2.1 The Effect of Subsoiling on Crop Production in Saskatchewan

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INTRODUCTION

Deep tillage has received much attention in the media over the past 4 to 5 years. Articles have appeared in farm publications such as Country Guide (November 1984) and GRAINEWS (September 1986), which indicated that with deep ripping crop production had been increased at particular farm sites. Furthermore, farmers have frequently reported on improved crop production in parts of their field following the installation of pipelines. In Saskatchewan, soil disturbance from the installation of pipelines has been found to increase soil productivity of Solonetzic soils (de Jong and Button, 1973). There has been much discussion amongst the farm community in Saskatchewan regarding the deep tillage work in Alberta, such as on so-called "alkali soils" around Vegreville. Deep tillage (deep plowing and/or deep ripping) in general is not recommended as a farm practice in Saskatchewan, particularly in areas sensitive to soil erosion and in areas with soil salinity problems. There was thus a need to investigate the feasibility of deep ripping under Saskatchewan conditions.

Deep ripping is considerably less expensive than deep plowing, but may cause insufficient mixing of soil layers to result in significant improvement in the productivity of Solonetzic soils (Alzubaidi and Webster, 1982). Bole (1986) found increased soil-water infiltration following deep ripping, however, the effect only lasted for 2 years. Alzubaidi and Webster (1982) found that deep ripping had resulted in increased deep leaching of salts. There has been little evidence to suggest that deep ripping results in considerable increases in crop yield of Solonetzic soils (Lavado and Cairns, 1980). Lickacz (1986) reported that deep ripping of Solonetzic soils was less beneficial in terms of increasing crop production in areas with severe moisture deficits, than in "wetter" areas. For example, he reported average wheat yield increases due to deep ripping of 130 kg/ha in the Brown soil zone compared to 400 kg/ha in the Dark Brown and Black soil zones.

Deep rippers or subsoilers, are used to loosen the soil without inverting it, and are used primarily to break through and shatter compact sub soils. Under most conditions subsoilers will break out a slot of soil that is slightly wider that the tool point (Cooper, 1971). The loosened soil resembles a triangular shaped trench (Bowen, 1981; Trouse and Humbert, 1959). Another type of subsoiler is the paraplow, which has been described as a "slant legged soil loosener" (Pidgeon, 1982). This tillage implement was originally designed to alleviate soil compaction in zero-tilled soils (Davies et al, 1982). Soil loosening is achieved through a lifting action along the legs of the plow, which results in the formation of cracks along natural planes of weakness (Davies et al, 1982). Soil loosening apparently is almost uniform with depth (Ehlers and Baeumer, 1988). Therefore, soil loosening with the paraplow is quite different from that with conventional subsoilers or deep rippers, where the soil is displaced forwards, sideways and upwards, leaving a V-shaped trench.

The objective of this research project was to investigate the effect of deep ripping and of paraplowing on the physical and chemical conditions of the soil and on crop production. A range of soil types were included, such as soils with varying degrees of solonetzic characteristics, with different textures and in different soil zones. The investigation was carried out over a four-year period.

MATERIALS AND METHODS

A total of 12 farm sites are included in the study, involving both deep ripping, ranging in depth from 50 cm to 76 cm and paraplowing to a depth of 50 cm (Table 2.1.1).

Table 2.1.1. Soil descriptions and tillage details of the research plots.

Site	Farm	Legal land location	Soil Zone	Soil Order	Soil Association	Deep tillage Year	Deep tillage Depth
				Deep Ripped			
							(cm)
Tisdale	Boxall	SE 25-45-15 W2	D.Gray	Solonetz	Arborfield C-CL	1985	76
	McEwen	SW 16-45-15 W2	D.Gray	Solon/Chern	Arborfield C-CL	1985	76
	Morgan	NE 7-46-14 W2	D.Gray	Solonetz	Arborfield C	1985	76
	Rice	NW 24-45-15 W2	D.Gray	Chernozem	Tisdale SiC-SiCL	1986	76
Arborfield	Chabot	NE 5-48-12 W2	D.Gray	Solon/Chern	Arborfield C	1986	76
	Cragg	NW 16-48-11-W2	D.Gray	Solonetz	Arborfield C	1986	76
Carrot River	Norrish	NW 31-49-9 W2	D.Gray	Chernozem	Tisdale C	1987	61
	Warner	SW 2-50-8 W2	D.Gray	Solonetz	Arborfield C	1987	61
Lucky Lake	Jessiman	NE 35-23-9 W3	Brown	Chernozem	Sceptre HC	1986	50
Cut Knife	Foisy	SE 35-43-21 W3	Black	Chernozem	Oxbow L	1986	50
				Paraplowed			
Tisdale	Boxall	SE 25-45-15 W2	D.Gray	Solonetz	Arborfield C-CL	1986	50
	McEwen	SW 16-45-15 W2	D.Gray	Solon/Chern	Arborfield C-CL	1986	50
Glenside	Harrington	SE 21-29-6 W3	D.Brown	Solonetz	Tuxford C	1986	50
Lucky Lake	Jessiman	NE 35-23-9 W3	Brown	Chernozem	Sceptre HC	1986	50
Cut Knife	Foisy	SE 35-43-21 W3	Black	Chernozem	Oxbow L	1986	50
Birsay	Millar	NE 5-24-7 W3	Brown	Chernozem	Fox Valley CL	1986	50

Solon/Chern = mixed Solonetzic-Chernozemic

The sites involve both Solonetzic and Chernozemic soils, representing the Brown soil zone, the Dark Brown soil zone, the Black soil zone and the Dark Gray soil zone. In all cases deep ripping and paraplowing were carried out in the fall. On the majority of sites deep ripping was done with a KELLO-BILT subsoiler, pulled with a 1150 VERSATILE tractor (450 HP), travelling between 5 and 6 km per hour. Paraplowing was done with a HOWARD 3-bottom paraplow (courtesy of Agriculture Canada @ Swift Current). The paraplow was pulled with a DEUTSCH DX130 tractor (~120 HP) for most of the sites, travelling between 6 and 8 km per hour. At Tisdale, A BELARUS tractor (~250 HP) was used. Tillage strips were a 1/2 mile in length and 40' to 60' in width, except at the Glenside Site, where the tillage plots consisted of a paraplowed and a control plot with dimensions of 12.8 by 250 m. Approximate cost of the deep ripping and subsequent secondary tillage operations were: $ 50 per acre on Solonetzic soils and between $ 15 and $ 25 per acre on Chernozemic soils. The costs associated with paraplowing were not computed since the unit is commercially unavailable in Saskatchewan. The treatments were replicated three times. The strips were separated by a control area of similar dimensions. Secondary tillage operations, such as discing and harrowing to smooth down the deep-tilled fields were considerable, in particular at the Tisdale, Arborfield and Carrot River Sites. At the Morgan farm, large depressions were left in the field, with subsequent exposed subsoil in some areas. At the Arborfield and Carrot River sites, subsequent secondary tillage operations in the spring had left the top 10 cm of the soil in a very dry and powdery condition for seeding.

Soil chemical criteria used to differentiate Solonetzic soils from Chernozemic soils are the exchangeable Ca/Na ratio and the % water soluble Na. A soil is considered to be Solonetzic if the exchangeable Ca/Na ratio of the B horizon is equal to or less than 10 (Canada Soil Survey Committee, 1978). A Solonetzic soil can also be identified, if the %

water soluble Na in the B horizon is equal to or greater than 50% (Ballantyne and Clayton, 1962). Based on soil chemical criteria, 5 of the sites (Boxall, Morgan, Cragg, Warner and Harrington) are Solonetzic, satisfying either the criteria for the exch. Ca/Na ratio for the B horizon or the % water soluble sodium (Tables 2.1.2 and 2.1.3). A further 2 sites (McEwen and Chabot,) have at least one of the 6 sampled profiles (worst profile) that classifies as "chemically" being Solonetzic. The remaining 5 sites (Rice, Norrish, Foisy, Jessiman and Millar) are non-Solonetzic, and deep tillage is therefore not expected to improve crop production.

Soil physical parameters that were measured include soil moisture, soil bulk density and soil strength. Soil water content was measured by neutron thermalization, using a DEPTH MOISTURE GAUGE (Troxler Electronic Laboratories Inc.). Soil bulk density was measured by gamma backscattering using a DEPTH DENSITY PROBE (Nuclear Chicago). A DEPTHPROBE CPN 501 (Hoskins Scientific) was used in 1988 for both the soil moisture and density readings. The scanning zone of the DEPTH DENSITY PROBE (Nuclear Chicago) has a vertical dimension of approximately 23 cm, while the scanning zone with the DEPTHPROBE CPN 501, has a vertical dimension of approximately 15 cm and is therefore more sensitive to "picking up" 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 the soil moisture content in-situ, using the depth probes. Readings were taken prior to seeding (1 to 2 weeks) and at harvest time. Soil strength was measured with a Proctor penetrometer. This method involves pushing a probe into the soil and measuring the force required to do so. Penetrometer measurements were taken at the time of harvest at each crop sampling area.

Crop yield was determined by taking square meter samples, in a series of paired row samples, 6 pairs in each tillage strip. At some sites, crop yields were also determined

Table 2.1.2. Soil chemical characteristics of the B horizons of the deep tillage sites.at the start of the experiment

Site	Farm	Means of all the profiles		Worst profile	
		E.C.N.[1]	P.W.S.S. [2]	E.C.N.[1]	P.W.S.S. [2]
Tisdale	Boxall	5	31	3	40
	McEwen	19	43	14	57
	Morgan	2	68	1	71
	Rice	133	14	110	19
Arborfield	Chabot	30	46	17	53
	Cragg	7	79	6	81
Lucky Lake	Jessiman	231	10	118	15
Carrot River	Norrish	121	8	97	12
	Warner	4	59	3	74
Glenside	Harrington	35	44	1	63
Cut Knife	Foisy	28	10	22	12
Birsay	Millar	30	22	27	23

1. Exchangeable calcium to exchangeable sodium ratio
2. Percent water soluble sodium

Table 2.1.3. Soil chemical characteristics in the subsoiled and in the control plots at the end of the experiment

Farm	Tillage	Depth	%WSS	SAR	EC	pH
		(cm)	(%)		mS/cm	
Boxall	Control	0-15	29.4	1.32	1.42	6.4
		15-30	44.8	1.96	1.02	7.0
		30-45	57.7	4.12	1.72	8.1
		45-60	49.6	7.40	6.90	8.0
Boxall	Paraplowed	0-15	21.6	0.83	1.17	6.1
		15-30	39.5	1.47	0.60	7.2
		30-45	50.2	2.83	1.13	8.0
		45-60	39.0	4.80	5.55	7.9
Boxall	Ripped	0-15	43.8	2.83	1.73	6.9
		15-30	51.5	3.10	1.20	7.1
		30-45	52.0	5.43	4.07	8.0
		45-60	51.7	8.10	7.20	8.0
Chabot	Control	0-15	27.1	0.93	0.73	5.7
		15-30	44.0	1.67	0.60	6.0
		30-45	61.9	2.70	0.57	7.0
		45-60	56.3	4.20	1.80	7.9
Chabot	Ripped	0-15	24.4	0.80	0.67	5.8
		15-30	41.7	2.00	1.17	6.1
		30-45	64.2	2.37	0.40	6.5
		45-60	60.7	3.50	0.90	7.6
Cragg	Control	0-15	65.7	4.57	1.17	6.4
		15-30	80.8	7.37	1.03	7.5
		30-45	76.2	10.43	3.40	8.0
		45-60	67.5	11.50	6.20	8.0
Cragg	Ripped	0-15	68.7	4.17	0.80	6.9
		15-30	82.3	7.30	0.97	7.6
		30-45	82.5	10.50	2.00	8.0
		45-60	74.0	11.90	4.70	7.9
Foisy	Control	0-15	4.8	0.17	1.03	5.2
		15-30	9.4	0.23	0.47	6.0
		30-45	17.6	0.60	0.60	6.9
		45-60	28.4	1.60	1.70	7.8
Foisy	Paraplowed	0-15	4.5	0.20	1.17	5.2
		15-30	10.5	0.20	0.43	6.0
		30-45	13.8	0.27	0.23	6.3
		45-60	17.6	0.50	0.50	7.5

%WSS= % water-soluble sodium, SAR= sodium adsorption ratio, EC= electrical conductivity

Table 2.1.3 Continued

Farm	Tillage	Depth	%WSS	SAR	EC	pH
		(cm)	(%)		mS/cm	
Foisy	Ripped	0-15	4.7	0.17	0.90	5.0
		15-30	10.5	0.23	0.50	6.0
		30-45	19.0	0.57	0.60	6.9
		45-60	42.5	1.50	0.50	8.1
Harrington	Control	0-15	31.4	1.33	0.77	7.3
		15-30	57.2	3.30	0.60	8.0
		30-45	66.3	8.60	3.43	8.3
		45-60	62.8	10.60	7.00	8.3
Harrington	Paraplowed	0-15	47.6	2.63	0.73	7.7
		15-30	66.7	4.73	0.80	8.2
		30-45	66.9	9.07	4.73	8.3
		45-60	60.7	12.20	9.60	8.2
Jessiman	Control	0-15	10.1	0.27	0.50	7.3
		15-30	17.7	0.43	0.33	7.8
		30-45	37.5	1.03	0.37	8.0
		45-60	50.0	2.70	1.00	8.1
Jessiman	Paraplowed	0-15	9.5	0.33	1.13	6.7
		15-30	20.0	0.53	0.47	7.2
		30-45	38.7	1.23	0.40	8.0
		45-60	48.2	2.80	1.30	8.1
Jessiman	Ripped	0-15	10.8	0.27	0.40	7.1
		15-30	17.3	0.43	0.33	7.8
		30-45	33.2	1.00	0.37	8.0
		45-60	64.6	3.50	0.70	8.1
McEwen	Control	0-15	17.4	0.73	1.48	5.5
		15-30	42.7	1.63	0.63	6.7
		30-45	51.2	3.00	0.98	7.5
		45-60	52.5	4.50	2.50	7.9
McEwen	Paraplowed	0-15	20.3	0.60	0.73	5.6
		15-30	43.1	1.40	0.43	6.5
		30-45	51.8	2.93	0.73	7.7
		45-60	56.2	4.60	2.10	8.0
McEwen	Ripped	0-15	22.9	0.97	1.43	5.3
		15-30	57.9	2.47	0.47	6.5
		30-45	56.2	3.80	1.57	7.7
		45-60	35.8	4.10	5.20	7.8

%WSS= percent water-soluble sodium, SAR= sodium adsorption ratio, EC= electrical conductivity

Table 2.1.3. Continued

Farm	Tillage	Depth	%WSS	SAR	EC	pH
		(cm)	(%)		mS/cm	
Millar	Control	0-15	36.2	1.53	0.77	7.2
		15-30	42.0	1.53	0.60	7.7
		30-45	58.3	3.57	0.97	8.2
		45-60	69.1	7.30	2.60	8.5
Millar	Paraplowed	0-15	26.0	1.23	1.27	7.3
		15-30	22.5	1.00	1.17	7.7
		30-45	45.5	2.30	0.90	8.2
		45-60	29.9	3.30	5.40	7.7
Morgan	Control	0-15	69.2	5.70	1.15	5.9
		15-30	80.6	7.95	1.15	7.2
		30-45	77.1	10.70	4.00	8.2
		45-60	70.0	10.80	5.00	8.1
Morgan	Ripped	0-15	63.5	4.60	1.50	5.6
		15-30	78.7	6.55	1.05	6.6
		30-45	81.9	10.70	2.50	8.2
		45-60	60.0	10.90	8.10	8.1
Norrish	Control	0-15	8.2	0.27	0.77	7.0
		15-30	12.9	0.40	0.50	6.9
		30-45	19.2	0.70	0.73	7.1
		45-60	13.1	0.70	1.80	7.7
Norrish	Ripped	0-15	7.4	0.30	1.00	6.7
		15-30	9.0	0.27	0.63	6.7
		30-45	12.0	0.37	0.80	7.1
		45-60	13.2	0.70	1.70	7.4
Rice	Control	0-15	10.5	0.43	1.10	6.6
		15-30	20.1	0.60	0.57	7.1
		30-45	21.7	0.60	0.43	7.6
		45-60	38.0	1.30	0.60	8.1
Rice	Ripped	0-15	8.7	0.30	0.97	6.5
		15-30	12.2	0.30	0.60	7.1
		30-45	20.2	0.57	0.43	7.8
		45-60	37.8	1.20	0.40	8.1
Warner	Control	0-15	74.1	5.87	1.23	5.2
		15-30	74.3	7.30	1.67	6.3
		30-45	67.6	9.07	4.10	7.5
		45-60	60.8	9.60	6.20	8.0
Warner	Ripped	0-15	65.4	4.23	1.00	5.6
		15-30	79.5	6.97	1.13	6.1
		30-45	74.5	9.23	2.90	7.5
		45-60	56.5	8.30	5.90	7.9

using weigh wagons. The crop samples were transported to the University, where the samples were dried, weighed, threshed and grain weights were taken. Crop water use (mm) was determined from the difference between the soil moisture content at seeding and at harvest, plus the growing season precipitation (from the nearest weather station). Crop water-use efficiency was determined by dividing the grain yield by the total crop water use (kg/ha/cm).

RESULTS AND DISCUSSION

Soil Bulk Density

The soil bulk density in the deep tillage plots in the spring of 1988 is listed in Table 2.1.4. The bulk density in 1987 was also measured, however, the instrumentation used in 1987 prevented the detection of small differences in density. The ripped plots were less dense and therefore had greater soil porosity at the 20-40 cm depth. In some cases (Boxall, McEwen and Morgan) this phenomena exists 3 years after the deep ripping operation. The density in the deep ripped plots compared to the control plots was lower by an average of 0.13 gm/cm^3 at the 25 cm depth, and by an average of 0.09 gm/cm^3 at the 40 cm depth. Comparable values for the paraplowed plots were 0.08 and 0.05 gm/cm3 for the 25 cm and for the 40 cm depths, respectively. The effect of paraplowing on soil bulk density was therefore less dramatic than the effect of deep ripping.

Soil-Water Recharge

Over-winter soil-water recharge was calculated from the soil moisture readings taken at harvest time (Aug/Sep) and in spring (April). The relative amount amount of soil-water recharge during this period therefore is indicative of differences in soil-water infiltration from rainfall and from melting snow, and of soil-water conservation during this

Table 2.1.4. Soil bulk density values in the spring of 1988, for the 25,40 and 60 cm depths.

Site	Farm	25 cm Cntl	25 cm Till	40 cm Cntl	40 cm Till	60 cm Cntl	60 cm Till
		gm/cm^3					
		Deep Ripping					
Tisdale	Boxall	1.419	1.311	1.489	1.425*	1.500	1.470
	McEwen	1.222	1.091	1.492	1.412*	1.542	1.508
	Morgan	1.310	1.228	1.503	1.403*	1.474	1.457
	Rice	1.147	1.137	1.689	1.477*	1.510	1.601
Arborfield	Chabot	1.286	1.048	1.442	1.330	1.495	1.505
	Cragg	1.428	1.297	1.383	1.256	1.425	1.465
Carrot Rvr	Norrish	1.479	1.312	1.456	1.422	1.446	1.419
	Warner	1.600	1.438	1.362	1.298	1.344	1.374
Lucky Lk	Jessiman	1.399	1.083*	1.508	1.336*	1.573	1.568
Cut Knife	Foisy	1.384	1.476	1.701	1.687	1.835	1.684*
		Paraplowing					
Tisdale	Boxall	1.419	1.394	1.489	1.374*	1.500	1.470
	McEwen	1.226	1.275	1.422	1.374	1.504	1.509
Lucky Lk	Jessiman	1.399	1.257	1.508	1.454	1.573	1.578
Birsay	Millar	1.414	1.178	1.513	1.529	1.637	1.620

Values followed by * are significantly different P 0.05
No values are available for the Harrington and Foisy paraplow tests.

period. The relative gain (cm H_2O) in soil moisture in the deep tillage plots compared to the gain in soil moisture in the control plots for the first three years following the deep tillage operations is listed in Tables 2.1.5 and 2.1.6. The ripped plots gained an additional 0.8 cm in the second year following deep ripping. No measurements had been taken for the first year. The paraplowed plots gained an additional 3.4 cm and 1.2 cm, in the first year and in the second year, respectively, following the paraplowing operations. There does appear to be a positive effect of either deep tillage treatment on soil-water recharge over the winter period, and the effect may last up to 2 years.

Soil Strength

Soil penetrometer measurements were taken at the time of harvest and results are shown in Table 2.1.7. In 1986, the soil strength in the deep ripped plots at 7.5 cm depth was less than the soil strength in the control plots for all the three sites. The soil moisture content at this depth (not shown) was also greater in the ripped plots. Consequently the differences in soil strength do not necessarily indicate differences in soil porosity. In 1987, there were two sites where deep ripping had resulted in reduced soil strength (Morgan and Jessiman), and two sites where paraplowing had reduced soil strength (Boxall and Jessiman). The soil moisture contents for these sites was similar amongst the tillage plots. In 1988, a more thorough investigation of soil strength with depth, revealed very little significant differences due to either deep ripping or due to paraplowing, except at the Tisdale sites at the 40 cm depth. In general, a trend in the data showed that deep ripping had reduced soil strength at the 20 and 40 cm depths, while paraplowing had reduced soil strength primarily at the 20 cm depth.

Table 2.1.5. Over-winter water recharge in the tillage plots for 1987/1988.

Site	Tillage	Soil moisture levels Fall	Spring	Gain	% Gain
		cm H_2O			
Boxall	Control	36.2	48.2	12.0	33
	Ripped	36.7	49.5	12.8	35
	Paraplowed	35.2	48.2	13.0	37
McEwen	Control	35.1	45.0	9.9	28
	Ripped	36.6	44.7	8.1	22
	Paraplowed	34.0	45.4	11.4	34
Morgan	Control	36.5	47.8	11.3	31
	Ripped	36.6	48.9	12.3	34
Rice	Control	27.6	35.0	7.4	27
	Ripped	23.8	30.0	6.2	26
Chabot	Control	40.7	50.7	10.0	25
	Ripped	36.8	46.9	10.1	27
Cragg	Control	37.8	52.6	14.8	39
	Ripped	36.6	53.1	16.5	45
Jessiman	Control	33.4	36.2	2.8	8
	Ripped	32.3	37.1	4.8	15
	Paraplowed	37.5	40.8	3.3	9
Millar	Control	25.2	27.8	2.3	9
	Paraplowed	25.6	29.8	4.2	16
Foisy	Control	21.8	24.4	2.7	12
	Ripped	22.6	24.0	1.4	6

No data available for the Harrington site

Table 2.1.6. Increase in soil water recharge in the deep tillage plots relative to that in the control plots for the first three years following the deep tillage operations.

Site	Year #1	Year #2	Year #3
	---------- cm H_2O	----------	
		Deep Ripping	
Boxall	n.d.	0.0	0.8
Morgan	n.d.	4.0	1.0
McEwen	n.d.	1.0	-1.8
Rice	n.d.	-1.2	n.d.
Chabot	n.d.	0.1	n.d.
Cragg	n.d.	1.7	n.d.
Jessiman	1.8	2.0	n.d.
Foisy	-1.7	-1.3	
Average	n.d.	0.8	0.0
		Paraplowing	
Boxall	2.8	1.0	n.d.
McEwen	5.5	1.5	n.d.
Jessiman	5.1	0.5	n.d.
Millar	0.0	1.9	n.d.
Average	3.4	1.2	n.d.

n.d. = no data

Table 2.1.7. Soil strength measurements in the top 40 cm in the tillage plots.

Site	Tillage	1986 7.5 cm	1987 7.5 cm	1988 10 cm	1988 20 cm	1988 30 cm	1988 40 cm
		-MPa-					
Boxall	Control	1.65	0.76	1.75	2.67	4.00	4.25
	Ripped	1.16	0.73	1.25	1.50	1.68	1.50
	Parapl.		0.64*	1.75	4.63	4.38	4.88
McEwen	Control	8.25		4.79	6.58	7.71	8.13
	Ripped	6.58		5.14	6.72	7.61	7.83
	Parapl.			4.94	6.36	7.44	7.67
Morgan	Control	7.35	2.93	3.38	4.38	5.46	6.25
	Ripped	3.46	2.04*	3.00	4.46	4.96	5.13
Rice	Control			1.67	2.75	3.97	5.94
	Ripped			1.36	2.03*	2.86	3.50*
Chabot	Control		0.39	6.97	7.22	8.19	8.28
	Ripped		0.38	6.47	7.14	7.94	8.03
Cragg	Control			5.61	6.36	6.94	7.28
	Ripped			4.92	5.78	6.33	6.67
Jessiman	Control		0.92	2.92	5.33	4.78	6.03
	Ripped		0.60*	2.56	3.53*	4.72	5.53
	Parapl.		0.75*	2.47	3.92	5.56	6.58
Norrish	Control			2.97	4.19	5.28	5.67
	Ripped			2.56	3.50	4.56	4.94
Warner	Control			5.44	5.56	4.89	4.94
	Ripped			4.25	4.83	5.06	5.46
Millar	Control		3.99	0.72	1.81	2.28	3.08
	Parapl.		4.96	0.64	1.44	1.94	2.53

Values followed by a * indicate significantly different from the value for the control

Soil NO_3-Nitrogen levels in the spring

In the third and fourth year following deep ripping of Solonetzic soils, spring soil NO_3-nitrogen levels in deep ripped plots were an average of 26 and 58 kg/ha higher compared to that of the control plots (Table 2.1.8). In the second year following deep ripping of Chernozemic soils, spring soil NO_3-nitrogen levels in deep ripped plots were an average of 42 kg/ha higher compared to that of the control plots. Paraplowing increased spring soil NO_3-nitrogen levels only in Solonetzic soils by an average of 35 kg/ha.

Water-Use Efficiency

The water-use efficiency (WUE) values were generally greater in the deep ripped plots compared to the control plots (Table 2.1.8). The WUE values in the second, third and fourth year following deep ripping of Solonetzic soils were 34%, 28% and 21% higher, respectively, compared to the corresponding control plots. On Chernozemic soils deep ripping affected the WUE values only in the second year, resulting in an increase of 20% relative to that of the control plots.There was little effect of paraplowing on the WUE of crops grown on either Solonetzic or Chernozemic soils.

Crop production over the four-year period following deep tillage.

There were considerable plant emergence problems in the first year after deep ripping at 6 sites; Boxall, McEwen, Morgan, Cragg, Chabot and Norrish. In each case spring secondary tillage operations required to "smooth down" the seedbed in the ripped strips, had resulted in relatively poor seedbed conditions. In 1986, timely spring rains alleviated the crop emergence problems at the Boxall, McEwen and Morgan sites. The crop in the ripped areas recovered and eventually out-yielded the crop in the control areas at these sites. In 1987, rainfall was relatively poor in the spring, and the crop in the ripped

Table 2.1.8. Grain yield and grain yield variability in the tillage plots.

Site	Farm	Year	Crop	Tillage	Spring seeding		Yield			WUE
					SMC	NO_3-N	Total	Grain	CV	
					(% w/w)	(kg/ha)	(kg/ha)	(Bu/A)	(%)	(kg/ha/cm
Tisdale	Boxall	1986	Wheat	Control	ND	ND	4262	34.3	22	ND
				Ripped	ND	ND	5795	43.1	19	ND
		1987	Wheat	Control	40.8	ND	3548	18.4	36	47
				Ripped	42.6	ND	5042	34.8	31	90
				Parapl.	43.6	ND	4574	29.5	31	69
		1988	Wheat	Control	46.8	94		Crop Failure		
				Ripped	49.5	135		Crop Failure		
				Parapl.	48.2	130		Crop Failure		
		1989	Wheat	Control	36.4	107	5673	37.4	27	131
				Ripped	33.8	198	6420	42.1	51	177
				Paraplowed	33.3	75	5522	35.3	13	152
Tisdale	McEwen	1986	Peas	Control	ND	ND	2899	22.7	23	ND
				Ripped	ND	ND	4217	32.9	25	ND
		1987	Flax	Control	44.0	ND	3195	21.0	12	46
				Ripped	45.8	ND	3830	24.0	8	50
		1987	Flax	Control	49.0	ND	3704	22.5	12	39
				Parapl.	51.3	ND	3652	23.1	7	38
		1988	Barley	Control	45.0	126	3927	30.3	32	74
				Ripped	44.7	139	5071	40.8	30	99
		1988	Barley	Control	42.9	95	3851	25.0	26	65
				Parapl.	45.4	133	5039	37.2	23	90

† Results from weigh wagon measurements

SMC= soil moisture content, CV= coefficient of variation in grain yield, WUE= water use efficiency, ND = no data available

Note: high values for WUE for some of the Tisdale and Carrot River Sites may have been due to soil-moisture recharge from below 130 cm

Table 2.1.8. Continued.

Site	Farm	Year	Crop	Tillage	Spring seeding SMC	Spring seeding NO_3-N	Yield Total	Yield Grain	Yield CV	WUE
					(% w/w)	(kg/ha)	(kg/ha)	(Bu/A)	(%)	(kg/ha/cm
Tisdale	McEwen	1989	Flax	Control	44.2	112	2716	11.5	14	22
				Ripped	43.3	84	2913	12.1	15	23
		1989	Flax	Control	44.2	112	2716	11.5	14	22
				Paraplowed	41.2	86	2438	10.0	38	19
Tisdale	Morgan	1986	Barley	Control	ND	ND	5362	48.6 (41)†	22	ND
				Ripped	ND	ND	6264	56.5 (47)†	20	ND
		1987	Flax	Control	36.7	ND	2963	23.0	18	69
				Ripped	36.5	ND	4246	27.1	10	81
		1988	HY320	Control	47.8	31	1825	14.3	30	51
				Ripped	48.9	69	2393	19.0	30	63
		1989	HY320	Control	34.7	68	5948	37.8	27	126
				Ripped	35.4	212	7240	43.3	3	160
Arborfield	Chabot	1987	Peas	Control	45.9	ND	5979	31.2	17	64
				Ripped	45.9	ND	6977	28.6	29	52
		1988	Flax	Control	50.9	85	1910	9.8	30	28
				Ripped	47.9	102	1964	9.8	25	28
		1989	Smf	Control	39.5	140		Fallow		
				Ripped	37.5	162		Fallow		
Arborfield	Cragg	1987	Wheat	Control	52.7	ND	6249	41.8	13	68
				Ripped	51.6	ND	5968	34.9	21	54

† Results from weigh wagon measurements
SMC= soil moisture content, CV= coefficient of variation in grain yield, WUE= water use efficiency, ND = no data available
Note: high values for WUE for some of the Tisdale and Carrot River Sites may have been due to soil-moisture recharge from below 130 cm

Table 2.1.8. Continued.

Site	Farm	Year	Crop	Tillage	Spring seeding		Yield			WUE
					SMC	NO_3-N	Total	Grain	CV	
					(% w/w)	(kg/ha)	(kg/ha)	(Bu/A)	(%)	(kg/ha/cm
Arborfield	Cragg	1988	Barley	Control	52.6	18	4319	23.8	28	73
				Ripped	53.1	16	5183	35.4	12	102
		1989	Smf	Control	39.3	27		Fallow		
				Ripped	39.3	32		Fallow		
Tisdale	Rice	1988	Wheat	Control	35.0	113	3795	29.1	25	60
				Ripped	30.9	131	4345	33.0	15	75
		1989	Flax	Control	26.8	120	3461	14.4	27	30
				Ripped	23.8	168	3501	15.0	8	33
Lucky Lake	Jessiman	1987	Wheat	Control	36.1	ND	6423	44.1	21	126
				Ripped	37.3	ND	6587	44.3	20	111
				Parapl.	42.5	ND	7040	46.4	21	117
		1988	W.Wheat	Control	36.2	20		Crop Failure		
				Ripped	37.1	31		Crop Failure		
				Parapl	40.8	31		Crop Failure		
		1989	Barley	Control	25.9	17	3759	30.9	17	66
				Ripped	27.6	20	4220	33.7	17	67
				Paraplowed	31.7	46	4154	30.2	11	65
Glenside	Harringt	1987	Wheat	Control	29.4	ND	2872	20.0	20	50
				Parapl.	31.2	ND	2840	19.8	22	48
		1988	Mustard	Control	26.4	14		Crop Failure		
				Parapl.	36.1	45		Crop Failure		

† Results from weigh wagon measurements
SMC= soil moisture content, CV= coefficient of variation in grain yield, WUE= water use efficiency, ND = no data available
Note: high values for WUE for some of the Tisdale and Carrot River Sites may have been due to soil-moisture recharge from below 130 cm

Table 2.1.8. Continued.

Site	Farm	Year	Crop	Tillage	Spring seeding		Yield			WUE
					SMC	NO_3-N	Total	Grain	CV	
					(% w/w)	(kg/ha)	(kg/ha)	(Bu/A)	(%)	(kg/ha/cm
Glenside	Harringt.	1989	Smf	Control	22.6	30		Fallow		
				Parapl.	30.9	43		Fallow		
Cut Knife	Foisy	1987	Lentils	Control	26.7	ND	7667	40.4	12	91
				Ripped	27.5	ND	7346	41.1	13	95
				Parapl.	27.7	ND	7326	42.3	13	85
		1988	Peas	Control	24.4	45		No yield data		
				Ripped	23.7	32		No yield data		
				Parapl.	24.0	37		No yield data		
		1989	Canola	Control	22.6	140	3351	16.6	8	40
				Ripped	23.2	140	3270	17.1	16	42
				Paraplowed	25.2	110	3751	18.4	10	42
Birsay	Millar	1987	Flax	Control	32.2	ND	6403	34.7 (29)†	13	76
				Parapl.	31.7	ND	6271	35.0 (33)†	10	78
		1988	Wheat	Control	27.8	32	5539	35.5	38	ND
				Parapl.	29.5	44	5273	37.7	38	ND
Carrot River	Norrish	1988	Canola	Control	49.2	47	5055	30.4	25	65
				Ripped	51.9	48	4616	25.9	38	56
		1989	Canola	Control	33.8	81	5118	25.7	8	87
				Ripped	35.4	147	5192	24.8	17	95

† Results from weigh wagon measurements
SMC= soil moisture content, CV= coefficient of variation in grain yield, WUE= water use efficiency, ND = no data available
Note: high values for WUE for some of the Tisdale and Carrot River Sites may have been due to soil-moisture recharge from below 130 cm

Table 2.1.8. Continued.

Site	Farm	Year	Crop	Tillage	Spring seeding		Yield			WUE
					SMC	NO_3-N	Total	Grain	CV	
					(% w/w)	(kg/ha)	(kg/ha)	(Bu/A)	(%)	(kg/ha/cm
Carrot River	Warner	1988	Canola	Control	64.6	8	2683	12.8	20	88
				Ripped	64.7	30	4228	20.2	29	132
		1989	Barley	Control	42.0	9	3014	25.8	7	95
				Ripped	40.7	19	7713	61.1	41	269

† Results from weigh wagon measurements
SMC= soil moisture content, CV= coefficient of variation in grain yield, WUE= water use efficiency, ND = no data available
Note: high values for WUE for some of the Tisdale and Carrot River Sites may have been due to soil-moisture recharge from below 130 cm

areas at Cragg's and at Chabot's was unable to fully recover, and as a consequence some of the crop never emerged and some of the crop was still quite green at the time of harvest. The same problems existed in 1988 at the Norrish site.

Deep ripping increased crop yields mainly on Solonetzic soils. Average grain yield increases on Solonetzic soils were 20%, 51%, 34% and 11%, in the first, second, third and fourth year, respectively, following deep ripping. Paraplowing increased grain yields on Solonetzic soils by 14% and 39% in the first year and second year, respectively, following paraplowing. There were no significant yield increases due to deep ripping or paraplowing of Chernozemic soils.

CONCLUSIONS

A total of 12 sites were included in the study involving 4 different soil zones. The sites include 7 Solonetzic soils and 5 Chernozemic soils. The deep tillage operations involved deep ripping and paraplowing, which had been carried out in the fall. Deep ripping and paraplowing had reduced soil bulk density and soil strength, and increased spring soil NO_3-nitrogen levels. The effects were most pronounced in deep ripped Solonetzic soils. Both deep ripping and paraplowing increased soil water recharge for up to two years following the deep tillage operation.

Crop emergence at some sites was decreased in the tillage plots, due to poor seedbed conditions, created as a result of the secondary tillage operations in spring that were required to smooth down the soil surface. In some cases poor emergence resulted in reduced yields. Results from four years of data indicate that crop yield was increased due to either deep ripping or paraplowing of Solonetzic soils. Increases were more dramatic following deep ripping than following paraplowing. The yield increases lasted up to three years following the deep ripping operations. Deep ripping and paraplowing did not increase yields on Chernozemic soils. Deep ripping increased the water-use-efficiecy of crops grown on both Solonetzic and Chernozemic soils

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