2.3 Ripping of Irrigated Solonetzic Soil to Increase Water Penetration and Crop Yield

M.C.J. Grevers

(This project was supported by a grant from the Saskatchewan Water Corporation)

INTRODUCTION

The suitability of soils for irrigation depends on a number of factors such as the structure of the soil, its drainability, the depth to water table and the soil salinity. Solonetzic soils are considered to be less suitable for irrigation than Chernozemic soils because of their impermeable Bnt horizon, moderate to high levels of subsoil salinity and their extreme spatial variability (Canada Soil Survey Committee 1987). Solonetzic B horizons (Bnt) are hard when dry and swell to a sticky mass of very low permeability when wet (Canada Soil Survey Committee 1987), these Bnt horizons effectively reduce water infiltration into the soil and also reduce root proliferation. In dry years, solonetzic "pockets" in a field are the first areas showing a crop under severe water stress. It was thought that the productivity and the irrigability of Solonetzic soils could be improved by disrupting the Bnt horizon using subsoilers.

This report represents a summary on the work carried out on the field monitoring of soil physical properties, soil chemical characteristics and crop growth following deep ripping of three irrigated Solonetzic soils north-east of Glenside, Saskatchewan. The objectives of the project were to determine the effect of deep ripping on crop production and on water infiltration, and to determine if deep ripping could increase the suitability of these soils for irrigation.

MATERIALS AND METHODS

A total of three farm sites were included in the study located northeast of Glenside, Sask. Legal locations of the sites are: Site DE (Dale Eliason farm) $S^1/_2$-27-29-6-W3, Site JE (Jerry Eliason farm) SW-2-30-6-W3, and Site RR (Randy Riopka farm)

$N^1/_2$-16-29-6-W3. The experimental plots consisted of 6 strips, 30 m wide and 800 m long (except at the JE Site: 30 m wide and 400 m long). Alternate strips were selected to be deep ripped (strips #'s 1, 3 and 5), while the other strips (strips #'s 2, 4 and 6) remained non-ripped (control). The 6 strips were divided into 3 sets of 2, each consisting of one deep ripped and one adjacent control plot. The 3 sets of plots are referred to as replicate blocks: north, middle and south. Deep ripping was carried out in the fall of 1987 to a depth of 61 cm, using shanks 1.12 m apart. The average soil moisture contents in the top 60 cm at the time of deep ripping were 19, 14 and 19%, for the DE, JE and RR Sites, respectively.

In the spring of 1988, 1989 and 1990, samples were collected to a depth of 60 cm from all the tillage strips, which were analyzed for NO_3-N content. In the fall of 1990 soil samples were collected for soil chemical analysis: 6 depth increments, 6 replicates, 6 tillage strips and 3 sites. Samples were taken to a depth of 120 cm, in increments of 0-15, 15-30, 30-45, 45-60, 60-90 and 90-120 cm. The samples were air-dried and then analyzed for pH, electrical conductivity (EC), water soluble cations and anions, and sodium adsorption ratio (SAR).

Soil physical parameters that were measured include soil moisture and soil bulk density. Soil water content was measured by neutron thermalization, using a DEPTH MOISTURE GAUGE (Troxler Electronic Laboratories Inc.) and a DEPTHPROBE CPN 501 (Hoskins Scientific). Soil bulk density was measured by gamma backscattering using the above CPN 501 probe. The scanning zone of the DEPTHPROBE CPN 501 has a vertical dimension of approximately 23 cm, and is therefore not sensitive to "picking up" relatively thin dense layers in the soil. Aluminum access tubes (2 per replicated plot) had been installed to a depth of 120 cm to facilitate the measurements of the soil bulk density and of the soil moisture content *in situ*, using the depth probes. During the 1990 growing season, soil moisture content and precipitation (rain gauges) at all three sites were measured bi-weekly. Bulk density measurements were taken prior to seeding and at harvest.

Crop yields were determined by taking square meter samples in a series of paired row samples, 6 pairs in each of the 6 tillage strips. The samples were then transported to the University of Saskatchewan, where the samples were dried, weighed, threshed and grain weights taken.

RESULTS AND DISCUSSION

Characterization of the Soils Based on Soil Chemical Criteria

All three soils are mapped as Tuxford Soil Association, which consists of Dark Brown Solonetzic soils. The soil at the JE Site meets at least one of the criteria for solonetzic B horizons, but the soils at the other two sites do not meet any of the criteria. However, there was a considerable amount of variability in soil chemical characteristics amongst the three replicate blocks at each site, as shown by soil chemical analysis in 1990 (Tables 2.3.9 through 2.3.14). At the DE Site, the south block was the most severe solonetzic (SAR ~15), the middle block was intermediate solonetzic (SAR between 5 and 10), and the north block was not solonetzic (SAR between 2 and 4). Similarly, at the JE Site, the middle and north blocks were solonetzic (SAR values between 5 and 12), whereas the south block was not solonetzic (SAR between 2 and 4). At the RR Site, the north and middle blocks are not solonetzic (SAR values <3), and the south block is slightly solonetzic (SAR values between 4 and 7). The soil at the JE site can thus be regarded as a Solonetzic soil, the soil at the DE site as a Solonetzic/Chernozemic intergrade (some parts of the field either Solonetzic or Chernozemic), and the soil at the RR site as a non-Solonetzic (Chernozemic) soil.

Soil Density

Deep ripping appeared to reduce the bulk density of the B horizon at each of the Sites as indicated by measurements taken in the spring of 1988 (Table 2.3.1); however, only at the JE Site were the differences significant ($P < 0.05$). By the fall of 1990, there were still trends in the data but there were no significant differences in density.

Table 2.3.1 Soil bulk density in the spring of 1988 and in the fall of 1990

Depth	Spring 1988		Fall 1990	
	Deep ripped	Control	Deep ripped	Control
cm	g/cm^3			
		DE Site		
5	1.250	1.250	1.250	1.250
25	1.332	1.623	1.449	1.441
40	1.431	1.442	1.486	1.457
60	1.655	1.517	1.584	1.470
80	1.651	1.480	1.575	1.473
100	1.680	1.476	1.642	1.512
120	1.692	1.617	1.690	1.605
		JE Site		
5	1.250	1.250	1.250	1.250
25	1.426*	1.604	1.326	1.518
40	1.398	1.295	1.479	1.409
60	1.467	1.499	1.553	1.551
80	1.616	1.620	1.572	1.589
100	1.633	1.657	1.614	1.662
120	1.736	1.736	1.693	1.663
		RR Site†		
5	1.300	1.300	1.300	1.300
25	1.458	1.548	1.396	1.389
40	1.365	1.468	1.413	1.438
60	1.590	1.584	1.462	1.384
80	1.668	1.621	1.505	1.382
100	1.684	1.642	1.466	1.414
120	1.713	1.698	1.398	1.514

Bulk density values for the 5 cm depth are those measured in the spring of 1988, and are assumed to be similar between ripped and control throughout the duration of the experiment
* Indicates mean of deep ripped is significantly (P <0.05) different from that of the control
† Bulk density values for 1990 for the RR Site represent one replicate block only, the other two replicate blocks could not be sampled because of water in the access tubes

The measurement of bulk density using a gamma probe involves a large sample volume and is not sensitive to small differences in density, particularly with respect to the density of specific soil layers. Furthermore, the spatial variability of soil density in Solonetzic soils is large (especially following deep ripping), therefore requiring a large number of replicate samples and/or large differences in the means before differences between the means can be regarded as significant at the $P < 0.05$ level. In light of the above, trends in the data will be discussed even though significant differences in bulk density between the deep ripped and the control plots were limited to the JE Site; the B horizon in the deep ripped plots at the JE Site was less dense than the B horizon in the control plots in 1988 and also in 1989.

The differences in bulk density density between the deep ripped and the non-ripped (control) parts of the field became smaller as time progressed (Table 2.3.1). By the fall of 1990, the differences in bulk density had disappeared in the soils at the DE and the RR sites, but were still apparent for the soil at the JE Site. The loosening of the Bnt horizon achieved with deep ripping thus lasted from 2 to 3 years. The degree of soil disturbance observed in 1987 during deep ripping was considerably less than what had been found when Solonetzic soils were deep ripped in the Tisdale area (Grevers 1989). There are two major reasons for the difference in soil disturbance; the spacing of the ripping shanks was narrower at Tisdale (0.56 m) but wider at Glenside (1.12 m), and soil moisture conditions at the time of ripping were very dry (and therefore ideal for soil shattering with the ripper) at Tisdale and moist at Glenside.

Soil-water Regime

Soil-water penetration in irrigated Solonetzic soils can be restricted because of impervious Bnt horizons. Disruption of the Bnt horizon by deep ripping should increase the penetration of water with depth. The saturated hydraulic conductivity (K-Sat) data reported earlier in the 1989 S.I.P. Field Research Report suggested that deep ripping had improved the hydraulic conductivity of the soil.

Substantial increases in soil moisture content in all of the plots were indicated by measurements taken with neutron probes during a 5 to 6 week period from early May to mid June of 1990 (Table 2.3.2). During this period there were no apparent differences in crop stand between the deep ripped and the control parts of the field. Consequently, the soil-water recharge during this period provided an opportunity to study if deep ripping would increase soil-water recharge with depth.

There were no significant differences between the deep ripped and the control plots in the total amount of soil-water recharge over that period. However, there were considerable differences in soil-water recharge with depth (Table 2.3.3). Soil-water recharge with depth was generally greater in the deep ripped plots compared to that in the control plots, where the recharge was more concentrated closer to the soil surface.

Soil-water depletion with depth during the growing season was not affected by deep ripping (results not shown).

Soil Nitrate-Nitrogen in the Spring

The soil disturbance associated with deep ripping (e.g. lower bulk density levels and increased soil porosity) could increase the rates of soil organic matter decomposition, nitrogen mineralization and nitrification. The levels of nitrate-nitrogen (NO_3-N) as measured in the spring of 1988, 1989 and 1990 are shown in Table 2.3.4. There is little difference in the nitrate levels between the deep ripped plots and the control plots, with the possible exception of Site JE for 1989. In this case the nitrate-nitrogen levels in the deep ripped plots were twice that of the control plots. However, there were no significant differences (P <0.05) between the deep ripped and the control plots for any of the Sites, for any of the three years.

Table 2.3.2 Soil profile moisture contents to a depth of 130 cm and precipitation during the 1988, 1989 and 1990 field seasons

Date	DE Site			JE Site			RR Site		
	Ptn	DR	Cntl	Ptn	DR	Cntl	Ptn	DR	Cntl
	---------- cm H_2O ----------								
1988 growing season									
Apr 19	nd	38.8	36.5	nd	33.6	33.6	nd	32.5	35.6
May 30	nd	nd	nd	nd	nd	nd	nd	34.4	37.2
Jun 12	nd	nd	nd	nd	nd	nd	nd	39.0	40.6
Jun 25	nd	nd	nd	nd	nd	nd	nd	33.3	34.5
Jul 23	nd	nd	nd	nd	nd	nd	nd	31.7	32.6
Aug 5	nd	nd	nd	nd	nd	nd	nd	30.8	30.8
Aug 23	nd	31.4	29.7	nd	36.6	36.0	nd	32.4	33.2
1989 growing season									
May 10	nd	29.9	33.2	nd	30.1	27.9	nd	29.2	33.7
Jun 15	nd	36.2	36.5	nd	40.8	39.1	nd	41.3	44.8
Jun 28	4.0	39.3	37.0	3.4	40.8	39.9	9.2	40.9	46.5
Jul 14	9.1	38.2	35.7	10.9	41.6	40.7	8.8	43.3	48.0
Jul 26	6.1	36.3	33.0	3.6	37.8	39.2	6.0	44.8	47.8
Aug 11	9.5	32.4	30.4	14.2	40.7	38.8	8.4	43.9	48.0
Aug 24	nd	31.7	34.6	3.1	36.4	35.4	11.8	40.4	43.8
1990 growing season									
May 2	nd	35.5	32.9	nd	35.7	33.7	nd	39.7	41.6
Jun 12	nd	44.2	41.9	nd	48.5	47.1	nd	51.4	53.6
Jun 28	3.6	45.8	43.0	2.5	47.3	48.6	nd	nd	nd
Jul 11	5.5	43.8	41.2	4.7	44.9	45.1	12.7	51.3	50.7
Jul 31	15.0	47.9	45.8	9.4	45.7	47.5	7.2	48.0	46.6
Aug 22	5.9	40.5	36.8	3.6	41.6	40.8	9.6	46.0	47.1

Ptn = precipitation and irrigation measured by rain gauges
DR = deep ripped, Cntl = control
nd = no data available

Table 2.3.3 Soil-water recharge with depth during the spring of 1990

Depth	DE Site		JE Site		RR Site	
	Control	Ripped	Control	Ripped	Control	Ripped
cm	cm H_2O per cm soil					
0-10	-0.016	-0.033	0.024	0.050	-0.007	-0.016
10-30	0.009	-0.042	0.070	0.005	0.028	0.027
30-50	0.067	0.001	0.053	0.066	0.054	0.035
50-70	0.043	0.058	0.046	0.055	0.056	0.015
70-90	0.002	0.034	0.065	0.062	0.045	0.107
90-110	0.005	0.073	0.058	0.090	0.035	0.112
110-130	0.026	0.046	0.040	0.114	0.040	0.127

Table 2.3.4 Soil NO_3-nitrogen levels in the spring of 1988, 1989 and 1990

Depth	1988		1989		1990	
	Rip	Cntl	Rip	Cntl	Rip	Cntl
cm	kg/ha					
			DE Site			
0-15	15.0	12.0	21.0	16.0	12.7	14.0
15-30	4.7	3.0	3.0	4.7	3.3	3.0
30-60	6.7	11.3	8.0	10.7	4.7	4.7
0-60	26.4	26.3	42.0	31.4	20.7	21.7
			JE Site			
0-15	20.3	16.0	13.3	13.7	11.3	14.0
15-30	6.0	4.7	8.7	5.0	4.0	3.0
30-60	6.0	8.7	23.0	11.3	2.7	2.7
0-60	32.3	29.4	45.0	30.0	18.0	19.7
			RR Site			
0-15	32.1	50.3	23.0	13.9	11.9	9.3
15-30	28.9	25.6	7.1	4.3	4.3	3.1
30-60	26.8	10.0	4.6	4.1	7.1	5.3
0-60	87.8	85.9	34.7	22.3	23.3	17.7

None of the above values for Rip (deep ripped) are significantly different ($P < 0.05$) from the corresponding values for Cntl (control)

Crop Yield and Water-use Efficiency

Deep ripping increased crop yields at the DE and the JE Sites, but not at the RR Site (Table 2.3.5). There were no yield increases in the first year at the DE Site; agronomic difficulties not related to deep ripping (poor weed control and inadequate water supply) limited the crop from reaching its full potential and thus may have hidden a possible effect of deep ripping on yield. However, deep ripping at this Site increased yields by 39 and 13% in the second and third year following deep ripping, respectively. At the JE Site, deep ripping resulted in a 26% yield increase in the first year, but not in subsequent years. There

Table 2.3.5 Crop yields and water-use efficiency during the first three years following deep ripping

Year	Crop	Grain yield		WUE (Grain)		Dry matter	
		DR	Check	DR	Check	DR	Check
		(Bu Acre^{-1})		(kg ha^{-1} cm^{-1})		(kg/ha)	
				DE Site			
1988	Lentils	17.0	11.2	nd	nd	2089	1564
1989	Durum	75.4*	54.1	169*	117	10868*	7483
1990	Durum	65.6*	58.2	131*	111	9573*	8110
				JE Site			
1988	Durum	49.7*	39.6	nd	nd	7667	6392
1989	Beans	38.0	33.0	65.7*	53.5	5527*	4184
1990	Spr. wheat	57.7	56.2	110	111	9772	9014
				RR Site			
1988	Spr. wheat	21.8	21.9	nd	nd	3968	3732
1989	Spr. wheat	48.7	46.7	nd	nd	7588	7113
1990	Spr. wheat	38.2	36.4	nd	nd	8002	7034

nd = no data available
WUE = water use efficiency (grain weight/total water use)
* Significant differences between the control and the deep ripped plots at $P < 0.05$

were difficulties with harvesting the beans in the second year at the JE Site; this could have masked any possible differences, since deep ripping did increase the total dry matter content of the bean crop.

For the RR site, it appears that deep ripping is of little value, since no significant yield increases were found in the first three years following deep ripping. The soil at the RR Site, on the other hand, was not considered to be Solonetzic based on soil chemical criteria, as was the case with the soil at the other two sites.

The water-use efficiency of the crops was determined in 1989 and in 1990 (rain gauges were installed in 1989 and 1990; but not in 1988). Deep ripping increased the WUE of the 1989 and 1990 durum crops at the DE Site by 44% and 19%, respectively. Deep ripping increased the WUE of the 1989 bean crop at the JE Site by 23% . It was not possible to determine crop WUE at the RR Site since many of the neutron access tubes were filled with water during the summer, which effectively reduced the number of samples for soil-moisture content determination.

Irrigation Suitability of Solonetzic Soils

The irrigation suitability of soils depends on the nature and degree of limitations imposed by a number of characteristics. The Working Group on Irrigation Suitability Classification (1985) used four categories of limitations from "none" to "severe" and listed ratings for soil structure, saturated hydraulic conductivity, soil drainability, available water holding capacity, soil-water infiltration rates, soil salinity and sodicity, geological uniformity, depth to bedrock and and depth to water table. According to their classification for electrical conductivity, the soil at the RR Site would present only a slight limitation for irrigation, the soil at the DE Site a moderate limitation, and the soil at the JE Site a moderate to severe limitation. Similarly using the rating for SAR, the soil at the RR Site would present no limitation, the soil at the DE Site would present a slight limitation, and the soil at the JE site would present a moderate limitation for irrigation.

The chemical criteria regarding the suitability of Solonetzic soils for irrigation according to Bennett and Entz (1990) are: (a) the electrical conductivity (EC) of the saturation past extract must be less than 6 dS m^{-1} within the top 0.5 m, (b) the EC must be less than 12 dS m^{-1} within the remainder of the 1-m root zone, and (c) the sodium adsorption ratio (SAR) must be less than 12 within the upper 1-m profile. Converting the above criteria on a 1:1 suspension basis for a clay loam, then the limits become: (a) the EC must be less than 3 dS m^{-1} within the top 0.5 m, (b) the EC must be less than 6 dS m^{-1} within the remainder of the 1-m root zone. Using the criteria from Bennett and Entz, it appears that only the soil at the RR Site is suitable for irrigation, while the soil at the JE Site is the least suitable for irrigation.

Soil disturbance with deep ripping should improve soil-water penetration, which, under irrigation should result in increased leaching of salts. Soil chemical characteristics measured in the fall of 1990, three years after deep ripping, revealed significant differences between the deep ripped and the control plots at the JE Site but not at the DE and RR Sites (Tables 2.3.6, 2.3.7 and 2.3.8). At the JE Site, deep ripping lowered the electrical conductivity in the top 90 cm, the sodium adsorption ratio in the top 45 cm and the percentage water-soluble sodium in the top 15 cm (Table 2.3.6). The leached salts included mostly Na_2SO_4 and $MgSO_4$ (Tables 2.3.7 and 2.3.8). Deep ripping improved the suitability of the soil at the JE Site from a "moderate to severe" to a "slight" limitation with respect to the EC value in the top 60 cm, from a "severe" to a "moderate" limitation with respect to the EC value in the 60-120 cm depth, and from a "moderate" to a "slight" limitation with respect to the SAR of the top 120 cm. Similarly, when using the criteria from Bennett and Entz (1990) the rating of the soil at the JE Site is improved by deep ripping from "not suitable" to "suitable".

Deep ripping had no significant effect on either the EC or the SAR of the soil at the DE Site; however, there were large differences between the deep ripped and the control plots in at least part of the plots (Tables 2.3.9 and 2.3.12). In the south replicate block of

Table 2.3.6 Chemical characteristics of deep ripped (DR) and adjacent check on Solonetzic soils at Glenside samples 3 years after deep ripping

Depth	EC		pH		SAR†		WSS‡	
	Check	DR	Check	DR	Check	DR	Check	DR
cm	-- dS m^{-1} --						----- % ----	
				DE Site				
(0-15)	0.69	0.77	7.3	7.2	1.7	1.9	34.1	35.2
(15-30)	0.73	1.32	7.8	7.8	4.2	4.4	54.0	51.8
(30-45)	3.86	2.80	8.2	8.2	8.9	6.8	51.1	54.5
(45-60)	6.52	4.08	8.3	8.2	7.3	7.8	44.7	50.9
(60-90)	7.47	6.95	8.3	8.3	10.0	10.6	50.9	55.3
(90-120)	8.34	8.24	8.2	8.2	11.1	12.2	50.8	52.4
				JE Site				
(0-15)	1.01	0.64**	6.9	6.9	4.2	1.8**	53.1	34.7**
(15-30)	2.21	0.65	7.9	7.1	7.3	2.9**	60.0	46.7
(30-45)	4.46	1.36*	8.2	7.5	9.4	4.6*	56.6	50.2
(45-60)	7.08	2.89*	8.2	8.0	9.4	7.7	43.5	52.7
(60-90)	9.51	4.56*	8.2	8.1	10.0	8.2	40.6	49.8
(90-120)	9.08	5.79	8.2	8.1	11.6	9.4	48.4	49.9
				RR Site				
(0-15)	0.78	0.73	7.6	7.4	1.6	1.9	30.1	34.4
(15-30)	0.78	0.81	8.1	7.9	2.6	3.7	42.1	48.3
(30-45)	1.40	1.87	8.2	8.1	4.3	5.6	51.4	54.6
(45-60)	2.86	2.54	8.2	8.4	6.6	8.1	53.7	62.8
(60-90)	5.42	4.52	8.1	8.3	7.8	9.0	47.6	55.4
(90-120)	7.63	6.88	8.0	8.0	10.4	9.2	50.8	47.2

† SAR is sodium adsorption ratio
‡ WSS is percentage water-soluble sodium
*,** Significant differences between check and DR at $P < 0.05$, $P < 0.01$, respectively

Table 2.3.7 Concentrations of soluble cations in deep ripped (DR) and adjacent check on Solonetzic soils at Glenside samples 3 years after deep ripping

	Ca		Na		Mg		K	
Depth	Check	DR	Check	DR	Check	DR	Check	DR
cm	mmoles kg^{-1}							
				DE Site				
(0-15)	1.34	1.31	2.4	2.9	0.9	1.2	0.31	0.46
(15-30)	0.86	1.83	5.0	7.9	0.8	2.4	0.09	0.09
(30-45)	5.61	3.46	39.9	18.9	10.6	6.0	0.32	0.22
(45-60)	7.85	6.23	41.6	31.4	20.5	11.5	0.58	0.46
(60-90)	7.58	7.26	50.8	49.4	19.8	16.8	0.64	1.39
(90-120)	8.16	9.56	58.6	66.3	21.4	22.0	0.72	0.87
				JE Site				
(0-15)	1.2	1.0	6.0	2.4***	1.1	0.8	0.39	0.56*
(15-30)	2.1	0.9	16.1	3.6*	4.4	0.7	0.23	0.16
(30-45)	3.7	1.8	32.4	7.6**	9.6	2.4	0.44	0.21
(45-60)	19.9	3.7	55.4	17.3**	20.7	7.4	0.74	0.42
(60-90)	21.8	5.6	75.8	30.0*	32.2	11.3*	0.94	0.61
(90-120)	9.1	6.0	73.6	39.8	26.8	14.0	0.74	0.74
				RR Site				
(0-15)	1.72	1.38	2.5	2.7	1.2	1.1	0.30	0.24
(15-30)	1.24	1.02	3.7	4.8	1.2	1.0	0.14	0.09
(30-45)	2.12	2.33	7.7	12.0	2.5	3.3	0.18	0.16
(45-60)	5.06	3.18	15.6	17.7	5.9	5.4	0.41	0.28
(60-90)	9.14	4.88	31.1	30.3	13.1	9.4	0.69	0.52
(90-120)	9.95	7.83	51.6	46.5	17.8	16.2	0.85	0.75

*,**,*** Significant differences between check and DR at $P < 0.05$, $P < 0.01$ and $P < 0.001$, respectively

Table 2.3.8 Concentrations of soluble anions in deep ripped (DR) and adjacent check on Solonetzic soils at Glenside samples 3 years after deep ripping

	Chloride		Sulfate		Cl/SO_4	
Depth	Check	DR	Check	DR	Check	DR
cm	mmoles kg^{-1}					
			DE Site			
(0-15)	1.12	1.41	1.2	1.8	0.932	0.804
(15-30)	0.61	0.57	1.7	5.6	0.367	0.101
(30-45)	0.96	0.70	25.2	14.3	0.038	0.049
(45-60)	1.29	0.82	46.1	31.5	0.028	0.024
(60-90)	1.13	0.99	49.6	47.4	0.023	0.021
(90-120)	1.55	1.10	57.4	62.6	0.030	0.020
			JE Site			
(0-15)	1.02	0.94	1.6	1.1	0.634	0.834
(15-30)	0.71	0.35	9.6	1.3	0.074	0.271
(30-45)	1.21	0.63	25.5	5.0*	0.048	0.126
(45-60)	1.52	0.70	49.9	15.3*	0.030	0.046
(60-90)	1.93	0.83	72.9	28.2*	0.026	0.029
(90-120)	1.79	1.21	64.4	35.1	0.028	0.034
			RR Site			
(0-15)	0.51	0.34	1.8	1.8	0.287	0.196
(15-30)	0.10	0.20	1.9	1.7	0.055	0.113
(30-45)	0.20	0.47	5.8	9.3	0.034	0.050
(45-60)	0.21	0.85	16.5	13.8	0.013	0.061
(60-90)	0.34	0.69	35.2	27.4	0.010	0.025
(90-120)	0.34	1.05	51.0	49.6	0.007	0.023

* Significant differences between check and DR at $P < 0.05$

Table 2.3.9 Soil salinity values per replicate block for Site DE: pH, EC, SAR and WSS

Site	Block	Tillage	Depth	Sat	pH	EC	SAR	WSS
				%		dS/m		%
DE	South	RIP	0-15	67	7.5	0.78	2.1	39
DE	South	RIP	15-30	69	8.2	0.77	4.3	62
DE	South	RIP	30-45	83	8.4	1.13	9.0	78
DE	South	RIP	45-60	93	8.2	2.67	9.2	56
DE	South	RIP	60-90	96	8.0	8.40	10.5	47
DE	South	RIP	90-120	91	7.9	8.53	12.4	54
DE	South	CNTL	0-15	67	7.7	0.65	1.5	32
DE	South	CNTL	15-30	66	8.1	0.60	3.8	58
DE	South	CNTL	30-45	78	8.4	0.75	6.4	69
DE	South	CNTL	45-60	81	8.2	3.70	6.5	55
DE	South	CNTL	60-90	100	7.9	7.40	8.7	43
DE	South	CNTL	90-120	93	8.0	8.80	11.1	49
DE	Mid	RIP	0-15	57	7.1	0.95	2.1	35
DE	Mid	RIP	15-30	57	7.8	3.20	7.8	53
DE	Mid	RIP	30-45	59	8.1	7.65	8.5	42
DE	Mid	RIP	45-60	74	8.2	9.35	9.9	44
DE	Mid	RIP	60-90	67	8.3	10.70	11.3	46
DE	Mid	RIP	90-120	56	8.5	10.0	12.7	52
DE	Mid	CNTL	0-15	54	7.3	0.73	1.8	36
DE	Mid	CNTL	15-30	58	7.9	0.80	5.6	61
DE	Mid	CNTL	30-45	66	8.3	6.23	7.8	47
DE	Mid	CNTL	45-60	77	8.4	10.73	10.2	42
DE	Mid	CNTL	60-90	52	8.5	9.97	11.6	49
DE	Mid	CNTL	90-120	46	8.4	10.07	12.6	52
DE	North	RIP	0-15	56	7.0	0.63	1.5	31
DE	North	RIP	15-30	59	7.5	0.63	2.3	41
DE	North	RIP	30-45	61	8.1	1.23	3.4	39
DE	North	RIP	45-60	48	8.3	1.97	5.0	51
DE	North	RIP	60-90	47	8.5	3.00	10.3	69
DE	North	RIP	90-120	51	8.2	6.77	11.8	51
DE	North	CNTL	0-15	55	6.9	0.63	1.6	36
DE	North	CNTL	15-30	57	7.5	0.77	3.3	46
DE	North	CNTL	30-45	65	8.0	3.33	4.0	35
DE	North	CNTL	45-60	59	8.2	4.60	6.2	47
DE	North	CNTL	60-90	47	8.4	5.00	9.1	57
DE	North	CNTL	90-120	55	8.2	6.90	11.1	55

Sat = saturation of soil sample, EC = electrical conductivity, SAR = sodium adsorption ratio, WSS = water-soluble sodium

Table 2.3.10 Soil salinity values per replicate block for Site JE: pH, EC, SAR and WSS

Site	Block	Tillage	Depth	Sat	pH	EC	SAR	WSS
				%		dS/m		%
JE	South	RIP	0-15	53	6.9	0.65	1.3	25
JE	South	RIP	15-30	53	7.1	0.55	1.3	29
JE	South	RIP	30-45	54	7.5	1.70	2.5	28
JE	South	RIP	45-60	53	7.8	4.45	3.9	29
JE	South	RIP	60-90	57	8.2	4.90	6.7	53
JE	South	RIP	90-120	54	8.1	5.35	6.9	44
JE	South	CNTL	0-15	56	7.3	0.70	1.5	28
JE	South	CNTL	15-30	57	7.4	0.63	2.8	47
JE	South	CNTL	30-45	70	7.8	0.80	5.5	58
JE	South	CNTL	45-60	68	7.8	2.63	7.5	47
JE	South	CNTL	60-90	68	7.9	6.10	7.1	36
JE	South	CNTL	90-120	75	8.0	6.77	8.2	40
JE	Mid	RIP	0-15	58	7.2	0.73	2.3	38
JE	Mid	RIP	15-30	60	8.0	0.83	3.8	50
JE	Mid	RIP	30-45	63	8.0	2.73	5.2	50
JE	Mid	RIP	45-60	70	8.2	3.90	8.7	60
JE	Mid	RIP	60-90	69	8.2	6.87	10.0	47
JE	Mid	RIP	90-120	75	8.1	7.67	10.7	48
JE	Mid	CNTL	0-15	62	7.0	0.77	4.0	61
JE	Mid	CNTL	15-30	67	8.2	1.27	9.1	76
JE	Mid	CNTL	30-45	78	8.3	3.33	11.0	67
JE	Mid	CNTL	45-60	70	8.2	7.37	11.3	53
JE	Mid	CNTL	60-90	75	8.2	9.53	12.8	53
JE	Mid	CNTL	90-120	59	8.1	9.83	13.8	56
JE	North	RIP	0-15	51	6.6	0.77	3.4	47
JE	North	RIP	15-30	52	6.8	1.13	5.0	53
JE	North	RIP	30-45	59	7.2	3.20	5.6	52
JE	North	RIP	45-60	68	8.0	3.37	9.3	58
JE	North	RIP	60-90	60	8.2	4.03	9.8	67
JE	North	RIP	90-120	55	8.2	5.50	12.3	68
JE	North	CNTL	0-15	51	6.8	1.4	5.8	62
JE	North	CNTL	15-30	75	8.0	5.1	8.7	57
JE	North	CNTL	30-45	73	8.4	6.2	12.5	62
JE	North	CNTL	45-60	61	8.3	9.0	9.3	37
JE	North	CNTL	60-90	52	8.3	11.4	9.4	33
JE	North	CNTL	90-120	52	8.1	11.0	12.6	49

Sat = saturation of soil sample, EC = electrical conductivity, SAR = sodium adsorption ratio, WSS = water-soluble sodium

Table 2.3.11 Soil salinity values per replicate block for Site RR: pH, EC, SAR and WSS

Site	Block	Tillage	Depth	Sat	pH	EC	SAR	WSS
				%		dS/m		%
RR	North	RIP	0-15	64	7.7	0.63	1.4	31
RR	North	RIP	15-30	63	8.1	0.67	3.0	45
RR	North	RIP	30-45	71	8.5	0.73	5.4	61
RR	North	RIP	45-60	87	8.8	0.93	7.6	74
RR	North	RIP	60-90	70	8.3	5.13	8.8	54
RR	North	RIP	90-120	55	8.0	7.77	8.7	43
RR	North	CNTL	0-15	60	7.6	0.77	1.2	24
RR	North	CNTL	15-30	65	8.0	0.83	1.7	33
RR	North	CNTL	30-45	63	8.2	0.80	3.3	50
RR	North	CNTL	45-60	68	8.3	1.87	6.3	57
RR	North	CNTL	60-90	83	8.5	2.27	8.7	65
RR	North	CNTL	90-120	70	8.1	5.63	10.7	59
RR	Mid	RIP	0-15	57	7.2	0.80	1.2	25
RR	Mid	RIP	15-30	62	7.5	0.70	1.7	35
RR	Mid	RIP	30-45	65	7.6	1.53	2.3	33
RR	Mid	RIP	45-60	60	7.9	2.20	3.5	41
RR	Mid	RIP	60-90	59	8.0	3.27	5.5	44
RR	Mid	RIP	90-120	70	8.0	4.17	6.7	46
RR	Mid	CNTL	0-15	61	7.8	0.97	1.4	26
RR	Mid	CNTL	15-30	64	8.0	0.77	1.6	32
RR	Mid	CNTL	30-45	61	8.2	1	2.6	41
RR	Mid	CNTL	45-60	62	8.2	2.2	4.6	45
RR	Mid	CNTL	60-90	51	7.9	5.73	4.8	31
RR	Mid	CNTL	90-120	57	7.8	7.23	8.4	44
RR	South	RIP	0-15	58	7.3	0.77	3.0	47
RR	South	RIP	15-30	63	8.0	1.07	6.3	65
RR	South	RIP	30-45	63	8.3	3.33	9.0	70
RR	South	RIP	45-60	83	8.5	4.50	13.2	74
RR	South	RIP	60-90	99	8.5	5.17	12.6	69
RR	South	RIP	90-120	96	8.1	8.70	12.2	53
RR	South	CNTL	0-15	62	7.5	0.60	2.1	40
RR	South	CNTL	15-30	58	8.3	0.73	4.4	61
RR	South	CNTL	30-45	78	8.3	2.40	7.1	63
RR	South	CNTL	45-60	92	8.2	4.50	9.0	59
RR	South	CNTL	60-90	99	8.1	8.27	9.9	47
RR	South	CNTL	90-120	81	7.9	10.03	12.0	50

Sat = saturation of soil sample, EC = electrical conductivity, SAR = sodium adsorption ratio, WSS = water-soluble sodium

Table 2.3.12 Soil salinity values per replicate block for Site DE: water-soluble cations and anions

Site	Block	Tillage	Depth	Na	Ca	Mg	K	Cl	SO_4
				me/l				ppm	
DE	South	RIP	0-15	3.2	2.5	2.4	0.34	38.0	142
DE	South	RIP	15-30	5.4	1.6	1.6	0.06	16.0	102
DE	South	RIP	30-45	10.8	1.5	1.4	0.08	13.7	313
DE	South	RIP	45-60	28.8	15.0	19.2	0.41	16.3	2824
DE	South	RIP	60-90	58.3	21.7	39.8	2.61	16.3	5727
DE	South	RIP	90-120	64.0	18.1	35.6	0.50	30.0	5543
DE	South	CNTL	0-15	2.3	2.5	2.1	0.20	34.5	75
DE	South	CNTL	15-30	4.4	1.4	1.3	0.04	6.0	83
DE	South	CNTL	30-45	6.3	1.2	1.0	0.05	5.5	119
DE	South	CNTL	45-60	23.4	12.5	16.1	0.30	6.0	2379
DE	South	CNTL	60-90	47.5	22.7	35.6	0.62	2.5	5065
DE	South	CNTL	90-120	62.7	22.0	40.5	0.58	20.0	6030
DE	Mid	RIP	0-15	3.7	3.5	3.0	0.59	48.0	300
DE	Mid	RIP	15-30	19.1	9.1	14.3	0.16	33.0	1824
DE	Mid	RIP	30-45	49.3	21.1	40.5	0.49	40.5	4405
DE	Mid	RIP	45-60	62.5	21.6	53.8	0.79	52.5	6540
DE	Mid	RIP	60-90	74.9	21.7	63.5	1.00	78.0	7560
DE	Mid	RIP	90-120	72.7	14.6	51.7	0.86	67.5	6330
DE	Mid	CNTL	0-15	2.6	3.1	1.8	0.37	30.0	154
DE	Mid	CNTL	15-30	5.9	1.5	1.5	0.08	19.7	183
DE	Mid	CNTL	30-45	41.9	14.8	35.8	0.40	54.0	4167
DE	Mid	CNTL	45-60	72.6	22.0	74.3	0.72	81.7	7590
DE	Mid	CNTL	60-90	69.2	16.4	62.4	0.71	68.0	6467
DE	Mid	CNTL	90-120	73.2	16.6	57.2	0.78	98.3	6907
DE	North	RIP	0-15	2.1	2.2	1.8	0.49	63.3	108
DE	North	RIP	15-30	2.8	2.1	1.8	0.08	16.0	126
DE	North	RIP	30-45	6.8	2.9	3.6	0.20	25.7	399
DE	North	RIP	45-60	13.2	3.8	6.1	0.29	26.0	894
DE	North	RIP	60-90	23.4	2.6	7.3	0.44	25.7	1371
DE	North	RIP	90-120	64.3	23.1	47.4	1.23	29.0	6267
DE	North	CNTL	0-15	2.2	2.1	1.6	0.37	52.0	101
DE	North	CNTL	15-30	4.6	2.0	1.9	0.12	36.7	202
DE	North	CNTL	30-45	19.1	9.5	18.6	0.40	40.7	2003
DE	North	CNTL	45-60	30.1	8.4	28.5	0.61	48.7	2901
DE	North	CNTL	60-90	34.5	7.4	23.5	0.64	44.0	2890
DE	North	CNTL	90-120	48.1	10.1	32.3	0.79	49.3	4113

Table 2.3.13 Soil salinity values per replicate block for Site JE: water-soluble cations and anions

Site	Block	Tillage	Depth	Na	Ca	Mg	K	Cl	SO_4
				---------------- me/l			----------------	---- ppm ----	
JE	South	RIP	0-15	1.7	2.1	1.7	1.10	39.5	89
JE	South	RIP	15-30	1.6	2.0	1.3	0.69	17.5	129
JE	South	RIP	30-45	7.0	5.0	6.8	0.78	43.5	669
JE	South	RIP	45-60	22.2	12.2	32.7	0.82	56.0	2715
JE	South	RIP	60-90	27.1	13.3	34.9	0.66	41.0	3141
JE	South	RIP	90-120	30.2	12.6	29.4	0.90	26.5	3253
JE	South	CNTL	0-15	2.4	3.1	2.2	0.56	28.7	101
JE	South	CNTL	15-30	3.8	1.8	1.7	0.09	9.0	118
JE	South	CNTL	30-45	6.0	1.2	1.6	0.07	14.0	166
JE	South	CNTL	45-60	17.6	8.0	13.4	0.23	9.7	1580
JE	South	CNTL	60-90	40.8	17.3	34.6	0.57	45.0	4279
JE	South	CNTL	90-120	45.7	18.6	35.0	0.70	36.0	4453
JE	Mid	RIP	0-15	3.2	2.4	2.0	0.35	42.3	126
JE	Mid	RIP	15-30	6.1	1.8	3.5	0.10	9.3	176
JE	Mid	RIP	30-45	16.6	7.7	14.2	0.29	10.7	1583
JE	Mid	RIP	45-60	28.1	6.2	18.0	0.44	16.0	2103
JE	Mid	RIP	60-90	46.8	16.7	36.5	0.74	35.3	4073
JE	Mid	RIP	90-120	53.7	17.3	36.7	0.77	41.3	4200
JE	Mid	CNTL	0-15	4.9	1.7	1.3	0.19	24.7	118
JE	Mid	CNTL	15-30	12.3	1.7	2.0	0.11	25.0	267
JE	Mid	CNTL	30-45	25.0	4.3	8.6	0.29	39.0	1383
JE	Mid	CNTL	45-60	53.4	13.7	34.0	0.68	53.7	4443
JE	Mid	CNTL	60-90	71.7	15.8	49.9	0.84	57.3	5920
JE	Mid	CNTL	90-120	74.1	15.9	50.8	0.74	70.0	6153
JE	North	RIP	0-15	4.4	1.8	1.5	0.43	30.3	193
JE	North	RIP	15-30	8.2	2.0	1.9	0.16	11.3	290
JE	North	RIP	30-45	21.2	7.7	15.1	0.35	17.3	1748
JE	North	RIP	45-60	24.9	5.0	14.7	0.36	11.7	1459
JE	North	RIP	60-90	32.3	5.2	17.5	0.43	20.3	2156
JE	North	RIP	90-120	42.5	7.3	21.2	0.56	54.7	2402
JE	North	CNTL	0-15	9.1	1.9	3.3	0.35	40.0	157
JE	North	CNTL	15-30	31.0	11.5	25.6	0.52	43.5	2732
JE	North	CNTL	30-45	47.0	5.6	27.2	0.66	70.0	3465
JE	North	CNTL	45-60	65.7	115.5	51.4	0.98	115.0	5900
JE	North	CNTL	60-90	83.9	114.3	74.9	1.10	148.0	8055
JE	North	CNTL	90-120	83.1	22.1	64.9	0.86	117.0	7680

Table 2.3.14 Soil salinity values per replicate block for Site RR: water-soluble cations and anions

Site	Block	Tillage	Depth	Na	Ca	Mg	K	Cl	SO_4
			- cm -	----	---- me/l	----	----	---- ppm	----
RR	North	RIP	0-15	2.1	2.6	2.0	0.23	14.0	136
RR	North	RIP	15-30	3.7	2.1	1.9	0.09	3.7	106
RR	North	RIP	30-45	5.2	1.4	1.5	0.17	5.0	145
RR	North	RIP	45-60	8.0	0.9	1.5	0.19	9.0	139
RR	North	RIP	60-90	32.6	15.8	25.1	0.81	16.7	3281
RR	North	RIP	90-120	50.2	22.6	38.5	1.05	52.7	5173
RR	North	CNTL	0-15	2.1	3.4	2.8	0.36	16.7	161
RR	North	CNTL	15-30	3.0	3.0	2.9	0.19	5.7	220
RR	North	CNTL	30-45	4.3	1.6	2.2	0.25	8.7	180
RR	North	CNTL	45-60	7.7	7.6	10.2	0.56	5.7	990
RR	North	CNTL	60-90	13.5	9.0	8.8	0.66	7.7	1226
RR	North	CNTL	90-120	39.0	14.6	26.0	0.97	12.7	3633
RR	Mid	RIP	0-15	2.1	3.5	2.6	0.34	10.3	215
RR	Mid	RIP	15-30	2.6	2.5	2.2	0.08	3.2	176
RR	Mid	RIP	30-45	5.5	7.3	6.3	0.16	23.3	751
RR	Mid	RIP	45-60	8.9	10.1	9.9	0.21	27.3	1157
RR	Mid	RIP	60-90	17.6	7.6	13.0	0.38	8.0	1711
RR	Mid	RIP	90-120	25.2	8.2	18.6	0.53	8.7	2325
RR	Mid	CNTL	0-15	2.8	4.7	2.9	0.28	19.0	275
RR	Mid	CNTL	15-30	2.7	2.7	2.7	0.19	3.3	217
RR	Mid	CNTL	30-45	4.3	2.3	3.9	0.16	5.7	303
RR	Mid	CNTL	45-60	9.2	10.2	8.9	0.34	9.7	1219
RR	Mid	CNTL	60-90	25.1	23.9	31.5	0.82	8.0	3723
RR	Mid	CNTL	90-120	43.9	22.0	32.1	0.91	9.7	4583
RR	South	RIP	0-15	3.8	2.1	1.9	0.17	12.3	155
RR	South	RIP	15-30	8.1	1.5	1.6	0.08	14.0	217
RR	South	RIP	30-45	25.3	5.3	12.3	0.15	21.3	1779
RR	South	RIP	45-60	36.2	8.1	21.2	0.45	53.7	2690
RR	South	RIP	60-90	40.7	5.8	18.6	0.38	48.7	2912
RR	South	RIP	90-120	64.1	16.2	39.9	0.68	50.0	5820
RR	South	CNTL	0-15	2.6	2.2	1.8	0.25	18.7	77
RR	South	CNTL	15-30	5.5	1.7	1.6	0.05	2.0	108
RR	South	CNTL	30-45	14.7	8.8	8.9	0.12	6.7	1196
RR	South	CNTL	45-60	29.8	12.5	16.5	0.32	7.0	2535
RR	South	CNTL	60-90	54.5	22.0	38.3	0.60	20.0	5200
RR	South	CNTL	90-120	71.8	23.1	48.5	0.65	13.7	6480

the plots, the SAR values in the Bnt horizon were around 15 in the control plot to less than 9 in the deep ripped plot.

CONCLUSIONS

Deep ripping had been carried out on three irrigated Tuxford soils to increase crop production and soil-water penetration, and to improve the suitability of these soils for irrigation. Two of the soils were classified as Solonetzic, either the entire field plot or part of it, and the third soil was classified as non-Solonetzic.

Deep ripping reduced the density of the B horizon (15-30 cm depth) and increased soil-water penetration with depth. Crop production was increased by deep ripping of the Solonetzic soils, but not of the non-Solonetzic soil. The increased crop production lasted from 2 years to at least 3 years. Greater water-use efficiency was the main reason for the increased crop production.

Deep ripping improved the suitability for irrigation of the most severe Solonetzic soil from "not suitable" to "suitable", which demonstrates the usefulness of deep ripping for managing irrigated Solonetzic soils. Deep ripping did not affect the irrigability of the second Solonetzic soil, but did appear to improve the irrigability of at least the Solonetzic part of the field plot of this Solonetzic/Chernozemic intergrade. There was no effect by deep ripping on the soil chemical characteristics of a non-Solonetzic soil, which was already rated as "suitable for irrigation" prior to deep ripping.

REFERENCES

Bennett, D.R. and T. Entz. 1990. Irrigation suitability of Solonetzic soils in the county of Newell, Alberta. Can. J. Soil Sci. 70: 705-715.

Canada Soil Survey Committee. 1987. The Canadian System of Soil Classification. Research Branch, Canada Dept. Agriculture Publication 1646.

Grevers, M.C.J. 1989. The effect of deep ripping and paraplowing on crop production in Saskatchewan, an up-date. Pages 47-54 *in* 1989 Soils and Crops Workshop. University of Saskatchewan, Saskatoon, Sask.

Working Group on Irrigation Suitability Classification. 1985. Irrigation suitability classification system for the Canadian Prairies. Preliminary Draft of Workshop Rept., Prairie Region.