The Effects of Imposing Tillage on Long Term No-till Soils

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Key Words: no-till, nutrient stratification, soil organic carbon

Abstract

During the last two decades**,** an increasing number of producers have adopted a no-tillage or minimum tillage system because of the potential to reduce soil erosion, conserve soil moisture, improve soil structure and increase net economic returns. Some potential concerns related to elimination of tillage include stratification of nutrients near the soil surface and lack of herbicide options to control certain weeds. These concerns have lead some producers in Western Canada to consider applying one or more cycles of tillage to their no-till fields. Little information exists on the impact of imposing one or more tillage operations on a long term no-till soil. Therefore a study was conducted to examine the effect of tillage on soil conditions and crop growth at three long-term no-till sites, one in each of the Brown, Black, and Gray soil zones of Saskatchewan. The sites were previously managed as no-till for 10 years or more. In this study, the sites were subjected to a one year cycle of tillage at three levels of intensity involving spring cultivation only, fall + spring, and fall + spring + disc, and a no-till control.

Soil cores were taken in the spring and fall after imposition of the tillage treatments. Total and particulate soil organic carbon, pH, EC, and mean weight diameter of the soil aggregates generally were not significantly affected by the tillage operations. However, there was a trend at all sites for tillage treatments to have lower mass of organic carbon in the 0-10 cm depth. Tillage tended to reduce the bulk density at the 5-10 cm depth and resulted in a small increase (~ 1^{o}C) in spring soil temperature at the 5 cm depth. Tillage reduced phosphorus stratification to some extent, but there appeared to be no associated effect on crop P uptake. There were no wheat yield differences due to the tillage treatments at the Brown soil zone site while canola yield at the Black soil zone site showed some small yield increases in tilled treatments that may be attributed to nitrogen (N) mineralization. The canola grown at the Gray soil zone site experienced canola grain yield reductions of approximately 100 to 600 $kg{\cdot}ha^{-1}$ in tilled treatments compared to the no-till control. At this site, lower soil available N due to incorporation of large amounts of fresh straw and subsequent immobilization is believed to be a contributing factor. Overall, the imposition of one cycle of tillage on long-term no-till soils does not appear to have a major impact on soil properties or crop growth.

Introduction

In the last two decades prairie agricultural practices have changed significantly. Traditionally, producers tilled the soil to prepare it for seeding and to eliminate weeds. Although effective for seed bed preparation and weed control, tillage can reduce the amount of organic C in the soil, increase soil erosion potential, and can reduce soil aggregation and moisture retention (Liebig et al., 2004). Today, most producers on the prairies have adopted reduced or no-till (NT) systems. The NT system has gained popularity because of the potential to improve efficiency of labour and capital, enhance soil moisture conservation, soil fertility and tilth, and increase net economic returns (Larney et al., 1997; Singh and Singh, 1994)

Despite these potential benefits, mature NT systems may also develop undesirable characteristics. Concerns have arisen with stratification of nutrients on the soil surface (Crozier et al., 1999; Grant and Bailey, 1994), low surface soil temperatures in the spring (Johnson and Lowery, 1985; Jones et al., 1990; Wolfe and Eckert, 1999), and the emergence of herbicide resistant perennial weeds (Derksen et al., 1993). Low spring soil temperatures can delay seeding activities and slow crop germination and emergence while nutrient stratification could reduce the amount of nutrients available to plant roots and increase potential for nutrient losses in water runoff. No-till systems rely on the application of chemical herbicides to control weeds. Over a number of years of NT cropping, this practice could result in the development of herbicide resistant weeds (Derksen et al., 1993; Donald, 1990). For some of these problems the reintroduction of tillage to the NT cropping system may be necessary. However, little information is available on the effects of imposing tillage on a NT soil in the prairie region of Canada.

We addressed this gap via a study instigated in 2004 to examine how different intensities of tillage affect selected soil properties, crop nutrient uptake and yield. Three long-term NT field sites were selected to represent the Brown, Black, and Gray soil zones respectively, and thereby provide information on how imposition of tillage on a no-till soil is related to soil-climatic zone and cropping system.

Materials and Methods

Three field research sites were selected, one in each of the Brown, Black and Gray soil zones to represent a typical no-till farming system in each zone. The transition from Brown to Black to Gray soil zones moving from southwest to northeast across Saskatchewan represents an environmental gradient of increasing precipitation effectiveness and reduced temperature (Bettany et al., 1973). The site in the Brown soil zone is located near Central Butte, the site in the Black soil zone is near Rosthern, and in the site in the Gray soil zone is near Tisdale SK, Canada.

Tillage Treatments

Four tillage treatments identified as no-till (NT), minimum-till (MT), conventional till (CT), and maximum till (MXT) were imposed on plots with dimensions of 7.3 m x 15.2 m. A completely randomized treatment design replicated four times was used in this study. The control treatment (NT) had no pre-seeding tillage. The minimum tillage treatment (MT) was subjected to a single tillage operation in the spring of 2005 using a 1.8 m cultivator equipped with 30 cm sweeps and a 30 cm row space, operating at a depth of approximately 7 to 8 cm and a travel speed of 6.4 km h^{-1}. The conventional tillage treatment (CT) included a fall tillage operation in 2004, followed by a spring tillage operation in 2005 using a cultivator. The "black" or maximum tillage treatment (MXT) included a fall 2004 and spring 2005 cultivation followed by an additional tillage operation using a tandem disc with notched blades traveling at 6.4 km h^{-1}. The tillage treatments were carried out with the same cultivator and disc at all sites in the fall of 2004 and the spring of 2005.

Central Butte (Brown) site

The research site near Central Butte, SK (legal location: NW 30-20-3 W3) had been previously cropped in a cereal – chemical fallow rotation using NT for 10 years. The site is located in the Brown soil zone and is classified as a mixture of Kettlehut and Ardill soil associations. The Kettlehut soil association is predominantly a Brown Solod to a Brown Solodized Solonetz, and the Ardill soil association is dominantly an Orthic Brown to a Calcareous Brown Chernozem (Canadian System of Soil Classification, 1987). The parent material is moderately fine textured, moderately calcareous, glacial till. Particle size analysis at this location indicated a loam soil texture. After the tillage treatments were imposed, the field was seeded to Hard Red Spring Wheat (*Triticum aestivum* L. cv Prodigy) in early May of 2005 using a John Deere air seeder equipped with 40 cm sweeps. The seeding rate was 94 kg ha^{-1} and a fertilizer blend with an analysis of 28-26-0 was seed placed at a rate of 67 kg ha^{-1}.

Rosthern (Black) site

The Rosthern site is located in the Black soil zone (legal location: SW 3-43-02 W2) on the Seager Wheeler farm. The site had been continuously cropped using a NT cereal-oilseed rotation for the last 12 years. The soil at the site as a Hamlin Orthic Black soil association with very fine loam to loam texture (Canadian System of Soil Classification, 1987). After the tillage treatments, the field was seeded to canola (*Brassica napus* L. cv. Banner) at 6.2 kg ha^{-1} with a side-banded fertilizer blend containing 56 kg ha^{-1} actual N, 22.4 kg ha^{-1} of actual P_2O_5, and 11.2 kg ha^{-1} of actual S using a Seed Hawk air-drill with a 1.27 cm knife opener in late May of 2005.

Tisdale (Gray) site

The research site in the Gray soil zone is located near Tisdale, SK (legal location: SW2-47-14 W2). The site has been continuously cropped using a NT cereal-oilseed rotation for the last 12 years. The soil at this site is classified as mixture of Eldersley and Tisdale soil associations with mainly Gray Wooded Eldersley soils on the uplands, including the research plot area. The soil texture at the site is silty clay loam to clay loam.

This site was seeded to canola (*Brassica napus* L. cv. Millenium) at 5.6 kg ha^{-1}, fertilized with a blend of 67.2 kg ha^{-1} actual N, 22.4 kg ha^{-1} of actual P_2O_5 and 22.4 kg ha^{-1} of actual S using a Flexicoil 5000 airdrill with 7.5 cm openers. Half the N was applied mid-row as NH_3 and the rest was applied as dry granular along with granular P and S.

Soil Sampling and Analysis

Plots were measured out in preparation for the tillage treatments as previously described. After the spring tillage operations were completed in the last week of April, 2005 and before seeding, each tillage plot was immediately sampled with a polyvinyl chloride (PVC) pipe punched down to a depth of 15 cm. The PVC pipes provided an intact soil core measuring 10 cm in diameter and 15 cm in depth. Three cores were removed from each plot. After extraction, the cores were transferred to plastic bags and then placed in an insulated container. The cores were transported to the University of Saskatchewan and stored at 4 ºC. After a period in which the soil cores were allowed to warm to room temperature and equilibrate, the soil cores were segmented into 0 to 5 cm, 5 to 10 cm, and 10 to 15 cm depth increments for analysis of soil properties. The corresponding depth segments from three sub-samples of each plot were weighed, bulked and air - dried before being ground to pass through a 9 mesh (2 mm) sieve.

Organic Carbon

Soil organic C was determined on soil core increments using a LECO CR-12 C Analyzer (Wang and Anderson, 1998) in which a 0.15 g sub-sample was placed into the LECO furnace at a temperature of 840 ºC. Soil organic C mass in the depth increments was calculated using soil carbon concentration and bulk density according to Ellert and Bettany (1995).

Particulate Organic Matter

Particulate organic matter (POM) is a dynamic and easily oxidizable part of soil organic matter. Hussain et al. (1999) reported that POM is an early indicator of SOC changes. Particulate organic matter was therefore measured at the soil surface (0 - 5 cm) of all treatments. Particulate (>53 µm) and mineral-associated organic matter (<53 µm) were separated by sieving after mechanical dispersion of the soil by agitation in water with glass beads according to the procedure outlined by Balesdent et al. (1991) as cited in Aoyama et al. (1999). The dispersed POM plus sand was collected on the surface of a 53-µm sieve and washed with 340 mL deionized water. The material > 53 µm was dried in a forced-air oven at 40ºC and weighed and the carbon concentration was directly determined by the LECO CR-12 Carbon Analyzer (Wang and Anderson, 1998).

Temperature

During core sampling a Pronto Plus™ thermocouple temperature gauge (Thermo Electric, Saddle Brook, NJ) was used to measure soil surface temperatures in the field at the Rosthern site. The Pronto Plus™ was calibrated in water and access holes were made in the field to a 5 cm depth after the tillage treatments were imposed. The thermocouple wire was then inserted into the hole and left to equilibrate for five minutes. After five minutes the temperature was recorded.

Midway through June, after the Rosthern site had been seeded, four Hobo® H8 Pro Series temperature probes were used to measure temperature differences in the NT and MXT treatments. Two probes were buried at random in a NT control plot and in a MXT plot. The probes were installed so that the surfaces of the temperature gauges were in full contact with the soil. Soil temperature measurements were made every six seconds for six days. Data were downloaded to a laptop computer using BoxCar® Pro 3.5 or BoxCar® 3.6 software.

Aggregation

Soil aggregation was assessed using the technique outlined by White (1993). Bulk hand samples were collected using a shovel and placed in a plastic bag for transport. The hand samples were subsequently air dried and placed in a rotary sieve with openings of 53.53 mm, 34.58 mm, 17.51 mm, 7.20 mm, 2.58 mm, 1.30 mm, and 0.50 mm and mean weight diameter (MWD) was calculated.

pH and Electrical Conductivity

The pH and electrical conductivity (EC) were determined following the technique of Hendershot and Lalande (1993) and Janzen (1993). The resulting 2:1 distilled water to soil suspension was analyzed for pH and EC with a Beckman 50 pH meter and a Horiba ES-12 conductivity meter.

Nutrient Extractions

Inorganic N was extracted using 2*M* KCl following the procedure of Keeney and Nelson (1982) and analyzed colorimetrically using a Technicon™ Auto-analyzer. A modified Kelowna (MK) extraction procedure was used to extract P as outlined by Qian et al. (1994) and the extractant was colorimetrically analyzed.

Crop Sampling and Analysis

Yields

Above ground crop samples were taken in the fall of 2005 just before the producer swathed the plot site. Sampling of each plot was conducted by using a 1 m^2 quadrat to obtain two biomass subsamples. Plants were harvested approximately 7.62 cm above the ground to simulate a swather cut level. Samples were placed in cotton bags and air dried. After drying the harvested plant material was weighed to obtain biomass yields. The plant material was processed through a threshing machine. The resulting seed was cleaned, weighed and grain yields recorded for each plot. A small amount of straw was kept for digestion and extraction to determine straw nutrient uptake.

Grain and Nutrient Uptake

Total plant P and N concentrations were determined on grain and straw samples using a standard H_2SO_4-H_2O_2 digestion method (Thomas et al., 1967). Total P and N concentrations were colorimetrically determined with the Technicon™ Auto-analyzer (Tarrytown, NY). Total plant nutrient uptake was determined by multiplying the grain and straw nutrient concentrations by grain and straw yield.

Statistical Analysis

This experiment was set up as a completely randomized design. A significant ANOVA result indicates that at least one of the mean treatments was different (Zar, 1999). Mean separation was done using least significant difference (LSD) at an $\alpha = 0.10$ unless otherwise stated (SPSS, 2005).

Results and Discussion

Soil Properties

Soil organic C is a key factor affecting soil productivity and represents a significant pool of stored C in the ecosystem (Schlesinger, 1997; Schoenau and Campbell, 1996). The imposition of one (MT), two (CT), or three (MXT) tillage operations in this study did not have a significant ($p<0.10$) impact on the amounts of total organic carbon and the fraction identified as POM (Tables 1 and 2). One cycle of tillage may not be enough to induce the accelerated decomposition and erosion that has been reported to result in significant decline in soil organic carbon after several years of tillage (Wu et al., 2006). However, the trend of lower organic carbon observed in the tilled treatments compared to no-till (Table 1) suggests that if the cycle of tillage was continued over a number of years, the decline in mass of organic carbon in the surface layer could become significant (Jenkinson and Rayner, 1977).

Table 1. Spring and fall total organic carbon mass (Mg C ha^{-1}) in intact soil cores taken after imposition of tillage treatments in segments of 5 cm to a total depth of 10 cm.†

	Central Butte			**Rosthern**			**Tisdale**		
Treatment	0-5 cm	5-10 cm	0-10 ‡ cm	0-5 cm	5-10 cm	0-10 cm	0-5 cm	5-10 cm	0-10 cm
				Spring 2005					
				Mg ha^{-1}					
NT	7.68	8.38	16.59	15.08	17.26	32.34	16.92	19.19	36.10
MT	7.62	7.17	14.78	14.43	16.85	31.27	14.36	15.58	29.94
CT	7.12	7.34	14.46	14.28	15.06	29.34	13.62	15.26	28.88
MXT	7.12	8.21	15.33	13.74	15.00	28.74	15.71	14.63	30.34
$LSD_{(0.10)}$	**NS§**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
				Fall 2005					
NT	7.59	7.98	15.39	14.36	16.24	30.60	16.35	18.52	34.87
MT	7.02	7.05	14.07	12.83	15.16	27.99	14.92	14.24	29.16
CT	7.23	7.70	14.93	12.84	14.21	27.05	12.35	13.92	26.27
MXT	8.13	7.97	16.10	12.56	13.73	26.29	14.86	13.71	28.57
$LSD_{(0.10)}$	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

† NT: no tillage; MT: spring cultivator tillage; CT: fall and spring cultivator tillage; MXT: fall, spring cultivator tillage and spring disc tillage; LSD: least significant difference

‡ Measurement of the 10 to 15 organic carbon mass was not done as the bulk density for this segment could not be calculated due to uneven breakage at the core base during extraction.

§ Not significant at $\alpha = 0.10$

Table 2. Carbon concentration in particulate organic matter fraction from the 0-5 cm depth of the intact soil cores taken after the imposition of tillage treatments.†

	Central Butte		**Rosthern**		**Tisdale**	
Treatment	Spring	Fall	Spring	Fall	Spring	Fall
	g/kg					
NT	11.6	9.30	21.4	19.9	44.8	46.8
MT	10.6	8.80	22.2	21.1	38.4	39.7
CT	10.0	8.60	20.7	20.1	36.3	36.0
MXT	11.3	10.4	22.3	19.5	36.5	38.1
LSD$_{(0.10)}$	**NS‡**	**NS**	**NS**	**NS**	**NS**	**NS**

† NT: no tillage; MT: spring cultivator tillage; CT: fall and spring cultivator tillage; MXT: fall, spring cultivator tillage and spring disc tillage; LSD: least significant difference

‡ Not significant at α = 0.10

The carbon concentration in the POM fraction did not show a significant difference among tillage treatments (Table 2). Although it has been noted that POM (sand plus organic matter) is the fraction of organic matter most sensitive to management, including tillage (Hussain et al., 1999; Wu et al., 2006), we did not see a tillage effect after one cycle of tillage. Variability in POM in the field due to uneven distribution of residue during the harvesting process and uneven distribution created by sample processing may have contributed to results that were too variable to reveal significant differences in POM between the tillage treatments.

Organic C plays a major role in binding soil aggregates together (Tisdall and Oades, 1982). Tillage treatments had no significant effect on aggregation (data not shown). The lack of significant effects of the tillage treatments on aggregation is consistent with no major changes in TOC or POM. Overall, one cycle of tillage involving one, two or even three successive operations does not appear to have a large impact on total surface soil C or recent sand sized C fractions in the form of POM. Wu et al. (2006) observed that 7 years of NT was required to produce a gain of 0.1 Mg C ha^{-1} in the sand sized fraction of the 0 to 5 cm layer at the Central Butte site. One cycle of tillage imposed on the NT soil did not decrease SOC significantly.

The bulk density of the soil in the top 5 cm did not differ in response to tillage at the three sites. The 5 to 10 cm soil depth did show some significant differences as tillage decreased the soil bulk density compared to the NT control at Central Butte and Rosthern sites (Table 3). This corresponds with the findings of Franzluebbers (1995) where soil bulk density was reduced by tillage. The bulk density measured at Tisdale was too variable to show a significant tillage effect, although there was a trend of decreased soil bulk density with increasing tillage at the 5 to 10 cm depth (Table 3).

Table 3. Bulk density of segmented cores taken after imposition of tillage treatments.†

	Central Butte		**Rosthern**		**Tisdale**	
Treatment	0-5 cm	5-10 cm‡	0-5 cm	5-10 cm	0-5 cm	5-10 cm
	g cm^{-3}					
NT	1.06	1.51	1.07	1.27	0.81	1.20
MT	1.08	1.20	0.98	1.23	0.82	1.04
CT	1.06	1.25	1.02	1.08	0.81	1.01
MXT	1.07	1.20	0.94	1.06	0.90	0.96
$LSD_{(0.10)}$	**NS§**	**0.16**	**NS**	**0.11**	**NS**	**NS**

† NT: no tillage; MT: spring tillage; CT: fall and spring tillage; MXT: fall, spring and spring disc tillage; LSD: least significant difference

‡ Measurement of the 10 to 15 cm bulk density could not be calculated due to uneven breakage at the core base during extraction.

§ Not significant at $\alpha = 0.10$

No significant differences in moisture and temperature due to the tillage treatments were observed in the spring prior to seeding (data not shown). Generally there was slightly higher soil temperature (≈ 1ºC) in the 0 to 5 cm depth of the tilled treatments compared to the NT. Temperature differences, monitored with the Hobo™ temperature probes, tended to persist between the NT and MXT treatments later in the season.

The soil EC in the 0 to 5 cm depth was slightly but significantly affected by the tillage treatments, with the EC increasing slightly at the Central Butte site and decreasing slightly at the Tisdale site (Figure 1). Shaw and Mask (2003) found that surface soil EC significantly increased when surface residues were removed, due to increased evaporation. The Central Butte site had limited residue on the soil surface since a fallow period preceded the study season. The increase in EC at the Central Butte site is probably a result of the mixing action of the tillage implements mixing gypsiferous material from the lower soil levels and thus increasing the EC of the top 5 cm of soil. The decrease in EC at Tisdale agrees with the findings of Qian et al (1994b) who reported that the opening and aeration of the top soil layers allowed increased leaching to occur in the top 5 cm. The Tisdale site is located in the Gray soil zone and experiences less evaporation and more leaching than the Central Butte site which is located in the Brown soil zone. Increased leaching would lead to the reduction of salts and thus reduction of EC in the top 5 cm of soil.

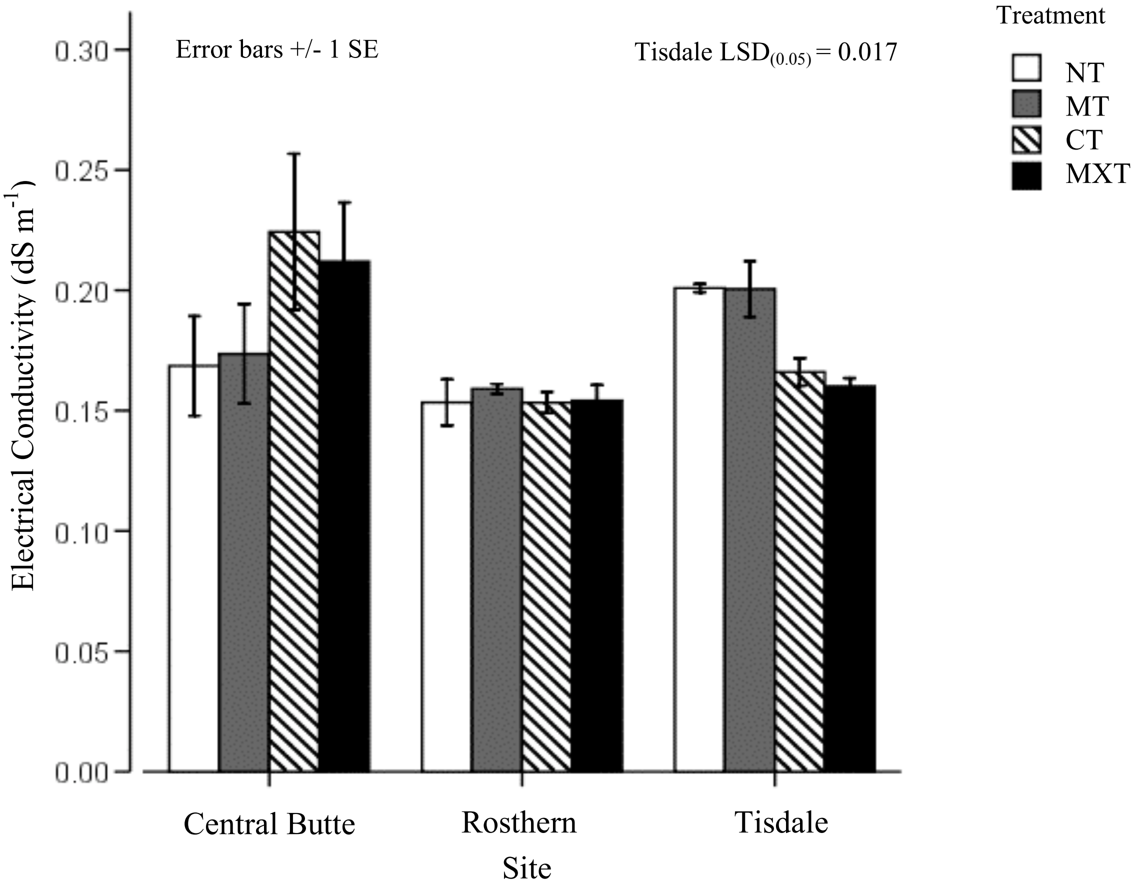

Figure 1. Mean electrical conductivity of intact cores (0 to 15 cm) taken in spring after imposition of tillage treatments.

Many researchers have found that fertilized NT soils develop lower pH values on the soil surface than tilled soils (Blevins et al., 1983; Tarkalson et al., 2006) due to lack of mixing with calcareous subsoil, along with accumulation of organic acids from residue decomposition on the soil surface. Increased microbial respiration can also contribute to a decrease in pH near the soil surface. The tillage imposed may not have been severe enough to mix sufficient amounts of calcareous subsoil with the surface to affect pH significantly, unlike repeated plowing with a moldboard plow.

Tillage and fertilization can significantly affect the amount of available N in the soil (Havlin et al., 2005). The tillage treatments in 2004 and 2005 resulted in evidence of increased net mineralization of NO_3-N in the form of higher spring NO_3-N concentrations at the Central Butte site (Table 4). Reduced spring NO_3-N concentrations with tillage at Rosthern and Tisdale sites may reflect initial N immobilization. This may be explained by the cropping history and the amount of reside that was incorporated during the tillage operations. Schoenau and Campbell (1996) noted that incorporation of large amounts of residues of high C:N ratio before seeding increased immobilization and reduced available N to the crop. The type, placement, and timing of residue input significantly alters the seasonal dynamics of the active soil C and N pools and the subsequent effect on N availability (Franzluebbers et al. 1995). At the Central Butte site there was only a small amount of weathered residue and thatch left from the 2003 cropping year due to the fallow period in 2004. Chemical fallow straw is not expected to immobilization large amounts of N (Gares and Schoenau, 1995), and the result of increased aeration and microbial activity due to tillage would be to accelerate the mineralization of humus. The Rosthern and Tisdale sites had large amounts of fresh cereal residue left from the 2004 crop year. The high C:N ratio, and the amount of C incorporated, was likely enough to cause the microbial biomass to immobilize the available NO_3-N and reduce NO_3-N concentrations in the surrounding soil (Table5).

The fall measurement of NO_3-N suggests some enhanced mineralization from tillage still evident in the 5 to 10 cm and the 10 to 15 cm depths at Central Butte. These findings support those of Kristensen et al. (2000) who showed that tillage exposes protected pools of soil N. Treatments at Rosthern showed no significant differences in the fall, probably because the soil had reached a steady state between mineralization and immobilization. The soil at the Tisdale site in the fall still showed the same reduced concentration of nitrate in the tilled treatments as was seen in the spring soil samples (Table 4). Ammonium concentrations (data not shown) were generally low and not significantly affected by the tillage treatments, likely because nitrification of mineralized ammonium to nitrate proceeded at a rapid rate in all the soils.

Table 4. Nitrate (NO_3-N) concentrations measured in intact segmented cores taken after imposition of tillage treatments.†

Treatment	**Central Butte**			**Rosthern**			**Tisdale**		
	0-5 cm	5-10 cm	10-15 cm	0-5 cm	5-10 cm	10-15 cm	0-5 cm	5-10 cm	10-15 cm
				Spring 2005					
				mg kg^{-1}					
NT	10.15	5.25	4.90	16.58	8.30	10.94	24.08	10.85	10.63
MT	11.15	5.43	5.35	17.93	12.00	14.18	21.43	11.50	10.35
CT	20.88	11.98	10.20	11.35	9.98	10.16	13.38	6.90	7.73
MXT	12.50	8.80	6.25	12.60	10.93	11.39	13.15	7.28	7.00
LSD$_{(0.10)}$	**4.56**	**2.35**	**3.23**	**3.51**	**2.00**	**NS‡**	**4.61**	**2.71**	**1.67**
				Fall 2005					
NT	4.57	3.24	2.69	7.92	5.09	3.54	11.37	5.92	4.82
MT	5.91	4.48	3.23	8.59	5.86	4.16	8.97	5.69	3.85
CT	5.62	4.69	4.06	7.19	6.26	4.03	7.87	6.10	4.44
MXT	6.77	6.35	5.34	9.11	7.02	4.43	6.77	5.95	3.53
LSD$_{(0.10)}$	**NS**	**1.20**	**1.58**	**NS**	**NS**	**NS**	**2.81**	**NS**	**NS**

† NT: no tillage; MT: spring tillage; CT: fall and spring tillage; MXT: fall, spring and spring disc tillage; LSD: least significant difference

‡ Not significant at $\alpha = 0.10$

Concerns about P stratification in long-term NT soils have been brought forward, and tillage has been proposed to reduce nutrient stratification (Essington and Howard, 2000; Hussain et al., 1999; Zibilske et al., 2002). All three study sites demonstrated some P stratification in the NT treatment with concentrations of extractable P in the 0 to 5 cm depth that were about three times or more the concentrations at the 10 to 15 cm depth (Table 5). Sampling of the treatments after the imposition of tillage in the spring of 2005 showed that tillage, particularly the MXT treatment, had some effect on reducing P stratification at all the experimental sites. The soil characteristics and the degree of the mechanical mixing associated with tillage equipment would have a major effect on the extent of the increase in P concentration in the lower soil depths and the degree to which the P concentration is homogenized among the soil depths. Essington and Howard (2000) found that in NT soils the compact band of fertilizer P that is applied may slow conversion of P to less soluble forms of P. Tillage at each of the sites may have also reduced the labile P concentration in the soil because of increased mixing by tillage reducing the concentration around the fertilizer band and increasing the contact of fertilizer P with soil constituents responsible for P fixation. The fall 2005 soil P extraction showed slightly lower amounts of P compared with the spring NT soil extractions (Table 5). This small reduction of extractable P concentration in the soil is probably due to P removal by the crop.

Table 5. Modified Kelowna extractable phosphorus concentrations measured in intact segmented cores taken after imposition of tillage treatments.†

	Central Butte			**Rosthern**			**Tisdale**		
Treatment	0-5 cm	5-10 cm	10-15 cm	0-5 cm	5-10 cm	10-15 cm	0-5 cm	5-10 cm	10-15 cm
					Spring 2005				
					mg kg^{-1}				
NT	27.54	16.72	8.76	29.32	19.50	10.94	44.82	24.73	10.00
MT	23.33	17.24	6.96	28.50	23.81	14.18	38.72	31.09	12.07
CT	24.58	18.20	9.64	22.08	19.54	10.16	32.56	22.58	11.39
MXT	26.35	21.42	11.55	25.61	21.86	11.39	35.13	20.61	14.56
LSD$_{(0.10)}$	**NS‡**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
					Fall 2005				
NT	21.55	13.10	7.21	22.88	16.28	8.89	34.15	14.53	9.09
MT	24.08	16.05	6.71	24.20	14.60	10.54	31.83	17.44	7.27
CT	20.90	16.60	8.77	19.78	15.63	8.11	28.78	15.08	8.21
MXT	25.48	21.58	12.45	19.48	15.53	8.79	29.95	17.23	9.40
LSD$_{(0.10)}$	**NS**	**5.46**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

† NT: no tillage; MT: spring tillage; CT: fall and spring tillage; MXT: fall, spring and spring disc tillage; LSD: least significant difference

‡ Not significant at α = 0.10

Crop Effects

Concentrations of N in the grain and straw samples were not significantly different among treatments, indicating that the tillage treatments did not have a large effect on the overall supply of available N and P to the crop over the growing season. The total N and P uptake by the crop, determined by multiplying concentration in grain and straw by grain and straw yields, were also not significantly different at the Central Butte and Rosthern sites (Table 6). Lower N and P uptake in tilled treatments at Tisdale site is explained by slightly lower yields at this site in the tilled treatments (Table 7). A general lack of significant effects of tillage treatments on P concentrations and uptake among treatments suggests that while the tillage reduced P stratification, its impact on P availability was minimal.

Table 6. Crop nitrogen and phosphorus uptake from fall 2005 grain and straw samples after spring imposition of tillage treatments.†

	Central Butte (Wheat)		**Rosthern** (Canola)		**Tisdale** (Canola)	
Treatment	N	P	N	P	N	P
	kg ha^{-1}					
NT	64.76	11.29	60.94	15.42	69.56	15.31
MT	69.44	11.02	70.94	15.35	52.12	11.53
CT	61.59	11.27	57.34	14.48	57.72	13.92
MXT	66.91	10.78	77.01	16.03	61.56	14.26
LSD$_{(0.10)}$	**NS‡**	**NS**	**NS**	**NS**	**9.04**	**2.04**

† NT: no tillage; MT: spring tillage; CT: fall and spring tillage; MXT: fall, spring and spring disc tillage; LSD: least significant difference

‡ Not significant at α = 0.10

Consistent with a lack of major effects of tillage on soil properties measured, grain yields showed no differences among tillage treatments at the Central Butte site (Table 7). A difference in grain production occurred at Rosthern and may be attributed to greater amounts of available N ultimately produced in the MXT treatment. The MXT treatment at Rosthern produced from 100 to 400 kg ha^{-1} more grain than the other tillage treatments, possibly due to enhanced mineralization of organic matter or some other factor. This is supported by the NO_3-N being the highest in the fall MXT treatment at this site (Table 4). Lower grain yield in the MT and CT treatments at Tisdale may be due to immobilization of NO_3-N in the spring (Table 8). Reduced availability at the Tisdale site early in the season may have had a negative impact on yield.

Table 7. Grain and straw yields in the fall of 2005 after spring tillage treatments.†

	Central Butte (Wheat)			**Rosthern** (Canola)			**Tisdale** (Canola)		
Treatment	Grain	Straw	G&S‡	Grain	Straw	G&S	Grain	Straw	G&S
	Mg ha^{-1}								
NT	2.43	4.02	6.45	1.70	3.37	5.81	1.77	4.32	6.10
MT	2.44	4.38	6.82	1.95	3.95	5.90	1.17	3.71	4.88
CT	2.38	4.15	6.52	1.73	3.49	5.97	1.38	4.19	5.57
MXT	2.46	3.72	6.17	2.13	4.36	6.49	1.64	4.15	5.78
LSD$_{(0.10)}$	**NS§**	**NS**	**NS**	**0.36**	**NS**	**NS**	**0.22**	**NS**	**0.63**

† NT: no tillage; MT: spring tillage; CT: fall and spring tillage; MXT: fall, spring and spring disc tillage; LSD: least significant difference

‡ G&S denotes total biomass (grain + straw) yield

§ Not significant at α = 0.10

Conclusions

This study examined the effects of a strategic tillage operation (cycle) imposed on a NT soil. Many soil properties like organic matter, aggregation, pH, moisture and temperature were not significantly affected. Bulk density was occasionally decreased and electrical conductivity was affected only slightly. Tillage reduced P stratification in no-till surface soils, but the overall effect on P availability to the crop was minimal. The significant effects that were observed tended to vary with soil zone and cropping system.

When considering tillage, producers will have to take into account the impact of residue incorporation. The Rosthern and Tisdale sites showed evidence of initial NO_3-N immobilization due to incorporation of large amounts of fresh cereal straw. If producers expect to incorporate large amounts of N-poor residues, they should take this into account when calculating their fertilizer requirements and possibly increase the amount of N-fertilizer applied to offset the immobilization effect.

In terms of net effects of the tillage regimes on grain yield, tillage at the Central Butte site did not have a significant effect on yields, while at Rosthern there was a higher yield in the MXT treatment that may be related to mineralization. At the Tisdale site some of the tillage treatments had reduced yield compared to NT, possibly due to N-immobilization. Overall the effects were not large. Differences in yield responses observed at the different sites suggest that a large number of factors interact to affect the net effect of the imposed tillage on crop yield.

Acknowledgements

The authors would like to thank Cory Fatteicher and Tom King for their technical assistance. We would also like to thank Terry Tollefson and Dr. Diane Knight for their assistance in the review of this manuscript as well as the Agricultural Development Fund (ADF) for financial assistance.

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