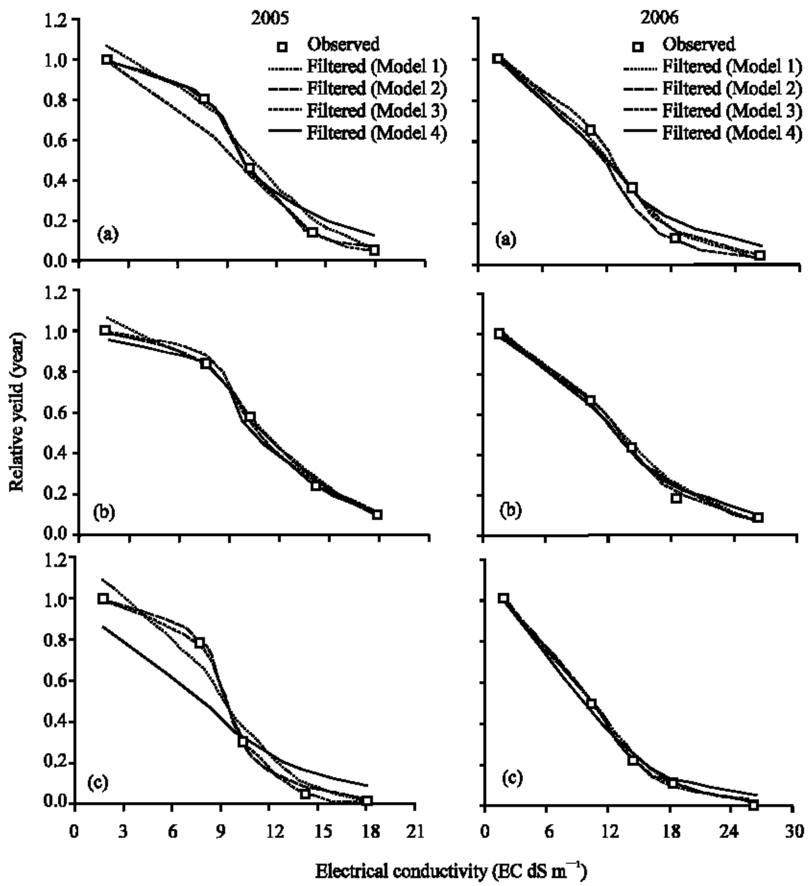

Fig. 2: Observed and fitted salt tolerance curves for three sorghum varieties obtained by fitting 4 models where (a) is Local, (b) is BK 16 and (c) is EC 90

BK 90, respectively. All the functions shown good correlation the correlation coefficient varied from 0.60 to 0.75. The agreement of observed and simulated average values (I_d) was good for all models. Compared others models model (3) shows the best agreement for all varieties. Table 2 presents the corresponding statistical analysis of the models. The parameters showed significant differences among the different sorghum varieties, indicating that the three varieties had significantly different response to salinity. Bi-Exponential models showed that the differences in parameters *a* and b were not significant among the varieties investigated. The values of a were 0.06±0.03, 0.05±0.02 and 0.08±0.05 and the values of b parameter were 0.01±0.00, 0.01±0.00 and 0.02±0.01 for bicolor, BK16 and EC 90, respectively in 2005, suggesting that the three varieties had a similar response to salinity. Similar observation was found in 2006. Modified discount Gompertz model showed significant differences in the fitted parameters between the varieties. In 2005 the values of a parameter were -25.6±3.10, -17.0±4.03 and -74.1±35.0 and that for b parameter were -0.36±0.01, -0.29±0.01 and -0.51±0.01 for bicolor, BK16 and EC 90, respectively. Modified discount function model had a two unknown parameters C_{50} and p. The data indicated significant differences between sorghum varieties. The values of C_{50} were 9.27±0.06, 10.44±0.06 and 11.08±0.21 dS m^{-1} in 2005 and 10.40±0.14, 12.28±0.22 and 12.86±0.33 dS m^{-1} in 2006 for EC 90, bicolor and BK 16, respectively. These data showed that 50% salinity grain yield reduction was high under BK 16 followed by bicolor. The parameter p indicated the degree of steepness of response curves to salinity. The values of p parameter were 4.23±0.15, 4.23±0.37 and 6.99±0.75 in 2005 and 3.18±0.37, 4.36±0.31 and 4.29±0.23 in 2006 for BK 16, bicolor and EC 90, respectively. These results indicated that EC 90 had the highest p compared to other varieties thus showing low salinity tolerance. The lowest p observed for BK 16 variety reflects its highest salinity tolerance.

Alternative S-shaped model had two parameters, maximum yield (Ym) and C_{50}. The highest C_{50} was observed under BK 16 (10.63±0.55 dS m^{-1} in 2005 and

Table 1: Statistical analysis of observed and fitted yield response to salinity tolerance estimated by 4 models

Sorghum Varieties	Number of data	Models	RMSE*	r**	I_d^{++}
2005					
Local	10	Model (1)	0.0129	0.68	0.80
	10	Model (2)	0.0003	0.69	0.98
	10	Model (3)	0.0001	0.69	1.00
	10	Model (4)	0.0369	0.60	0.96
BK 16	10	Model (1)	0.0047	0.68	0.96
	10	Model (2)	0.0027	0.69	0.80
	10	Model (3)	0.0001	0.65	1.00
	10	Model (4)	0.0063	0.66	0.80
EC 90	10	Model (1)	0.0286	0.68	0.96
	10	Model (2)	0.0007	0.69	0.80
	10	Model (3)	0.0003	0.65	1.00
	10	Model (4)	0.1162	0.66	0.80
2006					
Local	10	Model (1)	0.0036	0.69	0.99
	10	Model (2)	0.0147	0.69	0.97
	10	Model (3)	0.0017	0.69	1.00
	10	Model (4)	0.0115	0.60	0.98
BK 16	10	Model (1)	0.0055	0.69	0.97
	10	Model (2)	0.0032	0.69	0.99
	10	Model (3)	0.0030	0.65	0.99
	10	Model (4)	0.0065	0.66	0.96
EC 90	10	Model (1)	0.0014	0.69	0.98
	10	Model (2)	0.0027	0.69	0.96
	10	Model (3)	0.0006	0.75	1.00
	10	Model (4)	0.0062	0.66	0.94

RMSE* is root mean square error, r** is correlation coefficient and I_d^{++} is Index of agreement

Table 2: Comparison between three sorghum varieties by different parameters of 4 models

Sorghum varieties	2005 a*	2005 b**	2006 a	2006 b
Model 1				
Local	0.06±0.03	0.01±0.00	0.03±0.01	0.01±0.00
BK 16	0.05±0.02	0.01±0.00	0.02±0.01	0.01±0.00
EC 90	0.08±0.05	0.02±0.01	0.01±0.00	0.01±0.00
Model 2				
Local	-25.6±3.10	-0.36±0.01	-1.80±3.48	-0.21±0.02
BK 16	-17.0±4.03	-0.29±0.00	-8.11±2.94	-0.19±0.03
EC 90	-74.1±35.0	-0.51±0.01	-9.72±1.93	-0.25±0.02
Model 3				
	C_{50}^{+}(dS m^{-1})	p++	C_{50}(ds m^{-1})	p
Local	10.44±0.06	4.98±0.15	12.28±0.22	4.36±0.31
BK 16	11.08±0.21	4.23±0.37	12.86±0.33	3.18±0.37
EC 90	9.27±0.75	6.99±0.75	10.4±0.14	4.29±0.23
Model 4				
Local	9.49±0.37	3	11.71±0.74	3
BK 16	10.63±0.55	3	12.54±0.92	3
EC 90	8.64±0.92	3	9.73±0.49	3

a* and b** are empirical constants, C_{50}^{+} is salinity where crop yield equals 50% of the nonsaline yield and p++ is shape parameter without biophysical identity

12.54±0.92 dS m^{-1} in 2006) compared to 8.64±0.92 dS m^{-1} in 2005 and 9.73±0.49 dS m^{-1} for EC 90 variety in 2006, which is the lowest value. The differences in maximum yield were not significant among three sorghum varieties.

In general, all models used showed that the three sorghum varieties investigated had not the same response to salinity. Bi-Exponential model was an exception. The comparison of these four models clearly indicated that modified discount function model was the best model to fit the response of the sorghum varieties to salinity levels in irrigation water used for drip irrigation.

Table 3: Nonlinear parameter, discount parameter and salinity tolerance index (ST-Index)

Sorghum varieties	S^{+}	Ct (dS m^{-1})$^{++}$	ST-index
2005			
Local	0.16±0.003	6.88±0.06	10.03±0.10
BK 16	0.13±0.008	8.00±0.23	11.09±0.37
EC 90	0.21±0.011	6.11±0.15	9.26±0.28
2006			
Local	0.12±0.006	8.57±0.16	13.35±0.10
BK 16	0.10±0.008	9.40±0.43	13.81±0.37
EC 90	0.14±0.005	6.59±0.15	11.40±0.28

S^{+} is Absolute of nonlinear steepness parameter and Ct^{++} is threshold salinity parameter

Table 3 presents parameter of salinity tolerance calculated from nonlinear function. The steepness (s), threshold salinity (Ct) and ST-Index showed that the three sorghum varieties had significantly different response to salinity. The highest threshold salinity was observed for BK 16 8.00±0.007 dS m^{-1} in 2005 and 9.40±0.43 dS m^{-1} in 2006, compared to 6.88±0.003 dS m^{-1} in 2005 and 8.57±0.16 dS m^{-1} in 2006 for bicolor and (6.11±0.007 dS m^{-1} in 2005 and 6.59±0.15 dS m^{-1} in 2006) for EC 90. Steepness parameter was higher for EC 90 variety 0.21 and 0.14 compared to 0.16 and 0.12 for bicolor and 0.14 and 0.10 for BK 16 in 2005 and 2006, respectively. The ST-index parameter indicated higher tolerance for BK 16 variety followed by bicolor and EC 90 (Table 3). In general the data suggested that BK 16 variety had higher tolerance to salinity compared to EC 90 and bicolor.

CONCLUSIONS

The sensitivity of three sorghum varieties to salinity induced grain yield reductions were assessed using 4 salinity response models. The results indicated mirror image S-shape yield response curves and the selected 4 models fitted the functional relation well. The varietal differences in salinity induced sorghum grain yield response can be discriminated by the coefficients of the parameters of the models. The coefficients for parameters salinity threshold (Ct), salinity tolerance index (ST-Index) and the salinity in saline water at which 50% crop yield reduction (C_{50}) would occur indicated that variety BK 16 was the most tolerant to salinity stress and EC 90 was the least tolerant. The results also indicated that the salinity response models provide comparative quantitative assessment of varietal response to salinity taking into consideration several salinity associated yield parameters.

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