CROP TOLERANCE TO SALINE SOIL CONDITIONS IN NORTH EAST SASKATCHEWAN

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Introduction

Saline soils are widespread in Saskatchewan and each year severely affect crop productivity on many farms. The problem salts are mainly sodium calcium and magnesium sulfates. These salts are thought to affect crop growth by increasing the "osmotic pressure" of the soil solution and upsetting the soil nutrient balance.

This study was initiated to investigate the salt tolerance of several annual crops when grown on saline soils that occur north of the Quill Lakes in the northeastern corner of the agricultural area of Saskatchewan. In this study particular emphasis was placed on the performance of winter wheat and rye. Because these two winter cereals make much of their growth in the late fall and early spring, when the added stresses of moisture and high temperature are usually minimal, it was hypothesized that they should perform better than spring sown crops on saline soils.

Materials and Methods

In 1974-75 and 1976-77 trials were grown on a salinity gradient on the NE quarter of section 36-35-15 W2 (Municipality no. 337). This land is located in the transition area between the Yorkton and Whitewood soil associations.

Cultivars utilized in the study were: a) fall sown - 'Cougar' rye and 'Sundance' wheat; b) spring sown - 'Manitou' wheat, 'Bonanza' barley, 'Garry' oats, 'Gazelle' rye, 'Torch' rapeseed and 'Noralta' flax.

All tests were seeded into summerfallow and 67 kg/ha 11-55-0 was applied with the seed. The winter wheat and rye were seeded on August 30, 1974 and August 28, 1976. In 1974, seeding was done with a double disc drill followed by packing. In 1976 a hoe-press drill was utilized. Soil moisture was excellent both falls. The spring of 1975 was very wet and for this reason the spring cereals were not seeded until June 3. In contrast, in 1977, the spring cereals were seeded on May 3. Shortly after this there was an extremely wet period. All spring seeding was done with a double disc drill followed by packing.

A hot dry spell in July 1975 resulted in a drought stress on the crop. The summer of 1977 provided mor optimum growing conditions and near record crop yields were realized in this area.

Experimental design was a randomized complete block with 3 replicates and sub-samples (sub-plots). Plots were drill strips 2m wide seeded up a slight slope which provided the salinity gradient (total length 300 m).

At maturity 10 to 12 subsamples (0.6 x 3.6m in size) were taken within each plot within each replicate. Subsample location was determined by visual estimates of crop condition with the most frequent samples being taken near the lethal point on the salinity gradient. After harvest soil samples were taken at the point at which growth ceased in each plot and at each subplot. Based on the analyses of these samples a salinity map for the area was developed each year.

Measurements were made on 1) stand establishment, 2) height, 3) maturity, 4) total above ground plant dry weight, 5) grain yield, 6) hectoliter weight, 7) thousand kernel weight, 8) seed protein content, 9) soil conductivity, phosphate, nitrate, pH, water soluble ions, etc., on 0-15, 15-30, 30-60, 60-90 and 90-120 cm soil depths.

Soil conductivity was estimated by the 1:1 method on all soil samples. Although the saturated paste method is more generally accepted it is more time consuming and costly. For this reason only 175 and 56 samples were analysed by the saturated paste method in 1975 and 1977 respectively. These samples represented the entire conductivity range encountered and were utilized to determine the relationship between the two methods. To avoid confusion the saturated paste method has been used as the standard for all conductivities reported.

Five classes of soil salinity based on differences in conductivity (mmhos/cm) are generally recognized (Table 1). These levels have been utilized in this study for purposes of general description. However, where more detailed analyses were required groupings were based on conductivity increments of 2 mmhos/cm starting at 0.

Table 1. Degree of soil salinity.

	Non-Saline	Slightly saline	Moderately saline	Severely saline	Very Severely saline
Conductivity (mmhos/cm)	0-2	2-4	4-8	8-16	16+

Data from plots in the 0-2 mmhos/cm conductivity range were utilized to estimate the performance (p_n) of each cultivar on non-saline soils at this location for each year. Utilizing this data analyses of variance were conducted for each variable to determine the level of significance of differences that were attributable to years and cultivars. Then utilizing increments of 2 mmhos/cm conductivity, groupings were made for each variable within each year within each cultivar. Analyses of variance, utilizing a completely random design were then conducted for each variable to determine the level of significance of differences that were attributable to increases in salinity. Where significant differences were observed the degree of salinity required for a significant decrease in performance was estimated utilizing the non-saline mean as the control and the least significant difference method for comparing means. This conductivity was designated C_s.

A number of measurements were utilized to describe relative crop performance on saline soils (Fig. 1). These included:

P_n - Crop performance on non-saline soils.

C_s - Conductivity at which there was a significant decrease in crop performance.

C_m - Maximum conductivity for plant survival.

C_I - Conductivity at which crop performance was first reduced by soil salinity = $\frac{Pn - a}{b}$ where a is the y intercept of the regression of soil conductivity on crop performance and b is the slope of the regression line.

C_D - Percent decrease in crop performance per unit increase in conductivity = $\frac{b}{P_n} \times 100$.

Simple correlation coefficients based on variability within each cultivar each year were utilized to determine relationships among the variables measured. For the measurements of crop performance this resulted in a correlation coefficient for each pair of measurements for each cultivar for each year. These correlation coefficients were tested for homogeneity and homogeneous correlation coefficients pooled. Step-wise regression analyses were employed to further assess the complexity of these relationships with soil salinity. After consideration of various curves and transformations, linear regression lines were settled on to describe crop responses to increased soil salinity. In these regression analyses only data from sub-plots with soil conductivities greater than C_s-2 for the 0-60 cm depth were utilized.

On Aug. 30, 1977 six rows of both Sundance winter wheat and Cougar winter rye were seeded with a small plot hoe press drill on summer-fallow strips adjacent to the main test site. Plants were removed from these plots on Oct. 18 and 31, 1977 and assessed for cold hardiness by artificial freeze tests. Plant dry weight and crown fresh weight, dry weight, moisture content and Na, Ca, Mg, K and P content were also

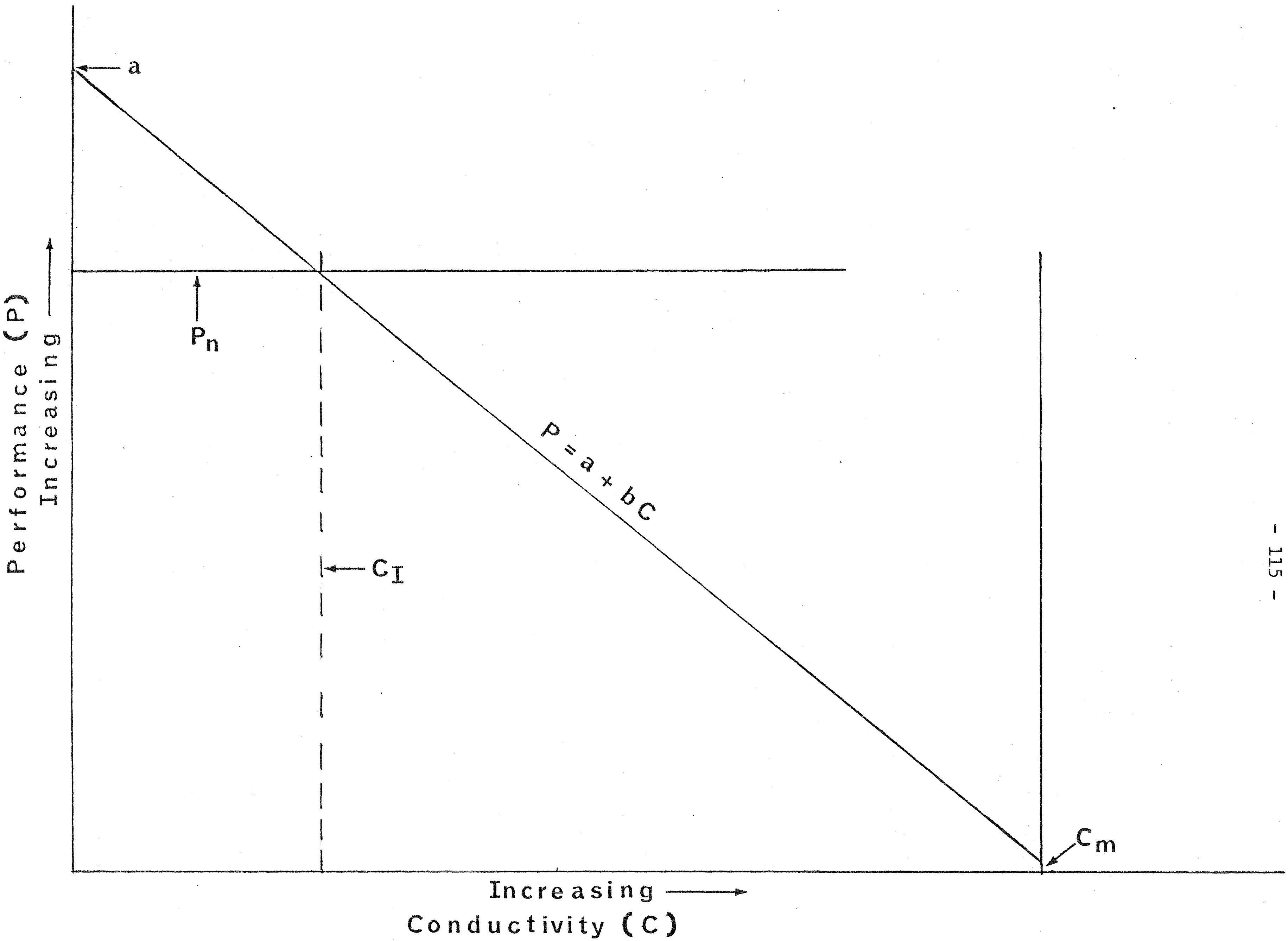


Fig. 1. Measurements used to describe crop response to saline soil conditions. See Materials and Methods for definitions.

determined. Soil samples for conductivity determination were taken to a depth of 15 cm at the time of plant sampling.

Results and Discussion

The soil

Within the test area level of soil salinity ranged from non-saline to very severely saline. The average pH, conductivity, concentration of water soluble ions and sodium absorption ratio for samples in the five classes of salinity are given in Table 2. The dominant salt in the 0-2 conductivity range was calcium sulfate. All salts increased in the 2-4 conductivity range with calcium sulfate nearing its maximum concentration. Magnesium and sodium sulfate were present in similar concentration in the 4-8 conductivity range and both continued to increase with increased conductivity. At higher conductivities sodium sulfate became the dominant salt. The high SAR for conductivities greater than 8 mmhos/cm also indicated soil structural problems in these areas.

Magnesium is highly toxic to some crops. Because of its high concentrations at conductivities above 8 mmhos/cm its importance in this regard should be given consideration.

Relationship between conductivities determined by the 1:1 and saturated paste methods.

Conductivities as determined by these two methods were closely related (Table 3). Because the 1:1 method was utilized on all soil samples these values were utilized in statistical analyses. However, for purposes of this report these conductivities were converted to saturated paste conductivities by utilizing the regression equation for the combined 1975-77 data.

Location of salt in the soil profile and its relationship to crop performance.

Emphasis in this study was placed on conductivity of the 0-15, 15-30, 30-60 and 0-60 cm depths. Levels of salinity followed an irregular pattern with salt concentrations often changing dramatically over short distances (Fig. 2 and 3). Highly significant correlation coefficients (Table 4) for conductivities at the depths considered indicated that salts were not concentrated at any particular point in the upper 60 cm of the profile. However, as expected, conductivity of the 0-15 cm depth was more closely related to that of the 15-30 cm than the 30-60 cm depth.

Table 2. Average pH ,conductivity, concentration of water soluble ions and sodium absorption ratio for samples in five ranges of soil salinity.

Conductivity range	Year	pH	Conductivity (mmhos/cm)	Water soluble ions (PPM) Na	Ca	Mg	K	Cl	SO_4	SAR
0-2	1975	7.6	1.3	40	152	74	18	20	571	.7
	1977	7.5	1.5	44	163	82	18	15	614	.7
2-4	1975	7.6	3.2	139	391	246	25	22	2071	1.4
	1977	7.5	3.4	136	457	242	31	17	2370	1.3
4-8	1975	7.7	5.5	461	435	529	34	29	4390	3.5
	1977	7.7	5.5	539	431	491	30	17	4300	4.2
8-16	1975	7.8	11.4	1792	398	1245	31	30	9183	9.9
	1977	7.9	12.5	2300	395	1138	37	20	8938	13.2
16+	1977	8.2	22.7	5138	392	2325	44	12	18781	22.6

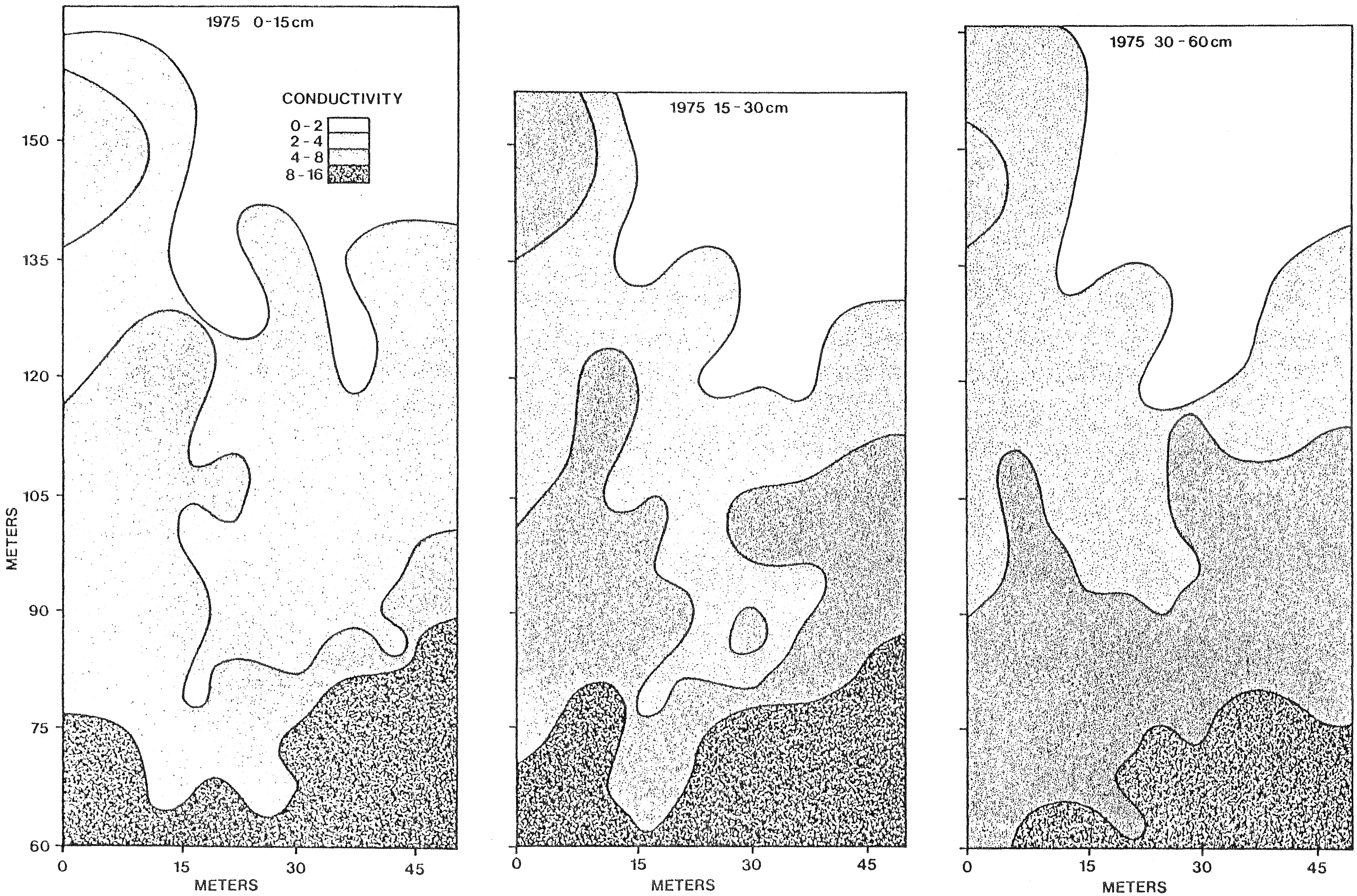


Fig. 2. Conductivity (mmhos/cm) of the surface 60 cm of soil for the main salinity transition area at the Clair test site.

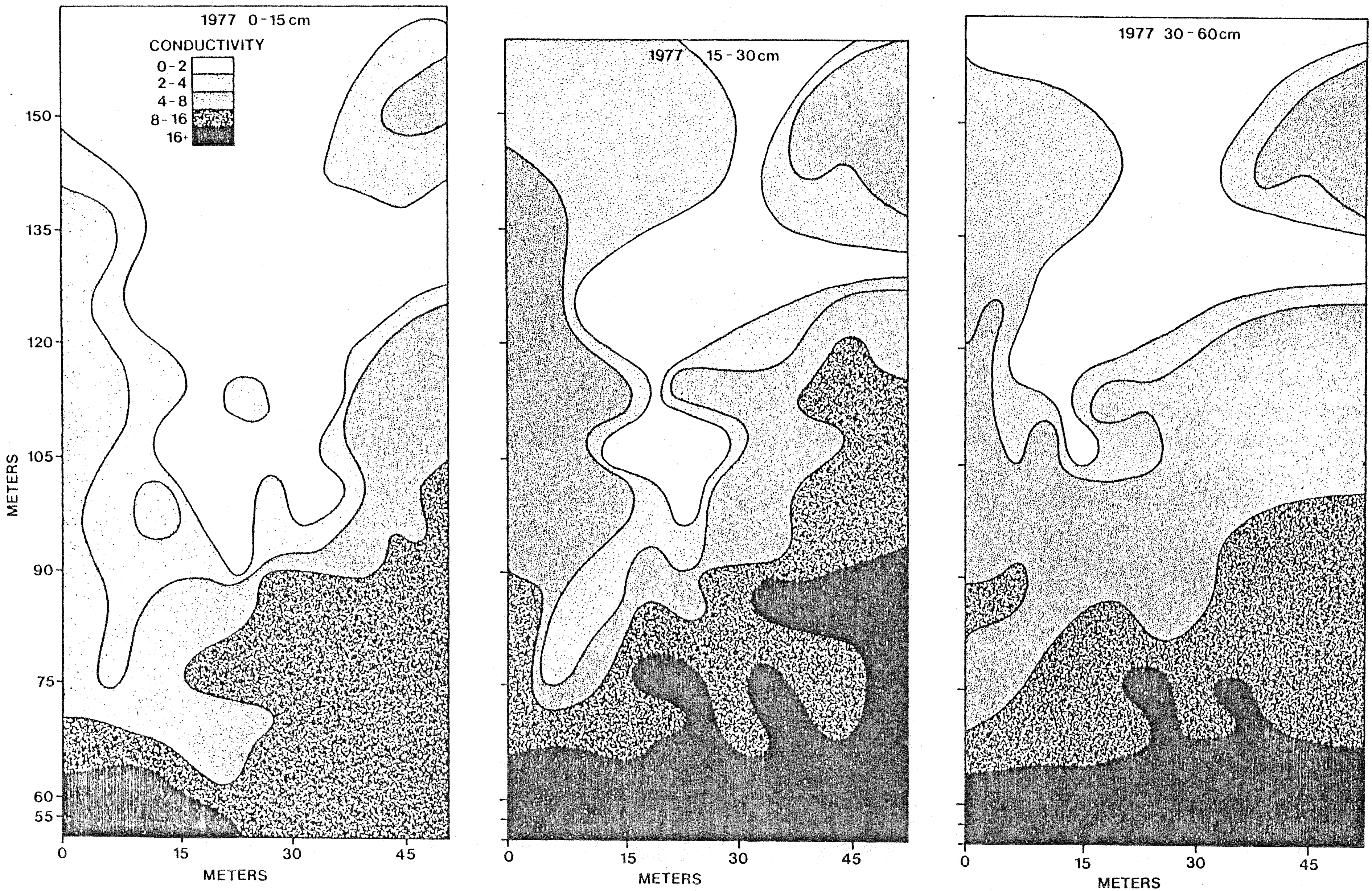


Fig. 3. Conductivity (mmhos/cm) of the surface 60 cm of soil for the main salinity transition area at the Clair test site.

Table 3. Relationship between conductivities (C) determined by the 1:1 (C_a) and saturated paste methods (C_b).

Year	Regression equation	Correlation Coefficient
1975	C_b = -.462 + 2.317 C_a	.98**
1977	C_b = -.664 + 2.128 C_a	.99**
Combined 75-77	C_b = -.202 + 2.115 C_a	.99**

**Significant at the 1 percent level

Close relationships were found among the measures of crop performance considered and conductivity at the 0-15, 15-30, 30-60 and 0-60 cm depths (Table 4). Conductivity for 0-60 cm was most closely correlated with crop performance. The addition of conductivities, for the component depths, in step-wise regression analyses usually did not explain any additional variability in crop performance. For this reason only conductivities of the 0-60 cm depth were utilized in further assessment of the effect of soil salinity on crop performance.

Due to these close relationships, crop performance offers a quick, inexpensive, means of assessing the extent of farm salinity problems. While the soil test is still necessary to thoroughly assess salinity problems, plant responses can serve as an excellent guide in determining where soil samples should be taken. Among the plant characters considered in this study crop height would provide the simplest index for identifying salinity problem areas.

Crop performance on non-saline soils

Table 5 gives the performance of the crop species considered when grown on non-saline soils in the trial area. These values served as the base line for determining the extent of reductions in crop performance on saline soils. Large differences in crop performance due to years were noted (Table 10). These differences reflect the earlier seeding date for the spring crops and more favorable growing conditions experienced in 1977.

Crop establishment on saline soils.

All crops except rapeseed established over the entire length of the plot. In both winters the winter cereals winterkilled to their points of maximum salinity tolerance (C_m). Hot dry summer weather, especially in July 1975, did most of the damage to the spring sown crops and determined their points of maximum salinity tolerance (C_m).

Table 4. Simple correlation coefficients

	Yield	DWT+	HT	0-15	15-30	30-60
DWT	.87 to .99†					
HT	.78 to .97	.83 to .99				
0-15	-.79§	-.81	-.78			
15-30	-.84	-.83	-.79	.94		
30-60	-.79	-.80	-.79	.83	.89	
0-60	-.85	-.85	-.82	.96	.98	.94

+Abbreviations - Yield - seed yield; DWT - total above ground plant dry weight; HT - plant height; 0-15, 15-30, 30-60, 0-60 - soil conductivities for listed depths.

†Heterogeneous correlation coefficients - values reported are the range of correlation coefficient obtained. All were highly significant (P=.01).

§Pooled value for homogeneous correlation coefficients. All were highly significant (P = .01).

Table 5. Crop performance (P_N) on non-saline soils. Mean for 1975 and 1977 - Clair salinity trial.

Cultivar	Seed Yield (Qu/ha)	Plant dry weight (Qu/ha)	Height (cm)	Hectoliter weight (kg)	1000 kernel wt (g)	Date Ripe (Da/mon)	1975 Protein (%)	1975 Oil (%)
Sundance	27.5b	109.4a	102bc	83a	36.5a	5/8de	9.0	
Cougar	29.4b	108.2a	121a	79b	25.5c	27/7e	7.4	
Neepawa	24.8c	95.6a	82e	83a	32.5b	30/8ab	14.4	
Bonanza	31.8a	105.7a	85de	68d	39.0a	17/8bcd	12.4	
Garry	27.8b	103.4a	98cd	57e	32.0b	28/8abc	12.1	
Gazelle	24.7c	100.4a	111ab	80d	27.0c	4/9a	11.3	
Torch	14.9d	76.5bc	85de	71cd	2.3e	13/8cde	34.0	41
Noralta	10.9e	69.2c	59f	72c	5.4d	2/9ab	33.0	44

a-f Within columns means followed by the same letter are not significantly different at the .05 level as tested by a Duncan's new multiple range test.

Conductivity (C_I) at which a reduction in crop performance occurred.

Seed yield, plant dry weight and height were the first characters influenced by increasing salinity stress (Table 6). Large decreases in performance for these three characters had occurred before the effects of increased soil conductivity were expressed for the remaining characters measured. Cougar winter rye and, to a lesser extent, Bonanza barley and Sundance winter wheat responded to salinity stress at the lowest conductivities. The more optimum growing conditions in 1977 resulted in a significantly higher soil conductivity being required that year before a reduction in crop performance was experienced (Table 10).

Percent decrease in crop performance per unit increase in soil conductivity.

Each additional unit increase in soil conductivity beyond the C_I point resulted in decreases in seed yield, plant dry weight and height which averaged 10.2, 9.8 and 8.8 percent respectively (Table 7). These rates of reduction in crop performance were similar for the two years considered (Table 10). Unit reductions were smallest for Bonanza barley and Garry oats.

Maximum soil conductivity levels for crop production

The more favorable environmental conditions of 1977 resulted in spring crop survival at higher soil conductivities (Table 10). Bonanza barley and Garry oats survived under much higher conductivities than did the other cultivars considered (Table 8).

Influence of soil salinity on winter survival of winter wheat and rye.

Both winters the Sundance winter wheat and Cougar winter rye winterkilled to their points of maximum salinity tolerance (C_m). Under normal conditions Cougar rye was more cold hardy than Sundance wheat (Table 9). However, soil conductivity at the point of maximum salinity tolerance was similar for both cultivars on both winters (Table 8). Consistent with this observation, artificial freeze tests conducted at the end of Oct. 1977 indicated that soil salinity reduced the cold hardiness of Cougar rye while having little effect on Sundance wheat (Table 9). Among the other characters measured at the time of cold hardiness evaluation increased soil salinity resulted in decreased seedling dry weight, crown fresh and dry weight and crown moisture and calcium contents for both cultivars (Table 9).

Table 6. Conductivity (C_1) at which a reduction in crop performance occurred. Mean for 1975 and 1977. Clair Salinity Trial.

	Seed Yield	Plant dry weight	Height	Hectoliter weight		1000 kernel weight		Date Ripe		Oil content
Cultivar				1975	1977	1975	1977	1975	1977	1975
Sundance	3.4bc	3.4ab	3.8ab	8.0	NS	8.0	NS	NS	NS	
Cougar	2.3d	2.6b	3.2b	7.0	9.0	6.5	7.0	NS	NS	
Neepawa	4.1ab	4.2a	4.1ab	NS	NS	NS	NS	NS	NS	
Bonanza	2.8cd	3.9a	4.1ab	9.0	NS	8.0	6.0	9.5	NS	
Garry	4.4a	4.2a	5.0a	12.5	9.0	NS	9.5	NS	NS	
Gazelle	3.9ab	4.2a	4.3ab	NS	9.0	8.0	9.0	NS	NS	
Torch	3.6abc	3.6ab	4.3ab	NS	NS	6.5	NS	NS	NS	8.0
Noralta	4.4a	3.9a	4.2b	NS	NS	NS	NS	NS	NS	8.0

a-d. Within columns means followed by the same letter are not significantly different at the .05 level as tested by a Duncan's new multiple range test.

ns - no significant change in performance for the range of conductivity encountered.

Table 7. Percent decrease in crop performance per unit increase in soil conductivity beyond the point (C_1) of initial response. Mean for 1975 and 1977. Clair salinity trial.

Cultivar	Seed Yield	Plant dry weight	Height
Sundance	11.5a	11.0a	9.9ab
Cougar	9.6bc	9.2ab	8.1abc
Neepawa	10.7ab	11.0a	10.3ab
Bonanza	6.7d	5.9c	6.1c
Garry	7.9cd	7.7bc	7.1bc
Gazelle	11.7a	11.4a	8.9abc
Torch	11.6a	11.0a	10.6a
Noralta	11.6a	10.6a	10.0ab

a-d. Within columns means followed by the same letter are not significantly different at the .05 level as tested by a Duncans new multiple range test.

Table 8. Soil conductivity (mmhos/cm) at which plant survival ceased (C_m). Mean for 1975 and 1977. Clair salinity trial.

Cultivar	C_m
Sundance	10.8b
Cougar	10.8b
Neepawa	11.5b
Bonanza	15.6a
Garry	15.6a
Gazelle	11.4b
Torch	11.5b
Noralta	11.9b

a-b. Means followed by the same letter are not significantly different at the .05 level as tested by a Duncan's new multiple range test.

Table 9. Influence of soil salinity on cold hardiness, plant dry weight and crown fresh and dry weight and moisture, Na, Ca, Mg, K and P contents of winter wheat and rye. Oct. 1977.

Conductivity range (mmhos/cm)	Mean conductivity (mmhos/cm)	Cold hardiness (LT_{50}) (°C)		Plant dry weight (g/10plt)		Crown: Fresh weight (g/10plt)		Crown: Dry weight (g/10plt)		Crown: Moisture content (%)		Crown: Na		Crown: Ca (ugm/g)		Crown: Mg (ugm/g)		Crown: K (%)		Crown: P (%)	
		W[+]	R	W	R	W	R	W	R	W	R	W	R	W	R	W	R	W	R	W	R
0-2	2	-18	-29	1.35	1.97	1.48	1.87	.33	.43	77.9	76.9	NS		523	745	1451	947	2.3	2.0	.65	.57
2-4	3	-18	-30	1.13	1.77	1.36	1.70	.31	.40	77.3	76.2			485	625	1843	2251	2.3	2.1	.62	.58
8-16	13	-18	-26	1.00	1.35	1.14	1.06	.27	.27	76.2	75.5			440	376	1164	1715	2.2	2.0	.67	.61
16+	16	-18	-23	.75	1.03	1.14	.92	.28	.22	75.4	75.8			388	108	1551	2380	2.2	2.1	.65	.61

+Abbreviations, W - Sundance winter wheat, R - Cougar winter rye.

NS; Sodium levels were not significantly different from those of the blanks.

Table 10. Comparison of crop performance in 1975 and 1977. Clair salinity trial.

	1975	1977
1. Performance on non-saline soils (P_n)		
Seed Yield (qu/ha)	20.3b	27.7a
Plant dry weight (qu/ha)	64.1b	128.0a
Height (cm)	92 a	93 a
Hectoliter weight (kg)	72 b	76 a
1000 kernel weight(g)	25 a	25 a
Date ripe (da/mon)	1/9 a	8/8 b
2. Point of initial response (mmhos/cm)		
Seed yield	2.8 b	4.5a
Plant dry weight	2.8 b	4.7a
Height	3.5 b	4.8a
3. Decrease in crop performance from salinity (%)		
Seed yield	10.4a	9.9a
Plant dry weight	9.9a	9.6a
Height	8.7a	9.0a
4. Maximum conductivity tolerated (mmhos/cm)	11.0 b	13.8a

a-b. Within rows means followed by the same letter are not significantly different at the .05 level as tested by a Duncan's multiple range test.

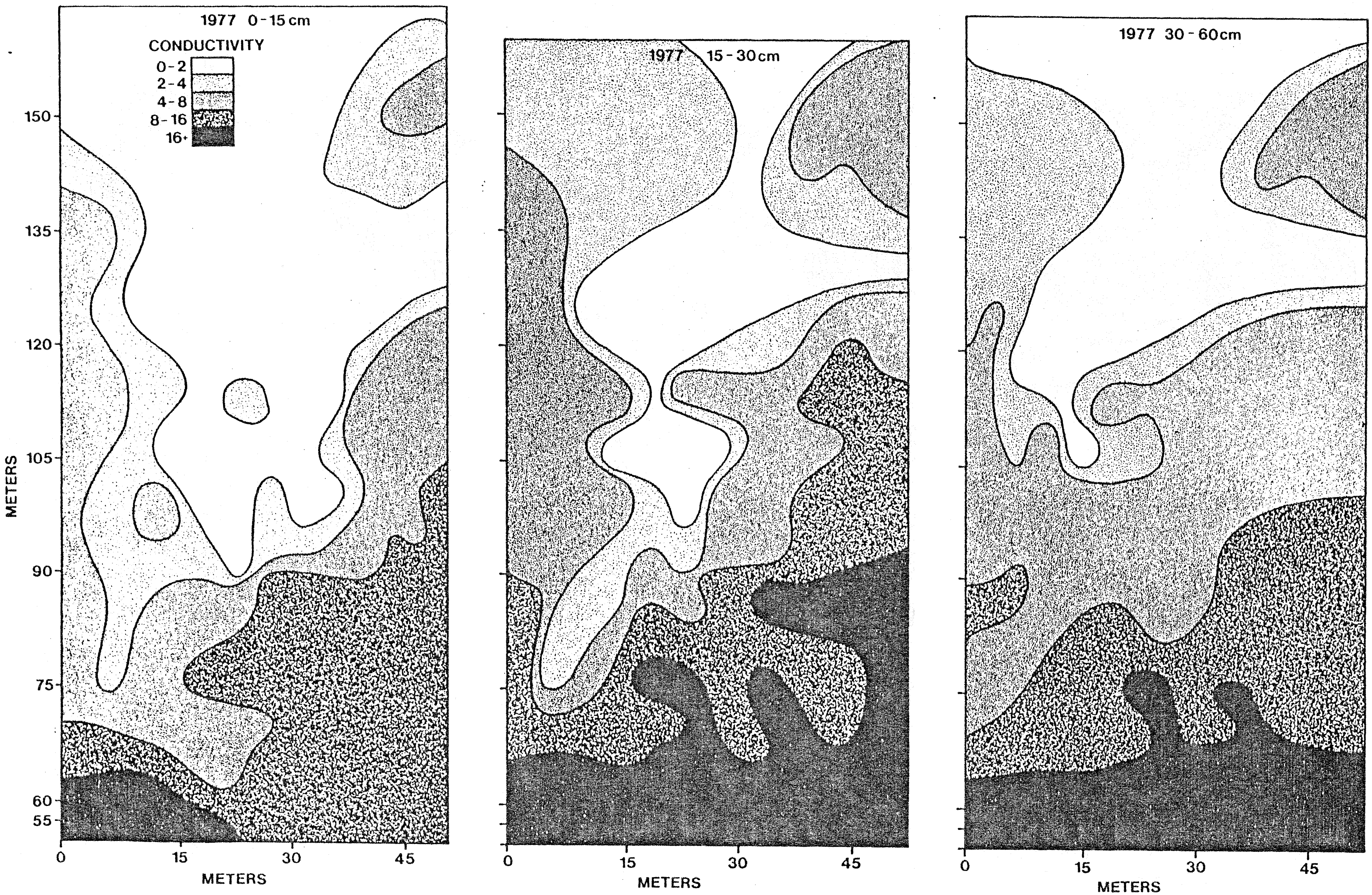
Crop production on severely saline and very severely saline soils

Results of this study indicate that on years with favorable environmental conditions, as in 1977, barley and oats could produce on very severely saline soils to conductivities up to 17.8 mmhos/cm. However even under the most favorable growing conditions significant yield losses would be experienced on severely saline soils and on most years production would be non-profitable in these areas. On the quarter section where these trials were conducted, prior to 1977, areas with soil conductivities greater than 8 mmhos/cm grew little more than Kochia and Russian thistle. In late May 1977, 10 hectares in this category were seeded to a mixture of Russian wild rye, Revenue slender wheat and common alfalfa (1:1:.6) at a rate of 11.5 kg/ha. The alfalfa stand was variable, reflecting variation in the level of soil salinity, but the grasses established over the entire area. In 1978 a hay crop averaging 2200 kg/ha was harvested.

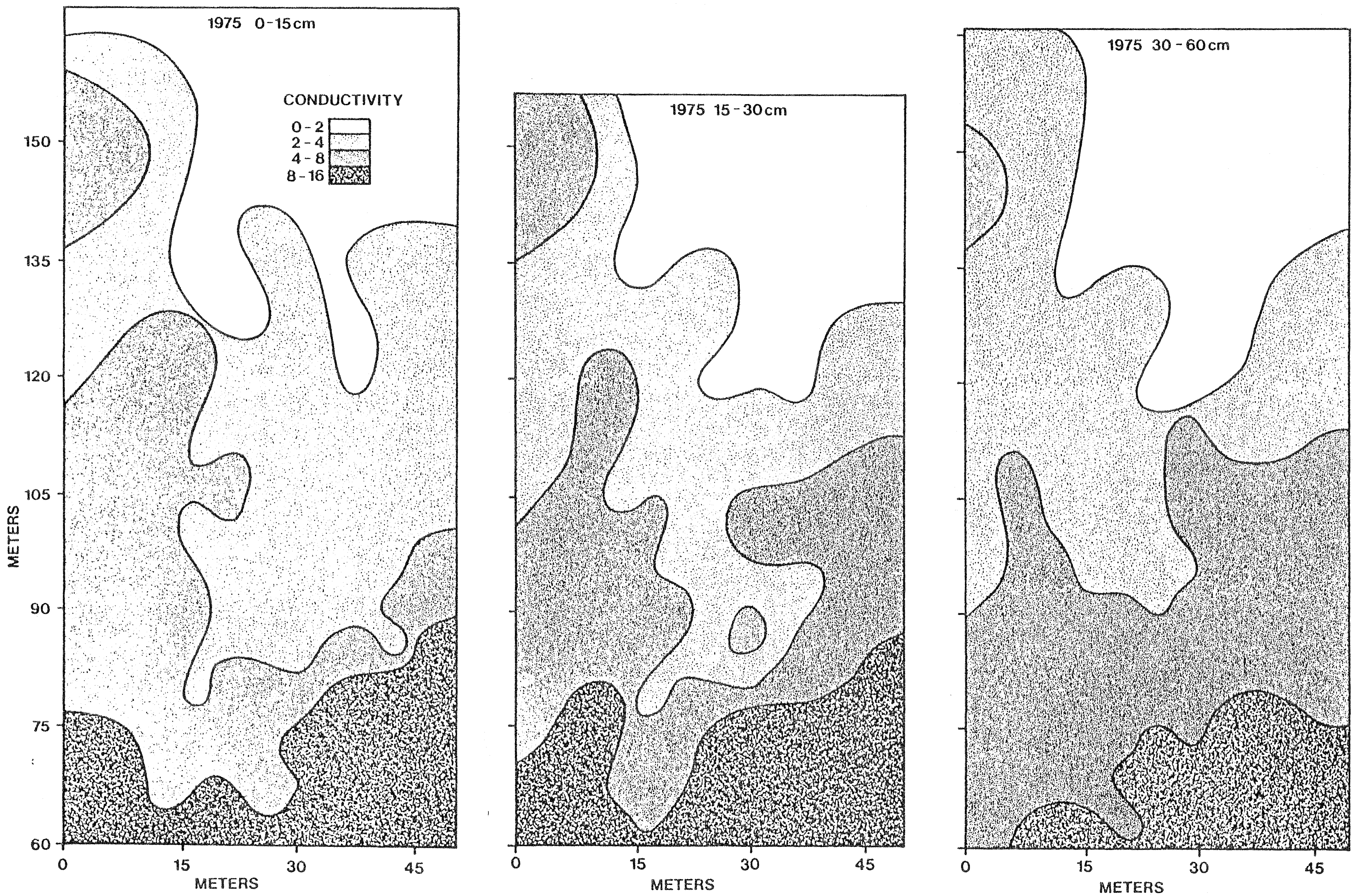
Summary

1. The dominant salts in moderately saline areas were magnesium and sodium sulfate. At higher conductivities sodium sulfate became the dominant salt.
2. High SAR's for the severely and very severely saline areas indicated soil structure problems.
3. Conductivities determined by the 1:1 method were closely related to those determined by the saturated paste method.
4. Levels of salinity followed irregular patterns, often changing dramatically over short distances.
5. Salts were not concentrated at any particular point in the upper 60cm of the profile.
6. Mean conductivity for the 0-15, 15-30 and 30-60 cm depths was most closely correlated with crop performance.
7. Plant height can be utilized as a guide in identifying salinity problem areas for soil testing.
8. Large differences in crop performance due to years were observed. More favorable growing conditions resulted in greater salt tolerance. Additional stress factors such as heat, drought, etc., have a cumulative effect, greatly reducing performance on saline soils.
9. Except for rapeseed, establishment was not a limiting factor in crop production on saline soils.
10. Large decreases in seed yield, plant dry weight and height occurred before the effects of increased soil conductivity were expressed for hectoliter weight, 1000 kernel weight, date of maturity, protein content and oil content.
11. Cougar winter rye and, to a lesser extent, Bonanza barley and Sundance winter wheat responded to salinity stress at lowest conductivities.
12. Each additional unit increase in soil conductivity beyond the point of initial response resulted in decreases in seed yield, plant dry weight and height which averaged 10.2, 9.8 and 8.8 percent respectively. Unit reductions were smallest for Bonanza barley and Garry oats.

13. Bonanza barley and Garry oats survived under much higher conductivities than did the other cultivars considered.
14. Under non-saline conditions Cougar winter rye was more winter hardy than Sundance winter wheat. However, under saline conditions they winterkilled to similar degrees on both winters. This winterkill point determined their maximum salinity tolerance.
15. Artificial freeze tests indicated that soil salinity reduced the cold hardiness of Cougar rye while having little effect on Sundance wheat. Increased soil salinity also resulted in decreased seedling dry weight, crown fresh and dry weight and crown moisture and calcium contents for both cultivars.
16. Increased osmotic pressure may be the primary factor affecting plant growth on saline soils. However, in this area, factors such as magnesium toxicity and induced calcium deficiencies should also be investigated.



1977 0-15 cm
CONDUCTIVITY
0-2
2-4
4-8
8-16
16+
150
135
120
105
90
75
60
55
METERS
0
15
30
45
METERS
1977 15-30 cm
0
15
30
45
METERS
1977 30-60 cm
0
15
30
45
METERS


1975 0-15cm
CONDUCTIVITY
0 - 2
2 - 4
4 - 8
8 - 16
1975 15 - 30cm
1975 30 - 60cm
METERS
150
135
120
105
90
75
60
0
15
30
45
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