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Yield, Vegetative Growth, and Fiber Length of Kenaf Grown on Saline Soil

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ABSTRACT

Kenaf (*Hibiscus cannabinus* L.) is an excellent supplement to wood as a source of fiber for paper pulp. With the introduction of kenaf into the western USA, plantings may be on soils where salinity problems already exist or may develop from the use of saline irrigation water. Because of the lack of salt-tolerance information on mature vegetative growth and yield, a 2-yr field-plot study was conducted at Brawley, CA. Two cultivars (Everglades-41 and 7818-RS-10) were grown with six salinity treatments imposed on a Holtville silty clay [clayey over loamy, montmorillonitic (calcareous), hyperthermic Typic Torrifluvent]. Electrical conductivities of the irrigation waters, containing NaCl and $CaCl_2$ (1:1 by weight), were 1.1, 2.0, 3.0, 4.0, 5.0, and 6.0 dS m^{-1}. Soil salinity (electrical conductivity of the saturated-soil extract, κ_e) ranged from 5.4 to 12.6 dS m^{-1} the first year, and from 6.0 to 14.9 dS m^{-1} the second year. Vegetative growth, stem yield, and fiber length were measured. The mean dry weight yields of the stems during the 2-yr experiment were reduced 11.6% for each unit increase in soil salinity above 8.1 dS m^{-1}. These results place kenaf in the salt tolerant category. Yield reduction resulted from both a reduction in plant height and stem diameter. Increased salinity did not significantly affect fiber length. Excessive Cl accumulation occurred in the leaf tissues at high soil salinity levels.

KENAF has long been recognized as a possible source of cellulosic fiber for pulp production (Ahlgren et al., 1950). The economical potential of this crop is related to the gradual diminishing supply of hardwoods and softwoods in the world, and the increasing per capita consumption of paper and paperboard materials. In 1987, newspaper publishers in the USA alone used 12 million t of newsprint, with two-thirds of it imported at a cost of nearly $4000 million. By 1996, the demand is expected to reach 14.5 million t a year (Bosisio, 1988). Since it is currently impossible for forests to produce an annual quantity of fibers to meet our domestic demands, the greatest potential rests with the production of annual species, such as kenaf, to meet the need.

Kenaf has been reported to be three to five times more productive per unit area than pulpwood trees and produces a pulp that is equal or superior to many wood pulps (Theisen et al. 1978). Paper produced from kenaf pulp has excellent ink-retention characteristics and its high tensile strength is ideal for high-speed presses (Robinson, 1988).

The entire kenaf plant can be utilized. The stems contain two distinct fibers, the bast or outer bark fibers and the inner core of short, woody fibers, both of which may be used in pulp production. The plant tops, when ground, have high digestibility and can be used as a source of roughage and protein for cattle and sheep (Hays, 1989).

White et al. (1970) summarized the numerous studies that had been conducted to determine the agronomic potential for kenaf in the USA. Since then, additional studies have been conducted on plant population density (Campbell and White, 1982; Bhangoo et al. 1986), N fertilization (Massey, 1974; Adamson et al, 1979), and fiber and pulping properties (Adamson and Bagby, 1975; Watson et al, 1976).

With the introduction of kenaf into the arid western USA, plantings may be on soils where salinity problems already exist or may develop from the use of saline irrigation water. Preliminary studies of salt stress on germination and seedling growth of kenaf have been conducted in the greenhouse (Curtis and Läuchli, 1985, 1986; Curtis et al. 1988), but these studies provided no information on the effect of salinity beyond the seedling stage of growth. Since salt tolerance data are not available to predict yield responses at later stages of growth, a 2-yr field plot study was initiated to determine the effect of salinity on vegetative growth and yield of field-grown kenaf.

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MATERIALS AND METHODS

This field plot study was conducted in 1987 and 1988 at the Irrigated Desert Research Station, Brawley, CA, on a Holtville silty clay soil. Each plot was 6.0 by 6.0 m and was enclosed by acrylic-fortified fiberglass borders that extended 0.75 m into the soil. The fiberglass borders protruded 0.15 m above the soil level of the plot and were covered with a berm 0.18 m high and 0.60 m 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 0.25 m of soil at the rate of 73 kg P ha^{-1}. To assure adequate N fertility throughout the experiment, $Ca(NO_3)_2$ was added at the rate of 0.14 kg N ha^{-1} mm^{-1} of water applied at every irrigation for a total application of 212 and 244 kg ha^{-1} for 1987 and 1988 respectively. The soil contained adequate levels of K, so no additional K was added.

The two cultivars used in this study were Everglades-41 (E-41) and 7818-RS-10 (RS-10). Previous studies (Robinson, 1988) at the nearby University of California Imperial Valley Agricultural Center had shown that both cultivars were well adapted to the climate and soil conditions of the test site. Both cultivars were seeded in level plots on 26 March 1987 and 19 April 1988. Each plot contained 5 rows of each cultivar. The rows were planted 0.5 m apart, with the seed placed approximately 50 mm apart within the row. This spacing provided a potential population of 394 700 plants ha^{-1}. All plants were counted at harvest to determine the harvest population.

The experimental design consisted of six treatments replicated three times in a split-plot design, with salinity as main plots and cultivars as subplots. At planting, the soil profiles were still salinized from previous experiments. The initial electrical conductivities of the saturated-soil extract κ_e averaged to a depth of 1.2 m for the six treatments in 1987 were 4.5, 4.9, 5.0, 6.6, 7.3, and 7.8 dS m^{-1}, while in 1988 they were 5.4, 6.2, 8.7, 9.9, 12.0, and 12.6 dS m^{-1}. To facilitate germination each year, 50 mm of low-salinity water (1.2 dS m^{-1}) was applied to each plot prior to seeding to leach salts from the top 0.15 m of soil; another 80 mm was applied in two increments after seeding to reduce soil crusting.

Differential salination was initiated 34 d after seeding in

Table 1. Average electrical conductivities of the saturated-soil extracts (κ_e) for two kenaf cropping seasons and six saline irrigation water salinities.

Soil Sample Depth	Average irrigation water salinities (κ_{iw}) – dS m^{-1}					
	1.1	2.0	3.0	4.0	5.0	6.0
m	dS m^{-1} (κ_e)					
			1987			
0–0.3	4.6 ± 0.2†	5.4 ± 0.2	7.0 ± 0.5	6.7 ± 0.2	7.5 ± 0.2	8.5 ± 0.8
0.3–0.6	5.6 ± 0.9	7.9 ± 0.6	10.0 ± 0.5	11.8 ± 0.6	13.2 ± 0.7	12.3 ± 1.6
0.6–0.9	6.0 ± 1.2	5.4 ± 1.3	9.1 ± 1.8	11.2 ± 1.0	15.2 ± 0.2	17.0 ± 1.9
Average	5.4 ± 0.7	6.2 ± 0.3	8.7 ± 0.3	9.9 ± 0.2	12.0 ± 0.2	12.6 ± 1.2
			1988			
0–0.3	3.2 ± 0.5	5.0 ± 0.7	7.2 ± 0.5	8.9 ± 1.1	10.1 ± 0.3	10.9 ± 0.3
0.3–0.6	7.5 ± 0.7	11.0 ± 1.3	13.8 ± 1.1	15.4 ± 0.8	15.6 ± 0.7	16.8 ± 1.2
0.6–0.9	7.3 ± 0.7	10.0 ± 1.3	14.4 ± 1.2	16.4 ± 0.4	16.3 ± 2.0	17.2 ± 0.7
Average	6.0 ± 0.5	8.6 ± 1.0	11.8 ± 0.8	13.6 ± 0.7	14.0 ± 0.9	14.9 ± 0.5

† Means ± SE of three samples

1987 and 30 d after seeding in 1988, when the plants were at the four to five leaf stage of growth. Irrigation-water salinities of the five saline treatments were increased stepwise in one-half increments over a 2-wk period by adding equal weights of NaCl and $CaCl_2$ until desired salt concentrations were achieved. The average electrical conductivities of the six irrigation waters (κ_{iw}) for the 2 yr were 1.1 (control), 2.0, 3.0, 4.0, 5.0, and 6.0 dS m^{-1} (referenced at 25 °C). During both growing seasons, all plots were irrigated approximately every 9 d to keep the soil matric potential of the control treatment above -85 J kg^{-1} at a soil depth of 0.15 to 0.3 m. A neutron probe and tensiometers were used to monitor soil matric potential and to guide irrigation frequency. The total amounts of irrigation

Table 2. Vegetative yield parameters for Everglades-41 (E-41) and 7818-RS-10 (RS-10) kenaf grown for 2 yr at six levels of salinity.

Soil salinity (κ_e)	Total dry wt	Dry stem wt	Total height	Stem diam	Total dry wt	Stem dry wt	Total height	Stem diam
dS m^{-1}	kg m^{-2}		m	mm	kg m^{-2}		m	mm
	E-41				RS-10			
				1987				
5.4	1.53	1.60	3.16	23.9	1.28	0.84	2.96	25.3
6.2	1.55	1.06	3.13	24.3	1.63	1.02	3.12	26.9
8.7	1.47	0.93	2.85	23.7	1.52	0.97	2.89	24.7
9.9	1.49	0.91	2.64	22.7	1.33	0.76	2.63	25.5
12.0	1.11	0.70	2.20	21.1	1.15	0.65	2.27	24.0
12.6	0.57	0.40	1.72	17.8	0.66	0.40	1.84	22.3
				1988				
6.0	1.56	1.15	3.50	23.9	1.82	1.34	3.37	22.3
8.6	1.36	0.98	3.04	21.7	1.54	1.09	2.76	20.1
11.8	1.20	0.77	2.41	20.0	1.06	0.67	2.20	18.1
13.6	0.69	0.43	1.97	17.3	0.73	0.45	1.74	15.9
14.0	0.55	0.38	1.67	15.9	0.51	0.34	1.54	15.5
14.9	0.28	0.19	0.85	13.7	0.26	0.18	0.82	12.0

Analysis of Variance

Source	df	Total dry wt	Dry stem wt	Total height	Stem diam	Total dry wt	Stem dry wt	Total height	Stem diam
		Mean Squares							
		E-41				RS-10			
					1987				
Salinity	5	0.45†	0.20†	95.3†	18.5†	0.34†	0.15†	70.0†	7.25
Linear	1	1.44†	0.78†	427.4†	67.1†	0.86†	0.50†	292.0†	22.50*
Quadratic	1	0.50†	0.10**	30.0†	14.5**	0.55†	0.16†	40.0†	4.73
Cubic	1	0.11*	0.02	2.1	0.8	0.02	0.02	0.5	0.02
Error	10	0.01	0.01	0.8	1.3	0.04	0.01	1.1	2.56
					1988				
Salinity	5	0.77†	0.43†	275.1†	44.1†	1.10†	0.61†	248.3†	40.13†
Linear	1	3.39†	2.00†	1246.1†	203.5†	5.29†	3.01†	1165.6†	182.63†
Quadratic	1	0.35†	0.11*	76.0†	11.2*	0.16*	0.02	33.9†	9.09*
Cubic	1	0.06	0.01	39.3**	5.4	0.02	0.00	35.9†	7.42
Error	10	0.02	0.01	3.2	1.6	0.02	0.01	1.3	1.72

*,**,† Significant at the 0.05, 0.01, and 0.005 levels of probability, respectively.

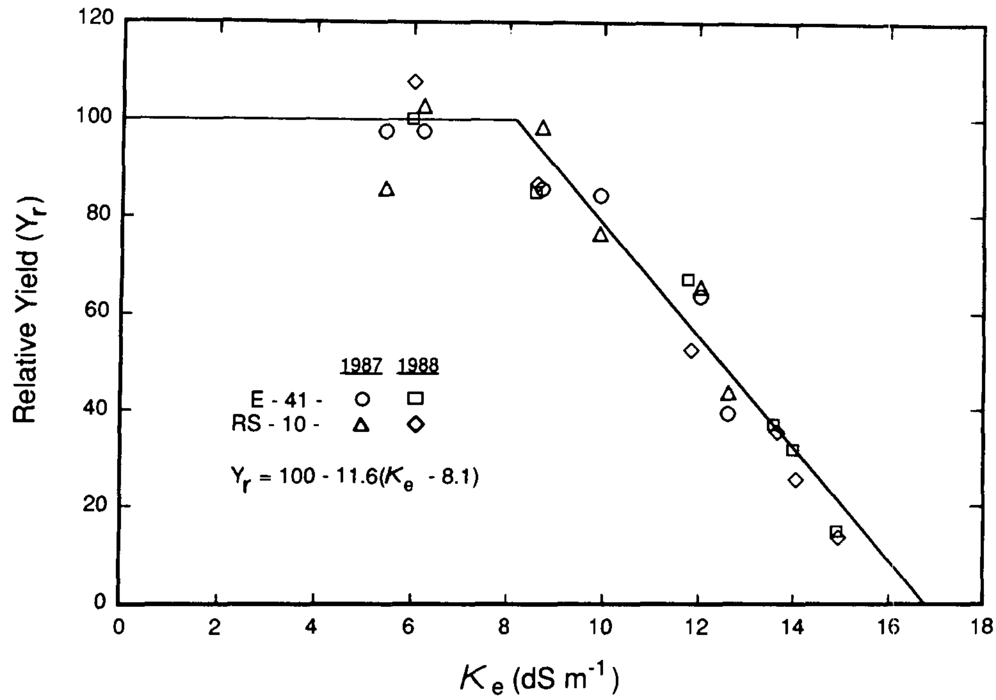

Fig. 1. Relative stem yield of two kenaf cultivars as a function of increasing soil salinity.

water applied to each plot after planting were 1594 mm in 1987 and 1823 mm in 1988. No rainfall occurred during either growing season.

Soil samples were collected from each plot approximately 8, 16, and 24 wk after salination was initiated. Two soil cores per plot were taken in 0.3-m increments to a depth of 0.9 m. The average κ_e for the three sampling dates for each depth in both years is presented in Table 1.

The monthly mean high temperatures in 1987 ranged from 33 °C in April to 41 °C in August; monthly mean low temperatures for the same period ranged from 11 °C to 23 °C. During the 1988 growing season, the monthly mean high temperatures were 28 °C for April and 41 °C for August, with corresponding low temperatures of 9 and 23 °C, respectively. The daily mean temperature, which is equivalent to thermal units per day, averaged 27.6 °C in 1987 and 27.5 °C in 1988.

Mature, fully expanded leaves were sampled on 28 July 1987 and 10 August 1988 when the plants were beginning to flower. Petioles were removed from the rest of the leaf blade for separate mineral analysis. The samples were washed in deionized water, dried at 70 °C, and finely ground. Chloride contents were determined on 0.1 *M* nitric acid in 1.7 *M* acetic acid extracts of the sample material by the Cotlove (1963) coulometric-amperometric titration procedure. Nitric-perchloric acid digests of the ground samples were analyzed for P by molybdovanadate-yellow colorimetry (Kitson and Mellon, 1944) and Na, Ca, Mg, and K by atomic absorption spectrophotometry.

Plants were harvested on 20 October in 1987 and on 31 October in 1988. To determine total fresh weight of shoots per unit area for each cultivar, plants were harvested from a 4.6-m^2 area from the center of each half of each plot and weighed. Ten plants were randomly subsampled from the harvested material and measured for height. Leaves and side branches were removed and weighed separately from the stems. Samples were oven-dried at 70 °C and percent dry matter determined. Stem diameter measurements were made 25 mm above the base of each plant. A 0.1-m section of stem was sampled 0.5 to 0.6 m above the stem base to determine the bast to woody fiber ratio. This same 0.1-m stem sample was used to determine the mineral composition of the two fibers. The separated fiber samples were processed and analyzed by the same methods as those used to determine leaf blade and petiole mineral content.

In 1987, a separate 0.1-m section of stem was sampled 0.5- to 0.6-m above the stem base for bast and woody fiber length analysis. The samples were analyzed at the USDA, Forest Products Laboratory, Madison, WI on a Model 100 Kajaani fiber length analyzer (Kajaani Electronics, Kajaani, Finland). Prior to fiber length determination, the bast and woody fibers for each sample were separated, macerated, and analyzed individually.

Calculated coefficients for unequally spaced treatments were used to determine single degree of freedom comparisons for vegetative yield parameters.

RESULTS AND DISCUSSION

Vegetative Growth and Yield

Total shoot and stem dry matter yields for both cultivars were significantly reduced by salinity in 1987

Table 3. Woody and bast fiber lengths in stems from two kenaf cultivars grown at two salinity levels in 1987.

Soil salinity (κ_e)	Cultivar	Vessel length Min.	Vessel length Max.	Vessel length Means†	Fiber length Min.	Fiber length Max.	Fiber length Means‡
dS m^{-1}		mm					
				Woody fibers			
5.4	RS-10	0.29	0.50	0.39±0.05	0.61	1.05	0.78±0.08
12.6	RS-10	0.31	0.55	0.40±0.06	0.59	1.06	0.80±0.11
5.4	E-41	0.40	0.56	0.46±0.05	0.57	2.38	0.84±0.31
12.6	E-41	0.30	0.53	0.40±0.06	0.75	2.35	1.14±0.31
				Bast fibers			
5.4	RS-10	—	—	—	2.84	4.66	3.70±0.45
12.6	RS-10	—	—	—	2.98	5.10	3.73±0.53
5.4	E-41	—	—	—	3.16	4.93	4.08±0.49
12.6	E-41	—	—	—	2.44	4.36	3.27±0.59

† Twenty-five vessel measurements ± SE.
‡ 100 woody fiber and 25 bast fiber measurements ± SE.

Table 4. Average mineral composition of blades (B) and petioles (P) of leaves from Everglades-41 kenaf grown for 2 yr at six levels of salinity.

Soil Salinity (κ_e)	Cl		Na		Ca		Mg		K		P	
	B	P	B	P	B	P	B	P	B	P	B	P
dS m^{-1}	mmol kg^{-1} dry wt											
						1987						
5.4	306	756	32.4	10.0	456	592	168	343	471	947	82.8	33.9
6.2	338	828	27.2	6.6	520	589	195	361	462	1005	63.8	35.3
8.7	417	1031	30.8	9.1	551	698	191	358	459	949	74.7	30.3
9.9	484	1088	39.2	14.6	548	756	165	310	478	864	85.8	36.5
12.0	592	1237	44.3	16.1	579	835	183	336	484	958	76.7	36.2
12.6	652	1591	58.0	30.6	626	976	163	325	535	1051	81.2	34.0
						1988						
6.0	342	770	40.8	14.9	522	625	230	413	450	1024	68.9	35.1
8.6	553	1128	53.9	19.0	647	768	216	378	518	1065	68.2	34.4
11.8	725	1515	75.4	32.8	666	971	190	331	579	1055	75.3	35.3
13.6	955	1913	111.5	53.0	708	1145	195	351	668	1123	75.7	35.8
14.0	1271	2065	148.0	80.3	801	1149	204	300	918	1231	82.1	37.0
14.9	1463	2496	182.3	111.1	771	1295	199	314	1031	1412	82.4	37.7

Analysis of variance

Source	df	Mean squares†											
		Cl		Na		Ca		Mg		K		P	
		B	P	B	P	B	P	B	P	B	P	B	P
							1987						
Salinity	5	57.1‡	273.9‡	0.38*	0.22‡	9.7	67.0‡	0.56	1.14	2.4	11.8**	0.18	0.02*
Error	10	2.7	5.5	0.05	0.01	3.4	0.9	0.22	0.63	1.0	1.9	0.04	0.00
							1988						
Salinity	5	550.5‡	1214.0‡	9.25‡	4.27‡	29.9**	195.3‡	0.66	5.26**	160.9‡	64.6‡	0.11*	0.00
Error	10	18.1	28.8	0.42	0.42	4.9	2.9	0.45	0.89	5.1	2.0	0.03	0.03

*,** Significant at the 0.05 and 0.01 levels of probability, respectively.
† Table value must be multiplied by 10^3.
‡ Significant at the 0.005 level of probability.

and 1988 (Table 2). The decrease in yield was attributed to the reduction in both stem diameter and plant height with increased levels of salinity.

Although the initial planting density for this study was 394 700 plants ha^{-1}, plant counts made at harvest indicated that the plant population both years was approximately 173 000 plants ha^{-1}. This lower plant population was not the result of salinity since the plant count on the higher salinity plots was not significantly different from the control plots (data not presented). Therefore, plant survival was not a contributing factor to yield reduction in this study.

Yields of RS-10 measured at the lower salinities both years were comparable to those reported by Robinson (1988) at the University of California Imperial Valley Field Station; whereas, those of E-41 were slightly lower. Environmental factors and soil conditions were nearly the same at both locations. Like most crops, kenaf yields will vary, depending upon climate, soil conditions, and cultural practices.

Stem yield data for the 2 yr were combined for each cultivar and statistically analyzed with a piecewise linear response model (Maas and Hoffman, 1977; van Genuchten and Hoffman, 1984). The combined data indicated that both cultivars had the same tolerance threshold (i.e. the maximum allowable κ_e without a decline in yield) and relative yield decline. Therefore, the yield data for both cultivars for both years were combined and analyzed again. The combined data indicated a threshold of 8.1 dS m^{-1}, with an 11.6% reduction in stem yield for each unit increase in salinity above the threshold (Fig. 1). Relative yield, Y_r, for any κ_e exceeding the threshold of 8.1 dS m^{-1} can be calculated with the formula in Fig. 1.

Data for total shoot yield were analyzed with the same procedure used for stem yield. The analyses indicate a threshold of 9.2 dS m^{-1} and a yield decline of 13.5% above this threshold. Although the threshold for total yield was slightly higher than for stem yield, the yield decline was slightly greater. Extrapolation of the data from the model indicates that zero yield will occur at 16.6 dS m^{-1} for total shoot yield and at 16.7 for stem yield. Therefore, the overall tolerance for the yield of the whole shoot is nearly the same as that for the stem.

The yield response curve does not fall within a single salt tolerance category as established by Maas and Hoffman (1977). It extends from the tolerant into the moderately tolerant category. However, since the economically important part of the yield response curve (i.e. <20% yield reduction) falls in the tolerant category, kenaf is classified as tolerant to salinity. This classification agrees with seedling tolerance reported by Curtis and Läuchli (1985), where their threshold occurred at 8.5 dS m^{-1}.

Fiber Analysis

Salinity did not significantly affect the length of the woody or bast fibers (Table 3). However, the length of both fibers were consistently longer than previously reported (White et al. 1970; Williams, 1966). The

Table 5. Average mineral composition of blades (B) and petioles (P) of leaves from '7818-RS-10' kenaf grown for 2 yr at six levels of salinity.

Soil Salinity (κ_e)	Cl		Na		Ca		Mg		K		P	
	B	P	B	P	B	P	B	P	B	P	B	P
dS m^{-1}	mmol kg^{-1} dry wt											
						1987						
5.4	255	720	15.6	8.0	458	579	180	342	469	838	87.5	37.3
6.2	265	651	12.4	4.0	447	558	174	318	425	864	86.4	34.5
8.7	364	941	11.6	4.6	520	637	168	350	417	828	89.5	35.2
9.9	527	1196	17.3	7.4	644	715	206	337	492	970	75.7	36.2
12.0	688	1482	19.2	9.2	713	879	213	336	500	972	81.7	43.7
12.6	736	1550	27.9	18.5	706	901	198	335	527	971	80.6	41.4
						1988						
6.0	312	726	19.8	6.8	523	604	230	341	512	1120	64.1	28.7
8.6	605	1081	20.6	8.3	569	717	213	334	535	1104	67.9	31.3
11.8	591	1464	28.1	14.7	589	938	181	303	589	1131	78.6	38.1
13.6	802	1715	43.6	28.2	642	1031	175	289	653	1139	78.7	36.6
14.0	1167	2015	64.1	44.8	728	1135	187	289	837	1233	85.1	38.2
14.9	1558	2468	107.4	65.5	860	1282	214	333	1069	1349	88.7	38.4

Analysis of variance

Source	df	Mean squares† Cl		Na		Ca		Mg		K		P	
		B	P	B	P	B	P	B	P	B	P	B	P
							1987						
Salinity	5	132.5‡	437.1‡	0.10	0.08‡	44.3‡	66.2‡	1.00	0.34	5.7**	15.1	0.08	0.04
Error	10	3.3	5.0	0.04	0.01	4.3	3.7	0.47	1.08	1.0	6.6	0.04	0.03
							1988						
Salinity	5	611.4‡	1192.4‡	3.45‡	1.62‡	45.9‡	194.9‡	1.43**	1.70	139.3‡	26.9**	0.27‡	0.05‡
Error	10	22.6	24.4	0.13	0.06	3.9	5.9	0.24	0.78	4.9	4.5	0.01	0.00

*,** Significant at the 0.05 and 0.01 levels of probability, respectively.
† Table value must be multiplied by 10^3.
‡ Significant at the 0.005 level of probability.

Table 6. Average mineral composition of woody (W) and bast (B) fibers from stems of 'Everglades-41' kenaf grown for 2 yr at six levels of salinity.

Soil Salinity (κ_e)	Cl		Na		Ca		Mg		K		P	
	W	B	W	B	W	B	W	B	W	B	W	B
dS m^{-1}	mmol kg^{-1} dry wt											
						1987						
5.4	284	545	169	44	62	196	147	287	147	565	10.4	19.4
6.2	421	706	195	43	69	245	167	336	162	555	10.5	16.4
8.7	679	920	317	61	127	282	235	360	165	534	12.0	16.5
9.9	539	1043	235	64	96	316	142	339	165	556	10.2	16.1
12.0	896	1247	451	125	180	416	170	366	216	542	13.4	17.1
12.6	1167	1413	594	185	248	596	201	503	203	393	13.0	18.6
						1988						
6.0	158	353	60	18	77	213	131	296	139	361	8.0	13.1
8.6	469	663	158	32	128	360	188	418	173	406	8.6	14.8
11.8	725	1082	235	47	231	572	248	527	186	375	12.7	18.7
13.6	1152	1474	419	114	351	798	304	526	185	288	15.4	20.3
14.0	1346	1615	476	138	401	976	314	562	188	278	16.5	19.6
14.9	—	—	—	—	—	—	—	—	—	—	—	—

Analysis of variance

Source	df	Mean squares† Cl		Na		Ca		Mg		K		P	
		W	B	W	B	W	B	W	B	W	B	W	B
							1987						
Salinity	5	315.7‡	318.3‡	82.7‡	9.6*	15.6‡	63.2‡	3.7‡	15.9‡	2.1	12.7*	0.00	0.00
Error	10	8.3	18.9	3.2	2.2	0.2	2.4	0.4	1.8	3.5	3.8	0.00	0.00
							1988						
Salinity	4	708.5‡	851.9‡	91.8‡	8.5‡	58.2‡	290.2‡	18.3‡	35.9‡	1.3	9.4	0.04‡	0.03*
Error	8	11.2	8.2	3.9	0.5	0.8	6.4	0.6	2.5	1.3	2.5	0.00	0.00

*,** Significant at the 0.05 and 0.01 levels of probability, respectively.
† Table value must be multiplied by 10^3.
‡ Significant at the 0.005 level of probability.

shorter woody fibers and the longer bast fibers were found to be comparable to the fiber length distribution normally found in hardwood and softwood trees (White et al, 1970), respectively.

The proportion of the woody and bast fiber components of the stem was not significantly affected by salinity (data not presented). The bast fibers accounted for approximately 36% of the stem weight at all salinity treatments. This percentage agrees closely with the bast fiber percentages reported by Muchow (1979) in Australia.

Foliar Injury and Leaf and Fiber Mineral Composition

The first injurious effect of salinity was noted approximately three months after salination was initiated. The injury occurred on the older, mature leaves of both cultivars and the severity was related directly to the salinity treatment. Leaf tips and margins exhibited a slight sporadic necrosis in the 8.7 and 8.6 dS m^{-1} treatments of 1987 and 1988. These salinity levels correspond closely to the 9.2 dS m^{-1} threshold for total plant yield. At higher salinities, the marginal necrosis was much more general, affecting the outer 6 to 8 mm and extending nearly to the base of the leaf.

Mineral composition of leaves sampled in 1987 and 1988 was nearly identical for both cultivars within a salinity treatment with the exception of Na (Tables 4 and 5). Everglades-41 accumulated about twice as much Na in the blades and petioles at all salinity levels as did RS-10. Concentrations, however, were significantly lower than those in the bast and woody fibers of the stem for both cultivars (Tables 6 and 7). Leaf Na concentrations increased with increased soil salinity but were at least an order of magnitude lower than those of Cl which was readily accumulated in all tissues analyzed. Increased soil salinity also significantly increased the concentration of K and Ca in both blades and petioles. Phosphorus, which remained relatively unchanged with increasing salinity in 1987, tended to increase in concentration in 1988. Magnesium showed an inconsistent response to salinity both years.

Sodium and P accumulation were two to three times greater in leaf blades than petioles. In contrast, petioles contained significantly higher concentrations of Ca, Mg, K, and Cl than the blades.

The concentrations of all ions determined in the two fiber components were approximately the same for both cultivars at all treatment levels (Tables 6 and 7). Concentrations of Na, Cl, and Ca increased several fold with increased soil salinity. Although statistically significant effects of salinity were found for Mg, K, and P concentrations in most of the woody tissue samples, none of the changes were considered physiologically important. Sodium was found predominately in the woody fiber tissue, while the concentration of all other ions was highest in the bast tissue.

Table 7. Average mineral composition of woody (W) and bast (B) fibers from stems of '7818-RS-10' kenaf grown for 2 yr at six levels of salinity.

Soil Salinity (κ_e)	Cl		Na		Ca		Mg		K		P	
	W	B	W	B	W	B	W	B	W	B	W	B
dS m^{-1}	mmol kg^{-1} dry wt											
						1987						
5.4	231	497	202	40	53	186	132	287	136	529	11.6	18.6
6.2	392	637	209	34	84	215	171	335	134	484	9.2	16.9
8.7	556	890	305	39	89	252	186	362	159	494	10.7	15.7
9.9	685	1019	319	62	126	309	213	351	145	445	13.9	15.4
12.0	829	1274	427	96	165	400	196	368	152	483	13.4	15.6
12.6	927	1504	565	156	205	515	224	479	101	360	15.9	17.8
						1988						
6.0	173	388	83	19	81	218	159	330	126	435	7.8	14.2
8.6	385	735	148	39	103	299	182	404	138	409	7.6	14.4
11.8	677	1121	250	59	190	527	229	503	176	411	11.5	18.6
13.6	960	1452	390	146	255	720	244	597	141	284	12.5	18.9
14.0	1156	1708	428	123	318	1041	272	610	159	280	15.3	22.4
14.9	—	—	—	—	—	—	—	—	—	—	—	—

Analysis of variance

		Mean squares†											
		Cl		Na		Ca		Mg		K		P	
Source	df	W	B	W	B	W	B	W	B	W	B	W	B
							1987						
Salinity	5	208.7‡	432.8‡	57.6‡	6.7‡	9.6‡	46.7‡	3.2*	12.2*	1.2	10.2*	0.02**	0.01
Error	10	5.4	8.7	4.0	0.2	0.2	2.4	0.5	2.4	0.7	2.6	0.00	0.00
							1988						
Salinity	4	486.9‡	850.3‡	66.7‡	9.1*	30.1‡	332.0‡	6.3**	44.2‡	1.2	17.0*	0.03‡	0.04‡
Error	8	5.4	7.4	2.8	1.5	0.7	4.0	0.8	1.1	1.2	2.9	0.00	0.00

*,** Significant at the 0.05 and 0.01 levels of probability, respectively.
† Table value must be multiplied by 10^3.
‡ Significant at the 0.005 level of probability.

The high concentration of Na found in the woody tissue indicates that Na is apparently sequestered in this tissue, with only a small fraction translocated to the leaves. Bernstein et al. (1956) suggested that Na retention in the woody tissue explained the low levels of Na in leaves of stone-fruit and almond trees. Sodium ion exclusion has been considered a mechanism of salt tolerance in nonhalophytes by some investigators (Greenway and Munns, 1980). Whether this mechanism is responsible for the salt tolerance of kenaf is unknown. Curtis and Läuchli (1985) hypothesized that salt exclusion may be an efficient mechanism for salt resistance only at low salinity levels. Clearly, excessive Cl accumulation, which was accompanied by increased Ca and K uptake, became a problem at high soil salinity levels as evidenced by salt burn on the leaves.

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