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Salinity Effects on Seed Yield, Growth, and Germination of Grain Sorghum[1]

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ABSTRACT

Grain sorghum [*Sorghum bicolor* (L.) Moench] is grown on saline soils in the western United States. Because of the lack of information on salinity effects on seed yield, a field plot study was conducted. Six saline treatments were imposed on a Holtville silty clay (clayey over loamy montmorillonitic (calcareous), hyperthermic Typic Torrifluvents) by irrigating with waters that were salinized with NaCl and $CaCl_2$ (1:1 by wt). The electrical conductivities of the irrigation waters were 1.5, 2.7, 5.0, 7.4, 9.8, and 12.1 dS/m. Germination, vegetative growth, and grain yield were measured. Relative grain yield of two cultivars, Double TX and NK-265, was unaffected up to a soil salinity of 6.8 dS/m (electrical conductivity of the saturation extract: κ_e). Each unit increase in salinity above 6.8 dS/m reduced yield by 16%. This indicated that grain sorghum is moderately tolerant to salinity. Yield reduction was due primarily to lower weight per head rather than a reduced number of heads. Vegetative growth was affected less by increasing soil salinity than was grain yield. Grain sorghum was significantly more salt tolerant at germination than at later stages of growth.

***Additional index words:* *Sorghum bicolor* (L.) Moench, Salt tolerance, Sodium chloride, Calcium chloride.**

SORGHUM [*Sorghum bicolor* (L.) Moench] continues to be a major grain crop grown in the United States. In 1980 (the last year of compiled data), 5.15 million ha of grain sorghum were harvested with an estimated value of $1.8 billion, ranking sorghum ahead of rice (*Oryza Sativa* L.) ($1.7 billion), barley (*Hordeum vulgare* L.) ($1.0 billion), and oats (*Avena sativa* L.) ($0.8 billion). Nearly 43% of this sorghum grain or 6.35 million t were exported (13).

Much of the sorghum is grown in the western United States where salinity problems already exist or may develop. Unfortunately, nearly all salt tolerance information on this crop is limited to germination (1, 7, 9) or vegetative growth (6, 12).

Because of the importance of grain sorghum in United States agriculture and the lack of information on mature plant growth under saline conditions, a study was initiated to determine the effect of soil salinity on mature growth and grain yield.

MATERIALS AND METHODS

This field plot study was conducted at the Imperial Valley Conservation Research Center, Brawley, Calif. on a Holtville silty clay soil [clayey over loamy, montmorillonitic (calcareous), hyperthermic Typic Torrifluvents]. Each plot was 6.0 × 6.0 m and was enclosed by acrylic fortified fiberglass borders which extended 76 cm into the soil. The top of the fiberglass borders protruded 15 cm above the soil level of the plot and was covered with a berm 18-cm high and 61-cm wide. Walkways, 1.2-m wide between plots, and good vertical drainage effectively isolated each plot.

Prior to planting, triple superphosphate was mixed into the top 25 cm of soil at the rate of 73 kg P/ha. To assure adequate N fertility throughout the experiment, 1.0 m*M* $Ca(NO_3)_2$ was added in every irrigation. Since the soil contained adequate levels of K no additional K was added.

Two grain sorghum cvs., Asgrow Double TX and Northrup King NK-265 were planted in the plots on 19 to 20 May 1982. Each plot contained 11 rows of Double TX and 11 rows of NK-265. The seeds were placed approximately 7.5 cm apart within rows that were 25 cm apart. A preliminary study conducted during the summer of 1981 indicated the appropriate planting density and salinity treatments for these cultivars.

The experimental design consisted of six treatments replicated three times in a randomized split-plot design. At the time of planting, the soil profiles were still salinized from a previous experiment. The initial average κ_e (electrical conductivity of the saturation extract) to a depth of 1.2-m for the six treatments were 3.3, 5.2, 7.0, 9.7, 12.0, and 12.8 dS/m (dS/m = mmho/cm). To facilitate germination, a 7-cm, nonsaline flood irrigation was applied prior to planting to leach salts from the top 15 cm of soil; another nonsaline irrigation was applied after planting.

Sixteen days after planting, when the plants were approximately 6 cm tall, differential salination was initiated. Irrigation water salinities were increased stepwise in one-third increments over a 3-week period by adding equal weights of NaCl and $CaCl_2$ until desired salt concentrations were achieved. The electrical conductivities of the six treatment waters during the experiment were 1.5 (control), 2.7, 5.0, 7.4, 9.8, and 12.1 dS/m. An 86-mm depth of saline irrigation water was applied approximately every 9 days for a total application of 602 mm during the growing season.

Soil samples were collected from each plot midway through the growing season and again at harvest. Soil cores (2/plot) were taken in 30-cm increments to a depth of 1.2 m. The average electrical conductivities of the saturation extracts (κ_e) for the six salinity treatments are presented in Table 1.

To determine grain and forage yield of each cultivar, six rows 3.05-m long were harvested from the center of each half of each plot. Seed heads were harvested by hand and counted. Total top growth from the harvest area was weighed and water content determined on a subsample. The forage subsample and seed heads were dried in a forced air drier at 70°C. After drying, the seed heads were weighed and the seed was threshed, cleaned, and weighed.

The fourth leaf below the flag leaf was sampled after head emergence. Samples of these leaves were dried (70°C), ground, and analyzed for Na, K, Ca, Mg, Fe, Cu, Mn, and Zn by atomic absorption spectrophotometry, Cl by the coulometric-amperometric titration procedure (3), and P by the molybdovanadate-yellow method (5).

Germination of the two cultivars at different salinities was tested in the laboratory. Four replicates of 25 seeds each were planted in trays containing fine, washed sand. The sand had been premoistened with solution containing equal weights

Table 1. Average electrical conductivities of the soil saturation extracts (κ_e) at 30-cm depth increments for six saline irrigation water treatments.

Soil sample depth	Irrigation water salinities (κ_{iw}) – dS/m					
	1.5	2.7	5.0	7.4	9.8	12.1
cm	(κ_e) – dS/m					
0–30	2.2	3.7	5.5	7.6	9.0	10.3
30–60	3.8	6.0	8.0	10.4	11.8	13.4
60–90	3.4	5.4	8.6	10.6	13.0	13.8
90–120	2.8	4.4	7.0	9.5	12.0	12.0
Average	3.0	4.9	7.3	9.5	11.4	12.4

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Table 2. Grain yield parameters for two sorghum cultivars grown at six salinity levels.

Mean root zone soil salinity (κ_e)	Grain yield†	Dry head wt	Weight head^{-1}	No. of seed heads	Weight of 100 seeds
dS/m	g/m²	g/m²	g	no./m²	g
		Double TX			
3.0	567	659	22.0	140	1.95
4.9	528	607	19.7	144	1.93
7.3	511	591	16.3	169	1.77
9.5	422	480	14.6	153	1.91
11.4	160	219	8.3	120	2.07
12.4	47	83	4.0	95	2.11
		NK – 265			
3.0	374	450	13.1	160	2.06
4.9	381	462	13.0	165	2.13
7.3	327	394	10.5	177	2.27
9.5	200	247	7.1	159	2.48
11.4	113	149	5.5	121	2.30
12.4	22	46	2.9	69	2.11

Analysis of variance

Source	df§	Grain yield‡	Dry head wt‡	Weight head^{-1}	No. of seed heads‡	Weight of 100 seeds
		Mean squares				
			Double TX			
Salinity	5	141.04**	165.86**	140.60**	2.04**	0.04
Linear	1	580.20**	696.20**	652.35**	3.44*	0.07
Quadratic	1	109.02**	117.17**	34.51*	6.03**	0.13**
Cubic	1	9.37	11.48	12.20	0.44	0.00
Error	12	1.62	1.83	3.52	0.33	0.01
			NK – 265			
Salinity	5	66.25**	88.39**	52.50**	4.86**	0.07
Linear	1	300.97**	402.20**	250.24**	13.34**	0.06
Quadratic	1	28.07	36.28	8.51	9.64**	0.18**
Cubic	1	0.56	1.20	0.79	1.15	0.10
Error	12	3.69	4.20	3.70	0.30	0.01

*,** Significant at 5 and 1% level of probability.
† Grain yield adjusted to 13% moisture.
‡ × 10³.
§ df = Degrees of freedom.

Table 3. Vegetative parameters for two grain sorghum cultivars grown at six salinity levels.

Mean root zone soil salinity (κ_e)	Plant wt†	Plant height	Harvest‡ index
dS/m	g/m²	cm	%
	Double TX		
3.0	817	101	33.6
4.9	756	85	33.9
7.3	673	75	35.7
9.5	638	65	33.1
11.4	584	46	17.1
12.4	564	40	5.6
	NK – 265		
3.0	817	87	25.2
4.9	814	81	25.5
7.3	794	73	23.8
9.5	751	60	17.2
11.4	720	43	11.2
12.4	654	35	2.7

Analysis of variance

Source	df¶	Plant wt§	Plant height	Harvest index
		Mean squares		
		Double TX		
Salinity	5	29.13**	1598.92*	454.87**
Linear	1	144.05**	7835.03**	1409.35**
Quadratic	1	0.91	32.70	750.42**
Cubic	1	0.11	67.82	107.21
Error	12	3.80	13.15	16.28
		NK – 265		
Salinity	5	12.16	1301.43**	252.98**
Linear	1	52.65**	6221.80**	1051.53**
Quadratic	1	6.54	266.05**	197.45
Cubic	1	0.40	4.84	4.82
Error	12	3.62	12.62	24.08

*,** Significant at 5 and 1% level of probability.
† Plant dry weight excluding weight of seed head.
‡ Harvest index = seed weight/total top growth × 100.
§ × 10³.
¶ df = Degrees of freedom.

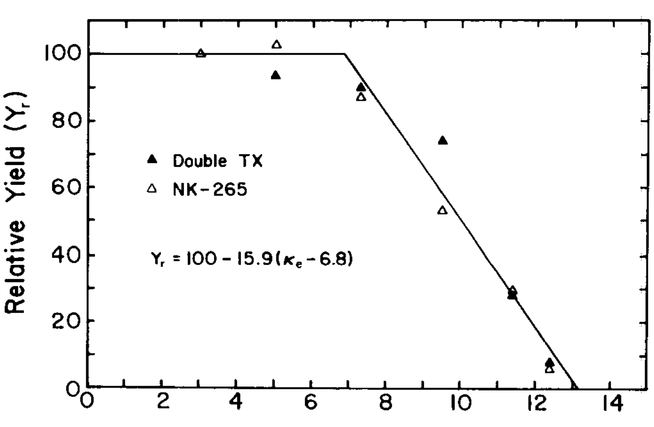

Fig. 1. Relative grain yield of two sorghum cultivars as a function of increasing soil salinity.

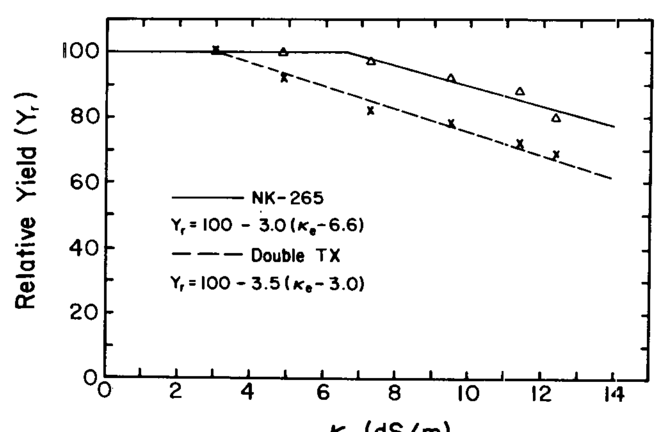

Fig. 2. Relative vegetative growth of two sorghum cultivars as a function of increasing soil salinity.

of NaCl and $CaCl_2$ to produce soil water salinity levels (κ_{sw}) of 0, 3.9, 8.3, 11.6, 15.8, and 22.1 dS/m. The trays were placed in a lighted, humid environment at 25°C. Seed germination counts were made daily over a 10-day period.

RESULTS AND DISCUSSION

Grain yields obtained from the control plots (3.0 dS/m) for both cultivars exceeded those reported for the 1982 field performance trials at the Imperial Valley Field Station (15). Double TX and NK-265 averaged 527 and 258 g/m² in those trials with comparable planting dates. Environmental factors and soil condition were nearly the same at both locations.

Yield of both cultivars was significantly reduced by a κ_e greater than 7.3 dS/m (Table 2). The reduction in dry head weight on a relative basis was nearly the same as that for total grain yield. Decreased yield was caused primarily by decreased weight per head rather than a

Table 4. Mineral composition of leaves from two sorghum cultivars grown at six soil salinities.

Mean root zone soil salinity (κ_e)	Cl	Na	Ca	Mg	K	P	Fe	Cu	Zn	Mn
dS/m	mmol/kg dry wt†									
				Double TX						
3.0	136	5.6	69	92	408	99	1.61	1.09	0.34	0.46
4.9	139	7.1	77	89	372	91	1.58	0.97	0.34	0.45
7.3	195	5.3	88	89	404	80	1.61	0.91	0.37	0.47
9.5	195	4.6	75	70	432	75	1.55	0.82	0.39	0.47
11.4	265	4.3	83	80	424	85	1.51	0.82	0.49	0.49
12.4	281	3.3	94	60	491	75	1.49	0.80	0.46	0.53
				NK − 265						
3.0	181	6.6	87	122	442	88	2.50	1.33	0.36	0.30
4.9	201	5.6	95	125	444	92	2.43	1.39	0.42	0.28
7.3	311	4.8	129	146	465	79	2.24	1.37	0.46	0.37
9.5	339	4.9	145	130	434	74	2.17	1.21	0.44	0.39
11.4	363	4.6	142	100	469	71	1.46	1.12	0.45	0.36
12.4	410	4.8	166	90	464	71	1.25	1.05	0.47	0.38

Analysis of variance

Source	df§	Cl‡	Na	Ca‡	Mg‡	K‡	P‡	Fe	Cu	Zn	Mn
		Mean squares									
					Double TX						
Salinity	5	11.20**	5.08	0.24	0.49**	4.74	0.28**	0.007	0.038**	0.013**	0.002
Linear	1	51.49**	18.00**	0.67	1.74**	14.05	0.96**	0.029	0.172**	0.054**	0.009
Quadratic	1	1.78	2.44	0.00	0.09	4.57	0.19**	0.005	0.013	0.003	0.001
Cubic	1	0.06	1.85	0.33	0.01	0.04	0.01	0.000	0.000	0.001	0.000
Error	12	1.38	1.47	0.14	0.08	1.82	0.02	0.008	0.003	0.001	0.003
					NK − 265						
Salinity	5	24.97**	1.65	2.80**	1.25**	0.66	0.24**	0.827*	0.060	0.005	0.006
Linear	1	119.59**	6.19**	13.12**	2.23**	1.00	1.05**	3.473**	0.239*	0.017**	0.021
Quadratic	1	0.39	1.77	0.06	3.47**	0.04	0.00	0.504	0.052	0.003	0.002
Cubic	1	0.05	0.07	0.00	0.08	0.30	0.10	0.056	0.006	0.003	0.003
Error	12	1.02	0.44	0.18	0.10	0.58	0.03	0.136	0.024	0.001	0.004

*,** Significant at 5 and 1% level of probability.
† Means of three replicates.
‡ $\times 10^3$.
§ df = Degrees of freedom.

decrease in number of heads per unit area. Only at salinities of 11.4 and 12.4 dS/m did the reduced number of seed heads contribute to the yield reduction. Individual seed weight, expressed as the weight of 100 seeds, did not contribute to the total grain reduction since it tended to increase with increasing salinity levels.

Double TX produced significantly higher yields at each salinity level than did NK-265; however, both cultivars had the same threshold and relative yield decline values. Regression analysis of the combined data indicated a maximum allowable soil salinity of 6.8 dS/m (the threshold value) before grain yield declined (Fig. 1). Each unit increase in salinity above this threshold reduced yield by 16%.

According to the salt tolerance categories established by Maas and Hoffman (8), grain sorghum would be classified as moderately tolerant to salinity. Although the threshold for sorghum is approximately the same as for wheat (*Triticum aestivum* L.). The rate of yield decline is much greater for sorghum.

The effect of salinity on vegetative growth of the two cultivars was quite different than on grain yield (Table 3 and Fig. 2). Although the thresholds of 3.0 dS/m for Double TX and 6.6 dS/m for NK-265 were significantly different, the reduction in vegetative growth for each unit increase in salinity above these thresholds were similar at 3.5% for Double TX and 3.0% for NK-265. Corn (*Zea mays* L.) (4) and rice (11) have also shown a greater reduction in grain yield, than in vegetation growth, under saline conditions.

A reduction in plant height, noted when the plants were approximately 1-month-old, was the first obvious effect of salinity. The maximum plant height of both cultivars at maturity was significantly reduced with increasing salinity (Table 3).

The harvest index (Table 3), a measure of the grain produced in relation to total top growth, decreased significantly for both cultivars at a κ_e of 11.4 dS/m. The lower harvest index for NK-265 than for Double TX, reflects the higher dry matter production and lower seed yield of this cultivar.

The concentrations of Na, K, and P in the leaf tissue were approximately the same for both cultivars (Table 4). However, NK-265 leaves contained considerably higher levels of Cl, Ca, and Mg than did those of Double TX. In both cultivars, increased soil salinity increased Ca and Cl concentrations and decreased Na, Mg, and P concentrations in the leaves. These results agree with previously reported leaf mineral concentrations for grain sorghum grown under saline conditions (10).

Although the soil used in this study is classified as calcareous (pH 7.8), at no time during the course of the study were Fe, Cu, or Zn-deficiency symptoms apparent. Despite the fact that Fe and Cu decreased and Zn increased with increasing salinity levels, the leaf concentrations of Fe, Cu, Mn, and Zn remained well above those concentrations reported as deficient in sorghum (2).

The effect of increasing salinity levels on germination was essentially the same for both cultivars (Fig.

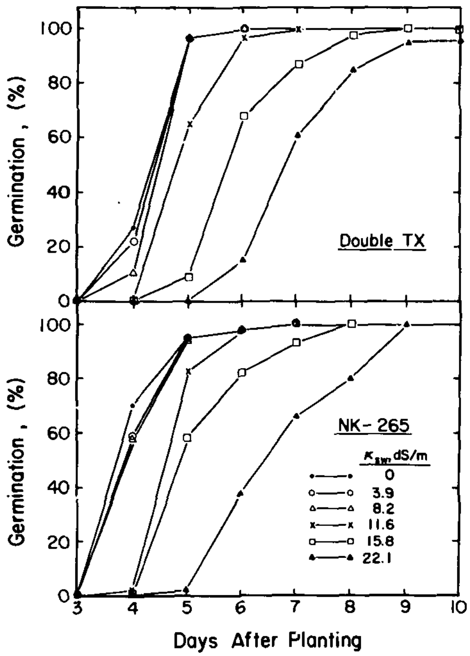

Fig. 3. Germination of two grain sorghum cultivars at six salinity levels.

3). Soil water salinity up to 8.2 dS/m had no significant effect on germination; however, salt levels greater than 8.2 dS/m delayed germination, but in no case was the final germination percentage significantly reduced. These results are consistent with other sorghum germination studies under saline conditions (1, 7).

Sorghum is considerably more salt tolerant at germination than at later stages of growth. The soil water salinity of 22.1 dS/m had no effect on final germination percentage. If one assumes that the soluble salt concentration of the soil solution at field capacity is about twice that at saturation (14); i.e., $\kappa_{sw} = 2\ \kappa_e$, the data in Fig. 1 indicate a 67% reduction in grain yield at $\kappa_{sw} = 22$ dS/m.

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