THE EFFECT OF DEEP RIPPING AND PARAPLOWING ON CROP PRODUCTION IN SASKATCHEWAN, AN UP-DATE

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Abstract

The feasibility of deep ripping and paraplowing in terms of improving crop production was investigated over a three-year period. A total of 15 sites from different soil zones were included in the study involving soils varying in texture and in solonetzic characteristics. In the spring of 1988, the soils tended to be less dense in the 25-40 cm depth in the deep ripped and in the paraplowed plots. The difference in density between the paraplowed and the control plots was less dramatic than the difference between the deep ripped and the control plots. Both deep ripping and paraplowing increased soil water recharge for up to 2 years following the deep tillage operation. Soil NO_3-N levels in the spring of 1988 were significantly higher in the ripped and in the paraplowed plots compared to the control plots. Crop emergence at some sites was decreased in the tillage plots, due to poor seedbed conditions. Deep ripping resulted in significant yield increases on 4 of the 6 solonetzic soils and on 1 of the 4 mixed solonetzic/chernozemic soils. There were no significant yield increases due to deep ripping on 5 non-solonetzic soils. Paraplowing significantly increased crop yield at only 1 of 5 sites. There was little effect of either deep tillage treatment on the percent protein in the crop. Deep ripping increased crop water-use efficency by an average of 22%. Results from three years of data indicate that crop yield was significantly increased due to either deep ripping or paraplowing on solonetzic soils. Increases were more dramatic following deep ripping than following paraplowing. The yield increases lasted at least two years following the deep tillage operations, and at two sites the yield increases lasted into the third year. Deep ripping and paraplowing increased yields on only 1 of the 4 mixed solonetzic/chernozemic soils, and in none of the 5 non-solonetzic soils.

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 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 tillage is defined as "a primary tillage operation which manipulates the soil to a greater depth than normal plowing" (American Society of Agricultural Engineers, 1971). Deep tillage or subsoiling is generally carried out to improve unfavorable characteristics of the subsoil such as plow pans and/or compacted layers (Russell, 1973). There is little evidence to suggest that soil compaction limits crop production in Saskatchewan (McConkey, 1987). On the other hand, solonetzic Bnt horizons have been found to severely limit crop production. These layers effectively reduce water infiltration into the soil, and subsequently reduce the amount of soil-water recharge over the winter period. In dry years, solonetzic "pockets" in a field are the first areas showing a crop under severe water stress.

Deep tillage of solonetzic soils has resulted in increased crop production in Alberta (Toogood and Cairns, 1978). Deep plowing of solonetzic soils results in both the disturbance of the impermeable layer, and the mixing of the Na-rich Bnt horizon with the Ca-rich C horizon. Generally, the physical and chemical properties of these deep plowed solonetzic soils are greatly improved (Cairns and Bowser, 1977). Much of the research on deep plowing of solonetzic soils has been done in Alberta (Cairns, 1961, 1962; Bowser and Cairns, 1967). In Saskatchewan, Ballantyne (1983) studied soil conditions and crop production following deep plowing of solonetzic soils north of Radville (near Weyburn). He found that the improved soil chemical conditions and crop growth from deep plowing persisted at least 5 years following deep plowing

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 three year period.

Materials and Methods

A total of 15 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 1). The sites involve both solonetzic chernozemic soils, representing the Brown soil zone (2), the Dark Brown soil zone (4), the Black soil zone (1) and the Dark Gray soil zone (8). 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). 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. At Tisdale, A BELARUS tractor (~250 HP) was used. At most sites, tillage strips were a 1/2 mile in length and 40' to 60' in width. 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 and Arborfield sites. At the Morgan farm, large depressions were left in the field, with subsequent exposed subsoil in some areas. At the Cragg and Chabot farms, subsequent secondary tillage operations in the spring had left the top 4" to 5" 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, 6 of the sites (Boxall, Morgan, Cragg, Warner,J. Eliason and Harrington) are solonetzic, satisfying either the criteria for the exch. Ca/Na ratio for the B horizon or the % Water Soluble Na (Table 2). A further 4 sites (McEwen, Chabot, Riopka and D. Eliason) have at least one of the 6 sampled profiles (worst profile) that classifies as "chemically" being solonetzic. The remaining 4 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. The samples were then transported to the University, where the samples were dried, weighed, threshed and analyzed for % nitrogen, by the Semi-Micro Kjeldahl method. 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 3. 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 0.132 gm/cm^3 at the 25 cm depth, and by an average of 0.089 gm/cm^3 at the 40 cm depth. Comparable values for the paraplowed plots were 0.077 and 0.050 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 period. Over-winter soil-water recharge in the tillage plots for 1987/1988 is listed in Table 4.

The average gain in soil moisture for the 1987/88 period was 23 % for the control plots, 26 % for the ripped plots and 24 % for the paraplowed plots. 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 table 5. The ripped plots gained an additional 0.8 cm and 0 cm, in the second and in the third year, respectively, 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 7. The penetrometer measurements are easily carried out in the field and are therefore a very convenient type of measurement. Soil strength however, is dependent not only on soil density (i.e porosity), but also on soil moisture content. Since deep ripping and paraplowing affect the soil density directly and soil moisture indirectly, the penetrometer measurements may become of little value for indicating differences in soil density in cases where soil moisture contents are not similar. In the three years of data presented in Table 6, there were a number of instances where soil moisture contents amongst the tillage plots were quite different.

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.

Crop Production

Crop growth was monitored during the growing season and harvest samples were taken one week prior to the farmer swathing the field (Table 8). Deep ripping resulted in significant yield increases on 4 of the 6 solonetzic soils and on 1 of the 4 mixed solonetzic/chernozemic soils. There were no significant yield increases due to deep ripping on 5 non-solonetzic soils. Paraplowing significantly increased crop yield at only 1 of 5 sites. There were considerable plant emergence problems at the Norrish site. Secondary tillage operations in the spring, required to "smooth down" the seedbed in the ripped strips, had resulted in relatively poor seedbed conditions (dry and loose). Seeding was carried out without adjusting for the different seedbed conditions that existed in the ripped strips. Crop emergence in the ripped areas was uneven and often delayed.

Crop response to strips of fertilizer nitrogen (30 and 60 kg/ha of N as 34-0-0) in 1988, was negligible in terms of crop yield and in terms of nitrogen content in the harvested material. Percent protein in the harvested crop was not significantly affected by either deep ripping or by paraplowing (Table 8).

Soil NO_3-Nitrogen levels in the spring

Soil NO_3-N levels in the spring were significantly (P 0.05) higher in the deep ripped and in the paraplowed plots (Table 8). Mean values for all the plots were: 62.2 kg/ha and 50.4 kg/ha of N in the comparison of deep ripped and control plots involving 13 sites, and 70.0 kg/ha and 51.2 kg/ha of N in the comparison of paraplowed and control plots involving 5 sites. The above indicates more favorable conditions for nitrogen mineralization from organic matter and/or less favorable conditions for denitrification in the deep tilled plots, since fertilizer applications were similar as well as N removal by previous crops.

Water-use efficiency

The water-use efficiency values for the 1988 crop are listed in Table 9. The average water-use efficiency for all the crops was 59 kg/ha/cm for the control plots and 72 kg/ha/cm for the ripped plots. These values are similar to the 1987 crop values of 67 kg/ha/cm for the control plots and 76 kg/ha/cm for the ripped plots. The increase in water-use efficiency due to deep ripping may be due in part because of higher soil NO_3-N levels in the spring as earlier indicated. Other factors such as improved water penetration and root proliferation may have also played a role, however, they were not measured as such. The effect of paraplowing on crop water-use efficiency was measurable at only one site, at McEwen, where paraplowing increased the W.U.E. from 65 kg/ha/cm to 90 kg/ha/cm.

Crop production over the three 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 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. In the first year following deep ripping, yield increases due to deep ripping were 26 % at Boxall, 16 % at Morgan, -20% at Cragg, 26 % at J.Eliason, and 58 % at Warner. In the second year following dep ripping, yield increases were 89 % at Boxall, 18 % at Morgan, and 49 % at Cragg. In the third year following deep ripping, there was a yield increase of 33% at Morgan, while at Boxall no crop could be harvested. In the mixed solonetzic-chernozemic soils, deep ripping improved yields only at one site, McEwen, where yield increases were 45 %, 14 %, and 35 %, in the first, in the second and in the third year, respectively, following deep ripping. At the other 3 sites (Chabot, Riopka and D.Eliason), there was no significant effect of dep ripping on crop yield. There was no significant effect of deep ripping on crop yield in any of the non-solonetzic soils (Rice, Jessiman and Norrish).

Conclusions

A total of 15 sites were included in the study involving 4 different soil zones. Based on soil chemical criteria, the sites include 6 solonetzic soils, 4 mixed solonetzic-chernozemic soils, and 5 non-solonetzic (chernozemic) soils. The deep tillage operations involved deep ripping and paraplowing, which had been carried out in the fall.

By the spring of 1988, the soils in the deep ripped plots were less dense in the 25-40 cm depth. The soils in the paraplowed plots were also less dense at these depths, however the differences were less dramatic. The same pattern was found in terms of soil strength.

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.

Soil NO-3-N levels in the spring of 1988, were significantly greater in the ripped plots and in the paraplowed plots compared to the control plots.

Deep ripping resulted in significant yield increases on 4 of the 6 solonetzic soils and on 1 of the 4 mixed solonetzic/chernozemic soils. There were no significant yield increases due to deep ripping on 5 non-solonetzic soils. Paraplowing significantly increased crop yield at only 1 of 5 sites. There was little effect of either deep tillage treatment on the percent protein in the crop, nor was there a significant response in terms of crop growth to different rates of nitrogen fertilizer levels. Deep ripping had increased the water-use efficiency by an average of 22%.

Results from three years of data indicate that crop yield was significantly increased due to either deep ripping or paraplowing on solonetzic soils. Increases were more dramatic following deep ripping than following paraplowing. The yield increases lasted at least two years following the deep tillage operations, and at two sites the yield increases lasted into the third year. Deep ripping and paraplowing increased yields on only one of the four mixed solonetzic/chernozemic soils, and in none of the 5 non-solonetzic soils.

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Table 1. Soil description and tillage details of the research plots

Site	Farm	Soil Zone	Soil Order	Soil Association	Year of Tillage	Depth of tillage
			Deep Ripped			
						(cm)
Tisdale	Boxall	D.Gray	Solonetz	Arborfield C-CL	1985	76
	McEwen	D.Gray	Solon/Chern	Arborfield C-CL	1985	76
	Morgan	D.Gray	Solonetz	Arborfield C	1985	76
	Rice	D.Gray	Chernozem	Tisdale SiC-SiCL	1986	76
Arborfield	Chabot	D.Gray	Solon/Chern	Arborfield C	1986	76
	Cragg	D.Gray	Solonetz	Arborfield C	1986	76
Carrot River	Norrish	D.Gray	Chernozem	Tisdale C	1987	61
	Warner	D.Gray	Solonetz	Arborfield C	1987	61
Lucky Lake	Jessiman	Brown	Chernozem	Sceptre HC	1986	50
Glenside	Riopka	D.Brown	Solon/Chern	Tuxford C	1987	61
	J.Eliason	D.Brown	Solonetz	Tuxford C	1987	61
	D.Eliason	D.Brown	Solon/Chern	Tuxford C	1987	61
Cut Knife	Foisy	Black	Chernozem	Oxbow L	1986	50
			Paraplowed			
Tisdale	Boxall	D.Gray	Solonetz	Arborfield C-CL	1986	50
	McEwen	D.Gray	Solon/Chern	Arborfield C-CL	1986	50
Glenside	Harrington	D.Brown	Solonetz	Tuxford C	1986	50
Lucky Lake	Jessiman	Brown	Chernozem	Sceptre HC	1986	50
Cut Knife	Foisy	Black	Chernozem	Oxbow L	1986	50
Birsay	Millar	Brown	Chernozem	Fox Valley CL	1986	50

Solon/Chern = mixed solonetzic-chernozemic

Table 2. Soil chemical characteristics of the B horizons of the deep tillage sites.

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
	Riopka	21	40	13	51
	J.Eliason	22	50	10	72
	D.Eliason	30	42	16	53
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 3. Soil bulk density values in the spring of 1988, for the 25,40 and 60 cm depths.

Site	Farm	25 cm		40 cm		60 cm	
		Cntl	Till	Cntl	Till	Cntl	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
Glenside	D.Eliason	1.623	1.332*	1.442	1.431	1.517	1.655
	J.Eliason	1.604	1.426	1.295	1.398	1.499	1.467
	Riopka	1.548	1.458	1.468	1.365	1.584	1.590
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.

Table 4. 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
Riopka	Control	32.2	39.9	7.7	24
	Ripped	32.2	42.4	10.2	32
D.Eliason	Control	31.3	36.5	5.2	17
	Ripped	31.3	38.8	7.5	24
J.Eliason	Control	31.1	33.6	2.5	8
	Ripped	31.1	33.6	2.5	8
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 5. 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 6. Soil strength measurements in the top 40 cm in the tillage plots.

Site	Tillage	1986	1987	1988			
		7.5 cm	7.5 cm	10 cm	20 cm	30 cm	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
Riopka	Control			1.46	2.31	3.60	4.33
	Ripped			1.17	2.01	2.94	4.25
J.Eliason	Control			0.92	1.47	2.19	3.00
	Ripped			0.94	1.81	2.56	3.92
D.Eliason	Control			2.61	5.06	6.19	6.53
	Ripped			2.33	4.08	5.75	6.58
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

Table 7. Crop yield and yield variability in the tillage plots

Site	Year	Crop	Tillage	Yield	Coeff. of V.
				(Bu/A)	(%)
Boxall	1986	Wheat	Control	34.3 a	22
			Ripped	43.1 b	19
	1987	Wheat	Control	18.4 a	36
			Ripped	34.8 b	31
			Parapl.	29.5 b	31
	1988	Wheat	Crop Failure		
McEwen	1986	Peas	Control	22.7 a	23
			Ripped	32.9 b	25
	1987	Flax	Control	21.0 a	12
			Ripped	24.0 a*	8
	1987	Flax	Control	22.5 a	12
			Parapl.	23.1 a	7
	1988	Barley	Control	30.3 a	32
			Ripped	40.8 b	30
	1988	Barley	Control	25.0 a	26
			Parapl.	37.2 b	23
Morgan	1986	Barley	Control	48.6 a	22
			Ripped	56.5 b	20
	1987	Flax	Control	23.0 a	18
			Ripped	27.1 b	10
	1988	HY320	Control	14.3 a	30
			Ripped	19.0 b	30
Chabot	1987	Peas	Control	31.2 a	17
			Ripped	28.6 a	29
	1988	Flax	Control	9.8 a	30
			Ripped	9.8 a	25
Cragg	1987	Wheat	Control	41.8 a	13
			Ripped	34.9 b	21
	1988	Barley	Control	23.8 a	28
			Ripped	35.4 b	12

Table 7. Continued

Site	Year	Crop	Tillage	Yield	Coeff. of V.
				(Bu/A)	(%)
Rice	1988	Wheat	Control	29.1 a	25
			Ripped	33.0 a	15
Jessiman	1987	Wheat	Control	44.1 a	21
			Ripped	44.3 a	20
			Parapl.	46.4 a	21
	1988	W.Wheat	Crop Failure		
Harrington	1987	Wheat	Control	20.0 a	20
			Parapl.	19.8 a	22
	1988	Mustard	Crop Failure		
Riopka	1988	Wheat	Control	21.8 a	29
			Ripped	21.9 a	29
D.Eliason	1988	Lentils	Crop Failure		
J.Eliason	1988	Durum	Control	39.6 a	32
			Ripped	49.7 a*	35
Foisy	1987	Lentils	Control	40.4a	12
			Ripped	41.1a	13
			Parapl.	42.3a	13
	1988	Peas	No Samples		
Millar	1987	Flax	Control	34.7 a	13
			Parapl.	35.0 a	10
	1988	Wheat	Control	35.5 a	38
			Parapl.	37.7 a	38
Norrish	1988	Canola	Control	30.4 a	25
			Ripped	25.9 a	38
Warner	1988	Canola	Control	12.8 a	20
			Ripped	20.2 b	29

Values that are followed by the same letter are not significantly different at the P 0.05 level (ANOV of block means)

* Denotes significantly different from the "control" when analyzed as paired observations instead of ANOV of block means

Table 8. Spring soil NO_3-N levels and % N in the grain of the 1988 crop.

Site	Farm	Tillage	Soil N	Grain Yield	Grain N content	
			kg/ha	kg/ha	%	kg/ha
Tisdale	Boxall	Control	119	292	3.05	10.3
		Ripped	166	396	3.00	13.9
		Parapl.	161	316	3.32	12.0
	McEwen	Control	141	1773	2.34	52.8
		Ripped	156	2393	2.25	67.4
		Control	106	1461	2.34	46.8
		Parapl.	149	2173	2.37	66.8
	Morgan	Control	35	1057	3.18	39.1
		Ripped	77	1405	3.33	54.2
	Rice	Control	127	1080	3.19	40.3
		Ripped	147	1222	3.19	45.8
Arborf.	Chabot	Control	95	700	4.07	39.6
		Ripped	114	679	4.04	39.1
	Cragg	Control	28	1763	1.96	45.8
		Ripped	26	2619	1.92	61.4
C.River	Norrish	Control	43	1877	3.86	100.1
		Ripped	54	1640	3.81	88.0
	Warner	Control	24	788	3.55	43.1
		Ripped	49	1247	3.69	70.8
Glenside	Harringt	Control	14			
		Parapl.	45			
	D.Eliason	Control	29	1102	3.04	41.8
		Ripped	29	1682	3.45	69.0
	J.Eliason	Control	35	2931	2.95	115.0
		Ripped	35	3680	2.84	136.6
	Riopka	Control	25	1613	2.71	60.8
		Ripped	21	1614	2.59	56.6
Lucky L.	Jessiman	Control	20			
		Ripped	31			
		Parapl.	31			
Birsay	Millar	Control	36	2627	2.88	92.8
		Parapl.	49	2789	2.73	93.0
Cut Knife	Foisy	Control	45			
		Ripped	32			
		Parapl.	43			

Table 9. Water-use efficiency of the 1988 crop

Site	Farm	Crop	Tillage	Yield	Water Use	W.U.E.
				kg/ha	mm	kg/ha/cm
Tisdale	Boxall	Wheat	Control	292	169	17.3
			Ripped	396	167	23.8
			Parapl.	316	169	18.8
	McEwen	Barley	Control	1773	239	74.3
			Ripped	2393	243	98.6
			Control	1461	226	64.7
			parapl.	2173	241	90.1
	Morgan	HY 320	Control	1057	207	51.0
			Ripped	1405	224	62.8
	Rice	Wheat	Control	1080	181	59.5
			Ripped	1222	162	75.5
Arborfield	Chabot	Flax	Control	700	247	28.3
			Ripped	679	242	28.0
	Cragg	Barley	Control	1763	242	72.9
			Ripped	2619	256	102.4
Carrot River	Norrish	Canola	Control	1877	291	64.5
			Ripped	1640	291	56.3
	Warner	Canola	Control	788	306	25.8
			Ripped	1247	322	38.8

Other sites: Harrington and Jessiman had crop failure, Foisy had swath the crop before samples could be taken, J.Eliason & D. Eliason & Riopka & Millar had irrigated crops