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Salinity Effects on Rye Grain Yield, Quality, Vegetative Growth, and Emergence

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ABSTRACT

Although current rye (*Secale cereale* L.) grain production is concentrated mainly in the northern half of the USA and Canada, some rye grain is grown in the arid southwest. Soils in this area are, or have the potential to become, highly saline from the application of saline irrigation water. Since there is nearly a complete lack of information about the response of rye grown under saline conditions, a 2-yr field plot study was conducted. Six salinity treatments were imposed on a Holtville silty clay (clayey over loamy, montmorillonitic [calcareous], hyperthermic Typic Torrifluvent) by irrigating with Colorado River water artificially salinized with NaCl and $CaCl_2$ (1:1 by weight). Electrical conductivities of the irrigation waters were 1.1, 4.0, 8.0, 12.1, 16.0, and 20.1 dS m^{-1} the first year, and 1.1, 3.9, 7.5, 11.6, 15.6, and 19.8 dS m^{-1} the second year. Grain yield and vegetative growth were measured. Relative grain yield of two cultivars, Maton and Bonel, was unaffected up to a soil salinity of 11.4 dS m^{-1} (electrical conductivity of the saturation extract;κ_e). Each unit increase in salinity above 11.4 dS m^{-1} reduced yield by 10.8%. These results place rye in the salt-tolerant category. Yield reduction was attributed primarily to reduced spike weight and individual seed weight rather than spike number. Bread quality decreased slightly with increasing levels of salinity. Straw yield was more sensitive to salinity than was grain yield. Plant emergence was determined in greenhouse sand cultures. Both cultivars were slightly less salt tolerant during plant emergence than during subsequent stages of growth.

Rye is a valuable, though minor, grain crop in the USA. In 1986 (last year of compiled data), 274 000 ha of rye were harvested for grain with an estimated value of $27.4 million, which ranks rye behind all other cereal crops (16).

Rye is considered the most widely adaptable of all cereal crops because of its cold tolerance and adaptation to a wide range of soil conditions (6,13,15). As a result, it is grown in many diverse environments. Although rye grain production is concentrated in the northern USA and Canada, some is grown in Georgia, and about 20 000 ha are grown in Oklahoma and Texas (16). With a possible increase in acreage in these and other arid southwestern states, plantings may be on soils where salinity problems already exist or may develop from the use of saline irrigation water. Since data are not available to predict rye yield or quality response to salinity, this field plot study was initiated.

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MATERIALS AND METHODS

This field plot study was conducted 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 74.3 and 70.7 kg N ha^{-1} for 1985 to 1986 and 1986 to 1987, respectively. Since the soil contained adequate levels of K, no additional K was added.

The two cultivars used in this study, Maton and Bonel, are joint releases from the Oklahoma Agricultural Experiment Station and the Samuel Roberts Noble Foundation, Ardmore, OK (2,14). Both cultivars were planted in level plots on 10 Dec. 1985 and 1 Dec. 1986. Each plot contained 15 rows of each cultivar. The 6-m long rows were seeded 0.18 m apart, with the seed placed approximately 25 mm apart within the row.

The experimental design consisted of six treatments replicated three times in a randomized, 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 κ_e (electrical conductivity of the saturated-soil extract) averaged to a depth of 1.2 m for the six treatments in 1985 were 3.9, 6.8, 10.2, 13.6, 14.6, and 16.5 dS m^{-1}, while in 1986 they were 4.8, 8.8, 11.2, 12.3, 14.9, and 16.0 dS m^{-1}. To facilitate germination each year, 70 mm of low-salinity water (1.1 dS m^{-1}) was applied to each plot prior to seeding to leach salts from the top 0.15 m of soil; another 56 mm was applied after seeding.

Eighteen days after planting, when the plants were approximately 60 mm tall, differential salination was initiated. Irrigation-water salinities of the five saline treatments were increased stepwise in one-third increments over a 2-wk period by adding equal weights of NaCl and $CaCl_2$ until desired salt concentrations were achieved. In 1985 to 1986, the electrical conductivities of the six irrigation waters (κ_{iw}) were 1.1 (control), 4.0, 8.0, 12.1, 16.0, and 20.1 dS m^{-1}, while in 1986

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

Soil sample depth	1985 to 1986 — Irrigation water salinities (κ_{iw})–dS m^{-1}					
	1.1	4.0	8.0	12.1	16.0	20.1
cm	ds m^{-1} (κ_e)					
0–30	2.5 ± 0.3†	4.7 ± 0.3	7.4 ± 0.3	10.0 ± 1.2	11.6 ± 0.5	12.9 ± 0.1
30–60	8.0 ± 0.8	10.5 ± 0.8	12.4 ± 1.4	15.1 ± 1.8	15.0 ± 0.1	17.5 ± 1.1
60–90	7.0 ± 1.1	10.2 ± 1.2	12.9 ± 1.0	15.4 ± 0.9	17.3 ± 0.6	17.3 ± 0.5
Average	5.8 ± 0.5	8.5 ± 0.6	10.9 ± 0.7	13.5 ± 1.0	14.6 ± 0.3	15.9 ± 0.3
	1986 to 1987					
	1.1	3.9	7.5	11.6	15.6	19.8
	ds m^{-1} (κ_e)					
0–30	2.0 ± 0.8	4.6 ± 0.5	7.9 ± 0.3	10.2 ± 0.9	11.9 ± 0.7	14.7 ± 2.3
30–60	6.2 ± 0.1	10.1 ± 0.6	15.4 ± 1.3	16.7 ± 1.3	16.1 ± 0.8	16.7 ± 1.3
60–90	9.0 ± 2.0	11.6 ± 2.0	16.9 ± 2.2	16.7 ± 1.9	17.0 ± 0.7	18.7 ± 3.5
Average	5.8 ± 0.5	8.8 ± 0.7	13.4 ± 1.3	14.5 ± 1.0	15.0 ± 0.4	16.7 ± 2.2

† Means ± SE of three samples.

to 1987 they were 1.1 (control), 3.9, 7.5, 11.6, 15.6, and 19.8 dS m^{-1}. During both growing seasons, all plots were irrigated approximately every 2 to 3 wk to keep the mean matric potential of the control treatment above -85 J kg^{-1} in the 0.15- to 0.3-m zone. A neutron probe and tensiometers were used to monitor soil matric potential and to guide irrigation frequency. The total amounts of irrigation water applied to each plot after planting were 531 mm in 1985 to 1986 and 505 mm in 1986 to 1987. Total rainfall during the two growing seasons was 25 mm in 1985 to 1986 and 7 mm in 1986 to 1987.

Soil samples were collected from each plot approximately 8, 14, and 21 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 ranged from 26.5°C in December 1985 to 34°C in May 1986; monthly mean low temperatures for the same period ranged from 5 to 12°C. During the 1986 to 1987 growing season, the monthly mean high temperatures were 22°C for December 1986 and 33°C for April 1987, with corresponding low temperatures of 4 and 13°C, respectively.

During the 1986 to 1987 growing season, plant growth and development was rated according to the Zadoks-Chang-Konzak (20) stage-of-growth scale.

After spike emergence, the second leaf below the flag leaf was sampled for elemental analysis. The leaves were washed in deionized water, dried at 70°C, and finely ground in a blender. Chloride contents were determined on 0.1 *M* HNO_3 in 1.7 *M* CH_3COOH extracts of the leaf material by the Cotlove (4) coulometric-amperometric titration procedure. Nitric-perchloric acid digests of the ground leaves were analyzed for P by molybdovanadate-yellow colorimetry (10), and Na, Ca, Mg, and K by atomic absorption spectrophotometry.

Plants were harvested on 15 May 1986, the first year, and on 7 May 1987, the second year. To determine grain and straw yield of each cultivar, a 4.6 m^2 area was harvested from the center of each half of each plot. Spikes were harvested by hand, weighed, counted, and threshed. The seed was then cleaned and weighed. Total straw yield from the harvest area was weighed and a subsample dried in a forced-air drier at 70°C to determine water content.

Milling and baking quality of the grain harvested in 1987 was evaluated at the Department of Food Science and Human Nutrition, Colorado State University. A grain sample from each plot was ground with a Quadrumat, Jr. Mill (Brabender Instr., South Hackensack, NJ). Flour extraction was determined from this ground sample. To evaluate baking quality, 100 g of the extracted flour was used to bake a "pup" loaf. Although commercial rye bread is generally produced with sourdough, or a mixture of lactic and citric acids as the levening agent, a baking test with yeast is commonly used for scientific purposes (5). Since there are no statutory grading and quality standards for rye bread in the USA (G.L. Rubenthaler, 1987, personal communication), the baked loaves were evaluated on the basis of the 20-point scoring system developed by the Detmold Institute for Cereals, Flour, and Bread at Detmold, West Germany (1). The bread evaluation factors and maximum point score for each factor used in this system are: shape (2 points), crust (3 points), crumb (grain [5 points], elasticity [3 points], texture [2 points]), and taste (5 points).

Plant emergence of the two cultivars at different salinities was tested in greenhouse sand cultures in Riverside, CA. One hundred seeds of each cultivar were planted in each sand tank on 22 April 1988. Irrigation solutions containing equal weights of NaCl and $CaCl_2$ were surface applied four times each day, with the sand completely saturated with each irrigation. Salinities of the irrigation waters were 0.6 (control), 4.6, 8.1, 11.8, 15.2, and 18.5 dS m^{-1}. Each salinity treatment was replicated three times. Since the washed sand used in this study possessed a very low exchange capacity, the salt concentration in the soil water (κ_{sw}) was essentially the same as the irrigation water (κ_{iw}). Greenhouse air temperatures during the course of the study ranged from 19 to 25°C with a mean temperature of 22°C. Plant counts were made daily over a 7-d period.

RESULTS AND DISCUSSION

Plant Development

When salination began on 19 Dec. 1986, the plants in all treatments had approximately three fully unfolded leaves. This would indicate that the presalinized soil profiles had little effect on seedling growth and development. On 25 Feb. 1987, midway through the growing season, the plants in all treatments averaged five leaves and three tillers per plant. Random height measurements taken 4 wk later showed that plants in the high salt plots (16.7 dS m^{-1}) were about 50% shorter than control plants. With the exception of plant height, salinity had no effect on subsequent

Table 2. Vegetative and grain yield parameters for Maton (M) and Bonel (B) rye grown at six levels of salinity during two crop seasons.

Soil salinity (κ_e)	Straw yield M	Straw yield B	Grain yield M	Grain yield B	No. of spikes M	No. of spikes B	Spike wt. M	Spike wt. B	1000-seed wt. M	1000-seed wt. B
dS m^{-1}	g m^{-2}		g m^{-2}		No. m^{-2}		g		g	
				1985 to 1986						
5.8	1022	1057	255	292	323	357	1.15	1.12	19.8	20.0
8.5	1029	995	265	296	339	397	1.15	1.05	19.0	19.1
10.9	900	889	234	244	364	355	0.99	0.97	17.3	17.7
13.5	707	758	220	194	329	373	0.90	0.83	15.8	15.6
14.6	585	613	133	127	344	339	0.75	0.67	14.0	12.3
15.9	479	511	96	81	308	298	0.62	0.60	11.7	11.6
				1986 to 1987						
5.8	1100	1144	238	208	–	–	–	–	18.5	18.0
8.8	992	889	223	231	–	–	–	–	16.6	17.4
13.4	1164	899	242	204	–	–	–	–	15.3	15.9
14.5	854	932	221	188	–	–	–	–	14.3	14.4
15.0	798	778	172	161	–	–	–	–	12.6	13.0
16.7	632	676	157	142	–	–	–	–	11.6	11.6

Analysis of variance

Source	df	Straw yield‡ M	Straw yield‡ B	Grain yield‡ M	Grain yield‡ B	No. of spikes‡ M	No. of spikes‡ B	Spike wt. M	Spike wt. B	1000-seed wt. M	1000-seed wt. B
		Mean squares									
					1985 to 1986						
Salinity	5	161.30†	139.14†	14.47†	23.38†	1.11	3.32*	0.14†	0.13†	28.58†	37.31†
Linear	1	733.55†	653.31†	53.35†	102.84†	0.92	6.42*	0.61†	0.62†	131.10†	169.40†
Quadratic	1	68.39†	37.49†	14.33†	12.67†	3.75*	6.25*	0.06*	0.03	9.80*	11.50†
Cubic	1	3.75	0.61	0.62	0.00	0.10	0.12	0.00	0.00	1.10	0.00
Error	10	5.14	1.46	1.02	0.88	0.63	0.98	0.01	0.01	1.54	0.67
					1986 to 1987						
Salinity	5	119.42*	74.91*	3.80†	3.21†	–	–	–	–	19.55†	19.00†
Linear	1	288.06**	267.83†	8.66†	10.06†	–	–	–	–	89.80†	81.50†
Quadratic	1	126.12*	0.48	4.35**	5.27†	–	–	–	–	2.60	10.00†
Cubic	1	66.62	81.56*	2.05*	0.09	–	–	–	–	1.80	0.40
Error	10	23.23	14.82	0.37	0.38	–	–	–	–	0.61	0.16

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

morphological development of the plants in terms of number of leaves and tillers, inflorescence emergence, anthesis, or maturity.

Grain Yield

Grain yield of both cultivars was significantly reduced by salinity in both harvest years (Table 2). As in wheat (*Triticum aestivum* L.) (8), this reduction was attributed primarily to a reduction in individual spike and seed weight (expressed as the weight of 1000 seeds) with increasing soil salinity. This is in contrast with triticale (X *Triticosecale* Wittm.), a hybrid of wheat and rye, where yield reduction from salinity was attributed primarily to a reduction in spike number (7). In the current study, spike numbers of Maton and Bonel were not significantly affected by soil salinity until κ_e exceeded 15.9 and 14.6 dS m^{-1}, respectively.

The grain yield data for each cultivar for individual years was statistically analyzed with a piecewise linear response model (11,18). The data indicate that the cultivar tolerance thresholds, i.e., the maximum allowable κ_e without a yield decline, were nearly the same in both years. The Maton thresholds were 12.8 and 12.2 dS m^{-1}, while the Bonel thresholds were 9.7 and 10.9 dS m^{-1} for the 1986 and 1987 harvests, respectively. In contrast with the thresholds, the yield reduction associated with each unit increase in salinity above the thresholds was quite different each year. In 1986, this reduction was 20.8 and 11.1%, while in 1987 it was 6.2 and 5.3% for Maton and Bonel, respectively.

The reason for the differences in slope between the two seasons for both cultivars is not definitely known. However, one explanation may be the significant difference in temperature during main stem apex development. With wheat, apex development is complete 28 to 30 d after seedling emergence (9), and apex differentiation in rye has been reported to follow the same pattern as wheat (3). Mean daily temperatures during this 30-d period in the current study were 24.5°C in 1985 to 1986 and 21.5°C in 1986 to 1987. Other studies with wheat have shown that high temperatures (19), osmotic stress (9), and salt stress (12) during this growth stage can significantly reduce grain yield. Although the yields of the control treatments were actually higher in the first season, the greater reductions in yield with increased soil salinity may have resulted from the combination of the higher temperatures and salt stress. It is well known that plants are more tolerant to salinity when grown under cool than hot climatic conditions (11). Because of the sensitivity of wheat (and presumably rye) to environmental stress during apex development, this interactive effect may be even more significant during this critical developmental period.

The combined data for both cultivars for both years indicate an average threshold of 11.4 dS m^{-1} and a grain yield reduction of 10.8% for each κ_e unit above that threshold (Fig. 1). Relative yield, Y_r, for any κ_e exceeding the threshold of 11.4 dS m^{-1} can be calculated with the equation presented in the figure.

Table 3. Milling and baking quality data for Maton and Bonel rye grown at six levels of salinity during 1986 to 1987.

Soil salinity (κ_e)	Flour extraction	Loaf volume	Baking‡ quality score
dS m^{-1}	g kg^{-1}	cm^3 g^{-1}	(points)
	Maton		
5.8	720	1.94	18.2
8.8	774	1.95	18.1
13.4	776	1.93	17.6
14.5	825	1.94	17.3
15.0	799	1.98	17.5
16.7	766	1.97	16.5
	Bonel		
5.8	799	1.99	18.2
8.8	771	2.02	18.4
13.4	757	2.11	18.6
14.5	762	2.08	17.6
15.0	813	2.11	17.6
16.7	762	2.13	17.9

Analysis of variance

Source	df	Flour§ extraction (Mean squares)	Loaf¶ volume (Mean squares)	Baking quality score (Mean squares)
		Maton		
Salinity	5	3.67*	1.08	1.16†
Linear	1	8.37**	1.00	4.45†
Quadratic	1	5.29*	1.00	0.99†
Cubic	1	0.22	1.00	0.16
Error	10	0.82	2.20	0.04
		Bonel		
Salinity	5	1.59	8.93*	0.53†
Linear	1	0.70	42.00†	0.76†
Quadratic	1	0.61	0.00	0.25
Cubic	1	0.85	0.00	0.11
Error	10	0.92	2.44	0.05

*,**,† Significant at the 0.05, 0.01, and 0.005 levels of probability, respectively.
‡ Score determined from loaf shape, crust, grain, elasticity, texture, and taste. Quality: Excellent = 19–20 points, good = 17–18 points, satisfactory = 16 points, unsatisfactory = <16 points.
§ Values must be multiplied by 10^3.
¶ Values must be multiplied by 10^{-3}.

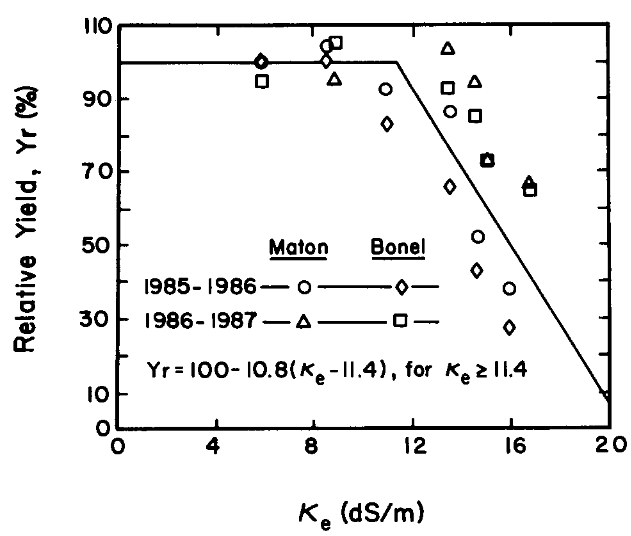

Fig. 1. Relative grain yield of two rye cultivars as a function of increasing soil salinity.

According to the Maas and Hoffman (11) salt tolerance classification system, rye would be classified as tolerant to salinity. This places rye in the same tolerance category as most other cereal crops (7, 8, 11). Although rye has a higher tolerance threshold at 11.4 dS m^{-1} than either wheat (8.6 dS m^{-1}) (8), triticale (7.3 dS m^{-1}) (7), or barley (*Hordeum vulgare* L.) (8.0 dS m^{-1}) (11), the rate of yield decline above the threshold is much greater for rye.

Grain Quality

Evaluation of the milling quality of the harvested grain showed average flour extractions that ranged from 720 to 825 g kg^{-1} for Maton and from 757 to 813 g kg^{-1} for Bonel (Table 3). These values are within the extraction range used in German rye breads (5). Although the flour extraction value for the Maton control (5.8 dS m^{-1}) is significantly lower than for all other treatments, there does not appear to be a trend in flour extraction due to treatment. What extraction differences there are among salinity treatments are attrib-

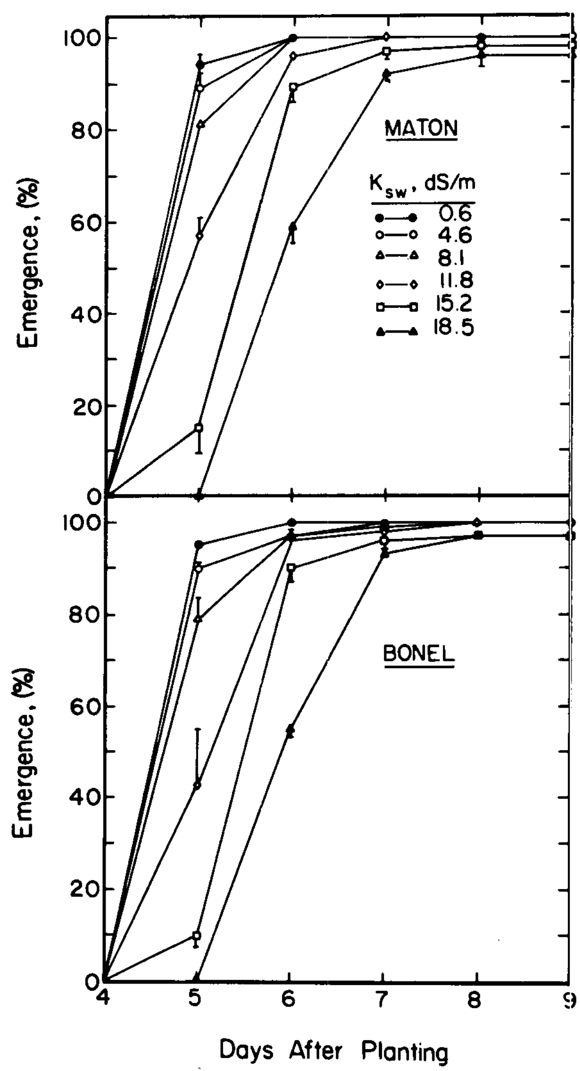

Fig. 2. Emergence of two rye cultivars at six salinity levels. Standard error of means indicated by bar when greater than symbol size.

uted to normal differences in size distribution and moisture content of the grain.

Maton grain, harvested from the 14.5, 15.0, and 16.7 dS m^{-1} treatments, produced flours that were slower to hydrate during mixing than flours from the three lower salinities. Dough made from the 16.7 dS m^{-1} flour was less cohesive after fermentation than were the other treatment flours. Although Maton showed no differences in bread volume among salinity treatments, overall bread quality decreased with higher treatment levels. Loaves baked from flours of the 16.7 dS m^{-1} treatment were not as well rounded, had a more open grain, a slightly less elastic crumb, and a slightly firmer texture. Salinity treatments did not affect taste characteristics of the breads. None of the Maton breads received a total baking quality score lower than 16 points (satisfactory).

In contrast with Maton, the Bonel flours showed no noticeable differences in rate of flour hydration during dough mixing or in dough condition after fermentation. In addition, loaf volumes using Bonel flours were slightly higher than those of Maton loaves. This increased loaf volume appeared to be associated with an increase in soil salinity. Compared with the control, the 14.5, 15.0, and 16.7 dS m^{-1} salinity treatments slightly decreased the average baking quality scores. Breads made from flours from these three salinity treatments had a slightly less elastic crumb and a slightly drier, firmer texture. However, all Bonel breads were rated 17 or higher (good) for baking quality.

Straw Yield

Reduction in straw yield, associated with increasing levels of salinity, was nearly identical for the two cultivars in each growing season (Table 2). However, between growing seasons, the effects of salinity on straw yield were quite different, with combined cultivar thresholds of 8.8 dS m^{-1} in 1985 to 1986 and 6.3 dS m^{-1} in 1986 to 1987. The reduction for each unit increase in salinity above these thresholds was less than that for grain yield at 7.0% in 1985 to 1986 and 2.8% in 1986 to 1987. The combined data for both cultivars for both years indicate an average threshold of 7.6 dS m^{-1} and a straw yield reduction of 4.9% for each κ_e unit increase above that threshold. These values indicate that rye is in agreement with wheat (8) and triticale (7), where straw yields were more sensitive to salinity than were grain yields.

Mineral Analysis

Mineral composition of the second leaf below the flag leaf was similar for both cultivars during both crop seasons (Table 4). Sodium and Cl concentrations in the leaf increased only moderately with increased levels of soil salinity. Calcium increased slightly in 1985 to 1986, but decreased slightly in 1986 to 1987. Po-

Table 4. Mineral composition of leaves from Maton (M) and Bonel (B) rye grown at six levels of salinity during two crop seasons.

Soil salinity (κ_e)	Cl		Na		Ca		Mg		K		P	
	M	B	M	B	M	B	M	B	M	B	M	B
dS m^{-1}	mmol kg^{-1} dry wt.											
	1985 to 1986											
5.8	737	696	3.00	3.57	184	169	100	95	807	767	76.7	79.4
8.5	729	751	3.03	3.13	187	182	92	92	818	798	77.9	71.9
10.9	771	738	3.62	4.39	189	194	74	76	828	791	70.8	71.8
13.5	770	741	6.18	6.49	200	195	74	71	818	790	70.2	73.4
14.6	824	825	7.60	8.85	226	209	63	63	843	810	71.6	72.2
15.9	816	843	9.17	10.34	204	207	58	62	864	819	72.0	73.9
	1986 to 1987											
5.8	703	776	7.01	6.47	285	290	141	152	650	662	69.4	69.1
8.8	755	816	5.89	4.11	276	278	121	131	678	655	65.5	68.3
13.4	862	840	12.21	8.46	263	255	100	103	768	761	66.9	64.2
14.5	961	950	26.07	16.10	269	291	93	98	807	779	64.6	62.9
15.0	936	982	22.73	18.60	257	262	78	82	838	849	61.8	62.8
16.7	1016	971	27.30	40.93	244	213	70	61	947	911	64.0	58.6

Analysis of variance

Source	df	Cl†		Na		Ca‡		Mg‡		K‡		P	
		Mean squares											
		M	B	M	B	M	B	M	B	M	B	M	B
		1985 to 1986											
Salinity	5	4.61*	9.59*	20.50**	26.30†	0.74*	0.70*	0.81†	0.59†	1.28	0.99	32.07*	25.05**
Linear	1	18.56**	34.92†	87.82†	109.82†	2.28†	3.29†	3.82†	2.82†	4.43	3.46	95.66**	36.76*
Quadratic	1	1.16	2.55	14.32	20.46†	0.04	0.03	0.00	0.00	0.52	0.00	10.23	69.09†
Cubic	1	0.29	5.12	0.01	0.04	0.28	0.01	0.00	0.05	0.92	1.12	29.77	13.16
Error	10	1.09	1.89	3.50	1.34	0.14	0.15	0.07	0.02	1.51	1.55	9.41	4.10
		1986 to 1987											
Salinity	5	44.92†	23.69†	280.32	550.35†	0.62	2.54**	2.11†	3.25†	35.69†	30.67†	20.38*	45.54*
Linear	1	214.25†	97.23†	1106.67**	1551.43†	2.59*	5.50†	10.20†	15.42†	157.68†	130.60†	61.77**	206.91†
Quadratic	1	4.83	2.98	117.76	1034.91†	0.16	1.84	0.08	0.45*	18.58**	19.40†	1.29	18.45
Cubic	1	0.03	0.16	24.06	106.30	0.12	2.18	0.06	0.21	2.13	0.00	3.64	0.75
Error	10	1.91	1.67	102.03	50.84	0.31	0.39	0.03	0.07	1.70	1.36	5.57	12.20

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

‡ Table values must be multiplied by 10^3.

tassium, which was not a treatment variable, also increased somewhat with increased salinity. Compared with K, Na was largely excluded from the leaves, although Na concentrations did increase as much as six fold in Bonel in the second year. In terms of this exclusion trait, rye behaves more like bread wheat and triticale than durum wheat (7,8). Chloride levels in rye were higher than those in wheat (8) and triticale (7), and tended to increase with increased soil salinity. Leaf Mg concentrations decreased appreciably in both cultivars in both years as a linear function of soil salinity; whereas that of P decreased only slightly.

Seedling Emergence

The effect of increasing salinity levels on seedling emergence was essentially the same for both cultivars (Fig. 2). Soil water salinity up to 8.1 dS m^{-1} had no significant effect on emergence; however, emergence was delayed by salt levels > 8.1 dS m^{-1}, but in no case was the final emergence percentage significantly reduced.

If the soluble salt concentrations of the saturated-soil extract is assumed to be half that of the soil solution (17) (i.e., $\kappa_{sw} = 2\,\kappa_e$), κ_e for the highest soil water salinity tested (κ_{sw} = 18.5 dS m^{-1}) would be equivalent to 9.25 dS m^{-1}. The data in Fig. 1 indicate no loss of grain yield up to κ_e of 11.4 dS m^{-1}. Therefore, these data indicate that, at the emergence stage of growth, rye is slightly less tolerant to salinity than during subsequent stages of growth.

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