Reprinted **from** *Agronomy Journal*
Vol. *86. No. 2*

1280

Growth, Seed Yield, and Oil Content of Canola Grown under Saline Conditions

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ABSTRACT

Due to health concerns regarding saturated fat in the human diet, canola (Brassica spp.) is becoming an increasingly important source of edible vegetable oil because of its low saturated fat content. This increased demand, and the need for crop diversification, will undoubtedly promote increased acreage of canola in the western USA, where some soils are or have the potential to become saline. Salt tolerance in two canola species (B. napus L. cv. Westar and B. campestris L. cv. Tobin) was determined in a 2-yr field plot study. Six salinity treatments were imposed on a Holtville silty clay (clayey over loamy, montmorillonitic [calcareous], hyperthennic Typic Torrifluvent) by irrigating with waters salinized with NaCl and $CaCl_2$ (1:l w/w). Electrical conductivities of the irrigation waters ranged from 1.2 to 9.7 dS m^{-1} the first year, and 1.2 to ll.5 dS m^{-1} the second year. Seed yield, vegetative growth, oil content, and protein content in the oil-free seed meal were measured. Relative seed yields of Westar and Tobin were unaffected by soil salinity up to 11.0 and 9.7 dS m^{-1} (electrical conductivity of the saturated soil extract: EC.), respectively. Each unit increase in salinity above the thresholds reduced the seed yield of Westar by l3.0% and Tobin by 14.3%. These results place both canola species in the salt-tolerant category. Increased salinity did not significantly affect the oil or protein content of the oil-free seed meal. Vegetative growth of both species was unaffected by soil salinity up to 10.0 dS m^{-1} and the growth decline above this threshold was ll.2% per unit increase in salinity.

ALTHOUGH RAPESEED (*Brassica napus* L.) WaS Originally grown as a forage crop in the Pacific northwestern USA in the early 1900s (Karow, 1986), it was not until the mid-1950s that it was grown for the oil bearing seed. The oil contains high levels of erucic acid, a 22-carbon-chain fatty acid that is used in a variety of polymer and lubricant products. More than 4.5 million kg of the oil are used annually in the USA, a large part of which is imported (Auld and Mahler, 1987).

Because of health concerns with the high erucic acid content (Downey, 1976; Thomas, 1986), only small quantities of the oil were utilized as an edible oil in the 1950s. These concerns prompted an intensive breeding program by Canadian scientists, where rapeseed had become a major crop, to develop cultivars with low erucic acid content. By 1974, the conversion to low erucic acid cultivars in Canada was essentially complete. Canola oil is now the world's third largest source of edible oil following soybean [(Glycine max (L.) Merr.] and palm [Elaeis *oleifera* (HBK) Cortes] oil (Nowlin, 1991).

In an effort to develop the low erucic acid cultivars, the Canadian plant breeders also attempted to **lower the** glucosinolate content of the oil-free seed meal. The meal is an excellent source of protein with a favorable balance of amino acids; however, the glucosinolates, which can cause nutritional problems, limit the use of the seed meal as a supplemental animal feed (Thomas, 1986).

This intensive breeding program resulted in Canada becoming the first country to produce rapeseed cultivars with low erucic acid in the oil and low glucosinolates in the meal. To differentiate between these ***double-low*** cultivars and other rapeseed cultivars, the double-lows were called canola. The name Canola was at first a trademark registered with the Canola Council of Canada (Thomas, 1986), but has since been released to the public domain. To be classified as canola, cultivars must have <20 g kg-' erucic acid in the oil and <30 μmol of aliphatic glucosinolates g^{-1} in the defatted meal (Campbell, 1986).

The increasing awareness of the health advantages of canola oil, which contains <70 g kg-' saturated fat, will undoubtedly result in an increasing demand for this product. This demand, as well as the search for alternative crops by growers, may result in plantings on soils where salinity problems already exist or may develop from the use of saline irrigation water. Although a few preliminary studies on the salt tolerance of rapeseed have been conducted in small pot cultures (Ashraf and McNeilly, 1990; Munshi et al., 1986), salt tolerance data are not available to predict canola yield responses in the field. Therefore, this field plot study was initiated to determine the effect of soil salinity on vegetative growth, seed yield, and oil content of the seed.

MATERIALS AND METHODS

This study was conducted at the Irrigated Desert Research Station, Brawley, CA, on a Holtville silty clay soil. The crops were grown in 6.0- by 6.0-m plots that were enclosed by acrylic-fortified fiberglass borders extending 0.75 m into the soil. The top of the fiberglass borders protruded 0.15 m above the soil level of the plot and was 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 super-phosphate was mixed into the top 0.25 m of soil at the rate of 73 kg P ha-'. 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. Because the soil contained adequate levels of K, no additional K was added.

The two canola cultivars used **in this study, Westar and Tobin, were developed at the Agriculture Canada Research Station, Saskatoon, Saskatchewan. Both cultivars were planted in level plots** on 1 Nov. 1988 and 3 Nov. 1989. Each plot contained 17 rows of each cultivar. **The rows were planted 0.15 m apart with the seed placed ≈ 25 mm apart within the row. After emergence, the plants were thinned to 0.15 m 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 the **time of planting,** the soil profiles were still salinized from a previous experiment. To assure good germination, **75 mm of nonsaline water (1.2 dS**

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Published in Agron. J. 86:233-237 (1994).

Abbreviations: EC., electrical conductivity of the saturated soil extract;

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

Soil sample depth	1988-1989 EC,. by irrigation water salinity (EC_{iw}, dS m^{-1})					
	1.2	2.1	3.9	6.0	1.9	9.7
m	dS m^{-1}					
o-o.3	4.0 ± 0.6†	4.7 ± 0.4	7.0 ± 0.4	8.1 ± 0.6	9.1 ± 0.5	11.2 ± 0.7
0.3-0.6	5.6 ± 1.1	7.2 ± 0.6	9.9 ± 0.4	11.2 ± 0.7	12.4 ± 0.1	13.6 ± 0.5
0.6-0.9	4.8 ± 1.4	10.3 ± 1.7	11.8 ± 1.5	11.8 ± 1.7	15.7 ± 1.5	15.4 ± 2.0
Average	4.8 ± 1.0	7.4 ± 0.9	9.6 ± 0.8	10.4 ± 1.0	12.4 ± 0.5	13.4 ± 0.7
	1989-1990 EC,, by irrigation water salinity (EC_{iw}, dS m^{-1})					
	1.2	2.0	3.1	5.8	9.0	11.5
	dS m^{-1}					
o-o.3	4.1 ± 0.8	5.3 ± 0.5	9.0 ± 0.7	10.5 ± 0.5	11.2 ± 0.4	13.6 ± 0.2
0.3-0.6	6.7 ± 1.2	10.5 ± 0.4	12.9 ± 0.8	14.9 ± 1.4	16.0 ± 0.5	18.3 ± 0.3
0.6-0.9	7.0 ± 1.3	9.9 ± 1.4	12.4 ± 0.9	12.4 ± 0.8	16.6 ± 0.4	17.1 ± 0.1
Average	5.9 ± 1.1	8.6 ± 0.4	11.4 ± 0.5	12.6 ± 0.6	14.6 ± 0.4	16.3 ± 0.1

† Means ± SE of 6 samples.

m^{-1}) was applied to each plot prior to planting to leach salts from the top 0.15 m of soil; another 50 mm nonsaline irrigation was applied after planting.

About 3 wk after planting, when the plants were at the four leaf stage of development, differential salination was initiated. Irrigation water salinities were increased in two increments over a 10-d period by adding equal weights of NaCl and $CaCl_2$ until desired salt concentrations were achieved. In 1988-1989, the electrical conductivities of the six irrigation waters (EC_{iw}) were 1.2 (control) 2.1, 3.9, 6.0, 7.9, and 9.7 dS m^{-1}, while in 1989-1990 they were 1.2, 2.0, 3.1, 5.8, 9.0, and 11.5 dS m^{-1}. During both growing seasons, all plots were irrigated about every 2 to 3 wk to keep the soil matric potential of the control treatments above -85 J kg^{-1} in the 0.15 to 0.3-m zone. The total amounts of irrigation water applied after planting were 443 mm in 1988-1989 and 451 mm in 1989-1990. Total rainfall during the two growing seasons was 22 mm in 1988-1989 and 7 mm in l989- 1990.

Soil samples were collected from each plot about I2 and 22 wk after planting. Two soil cores per plot were taken in 0.3-m increments to a depth of 0.9 m. The average EC, for each of the three depths for both years is presented in Table 1.

The monthly mean high temperatures for both growing seasons ranged from 21 °C in January to 29°C in March; corresponding low temperatures ranged from 3 to 10°C. During flowering, which occurred from about 10 January to 1 March both years, the mean high and low temperatures were 21 and 4°C, respectively.

Mature, fully expanded leaves were sampled for mineral analysis at the beginning of flowering in both years. Samples were collected about the middle of January for Tobin and the beginning of February for Westar. The leaves were washed with deionized water, dried at 70°C. and finely ground in a blender. Chloride contents were determined in 0.1 *M* nitric acid in 1.7 *M* acetic acid extracts of the leaf material by the Cotlove (1963) coulometric-amperometric titration procedure. Nitric-perchloric acid digests of the ground leaves were analyzed for P by molybdovanadate-yellow colorimetry (Kitson and Mellon, 1944), and Na, Ca, Mg, and K by atomic absorption spectrophotometry.

Plant harvest began on 29 Mar. 1989 and 28 Mar. 1990. Because of differences in maturity between species and salinity treatments, the harvest extended over a 10-d period both years, To determine seed yield and vegetative growth of each cultivar, a 2.3-m^2 area was harvested from the center of each half of each plot. Seed pods were harvested by hand, weighed, and threshed. The seed was then cleaned and weighed. After pod removal, the remaining vegetative growth from the harvest area was dried in a forced-air drier at 70°C and weighed.

Seed analysis for oil and protein was conducted at the Agriculture Canada Research Station, Saskatoon, Saskatchewan. Oil contents were determined on samples of whole seed with a Newport Mark IIIA NMR Spectrometer' (Newport Instr., Oxford, England). Nitrogen analysis of the oil free seed meal was determined with a LECO FP-428 Nitrogen Analyzer (LECO Corp., St. Joseph, MI). Protein content was calculated by multiplying the N content by 6.25 (Padmore, 1990) and expressed as grams protein per kilogram dry weight.

RESULTS AND DISCUSSION

When salination began, the plants of both species in all treatments were about the same height and had the same number of expanded leaves. This would indicate the presalinized soil profiles had little effect on early seedling growth and development. However, random height measurements taken midway through the growing season showed that plants grown on the high salt treatments were between 40 to 50% shorter than control plants. The only other observable effect on morphological development from increased salinity was a 6 to 7 d delay in flowering between the control and high salt plants. This difference in flowering among treatments was considerably less than that observed between species. While Tobin began flowering about 10 January, the first flowers on Westar were not visible until nearly 4 wk later, at which time Tobin was nearly finished. Although these morphological differences between species were apparent at flowering, both species reached maturity within about 10 d of each other.

Seed yields of both cultivars at all salinity levels were significantly lower in 1989 than in 1990 (Table 2). The low yields were assumed to be the result of irrigation timing in relation to flowering, since water availability at peak flowering is reported to be the most critical factor affecting seed yield of rapeseed (Stoker and Carter, 1984; Wright et al., 1988). In 1989, irrigations were applied prior to flowering and not again until after peak flowering had oc-

[1] Reference to specific products is made for identification purposes only and does not imply endorsement by the U.S. government.

Table 2. Average seed **yield and vegetative growth of two canola cultivars grown at six soil salinity levels (EC_e) in two years.**

soil salinity		Seed yield	Vegetative dry matter	Total shoot dry wt.	Seed yield	Vegetative dry matter	Total shoot dry wt.
dS m^{-1}		g m^{-2}					
		Westar, 1989			Tobin, 1989		
4.8		87	633	720	56	533	589
1.4		125	618	743	61	469	531
9.6		123	575	699	64	486	550
10.4		114	570	684	33	410	456
12.4		121	557	678	23	261 284	283 318
13.4		72	423	495			
		Westar 1990			Tobin 1990		
5.9		179	727	906			865
a.6		202	725	927	148	688	856
11.4		154	583	737	156	641	1%
12.6		163	505	668	108	563	671
14.6		90	262	352	30	323	353
16.3		60	208	268	22	244	266
source	df	Analysis of variance, mean squares‡					
		Westar, 1989			Tobin, 1989		
Treatment	5	1.47†	16.59	23.01*	0.82†	37.45†	47.52†
Linear	1	0.06			2.54†	158.80†	193.83†
Quadratic	1	5.45†	58.74* 10.43	55.12* 34.89*	1.30†	16.80	29.76
Cubic	1	0.09	4.31	4.86	0.00	0.71	0.46
Error	10	0.13	6.50	5.88	0.12	5.29	6.35
		Westar, 1990			Tobin, 1990		
Treatment	5	9.05†	150.48†	230.98†	12.31†	119.72†	206.68†
Linear	1	34.32†	673.49†	1011.89†	43.25†	504.89†	843.68†
Quadratic	1	8.53†	54.38†	105.98†	12.65**	74.01†	147.84†
Cubic	1	0.50	13.88	19.63	2.78	0.62	6.04
Error	10	0.24	3.48	4.85	1.00	5.31	5.61

●,**,† Significant at the 0.05, 0.01, and 0.005 levels of probability, respectively.
‡ To obtain actual values. multiply reported values by 10^3.

curred for both species. In contrast, the higher yields obtained in 1990 at the low salinity treatments, when irrigations were applied during flowering, were comparable to canola seed yields reported in Canada (Klassen et al., 1987; Nuttall et al., 1992).

Yield differences between the two cultivars at the low salinity treatments were not unexpected. Tobin yields are generally reported to be 10 to 15% less than Westar, when grown under nonsaline, irrigated conditions (Kephart et al., 1988). However, under the saline conditions in our study, the seed yield differences of the two cultivars were consistently greater at the high salinity levels than at the low salinity levels. For example, in 1994 Tobin seed yield was 63% less than Westar at a soil salinity of 16.3 dS m^{-1}. while the seed yield difference was only 20% at 5.9 dS m^{-1}. This response to salinity is quite different than the response of these two cultivars to moisture stress. Tobin, which is reported to possess better drought tolerance than Westar, produces seed yields equal to Westar when both cultivars are subjected to moisture stress (Kephart et al., 1988)

Seed yield of both species was significantly reduced by salinity in both harvest years (Table 2). This yield reduction was attributed primarily to a reduction in total seed number, since seed index (wt of 100 seeds) was not significantly affected (data not presented). Mean seed index for Westar and Tobin was 308 and 170 mg, respectively.

It has been reported that the seed pod hulls of rapeseed grow and compete strongly with developing seeds for assimilates. When environmental stresses are severe enough competition for assimilates can become intense, resulting in seed loss due to pod abortion (Wright et al., 1988). Therefore, the reduction in seed number as salinity levels increased, is believed to be the result of decreasing assimilate production associated with decreased plant size.

The combined seed yield data for the 2 yr was statistically analyzed with a piecewise linear response model (Maas and Hoffman, 1977; van Genuchten and Hoffman, 1984). The data indicate that the tolerance thresholds (i.e., the maximum allowable EC, without a decline in seed yield) were 11.0 and 9.7 dS m^{-1} for Westar and Tobin, respectively (Fig. 1). Each unit increase in salinity above the threshold reduced the yield of Westar 13.0% and Tobin 14.3%. Relative yield, Y_r, for any EC, exceeding the thresholds of the two species can be calculated with the equations presented in Fig. 1.

According to the Maas and Hoffman (1977) salt tolerance classification system, both canola species would be classified as tolerant to salinity. This places both canola species in the highest salt tolerance category. Although both species exhibit high salinity thresholds, the rate of yield decline above the thresholds is much greater than most other crops in the tolerant category (Maas. 1990).

Unlike seed yield, oil content was not significantly affected over the salinity range tested (data not presented). The mean oil content for Westar and Tobin was 400 and 376 g kg-', respectively. The long-term mean oil content for these two cultivars in Canada is 430 g kg-' for Westar and 416 g kg-' for Tobin (J. Capcara, personal communication, 1993). The differences in our oil content data

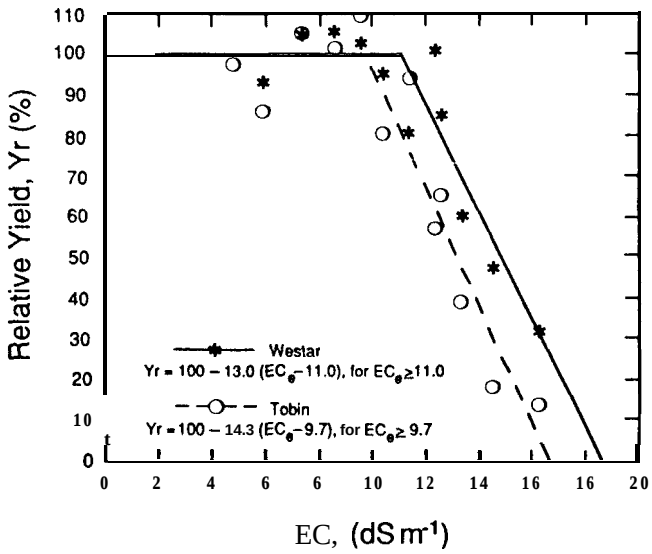

Fig. 1. Relative seed yield of two canola cultivars as a function of increasing soil salinity.

and that obtained in Canada is attributed to differences in climatic conditions between the two locations. Shafii et al. (1992) reported that winter rapeseed cultivars grown in the Pacific northwest contain significantly higher oil content than when the same cultivars are grown in the Southeastern USA. Other oil seed crops such as flax *(Linum usitatissimum* L.) and safflower *(Carthamus tinctorius* L.) have also been reported to produce rather wide differences in oil content caused by variable climatic conditions during seed formation (Painter et al., 1944; Sims et al., 1961).

Protein content of the oil-free seed meal was unaffected by increasing salinity levels. Westar meal averaged 441 g kg-' protein, while Tobin averaged 372 g kg-' protein. These protein levels are comparable to the protein levels found in the more common animal feed supplements, such as soybean oil meal (410-450 g kg-'), peanut *(Arachis hypogaea* L.) oil meal (450 g kg-'), linseed oil meal (370 g kg-'), and cottonseed *(Gossypium hirsutum* L.) meal (410 g kg-') (Morrison, 1956).

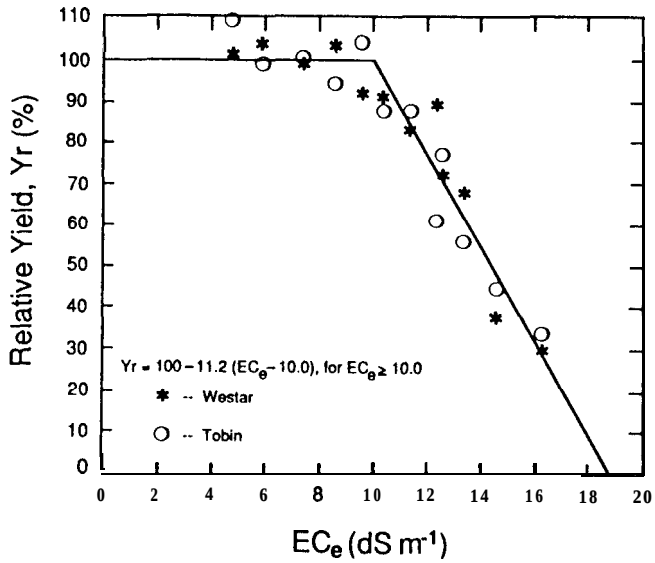

Fig. 2. Relative vegetative growth of two canola cultivars as a function of increasing soil salinity.

Table 3. Mineral composition of leaves from Westar canola grown at six levels of soil salinity (EC_e) during two crop seasons.

Soil salinity		Cl	Na	Ca	Mg	K	P
dS m^{-1}		mmol kg^{-1} dry wt.					
				1989			
4.8		1100	710	636	180	1335	98
7.4		1570	888	594	171	1326	93
9.6		1655	866	634	166	1243	97
10.4		1753	853	671	146	1225	100
12.4		1848	865	696	143	1244	99
13.4		1880	917	663	133	1224	104
				1990			
5.9		1143	647	709	178	1006	82
8.4		1441	746	714	187	933	87
11.4		1869	869	678	177	1123	83
12.6		1964	822	687	150	990	89
14.6		2141	881	718	151	1013	91
16.3		2101	971	757	159	931	88
Source	df	Analysis of variance, mean squares‡					
				1989			
Salinity	5	245.98†	15.56†	3.75	1.00**	7.67	0.04
Linear	1	1109.21†	46.46†	8.70*	4.59†	30.22	0.08
Quadratic	1	92.39†	10.65*	1.17	0.08	1.38	0.06
Cubic	1	17.06	20.67**	8.28*	0.01	3.13	0.01
Error	10	4.46	1.62	1.55	0.15	13.74	0.15
				1990			
Salinity	5	476.68†	38.40*	2.32	0.74**	14.83	0.04
Linear	1	2231.27†	177.81†	2.00	2.08†	0.96	0.10
Quadratic	1	109.03	0.58	7.02	0.00	15.47	0.01
Cubic	1	39.08	4.33	1.78	1.16*	16.42	0.00
Error	10	22.67	9.18	1.97	0.12	10.36	0.06

*, **, † Significant at the 0.05, 0.01, and 0.005 levels of probability, respectively.
‡ To obtain actual values, multiply reported values by 10^3.

Westar generally produced more vegetative growth at each salinity level than did Tobin. The combined data normalized for 2 yr, however, indicated that both cultivars had the same threshold and relative growth decline. Therefore, the vegetative growth data for both cultivars for both years was combined and statistically analyzed, using the same piecewise linear response model as was used to analyze seed yield. The combined data indicate an average threshold of 10.0 dS m^{-1} and a decline in vegetative growth of 11.2% per unit increase in salinity above the threshold (Fig. 2). These data suggest that the vegetative response to salinity was about the same as was determined for seed yield for both canola species.

Mineral composition of leaves sampled both years was nearly identical for both cultivars (Table 3 and 4). Increased soil salinity caused a significant increase in leaf Cl and a significant decrease in Mg. The high level of Na accumulation found in the leaves of both cultivars at all treatment levels would indicate that, like other Cruciferae (Francois, 1984; Francois and Kleiman, 1990), both canola species tend to be Na accumulators.

Since leaf K showed little change with increasing substrate salinity, the uptake antagonism between Na and K, reported by He and Cramer (1992), was not apparent in this study. Calcium, one of the treatment ions, showed only a slight increase in concentration with increased sa-

Table 4. **Mineral composition of leaves from Tobin canola grown** at six levels **of soil salinity** (EC,) **during two crop seasons.**

Soil salinity		Cl	Na	Ca	Mg	K	P
dS m^{-1}		mmol kg-' dry wt.					
				1989			
4.8		1321	949	618	131	1442	113
7.4		1627	918	548	133	1314	137
9.6		1898	994	577	116	1335	131
10.4		1908	860	586	105	1353	139
12.4		2048	944	656	102	1250	140
13.4		2152	934	674	105	1277	130
				1990			
5.9		1196	852	728	147	856	99
8.6		1560	778	811	163	846	112
11.4		1769	889	684	117	1082	115
12.6		2037	944	699	113	1193	112
14.6		2212	1006	774	123	1214	111
16.3		2277	908	756	119	1046	120
Source	df	Analysis of variance, mean squares‡					
				1989			
Salinity	5	276.83†	5.80	7.08'	0.56†	13.53	0.31*
Linear	1	1352.77†	0.25	12.02*	2.30†	48.75*	0.60.
Quadratic	1	22.28	0.65	21.53†	0.00	1.09	0.60*
Cubic	1	0.43	0.04	1.60	0.47*	5.95	0.02
Error	10	19.22	10.71	1.56	0.06	7.09	0.09
				1990			
Salinity	5	548.45†	18.35	6.82	1.18†	76.21'	0.14
Linear	1	2657.73†	44.27	0.00	3.20†	220.34**	0.44*
Quadratic	1	17.32	0.06	2.20	0.16	47.17	0.04
Cubic	1	12.79	46.35	9.32	1.30†	113.09	0.17
Error	10	45.47	11.81	2.12	0.07	17.76	0.08

● ,**,t Significant at the 0.05.0.01, and 0.005 levels of probability, respectively.
‡ To obtain actual values, multiply reported values by 10^3.

linity. Leaf P tended to be slightly higher in 1989 than in 1990 for both cultivars.

The results of this study indicate that both canola species tested are tolerant to soil salinity. Therefore, they can be grown successfully on soils that would generally be considered too saline for most crops (Maas and Hoffman, 1977). The oil content of the seed, for which the crop is grown, is not significantly affected by salinity.

ACKNOWLEDGMENTS

I **express appreciation to John Capcara, Agriculture Canada Research Station, Saskatoon, SK, for** oil and protein analyses of the seed, and Donald L. Layfield for leaf mineral analyses.

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