

SALINITY, SNOW, AND SALVATION

Best Paper Award, WSC 2005 - H. Steppuhn¹

ABSTRACT

The reclamation of salinized soil involves lowering ground water levels, draining the vadose zone, and leaching the salts from the root zone. Plastic drain tubing placed 1.5 to 1.8 m below the land surface can lower watertables and drain phreatic water, but irrigation is usually required to leach the offending salts. The leaching process in non-irrigated drylands depends on natural precipitation. Rows of tall wheatgrass, *Thinopyrum ponticum* (Podp.) Lui & Wang, (1.2 m mean height) spaced on 15.2-m centers across saline fields can retain blowing snow, augment water for leaching salts, and moderate evapotranspiration when grown in conjunction with subsurface drainage. The mean salinity of saturated soil paste extracts from sets of soil samples taken every fall from such a site in southwestern Saskatchewan averaged 14.1 dS/m during 1985-90 before the drainage was installed, 13.0 dS/m for 1991-92 after drainage but before the grass windbreaks became established, and 9.6 dS/m for 1993-99 with both drainage and windbreaks in place.

INTRODUCTION

Salinity has plagued agriculture in arid and semiarid climates for thousands of years. Whenever near-surface waters containing dissolved salts encounter drainage impediments in soils, subsoils, or parent materials, a possibility exists for the concentrations of the solutes to increase. In very arid lands, salinization stems mostly from the distribution and collection of irrigated waters in amounts incompatible with the water-holding and drainage capacities of the soils. In semiarid regions, such as found across western North America, salinity also results from the convergence of natural waters.

Beneath each farm and ranch located on the Great Plains or the Canadian Prairies, the subsurface geology dictates a history and an influence on the site's salinity. Approximately 100 million years ago, oceans covered all of these lands (Nielsen, 1973). These ancient seas left saline marine deposits which provide the salts causing today's root-zone salinity (Miller et al., 1981). A series of non-marine sedimentary deposits followed in geologic time and, wherever not subsequently eroded, now cover the marine deposits. During the passing eons, the Rocky Mountains were born, and the land surface developed a generally decreasing slope toward Louisiana and Hudson's Bay. Water moving down these slopes formed valleys through which the marine salts began moving back to the oceans. Within the last two million years, continental glaciers covered and scraped the more northern landscapes, extending at one time as far south as the Missouri River.

The marine deposits consist primarily of silt-stones, shales, and unconsolidated clays through which water passes very, very slowly. The subsequent non-marine deposits include coarser particles and generally transmit water and dissolved salts much more readily. The glacial deposits (mostly till) feature a mix of the marine and non-marine material across which the ice traveled. Consequently, water transmission rates through glacial tills vary from place to place and from layer to layer, leaving ample quantities of marine salts in today's till deposits. When the glaciers melted, they released large quantities of surface water which tended to separate the fine from the coarse-textured material. This resulted in the silts, sands, and gravels found near the margins of the old glacier fronts, and the clays comprising the downstream glacial lakebeds found today. Also, before vegetation could cover many of the landscapes exposed by the retreating glaciers, the wind entrained the finer particles at some places carrying them afar and leaving the typical coarser sands and gravels of glacial outwash plains. The continental glaciers moved from the Canadian Shield south, southwestward, traveling upslope against the regional lay of the land. Consequently, glacial till deposits are generally thinner toward the southwest, ranging from 125 m thick in the northern reaches of the Canadian Prairies to a meter or less in some places in Montana and the Dakotas.

Paper presented Western Snow Conference 2005

¹ Research Scientist, Semiarid Prairie Agricultural Research Centre, Agriculture & Agri-Food Canada, Swift Current, Saskatchewan S9H 3X2, Tel.(306)778-7243, Fax(306)778-3188, Email: SteppuhnH@agr.gc.ca

Depending on location, either the generally finer-textured marine or the coarser-textured non-marine sediments underlie the rather mixed glacial drift. The mixing and layering of water-transmitting and water-confining material and strata in the glacial deposits and bedrock, including in the soils which developed from them, can alter the flow rates of the subsurface water moving through these media in response to gravitational forces. This alternation delays the movement of infiltrated snowmelt, rain, or surface waters. These delays also increase the waters' subsurface residence times and enhance the efficacy of the water to dissolve available salts. If the delay is sufficiently long and widespread, large volumes of the glacial deposits beneath field soils can accumulate water. At the same time, matrix salts are dissolved by the delayed water, because internal drainage is slowed or impeded. With time and without recharge, the accumulated waters drain slowly in response to gravitational and other forces.

During spring on the Plains and Prairies (March-June), day length increases, temperature rises, snow melts, and on average, seasonal precipitation peaks. At this time, more water tends to enter the subsurface than drains from it, and internal water accumulations occur. A wet subsurface environment, recharged yearly with snowmelt and early rains and occurring intermittently with dry periods, encourages salinization. When the accumulated ground water approaches or intersects land surfaces, evapotranspiration causes the solutes to concentrate in soil root zones. Soil salinization naturally results unless the process is countered by other natural processes or anthropological practices, such as irrigation, which dissolve, leaches, and moves the excess salts out of root zones (U.S. Salinity Laboratory Staff, 1954).

Engineered subsurface drainage systems offer one method for lowering watertables, removing dissolved salts, and reducing salinization by purging excess water from root zones (Rhoades, 1974). When installed on irrigated lands, subsurface drainage usually lowers the watertable and reduces salinity (Rapp, 1968). However, on non-irrigated, semiarid lands, subsurface drains give mixed results. On drylands, drainage usually lowers the watertable, but does not initially reduce soil salinity (Buckland and Hendry, 1992). After many years, drainage systems placed in non-irrigated, saline soils have lowered the electrical conductivity of soil solutions in the top 0.3 m of soil at some but not all sites (Vander Pluym et al., 1985).

The U.S. Salinity Laboratory Staff (1954) set the standard for measuring soil salinity based on laboratory determinations. They defined the electrical conductivity of a water-saturated soil paste extract (soil-EC) as the most consistent measure. Their procedure starts with dried soil samples obtained from the field. Placed on filter paper in a funnel and saturated with de-ionized water, the soil sample is subjected to overnight vacuum producing the extract. Saturation percentages can vary among samples.

Black and Siddoway (1971) suggest that rows of tall wheatgrass, (*Thinopyrum ponticum* (Podp.) Lui & Wang), offer an alternative to tree and shrub windbreaks commonly planted throughout the Great Plains and Canadian Prairies. Tall wheatgrass, a salt-tolerant perennial bunchgrass, typically develops seed culms averaging 1.2 m tall when grown in double rows. These serve as windbreaks placed on 15.2-m (50-foot) centers across fields producing dryland crops. Research has shown that this grass shelterbelt system reduces ground windspeeds, controls soil erosion, deepens snowcovers, extends the geographic range of overwintering crops, conserves water, increases or stabilizes grain production, and minimizes the need for summerfallow (Aase and Siddoway, 1974; Black and Aase, 1986; Steppuhn and Nicholaichuk, 1986). The soil water enrichments resulting from windbreaks are attributed to greater snow catch in the shelter than in the open field and to reductions in evapotranspiration of the wind-sheltered crop (Siddoway 1970). An evaluation of combining tall wheatgrass windbreaks with plastic drainage tubing trenched into a dryland saline site formed the objective of the study reported herein.

STUDY SITE

This study was conducted on a site located 3 km southwest of Swift Current, Saskatchewan, (50.3° N, 107.8° W). The long-term mean annual precipitation equals 359 mm, with as much as one-third falling as snow. The growing season (May, June, July, August) precipitation and Class A pan evaporation averages 210 and 883 mm, respectively, reflecting a semiarid climate. Winter-to-summer air temperatures range within -40 to +40 °C. Two parcels of severely salinized land, aligned north and south, characterize the site (Figure 1). The parcels, each about one hectare in area, form part of a slightly undulating plain sloping 3% to the southeast; a slight rise in topography separates the two parcels.

The soil of the plain is mapped as a degraded, salinized Swinton silt loam (Ayres et al. 1985) and is classified a

Saline Brown Chernozem (Salic Aridic Haploboroll in the U.S. nomenclature). The topsoil developed from a partially-eroded veneer of loess (25 cm or less thick) overlying glacial till. Cretaceous Bearpaw shale underlies the till at depths below land surface ranging from 6 m along the west boundary of the saline parcels to 1.5 m on the east side (Figure 2). The texture of the till and subsoil changes rather abruptly from a silty loam with sand lenses

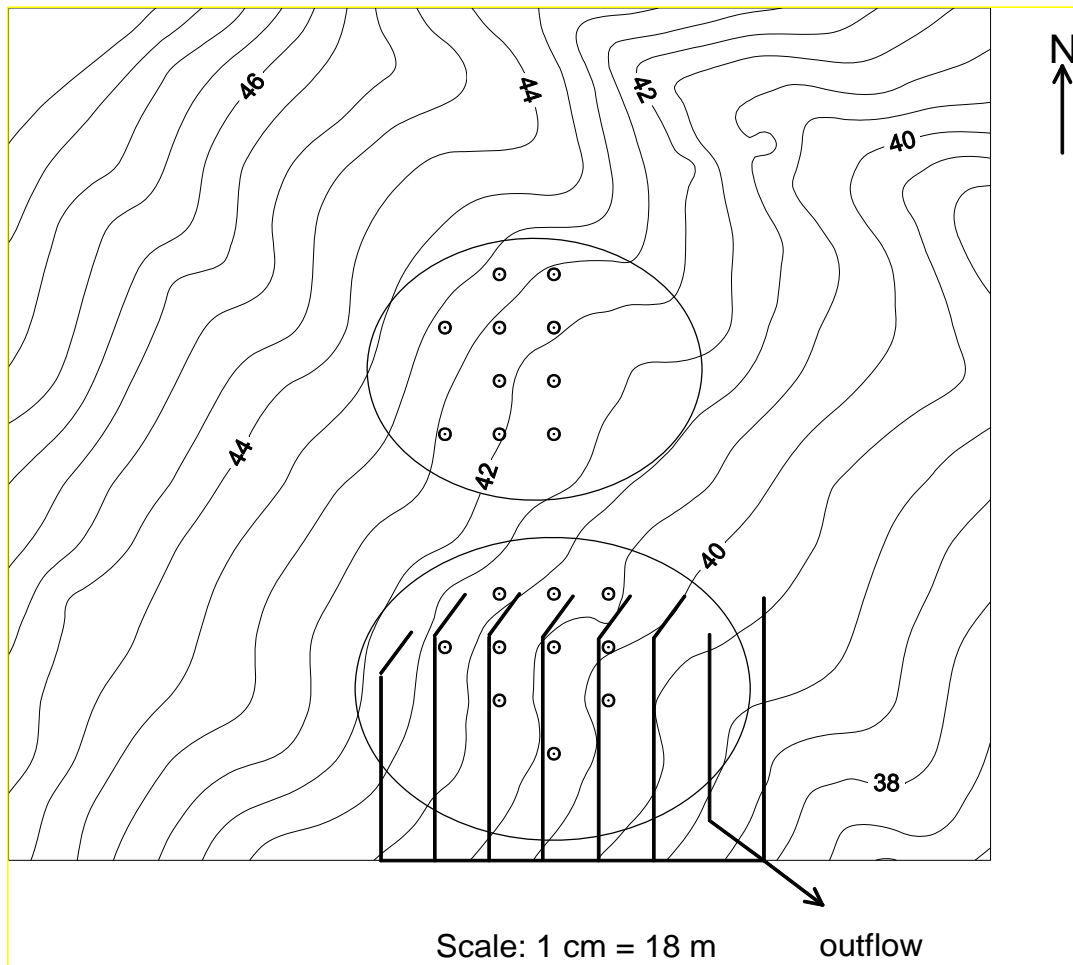


Figure 1. Subsurface drain lines, wells, and soil sampling locations on the South and North Parcels at a saline site (50.3° N, 107.8° W) near Swift Current, Saskatchewan; contour interval equals 0.5 m with arbitrary datum.

on the west side to a loamy clay on the east side. The transition occurs along a line trending north-south that transects both parcels of saline soils. We have concluded that the shallower bedrock and textural discontinuity created a “textural dam” behind which ground water accumulates and causes the root-zone salinity associated with both parcels.

STUDY METHODS

Soil sampling in the two parcels began in 1985 followed by watertable measurements in 1987 after the observation wells were installed. A grid of ten soil sampling points and well locations west of the textural transition was established in each parcel (Figure 1). A 3-cm, perforated, plastic pipe surface-sealed within a hole augured just above bedrock at each location served as the observation well for weekly depth-to-watertable measurements. Every fall (October or November) from 1985 through 1996, a cylindrical core of soil, 50 mm in diameter, was removed from the upper 900 mm of the root zone within a 2 m radius of each sampling point. The core was sectioned into 150-mm depth increments, and the soil electrical conductivity of the saturated soil paste extract (soil-EC) was determined for each increment.

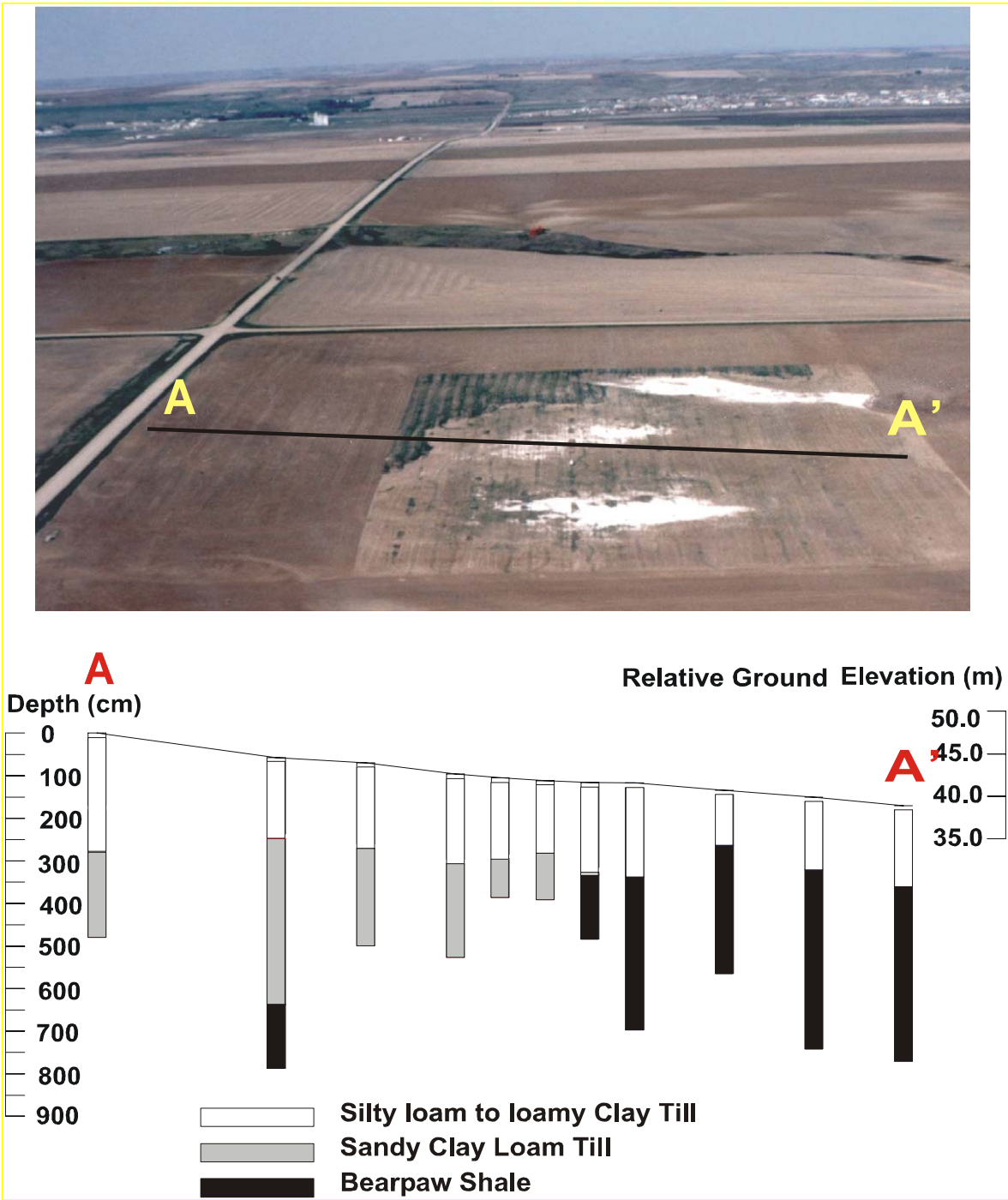


Figure 2. View northward showing the South and North Parcels with subsurface depth profile along transect A-A' (west to east), salinity study site near Swift Current, Saskatchewan. (A saline, intermittent watercourse is also visible northeast of the parcels.)

In August and September of 1990, plastic drain-tubing covered with a polyester filter was buried on grade within 1.5 and 1.8 m of the surface of the South Parcel using a laser-controlled trencher; the North Parcel was left untreated. The drain system consisted of north-south oriented, 100-mm, louvered tubing spaced on 15.2-m centers feeding an east-west, non-perforated, 150-mm collector conduit (Figure 1). Where possible, drain lines were placed approximately 5 m west of the water wells and soil sampling points.

In October, 1991, a dormant-season seeding of tall wheatgrass (variety: Orbit) was expected to form single rows located parallel and 3.8 m west of each drain line. Dry conditions during the following spring limited establishment of the wheatgrass. We seeded a second row about 150 mm adjacent the first in the spring of 1992. This resulted in effective windbreaks spaced 15.2 m apart across the South Parcel averaging 0.7 m in height by November, 1992. A year later, the living windbreaks reached their mature height (1.2 m) and width (0.5 m).

We surveyed the accumulated snowcover on each parcel at about the time of peak accumulation each year beginning in January 1993, except in the snow-limited winter of 1998. Each survey included from 10 to 30 observations of snowcover depth and 3 to 5 measurements of the specific gravity from vertical snow cores taken between each of eight windbreaks. After each survey, the observations were used to calculate the mean snowcover water equivalent for each parcel according to the method described by Steppuhn (1976).

The mean depth-to-watertable and soil-EC values from the South Parcel obtained during the pre-treatment period (1985-1990) were regressed with those from the North Parcel using a linear model (SAS 1995). The regression statistics for watertable depths and for each sampled soil layer and three combinations of layers (0-450, 450-900 & 0-900 mm) provided comparisons for selecting the most reliable predictors. Predicted pre-treatment soil-EC values for the South Parcel from the selected regressions were analyzed covariantly with the measured values resulting in differences statistically evaluated with the pre-treatment-based least-significant-difference (LSD). Differences in measured post-treatment EC values for the parcels compared to the LSD allowed statistical inferences pertaining to the merits of the treatment.

During the study, Bonanza barley was seeded across the entire site every year. Each land parcel provided square-meter hand samples for grain yield comparisons before and after treatments. The samples were threshed, and the grain oven-dried and weighed.

RESULTS AND DISCUSSIONS

The annual precipitation during the six pretreatment years exceeded the long-term mean (359 mm) in two years out of six in comparison to five out of the eight post-treatment years. Precipitation volumes averaged less before the drainage system was installed (316 mm) than after installation (412 mm).

Once established, the tall wheatgrass windbreaks accumulated more snow on the wind-sheltered (South) parcel than on the open (North) parcel (Table 1). Over the six surveys (1993-99), the mean peak, areal water equivalent averaged 72.8 mm on the South Parcel and 25.5 mm on the North Parcel. But, the snowcover over the sheltered parcel was usually not uniform, accumulating in the usual wind-foil pattern behind the windbreaks.

Table 1. Mean snowcover water equivalents from surveys across saline land parcels located near Swift Current, Saskatchewan, measured at about the time of peak accumulation, 1993-1999. (No snow accumulated in 1998.)

Date	Parcel ¹		Date	Parcel ¹		Date	Parcel ¹	
	North	South		North	South		North	South
	--	mm	--		--		--	mm
22 Jan. 1993	26	31	28 Mar. 1995	11	31	13 Jan. 1997	42	136
15 Feb. 1994	29	78	11 Jan. 1996	23	95	28 Jan. 1999	22	66
						Average	25.5	72.8

¹ South Parcel has subsurface drainage and grass windbreaks; North Parcel has neither.

Surface-to-watertable measurements (n=384) taken at least weekly throughout the year during the pre-treatment period (1985-90) correlated closely between the two parcels ($r^2 = 0.825$, $se < 0.01$ m) but showed considerable variability within and between years (Figure 3). Based on this regression, the median difference in depth-to-watertable between the South Parcel measured and predicted during the pre-treatment period was 0.088 m with a LSD of 0.060 m. After the subsurface drainage system was installed in the South Parcel, but before the tall wheatgrass windbreaks became effective (1993), the average depth-to-water (n=331) in the ten wells within each of the parcels equaled 1.744 and 1.298 m for the South and North, respectively. After the snow-trap grass windbreaks became effective (from 1993 through 1997), the South depths averaged 1.716 m and the North 1.070 m, a difference of 0.646 m (n=261). The differences in measured and predicted (based on the North Parcel measurements) depths averaged across the South Parcel for the drainage only and the drainage plus windbreak treatment periods, equaled 0.506 and 0.730 m, respectively.

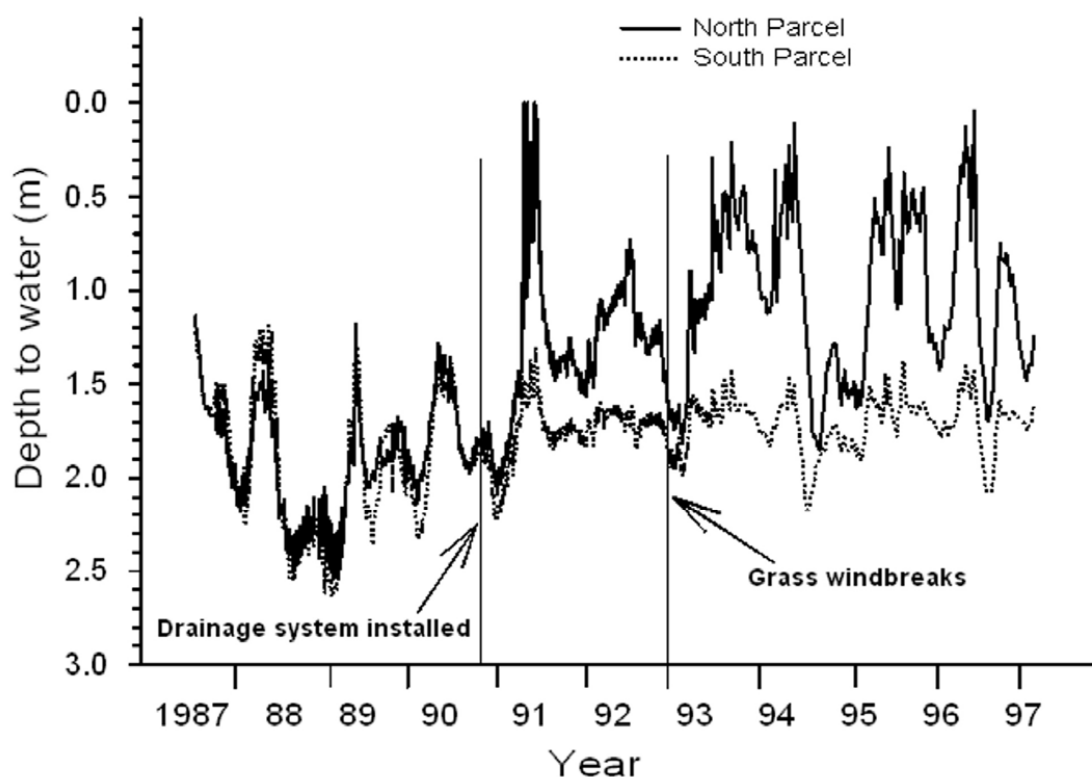


Figure 3. Average depths from ground surface to watertable with time for the ten wells in the South Parcel (pre-treatment, subsurface drainage only, and drainage plus grass windbreak periods) and the ten wells in the North Parcel (untreated control), near Swift Current, Saskatchewan.

The soil-EC covariance testing covering the six pre-drainage years (1985-1990) between the North and South Parcels showed significant correlation in the 0-150, 600-750 and 750-900 mm soil layers only (Table 2). The salinity status among the soil layers within a soil profile is very dynamic. Therefore, we combined the results into mean soil-EC values for the 0-450, 450-900, and 0-900 mm depth units. The 0-900 mm unit did not correlate well ($r^2 = 0.48$), but the splits into the 0-450 and 450-900 mm units did ($r^2 = 0.95$ and 0.74). The covariant linear regression slope for the 0-450 mm unit approached unity (0.958), and the intercept indicated that the South Parcel was, on average, more saline (by 2.3 dS/m) than the North Parcel during the pre-treatment years.

Table 2. Parameters and statistics from linear regressions between the electrical conductivities of saturated soil-paste extracts (soil-EC) from the South Parcel with those from the North averaged from ten soil cores per parcel sampled each fall during 1985-1990 (n = 6) and stratified by soil layers and depth units to 900 mm.

Depths mm	r^2	Error dS/m	Prob.(slope>0)	Slope	Intercept dS/m
0-150	0.92	1.51	0.003*	0.977	1.572
150-300	0.63	1.62	0.733	5.510	
300-450	0.61	1.12	1.132	0.500	
450-600	0.55	1.18	1.102	0.049	
600-750	0.71	0.89	1.735	-6.102	
750-900	0.77	0.81	1.337	-1.333	
0-450	0.95	0.54	0.958	2.331	
450-900	0.74	0.78	1.469	-3.344	
0-900	0.48	0.74	0.771	4.152	

r^2 = coefficient of determination

Error = standard error of the regression

Prob.(slope>0) = error probability that the slope of the regression does not equal zero

* The slope is significantly greater than zero at an α -error probability of 0.05 or less.

The least significant difference at a statistical α -error probability (p) less than 0.05 for predicting the 0-450 mm, fall-measured soil-EC in the South Parcel based on the North EC-measurements prior to drainage equaled ± 0.66 dS/m (± 0.86 dS/m at $p < 0.01$). This implies that, if all else is equal between the two parcels, results from imposing a subsurface drainage and concomitant grass windbreak system on the South Parcel could be evaluated in comparison to that parcel's predicted behavior based on its pre-treatment covariance with the North Parcel. Table 3 contains: the mean fall soil-EC values for the 0-450 mm depth unit by year; the measured North and South EC-

Table 3. South Parcel soil salinity (soil-EC) averaged from actual fall-season measurements and from regression-predictions based on North Parcel measurements; ten soil cores per parcel, 0-450 mm depth.

Year	North Parcel	South Parcel		
	Measured	Measured	Difference ¹	Predicted
	----- dS/m -----			
1985	12.07	13.18	0.71	13.89
1986	8.84	10.68	0.12	10.80
1987	15.32	16.74	0.27	17.01
1988	12.21	14.69	0.66	14.03
1989	11.40	13.40	0.15	13.25
1990	13.73	15.78	0.30	15.48
1991	15.71	12.02	+5.36 ²	17.38
1992	15.75	14.04	+3.38 ²	17.42
1993	13.77	9.74	+5.78 ²	15.52
1994	13.91	9.93	+5.73 ²	15.66
1995	15.33	8.66	+8.36 ²	17.02
1996	15.53	9.09	+8.12 ²	17.21
1997	14.60	9.10	+7.22 ²	16.32
1998	17.13	10.97	+7.77 ²	18.74

¹ The Difference equals the South predicted minus the South measured values.

² Based on the 1985-1990 regression, the least significant differences equal: ± 0.66 dS/m at $p < 0.05$ and ± 0.86 dS/m at $p < 0.01$ (p = statistical α -error probability).

values; and, the predicted South EC-values. The average post-treatment difference between the measured and predicted South soil-EC equaled 6.46 dS/m which exceeded the 0.86 dS/m LSD seven fold. These changes in mean measured EC-values with time after drainage are visually evident in Figure 4 for the 0-450 mm depth unit and in the post-treatment photograph of Figure 5.

Barley grain harvested from either parcel during 1984-1990 before treatments yielded 330 kg/ha or less per parcel. After installation of the subsurface drainage system, grain yields averaged 2413.6 (43.3) and 140.4 kg/ha (2.1 bushels per acre) from the South and North Parcels, respectively.

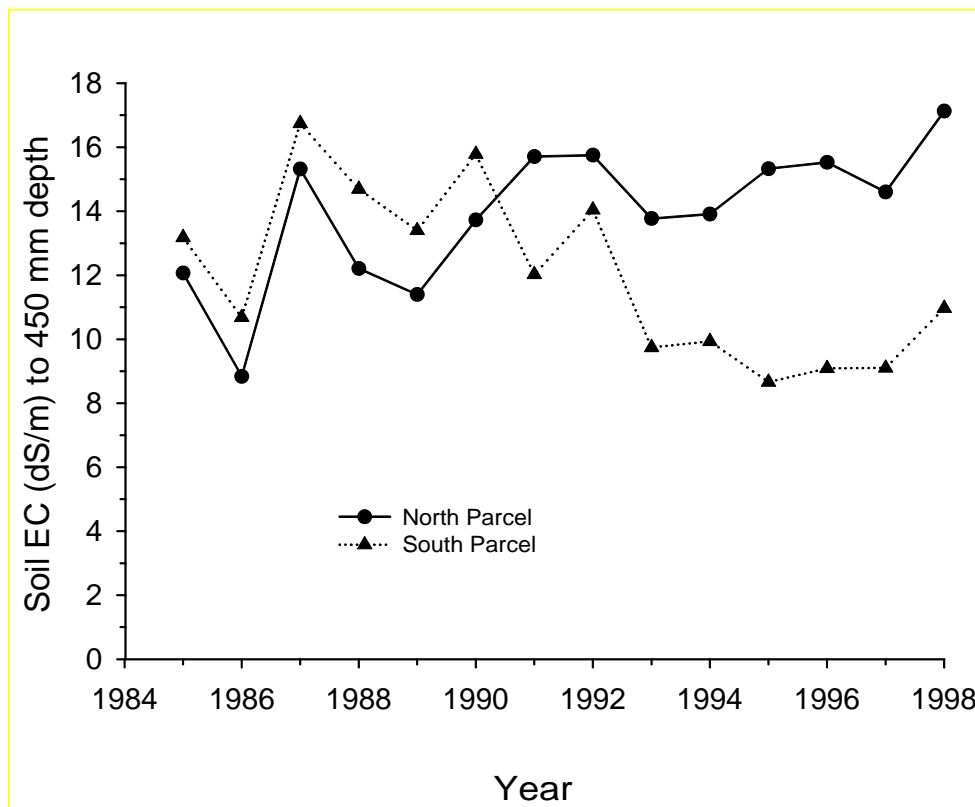


Figure 4. Average soil-EC to a depth of 450 mm for each year. The drain tubing in the South Parcel was installed during 1990. Soil samples were extracted in October or November of each year.

CONCLUSIONS

This study has led to four inferences: (1) that snow management can increase the water available to leach salinized root zones, (2) that engineered subsurface drainage can lower watertable elevations, especially at the critical time just before spring seeding, (3) that a combination of subsurface drainage and grass windbreak technologies in semiarid, non-irrigated environments can result in a gradual reduction of salinity in the top 450 mm of soil, and (4) that the combined drainage-windbreak treatment can increase barley grain yields 20-fold. The windbreak system in our study covers a limited area of 1.1 ha. If our system, because of its size and upwind fetch, allowed extra measures of snow to accumulate in it, a larger windbreak system may not prove as beneficial. Also, if the subsurface water volumes or their dissolved salt concentrations discharging from the drainage system are large, additional disposal techniques may be necessary.



Figure 5. View northward showing South Parcel after subsurface drainage and tall wheatgrass windbreak treatments, the untreated North Parcel, and the saline, intermittent watercourse at the salinity study site near Swift Current, Saskatchewan.

ACKNOWLEDGMENTS

This study was conducted on the Smith Brothers Farm. The author, on behalf of Agriculture and Agri-Food Canada, gratefully acknowledges and thanks Murray, Allan, Stuart, and Doug Smith for allowing the use of their land and their contributions to this study. Extra thanks and appreciation are also extended to Ken Wall, Ken Deobald, Don Sluth, Evan Powell, Darcy Schott, Tom Olfert, Gary Winkleman, Rod Ljunggren, and many other contributors at the Semiarid Prairie Agricultural Research Centre.

REFERENCES

- Aase, J.K., and F.H. Siddoway. 1974. Tall wheatgrass barriers and winter wheat response. *Agricultural Meteorology* 13:321-338.
- Ayres, K.W., D.F. Acton, and J.G. Ellis. 1985. The soils of the Swift Current map area 72J Saskatchewan. Saskatchewan Institute of Pedology, Extension Publ. 481, Extension Division, University of Saskatchewan, Saskatoon, SK. 226 p.
- Black, A.L., and F.H. Siddoway. 1971. Tall wheatgrass barriers for soil erosion control and water conservation. *Journal Soil & Water Conservation* 26:104-111.
- Black, A.L., and J.K. Aase. 1986. Cropping system's dependence on snow management. In: *Symposium Proceedings Snow Management for Agriculture* (H. Steppuhn & W. Nicholaichuk, editors), Great Plains Agricultural Council Publ. No 120, pp. 461-475, Swift Current, SK.

- Buckland, G.D., and M.J. Hendry. 1992. Groundwater response and salt removal in a saline-seep soil in southern Alberta. *Canadian Agricultural Engineering* 34(2):125-134.
- Miller, M.R., Brown, P.L., Donovan, J.J., Bergantino, R.N., Sonderegger, J.L. and Schmidt, F.A. 1981. Saline seep development and control in the North American Great Plains - Hydrological aspects. *Agricultural Water Management* 4:115-141.
- Nielsen, G.L. 1973. Geology and macro-ground water movement, saline lands, Alberta. pp. 16-40 In: *Proceedings Alberta Dryland Salinity Workshop, Soils Branch, Alberta Department of Agriculture, Lethbridge, AB.*
- Rapp, E. 1968. Performance of shallow subsurface drains in glacial till soils. *Transactions American Society of Agricultural Engineering* 11:214-217.
- Rhoades, J.D. 1974. Drainage for salinity control. Chap. 16, pp. 433-461 In: *Drainage For Agriculture* (J. Van Schilfhaarde, editor), *Agronomy Monograph 17, American Society of Agronomy, Madison, WI.*
- SAS. 1995. JMP (Version 3.2.1) Statistical Discovery Software. SAS Statistical Analysis System Institute Inc., Cary, NC, 27513. 593 pp.
- Siddoway, F.H. 1970. Barriers for wind erosion control and water conservation. *Jour. of Soil & Water Conservation* 25(5):180-184.
- Steppuhn, H. 1976. Areal water equivalents for prairie snowcovers by centralized sampling. *Proceedings of the 44th Western Snow Conference, Calgary, AB.* pp. 63-68.
- Steppuhn, H., and W. Nicholaichuk. 1986. Managing snow to extend the areal range of winter wheat production. *Proceedings of the 54th Annual Western Snow Conference, Phoenix, AZ.* pp. 30-40.
- U.S. Salinity Laboratory Staff. 1954. *Diagnosis and improvement of saline and alkali soils.* (L.A. Richards editor), *Agriculture Handbook 60, United States Department of Agriculture, Washington, DC.*
- Vander Pluym, H.S.A., C. Livergood, and L. Healy. 1985. Development of agricultural subsurface design standards for Alberta. Final Report, Farming For The Future Project 83-2042, Alberta Agriculture, Lethbridge, AB.