ISSN 1927-050X E-ISSN 1927-0518
Published by Canadian Center of Science and Education

Effects of Short-term Tillage of a Long-term No-Till Land on Crop Yield and Nutrient Uptake in Two Contrasting Soil Types

Miles Dyck[1], Sukhdev S. Malhi[1,2], Marvin Nyborg[1] & Dyck Puurveen[1]

[1] Department of Renewable Resources, University of Alberta, Edmonton, AB T6G 2H1, Canada

[2] Previous Address: Agriculture and Agri-Food Canada, Melfort, Saskatchewan, Canada

Correspondence: Miles Dyck, Department of Renewable Resources, University of Alberta, Edmonton, AB T6G 2H1, Canada. E-mail: mdyck@ualberta.ca

Received: May 4, 2015 Accepted: January 19, 2016 Online Published: May 26, 2016

doi:10.5539/sar.v5n3p32 URL: http://dx.doi.org/10.5539/sar.v5n3p32

Abstract

Pre-seeding tillage of long-term no-till (NT) land may alter crop production by changing the availability of some nutrients in soil. Effects of short-term (4 years) tillage (hereafter called reverse tillage [RT]) of land previously under long-term (29 or 30 years) NT, with straw management (straw removed [SRem] and straw retained [SRet]) and N fertilizer rate (0, 50 and 100 kg N ha^{-1} in SRet, and 0 kg N ha^{-1} in SRem plots), were determined on plant yield (seed + straw, or harvested as forage/silage at soft dough stage), and N and P uptake in growing seasons from 2010 to 2013 at Breton (Gray Luvisol [Typic Cryoboralf] loam) and from 2009 to 2012 at Ellerslie (Black Chernozem [Albic Argicryoll] loam), Alberta, Canada. Plant yield, N uptake and P uptake tended to be greater with RT compared to NT in most cases at both sites, although significant in a few cases only at Ellerslie. On average over both sites, RT produced greater plant yield by 560 kg ha^{-1} yr^{-1}, N uptake by 5.8 kg N ha^{-1} yr^{-1}, and P uptake by 1.8 kg P ha^{-1} yr^{-1} than NT. There was no consistent beneficial effect of straw retention on plant yield, N uptake and P uptake in different years. Plant yield, N uptake and P uptake increased with N fertilization at both sites, with up to the maximum rate of applied N at 100 kg N ha^{-1} in 3 of 4 years at Breton and in 2 of 4 years at Ellerslie. In conclusion, our findings suggested some beneficial impact of occasional tillage of long-term NT soil on crop yield and nutrient uptake.

Keywords: crop yield, N fertilizer, N uptake, P uptake, pre-seeding tillage, reverse tillage, straw management, tillage system

1. Introduction

In the Prairie Provinces of Canada, farmers traditionally used tillage for seedbed preparation, but this practice, along with tillage during fallow phases for weed control, was shown to decrease soil quality. Increased organic C mineralization as a result of long-term tillage decreased aggregation, water storing capacity and nutrient supplying power, and increasing the potential for soil erosion (McGill et al., 1988; Lal et al., 1990; Franzluebbers & Arshad, 1996; Franzluebbers, 2004). Further, tillage redistribution of soil significantly increased the variability of yield and productivitiy in non-level landscapes (Pennock et al., 1994). Starting in the 1980s, farmers began adopting no-till management (NT, also called zero-tillage, or direct seeding) because of the development of more effective herbicides for weed control and the development of seeding implements which allowed seed and fertilizer to be injected directly into the soil without further seedbed preparation or incorporation of the previous crop residues. These technological advances have resulted in economic benefits such as lower labor and fuel costs and increased efficiency (Malhi et al., 1988; Singh & Singh, 1994; Larney et al., 1997). Additional benefits of NT over the conventional tillage (CT) are increased soil water storage because of enhanced infiltration of spring snowmelt, improved soil tilth and organic matter, soil carbon sequestration and increased nitrogen supplying power (Richter et al., 2007). Disadvantages associated with adoption of long-term NT are: 1) infestation of perennial grassy weeds, such as quackgrass (Malhi et al., 1988; Campbell et al., 1990; Tessier et al., 1990); 2) stratification of nutrients, especially P, in the surface soil (Grant & Lafond, 1994; Crozier et al., 1999; Baan et al., 2009), resulting in reduced availability of these nutrients to roots; 3) emergence of herbicide-resistant perennial weeds (Donald, 1990; Derksen et al., 1993); 4) relatively cool and wet surface soil in spring (Johnson & Lowery, 1985; Jones et al., 1985; Malhi & O'Sullivan, 1990; Wolfe & Eckert, 1999) which can delay seeding and slow crop emergence/early growth, and increase in the potential of nutrient loss in surface water run-off which may cause pollution of water bodies (Furguson et al., 1996). If previous crop residues are heavy, adequate seed-soil contact may be difficult to achieve because even the most advanced direct seeding equipment may have trouble penetrating or clearing the previous growing season's crop residues.

Because of the above-mentioned undesirable characteristics of long-term NT and for economic reasons, many producers are interested to re-introduce tillage occasionally. Tillage is expected to expose some of the protected soil organic C (SOC) to decomposition by breaking the aggregates through physical action and making it more accessible to soil microorganisms. Information about these risks is needed, since there is very limited research on the effects of tillage of previously long-term NT soil on crop yield and nutrient uptake, soil fertility, and persistence of organic C in soil that was gained/stored under NT on individual farm fields (Lal et al., 1990; Campbell et al., 1996, 1998; Hassink, 1997; Yang & Kay, 2001a; Six et al., 2002b; Vandenbygaart & Kay, 2004; Baan et al., 2009), especially in the Parkland region of western Canada where large quantities of crop residue are produced and left on land after harvest. Therefore, the objectives of this study were to examine the effects of short-term (4 years) pre-seeding shallow tillage (hereafter called reverse tillage – RT) of land previously under long-term NT (29 or 30 years) on crop yield and nutrient uptake [seed and straw yield, N and P uptake in seed and straw of annual cereals/oilseeds]; soil quality [total organic C (TOC) and N (TON), light fraction organic C (LFOC) and N (LFON) and mineralizable N (Nmin) in the 0-7.5 and 7.5-15 cm soil layers]; and soil fertility [nitrate-N, ammonium-N and extractable P in the 0-7.5, 7.5-15 and 15-20 cm soil layers] in two contrasting soil types (a Gray Luvisol soil at Breton and a Black Chernozem [Albic Argicryoll] soil at Ellerslie, Alberta, Canada). This paper discusses the effects of tillage, straw and N management on crop yield and nutrient uptake.

2. Methods

2.1 Location and Experimentation

Field experiments were conducted at Breton (53°07'N, 114°28'W; elevation 830 m) and Ellerslie (53°25'N, 113°33'W; elevation 692 m), Alberta, Canada. The soil at Breton is an Orthic Gray Luvisol (Typic Haplocryalf), with loam texture on a rolling, glacial till landscape which is part of the Peace Lowland/Boreal Transition ecological region. Initial soil chemical properties were pH = 6.6 and total C = 13.75 g C kg^{-1}. The mean annual precipitation at Breton is 475 mm and the growing season is from May to August with average, base-0 ^{o}C growing degree days (GDD) of 2356, 335 base-5^{o}C GDD, 118-day frost free period, mean growing season precipitation (GSP) 335 mm (range of 182 to 514 mm) and a growing season mean temperature of 14^{o}C (7^{o}C to 20^{o}C). The Ellerslie soil is a Black Chernozem (Albic Argicryoll), with loam texture, pH 6.0 and initial total organic C concentration of 56.45 g C kg^{-1} on a flat glacio-lacustrine landscape belongingto the Aspen Parkland ecological region. The long-term mean annual precipitation at Ellerslie is about 450 mm and the growing season is from May to August, with mean GSP of 335 mm (range of 190 to 440 mm). The average growing season has a 120-day frost free period, and a mean daily temperature of 14^{o}C (8^{o}C to 21^{o}C) with 2419 and 1402 base-0 ^{o}C and base-5^{o}C GDDs , respectively.

The original experiments were established in autumn 1979 (with the first growing season in 1980) at the University of Alberta Experimental Farms Breton and Ellerslie, Alberta, Canada, to examine the influence of fertilizer N-straw management-tillage interactions on crop productivity and soil properties (Malhi et al., 2010, 2011a, 2011b). The treatments were arranged in a randomized complete block design in four replications. Initially, the plots were planted to a continuous barley (*Hordeum vulgare* L.) rotation with two tillage systems (conventional tillage [CT] and zero tillage [ZT]), two straw disposals (straw removed [S_{Rem}] and straw retained [S_{Ret}]) and two N treatments (0 and 56 kg N ha^{-1} annually) (Nyborg et al., 1995). However, in 1991, another N treatment was added (100 kg N ha^{-1} annually and the 56 kg N ha^{-1} was reduced to 50 kg N ha^{-1} annually (Table 1). At the same time, the barley rotation was changed to spring wheat (*Triticum aestivum* L.). In 1997, the rotation was then changed to a barley-wheat-canola (*Brassica napus* L.) rotation. Individual plots were 2.8 m x 6.9 m. Plots under CT were tilled twice, once in the autumn and once in the spring, with a chisel cultivator followed by a coil packer. The ZT plots did not undergo any disturbance, except for seeding drill. The original NT and CT treatments were seeded to various crops in rotations from 1980 to 2010 growing seasons at Breton and from 1980 to 2009 growing seasons at Ellerslie. The NT treatments were split into two (in spring 2010 at Breton and in spring 2009 at Ellerslie) to include: 1) Control NT (original NT) treatment with no pre-seeding tillage; and 2) Tilled treatment with one tillage using rotary tiller in spring prior to seeding (hereafter called reverse tillage [RT]). The crop was harvested every year from 1980 to 2012 for seed, straw, or whole plant yield, and N and P concentration/uptake in seed, straw or whole plant. In all 4 years after RT (2010, 2011, 2012 and 2013 at Breton, and 2009, 2010, 2011 and 2012 at Ellerslie) the crop grown was barley. The N fertilizer urea was mid-row banded in alternate rows at seeding.

2.2 Crop Yield and Nutrient Uptake

Every year, the crop was harvested for seed, straw, or whole plant yield. In each plot, plant biomass sample at maturity was harvested from the four 3.6 m long central rows, dried at 65°C, and threshed for seed and straw yield. Representative seed, straw, or whole plant samples were ground through 0.3-mm sieve and analyzed for total N by using method of Noel and Hambleton (1976) and for total P by using method as outlined by Huang and Schulte (1985). The amounts of N and P uptake in seed, straw, or whole plant were calculated by multiplying yield of seed, straw, or whole plant, respectively, with % N or % P in seed, straw, or whole plant.

2.3 Statistical Analysis

The data on whole plant yield, N uptake and P uptake (seed + straw, or whole plant) were subjected to analysis of variance (ANOVA) using procedures as outlined in SAS (SAS Institute Inc. 2004). Significant ($p \leq 0.05$, or $p \leq 0.10$ when $p \leq 0.05$ not significant) differences between treatment means were determined using least significant difference test ($LSD_{0.05}$, or $LSD_{0.10}$ when $LSD_{0.05}$ not significant) for various parameters, to compare all treatments, tillage systems (NT vs. RT), straw management (S_{Rem} vs. S_{Ret} for the zero-N treatment) and N fertilizer rates (0, 50 and 100 kg N ha^{-1}).

Table 1. Description of treatments sampled after reverse tillage (RT) of long-term no-till (NT) plots under two straw managements (straw removal – S_{Rem} and straw retained – S_{Ret}) and three N fertilizer rates (0, 50 and 100 kg N ha^{-1}) in spring 2010 at Breton (Gray Luvisol) and in spring 2009 at Ellerslie (Black Chernozem), Alberta, Canada (experiments established in autumn 1979)

Treatment[z]				Annual
No.	ID	Tillage system	Straw management	Rate of N (kg N ha^{-1})
1a	$NTS_{Rem}0$	No-tillage	Straw removed	0
1b	$RTS_{Rem}0$	Reverse tillage	Straw removed	0
4a	$NTS_{Ret}0$	No-tillage	Straw retained	0
4b	$RTS_{Ret}0$	Reverse tillage	Straw retained	0
3a	$NTS_{Ret}50$	No-tillage	Straw retained	50
3b	$RTS_{Ret}50$	Reverse tillage	Straw retained	50
6a	$NTS_{Ret}100$	No-tillage	Straw retained	100
6b	$RTS_{Ret}100$	Reverse tillage	Straw retained	100

[z]The N fertilizer urea was mid-row banded in alternate rows at seeding.

Table 2. Precipitation and growing degree days (GDD) for the Breton and Ellerslie research sites

	Fall/winter[z] precipitation (October – March) - mm		Growing season precipitation (April – September) - mm		Growing Degree Days (April – September)	
Year	Breton	Ellerslie	Breton	Ellerslie	Breton	Ellerslie
2009	88	105	190	165	1296	1374
2010	99	91	544	409	1155	1259
2011	151	108	380	302	1250	1322
2012	104	58	452	359	1380	1444
2013	150	114	293	268	1377	1444

[z]Fall/winter precipitation is cumulative precipitation (including snow water equivalent) from the 7 months (October – March) prior to the growing season. Thus, the October through December precipitation data are from the previous calendar year.

3. Results

Growing conditions from 2009 to 2013 are presented in Table 2. At both Breton and Ellerslie, there was a significant tillage-by-fertilization interaction with respect to yield, N uptake and P uptake, cumulatively and in individual growing seasons (Tables 3, 4 and 5).

Table 3. Seed + straw yield (plant yield) in different years and cumulative plant yield of all 4 years after reverse tillage (RT) of long-term no-till (NT) plots under two straw managements (straw removal – S_{Rem} and straw retained – S_{Ret}) and three N fertilizer rates (0, 50 and 100 kg N ha^{-1}) in spring 2010 at Breton (Gray Luvisol soil) and in spring 2009 at Ellerslie (Black Chernozem soil), Alberta, Canada (experiments established in autumn, 1979)

Treatment[z] (tillage/straw/ kg N ha^{-1})	Plant yield (kg ha^{-1}) in different years at Breton					Plant yield (kg ha^{-1}) in different years at Ellerslie				
	2010	2011	2012	2013	Total	2009	2010	2011	2012	Total
Treatment mean										
NTS_{Rem}0	1724	421	273	195	2613	2016	2474	1732	2251	8473
RTS_{Rem}0	1908	948	554	175	3586	2317	2646	2340	2131	9434
NTS_{Ret}0	1941	694	140	285	3060	1902	3302	2210	759	8173
RTS_{Ret}0	2454	798	232	535	4018	2384	4577	3039	1676	11676
NTS_{Ret}50	2626	2679	1338	789	7431	3557	3605	3240	3540	13943
RTS_{Ret}50	3401	2118	1551	1397	8467	3452	5284	4840	3866	17441
NTS_{Ret}100	3894	2172	1247	1435	8747	3204	6168	4198	3084	16654
RTS_{Ret}100	4149	3826	1728	1862	11565	3340	7069	5938	3502	19848
$LSD_{0.05}$	1225	886	343	827	2335	603	1975	1494	1109	3192
SEM	404	292	113	272	667	205	671	508	377	1085
Significance	**	***	***	***	***	***	***	***	***	***
Tillage effect										
NT mean	2546	1492	749	676	5463	2670	3887	2845	2409	11811
RT mean	2978	1923	1016	992	6909	2873	4894	4039	2794	14600
$LSD_{0.05}$	940	1080	570	644	2957	564	1454	1157	918	3397
SEM (Prob)	319	366	193	218	1002	194	501	399	316	1171
Significance	ns	ns	ns	ns	ns	ns	ns	*	ns	*
Straw effect at 0 N										
S_{Rem}mean	1816	685	413	185	3100	2166	2560	2036	2191	8953
S_{Ret} mean	2198	746	186	410	3539	2143	3940	2624	1218	9925
$LSD_{0.05}$	584	383	211	517	962	438	1039	1029	736	2508
SEM (Prob)	179	118	65	159	295	141	334	331	236	806
Significance	ns	ns	*	ns	ns	ns	*	ns	*	ns
N rate effect with S_{Ret}										
0 mean	2198	746	186	410	3539	2143	3940	2624	1218	9925
50 mean	3013	2399	1444	1093	7949	3504	4445	4040	3703	15692
100 mean	4021	2999	1488	1648	10156	3272	6619	5068	3293	18252
$LSD_{0.05}$	947	957	333	627	2150	446	1686	1418	881	3185
SEM	2130	313	109	205	704	150	567	477	296	1097
Significance	**	***	***	**	***	***	**	**	***	***

[z]NT = No-tillage, RT = Reverse tillage, S_{Rem} = Straw removed, S_{Ret} = Straw retained, 0, 50 and 100 kg N ha^{-1}.

●, *, **, *** and ns refer to significant treatment effects in ANOVA at $P \leq 0.10$, $P \leq 0.05$, $P \leq 0.01$, $P \leq 0.001$ and not significant, respectively.

Table 4. Total N uptake in seed + straw (plant) in different years and cumulative total N uptake in plant of all 4 years after reverse tillage (RT) of long-term no-till (NT) plots under two straw managements (straw removal – S_{Rem} and straw retained – S_{Ret}) and three N fertilizer rates (0, 50 and 100 kg N ha^{-1}) in spring 2010 at Breton (Gray Luvisol soil) and in spring 2009 at Ellerslie (Black Chernozem soil), Alberta, Canada (experiments established in autumn, 1979)

Treatment[z] (tillage/straw/ kg N ha^{-1})	Total N uptake in plant (kg N ha^{-1}) in different year at Breton					Total N uptake in plant (kg N ha^{-1}) in different years at Ellerslie				
	2010	2011	2012	2013	Total	2010	2011	2012	2013	Total
Treatment mean										
$NTS_{Rem}0$	16.8	3.4	2.7	1.8	24.7	22.8	28.3	15.6	18.2	84.9
$RTS_{Rem}0$	19.8	7.8	5.2	1.8	34.6	25.4	30.5	22.8	19.0	97.7
$NTS_{Ret}0$	19.2	7.0	1.5	3.2	30.8	19.0	33.4	30.0	7.1	79.5
$RTS_{Ret}0$	24.2	7.4	2.7	4.7	38.9	24.5	52.3	29.4	17.9	124.1
$NTS_{Ret}50$	24.3	25.7	12.5	8.0	70.5	47.7	35.2	31.0	44.6	158.5
$RTS_{Ret}50$	34.6	20.6	14.2	13.8	83.3	45.6	58.0	45.3	38.3	187.2
$NTS_{Ret}100$	42.1	23.1	13.0	13.5	91.7	46.6	80.4	55.1	45.6	227.7
$RTS_{Ret}100$	42.0	36.2	18.8	17.4	114.4	45.5	86.7	76.6	52.2	261.0
$LSD_{0.05}$	12.7	8.8	3.4	7.1	22.8	8.8	25.2	15.5	12.2	32.6
SEM	4.2	2.9	1.1	2.4	7.5	3.0	5.6	5.3	4.1	11.1
Significance	**	***	***	**	***	***	***	***	***	***
Tillage effect										
NT mean	25.6	14.8	7.4	6.6	54.4	34.0	44.3	30.4	28.9	137.6
RT mean	30.2	18.0	10.2	9.4	67.8	35.2	56.8	43.5	31.9	167.4
$LSD_{0.05}$	10.1	10.7	5.7	6.0	29.9	10.1	19.6	15.9	13.4	50.9
SEM (Prob)	3.4	3.6	2.0	2.0	10.1	3.5	3.7	5.5	4.6	17.5
Significance	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Straw effect at 0 N										
S_{Rem}mean	18.3	5.6	4.0	1.8	29.6	24.1	29.4	19.2	18.6	91.3
S_{Ret} mean	21.7	7.2	2.1	3.9	34.9	21.8	42.8	24.7	12.5	101.8
$LSD_{0.05}$	5.5	3.3	2.0	4.3	10.0	4.2	12.7	9.9	7.7	27.0
SEM (Prob)	1.6	1.0	0.6	1.3	3.1	1.4	4.1	3.2	2.5	8.7
Significance	ns	ns	*	ns	ns	ns	*	ns	*	ns
N rate effect with S_{Ret}										
0 mean	21.7	7.2	2.1	3.9	34.9	21.8	42.8	24.7	12.5	101.8
50 mean	29.5	23.2	13.4	10.9	76.9	46.6	46.6	38.2	41.5	172.9
100 mean	42.1	29.7	15.9	15.5	103.1	46.1	83.5	65.8	48.9	244.6
$LSD_{0.05}$	10.4	8.6	3.5	5.5	20.1	6.7	21.6	15.2	10.0	33.1
SEM	3.4	2.8	1.2	1.8	6.6	2.3	7.3	5.2	3.4	11.1
Significance	**	***	***	**	***	***	**	***	***	***

[z]NT = No-tillage, RT = Reverse tillage, S_{Rem} = Straw removed, S_{Ret} = Straw retained, 0, 50 and 100 kg N ha^{-1}.

•, *, **, *** and ns refer to significant treatment effects in ANOVA at $P \leq 0.10$, $P \leq 0.05$, $P \leq 0.01$, $P \leq 0.001$ and not significant, respectively.

Table 5. Total P uptake in seed + straw (plant) in different years and cumulative total P uptake in plant of all 4 years after reverse tillage (RT) of long-term no-till (NT) plots under two straw managements (straw removal – S_{Rem} and straw retained – S_{Ret}) and three N fertilizer rates (0, 50 and 100 kg N ha^{-1})in spring 2010 at Breton ((Gray Luvisol soil) and in spring 2009 at Ellerslie (Black Chernozem soil), Alberta, Canada (experiments established in autumn, 1979)

Treatment[z] (tillage/straw/ kg N ha^{-1})	Total P uptake in plant (kg P ha^{-1}) in different year at Breton					Total P uptake in plant (kg P ha^{-1}) in different years at Ellerslie				
	2010	2011	2012	2013	Total	2010	2011	2012	2013	Total
Treatment mean										
$NTS_{Rem}0$	5.1	1.3	0.8	0.5	7.8	5.6	5.9	5.6	6.0	23.1
$RTS_{Rem}0$	5.3	3.2	1.8	0.5	10.8	6.0	6.4	7.9	5.6	25.9
$NTS_{Ret}0$	5.5	2.3	0.4	0.7	8.9	4.4	8.0	6.1	1.9	20.4
$RTS_{Ret}0$	6.7	2.6	0.8	1.4	11.5	5.5	13.6	9.4	5.2	33.7
$NTS_{Ret}50$	6.9	6.8	3.7	2.1	19.4	7.2	8.4	7.8	9.4	32.8
$RTS_{Ret}50$	10.4	6.0	4.3	4.2	24.9	6.6	12.8	12.3	9.7	41.4
$NTS_{Ret}100$	9.7	4.7	3.5	3.3	21.2	6.2	14.1	9.4	7.0	36.7
$RTS_{Ret}100$	11.2	8.2	4.5	4.7	28.5	5.8	15.9	14.2	9.0	44.9
$LSD_{0.05}$	3.2	2.1	1.1	2.1	6.1	1.5	4.8	4.1	2.7	8.1
SEM	1.1	0.7	0.4	0.7	2.0	0.5	1.6	1.4	0.9	2.8
Significance	**	***	***	**	***	*	**	**	***	***
Tillage effect										
NT mean	6.8	3.8	2.1	1.6	14.3	5.8	9.1	7.2	5.2	27.3
RT mean	8.4	5.0	2.9	2.7	18.9	6.0	12.2	11.0	6.8	36.0
$LSD_{0.05}$	2.4	2.2	1.5	1.6	7.0	0.9	3.3	2.5	2.2	6.6
SEM (Prob)	0.8	0.8	0.5	0.6	2.4	0.3	1.2	0.8	0.8	2.3
Significance	ns	ns	ns	ns	ns	ns	*	**	ns	*
Straw effect at 0 N										
S_{Rem}mean	5.2	2.3	1.3	0.5	9.3	5.8	6.2	6.7	5.8	24.5
S_{Ret} mean	6.1	2.5	0.6	1.0	10.2	5.0	10.8	7.8	3.6	27.2
$LSD_{0.05}$	1.2	1.3	0.7	1.3	3.1	1.0	3.4	3.0	2.2	7.6
SEM (Prob)	0.4	0.4	0.2	0.4	0.9	0.3	1.1	1.0	0.7	2.4
Significance	*	ns	*	ns	ns	*	*	ns	*	ns
N rate effect with S_{Ret}										
0 mean	6.1	2.5	0.6	1.0	10.2	5.0	10.8	7.8	3.6	27.2
50 mean	8.7	6.4	4.0	3.1	22.1	6.9	10.6	10.1	9.5	37.1
100 mean	10.5	6.5	4.0	4.0	24.9	6.0	15.0	11.8	5.1	40.9
$LSD_{0.05}$	2.8	2.1	0.9	1.7	5.9	1.1	4.5	4.0	2.4	8.8
SEM	0.9	0.7	0.3	0.6	1.9	0.4	1.5	1.3	0.8	3.0
Significance	*	**	***	**	***	**	*	ns	***	*

[z]NT = No-tillage, RT = Reverse tillage, S_{Rem} = Straw removed, S_{Ret} = Straw retained, 0, 50 and 100 kg N ha^{-1}.

•, *, **, *** and ns refer to significant treatment effects in ANOVA at $P \leq 0.10$, $P \leq 0.05$, $P \leq 0.01$, $P \leq 0.001$ and not significant, respectively.

Cumulative plant yield, N uptake and P uptake at Breton (total of 4 years) tended to be greater with RT than NT (Tables 3, 4 and 5). At Ellerslie, cumulative (total of 4 years) plant yield was greater at $p \leq 0.10$, N uptake tended to be greater and P uptake was significantly greater with RT than NT. The differences in plant yield, N uptake and P uptake between RT and NT were much greater at Ellerslie than at Breton. For example, on average at Breton, RT produced greater plant yield by 377 kg ha^{-1} yr^{-1}, N uptake by 3.5 kg N ha^{-1} yr^{-1} and P uptake by 1.2 kg P ha^{-1} yr^{-1} than NT. In the same order at Ellerslie, RT produced greater plant yield by 697 kg ha^{-1} yr^{-1}, N uptake by 7.5 kg N ha^{-1} yr^{-1}, and P uptake by 2.2 kg P ha^{-1} yr^{-1} than NT. On average, S_{Ret} produced greater plant yield, N uptake and P uptake than $S_{Rem,}$ respectively, by 72 kg ha^{-1} yr^{-1}, 1.0 kg N ha^{-1} yr^{-1} and 0.1 kg P ha^{-1} yr^{-1} at

Breton. The corresponding values at Ellerslie were 243 kg ha^{-1} yr^{-1} for plant yield, 2.6 kg N ha^{-1} yr^{-1} for N uptake and 0.7 kg P ha^{-1} yr^{-1} for P uptake, suggesting that the differences between S_{Ret} and S_{Rem} were much wider a Ellerslie than at Breton.

At Breton, averaged over straw management and N rates, RT tended to produce greater (although not significant) plant yield (seed + straw, or whole plant harvested as forage/silage at soft dough stage), N uptake and P uptake than NT in all 4 years (Tables 3, 4 and 5). In the zero-N treatment, there was no consistent beneficial effect of straw retention on plant yield, N uptake and P uptake in different years. For example, average plant yield, N uptake and P uptake tended to be greater with S_{Ret} than S_{Rem} in 2010 and 2013, but the opposite happened in 2012 at both sites where plant yield, N uptake and P uptake were significantly lower with S_{Ret} than $S_{Rem.}$ Averaged over tillage systems in the S_{Ret} treatment, plant yield, N uptake and P uptake increased with increasing N rate up to 100 kg N ha^{-1} in 3 of 4 years. In the S_{Ret} treatments, RT usually produced greater plant yield, N uptake and P uptake than NT in all 4 years for zero-N and 100 kg N ha^{-1} treatments, and in 3 of 4 years for the 50 kg N ha^{-1} rate treatment. In the RT treatment, plant yield, N uptake and P uptake increased with increasing N rate up to the 100 kg N ha^{-1} rate in all 4 years. But, in the NT treatment, plant yield, N uptake and P uptake increased up to the 100 kg N ha^{-1} rate in only 2 of 4 years (i.e., 2009), with lower maximum plant yield, N uptake and P uptake. In the S_{Rem} treatment with zero-N, plant yield, N uptake and P uptake were also greater with RT than NT in all 4 years.

At Ellerslie, averaged over straw management and N rates, plant yield, N uptake and P uptake tended to be greater in 3 years (2009, 2010 and 2012) and significantly greater in 1 year (2011) with RT than NT (Tables 3, 4 and 5). In the zero-N treatment, there was no consistent beneficial effect of straw retention on plant yield, N uptake and P uptake in various individual years. For example, average plant yield, N uptake and P uptake tended to be greater in 2010 or significantly greater in 2011 with S_{Ret} than S_{Rem}, with no beneficial effect of straw management in 2009, but the opposite effect occurred in 2012 where plant yield, N uptake and P uptake tended to be lower with S_{Ret} than $S_{Rem.}$ Averaged over tillage systems in the S_{Ret} treatment, plant yield, N uptake and P uptake increased with N fertilization, up to 100 kg N ha^{-1} in 2 of 4 years and up to 50 kg N ha^{-1} in the other 2 years (i.e., 2009 and 2012). In the S_{Ret} treatments, RT produced greater plant yield, N uptake and P uptake than NT in all 4 years for the zero-N treatment and in 3 of 4 years for the 50 and 100 kg N ha^{-1} rate treatments. In the S_{Rem} treatment with zero-N, plant yield, N uptake and P uptake were greater with RT than NT in 3 of 4 years and lower with RT than NT in 1 year. In both RT and NT systems, plant yield, N uptake and P uptake increased with increasing N rate up to the 100 kg N ha^{-1} rate in 2 years (i.e., 2010 and 2011) and up to the 50 kg N ha^{-1} rate in the other 2 years (i.e., 2009 and 2012). In 2010 and 2011, the maximum plant yield, N uptake and P uptake were greater with RT than NT.

4. Discussion

Earlier research has shown that elimination of tillage (NT), especially when straw is retained, can produce greater plant yield and nutrient uptake than CT (or RT) (Malhi et al. 2006; Malhi and Lemke 2007), because of increased soil water storage/conservation (Jones et al. 1969; Malhi and O'Sullivan 1990; Singh et al. 1998) and N-supplying-power of soil (Malhi et al. 2010, 2011). However, this did not happen in our study. This suggests that soil moisture most likely was not the major limiting factor for crop growth at these sites in these years, using up to the maximum rate of 100 kg N ha^{-1} used in this study. Therefore, it is possible that this crop response trend/pattern in our study may be due to increased immobilization of N caused by addition of straw with a wide C:N ratio on the surface under NT, resulting in reduced amount of available N under NT. In addition, it is also possible that there was much more N that became available to crop plant during growing season under RT/CT, particularly at Ellerslie, because of increased N mineralization from crop residue (that accumulated at the soil surface over many years under NT) by RT compared to NT. Overall, increased immobilization of N due to straw addition under NT and greater N mineralization from crop residue under RT/CT may have contributed to greater nutrient uptake and subsequently to greater crop growth/yield with RT compared to NT, particularly at Ellerslie. The increase of crop yield and N uptake with increasing N rate up to the 100 kg N ha^{-1} rate in most cases suggests that N was more limiting than moisture for crop growth in these years at these sites.

The lack of consistent high beneficial effect of straw retention on crop yields and nutrient uptake in some years, especially at Ellerslie, was probably due to immobilization of nitrate-N in soil in spring by incorporation of large amounts of crop residue that accumulated at the soil surface over 32 years under NT. This decreased availability of N may have resulted in negative effect on crop growth and yield. However, we do not have clear explanation for the reverse effect of straw retention on crop yields and nutrient uptake in 2012 (fourth growing season after RT).

Crop yield and nutrient uptake were very low in 2012, especially in the zero-N treatment and particularly under NT. It is possible that very wet weather conditions in 2012 growing season may have caused significant nitrate-N loss by leaching and/or denitrification, resulting in very poor crop growth in plots receiving no fertilizer N and also limited effect of applied N on crop yield even at higher N rate. Because of greater mixing of crop residue and soil, and thereby increasing level of soluble C and potential to denitrify N in soil, we anticipated and expected RT to cause greater N loss through denitrification and then producing lower crop yield and N uptake than NT, as suggested by Campbell et al. (1998). However, this did not occur and opposite happened in our study, which was most likely due to greater N mineralization and relatively drier soil conditions less conducive to denitrification, causing greater crop yield and N uptake under RT compared to NT.

Although not directly measured, it is possible that improved seedbed conditions in RT improved yields and nutrient uptake in addition to the abovementioned reasons. As mentioned previously, spring soil temperatures are generally reduced under NT management, reducing seedling vigor and germination. Further possible consequences of long-term NT management on small plots like this are soil compaction from seeding and pesticide application equipment and residue build up (in S_{Ret}) that could result in poor seed and fertilizer placement. These physical effects of NT are likely more intense at the small plot scale and likely accumulate over the long-term, creating conditions favorable for crop response to improved seedbed conditions as a result of RT.

Overall, crop yield and nutrient uptake did not show any negative impact of converting long-term NT soil to tilled (RT) system during the 4-yr period in our study, as also previously reported by other researchers in Saskatchewan (Campbell et al. 1998; Baan et al. 2009). In our study, however, crop yields and nutrient uptake were usually greater under RT than NT. This may be due to a difference in soil type and soil moisture conditions between our and previous studies, as soil moisture was not a limiting factor for optimum crop growth and yield in our study. The results may have been different in our study, if soil moisture was more limiting for crop growth, as NT with stubble promotes trapping of snow and storage/conservation of water in soil while tillage increases drying of surface soil and promotes loss of water as suggested by Campbell et al. (1988).

Crop yield, N uptake and P uptake tended to be greater under RT compared to NT in most caes at both sites, but significant in a few cases only at Ellerslie. On average over both sites, RT produced greater plant yield by 560 kg ha^{-1} yr^{-1}, N uptake by 5.8 kg N ha^{-1} yr^{-1}, and P uptake by 1.8 kg P ha^{-1} yr^{-1} than NT. Although there was no consistent beneficial effect of S_{Ret} on crop yield and nutrient uptake in different years, cumulative crop yield and/or nutrient uptake was/tended to be greater with S_{Ret} than S_{Rem}. On average over both sites, SRet produced greater plant yield by 170 kg ha^{-1} yr^{-1}, N uptake by 1.9 kg N ha^{-1} yr^{-1} and P uptake by 0.4 kg P ha^{-1} yr^{-1} than SRem. There was a substantial response of crop yield to applied N under both RT and NT. Plant yield, N uptake and P uptake in individual years increased with N fertilization at both sites, with up to the maximum rate of applied N at 100 kg N ha^{-1} in 3 of 4 years at Breton and in 2 of 4 years at Ellerslie. In these years, the responses of plant yield, N uptake and P uptake to applied N were greater under RT than NT. Cumulative plant yield, N uptake and P uptake all increased with increasing rate of applied N up to the maximum rate of 100 kg N ha^{-1} used at both sites. In summary, RT tended to produce greater crop yield and nutrient uptake than NT, most likely due to the increase in the availability of N, P and other nutrients to crop plants from the decomposition/mineralization of crop residue. Our findings suggest some beneficial impact of occasional tillage of long-term NT soil on crop production/soil productivity.

Acknowledgments

The authors thank K. Strukoff for technical help, D. Leach for statistical analysis.

References

Baan, C. D., Grevers, M. C. J., & Schoenau, J. J. (2009). Effects of a single cycle of tillage on long-term no-till prairie soils. *Can. J. Soil Sci., 89*, 521-530. http://dx.doi.org/10.4141/cjss08041

Campbell, C. A., McConkey, B. G., Zentner, R. P., Dyck, F. B., Selles, F., & Curtin, D. (1996). Carbon sequestration in Brown Chernozem as affected by tillage and rotation. *Can. J. Soil Sci., 75*, 449-458. http://dx.doi.org/10.4141/cjss95-065

Campbell, C. A., Tessier, J. S. J., & Selles, F. (1988). Challenges and limitations to adoption of conservation tillage – soil organic matter, fertility, moisture and soil environment. Pp. 140-185. In: Land Degradation and Conservation Tillage. *Proc. 34th Annual CSSS/AIC Meeting*, AIC, Calgary, Alberta, Canada.

Campbell, C. A., Thomas, A. G., Biederbeck, V. O., McConkey, B. G., Selles, F., Spurr, D., & Zentner, R. P. (1998). Converting from no-tillage to pre-seeding tillage: influence on weeds, spring wheat grain yields and

N, soil quality. *Soil Tillage Res., 46*, 175-185. http://dx.doi.org/10.1016/S0167-1987(98)00031-2

Campbell, C. A., Zentner, R. P., Janzen, H. H., & Bowren, K. E. (1990). Crop rotation studies on the Canadian Prairies. Canadian Government Publication Centre, Supply and Services Canada, Hull, Quebec, Canada. Publ. No. 184/E, 133 pp.

Crozier, C. R., Naderman, G. C., Tucker, M. R., & Sugg, R. E. (1999). Nutrient and pH stratification with conventional and no-till management. Commun. Soil. *Sci. Plant Anal., 30*, 65-74. http://dx.doi.org/10.1080/00103629909370184

Derksen, D. A., Lafond, G. P., Thomas, A. G., Loeppky, H. A., & Swanton, C. J. (1993). Impact of agronomic practices on weed communities – tillage systems. *Weed Sci., 41*, 409-417. http://www.jstor.org/stable/4045366

Donald, W. W. (1990). Primary tillage for Foxtail barley (*Hordeum jubatum* L.) control. *Weed Technol., 4*, 318-321. http://www.jstor.org/stable/3987080

Essington, M. F., & Howard, D. D. (2000). Phosphorus availability and speciation in long-term no-till and disk-till soil. *Soil Sci., 165*, 144-152.

Franzluebbers, A. (2004). Tillage and residue management effects on soil organic matter. In F. Magdoff & R. R. Weil (eds.), *Soil organic matter in sustainable agriculture* (pp. 227-268). CRC Press, Boca Raton, FL.

Franzluebbers, A., & Arshad, M. A. (1996). Soil organic matter pools with conventional and zero tillage in a cold, semiarid climate. *Soil and Tillage Res., 39*, 1-11. http://dx.doi.org/10.1016/S0167-1987(96)01055-0

Ferguson, A. J. D., Pearson, M. J., & Reynolds, C. S. (1996). Eutrofication of natural water and toxic algal blooms. *Issues Environ. Sci. Technol., 5*, 27-41.

Grant, C. A., & Lafond, G. P. (1994). The effects of tillage systems and crop rotations on soil chemical properties of a Black Chernozemic soil. *Can. J. Soil Sci., 74*, 301-306. http://dx.doi.org/10.4141/cjss94-042

Hassink, J. (1997). The capacity of soils to physically protect organic C and N. *Plant Soil, 191*, 77-87. http://dx.doi.org/10.1023/A3A1004213929699

Huang, C. L., & Schulte, E. E. (1985). Digestion of plant tissue for analysis by ICP emission spectroscopy. Commun. *Soil Sci. Plant Anal., 16*, 943-958. http://dx.doi.org/10.1080/00103628509367657

Johnson, M. D., & Lowery, B. (1985). Effect of three conservation tillage practices on soil temperature and thermal properties. *Soil Sci. Soc. Am. J., 49*, 1547-1552. http://dx.doi.org/10.2136/sssaj1985.03615995004900060043x

Jones, O. R., Allen, R. R., & Unger, P. W. (1990). Tillage systems and equipment for dryland farming. Pages 89-125. In R. P. Singh, F. Parr & B. A. Stewart (eds.), *Dryland Agriculture: Strategies for Sustainability* (vol. 13). Springer-Verlag, New York, NY, U.S.A.

Lal, R., Logan, T. J., & Fausey, N. R. (1990). Long-term tillage effects on a Mollic Ochraqualf in north-west Ohio III. Soil nutrient profile. *Soil Tillage Res., 15*, 371-382. http://dx.doi.org/10.1016/0167-1987(90)90110-Y

Larney, F. J., Bremer, E., Janzen, H. H., Johnston, A. M., & Lindwall, C. W. (1997). Changes in total, mineralizable and light fraction soil organic matter with cropping and tillage intensities in semiarid southern Alberta, Canada. *Soil Tillage Res., 42*, 229-240. http://dx.doi.org/10.1016/S0167-1987(97)00011-1

Malhi, S. S., & Lemke, R. (2007). Tillage, crop residue and N fertilizer effects on crop yield, nutrient uptake, soil quality and greenhouse gas emissions in the second 4-yr rotation cycle. *Soil Tillage Res., 96*, 269-283. http://dx.doi.org/10.1016/j.still.2007.06.011

Malhi, S. S., & O'Sullivan, P. A. (1990). Soil temperature, moisture and compaction under zero and conventional tillage in central Alberta. *Soil Tillage Res., 17*, 167-172. http://dx.doi.org/10.1016/0167-1987(90)90014-5

Malhi, S. S., Brandt, S. A., Lemke, R., Moulin, A. P., & Zentner, R. P. (2009). online. Effects of input level and crop diversity on soil nitrate-N, extractable P, aggregation, organic C and N, and N and P balance in the Canadian Prairie. *Nutr. Cycl. Agroecosyst, 84*, 1-22. http://dx.doi.org/10.1007/s10705-008-9220-0

Malhi, S. S., Lemke, R., Wang, Z. H., & Chhabra, B. S. (2006). Influence of tillage and crop residue management on crop yield, greenhouse gas emissions and soil quality. *Soil Tillage Res., 90*, 171-183. http://dx.doi.org/10.1016/j.still.2005.09.001

Malhi, S. S., Mumey, G., O'Sullivan, P. A., Harker, K. N. (1988). An economic comparison of barley production under zero and conventional tillage. *Soil Tillage Res., 11*, 159-166. http://dx.doi.org/10.1016/0167-1987(88)90023-2

Malhi, S. S., Nyborg, M., Goddard, T., & Puurveen, D. (2010). Long-term tillage, straw and N rate effects on quantity and quality of organic C and N in a Gray Luvisol soil. *Nutr. Cycl. Agroecosys., 90*, 1-20. http://dx.doi.org/10.1007/s10705-010-9399-8

Malhi, S. S., Nyborg, M., Goddard, T., & Puurveen, D. (2011a). Long-term tillage, straw management and N fertilization effects on quantity and quality of organic C and N in a Black Chernozem soil. *Nutr. Cycl. Agroecosys, 90*, 227-241. http://dx.doi.org/10.1007/s10705-011-9424-6

Malhi, S. S., Nyborg, M., Goddard, T., & Puurveen, D. (2011b). Long-term tillage, straw and N rate effects on some chemical properties in two contrasting soil types. *Nutr. Cycl. Agroecosys, 90*, 133-146. http://dx.doi.org/10.1007/s10705-010-9417-x

Malhi, S. S., Nyborg, M., Goddard, T., & Puurveen, D. (2011c). influence of long-term tillage, straw and N fertilizer management on crop yield, N uptake, and N balance sheet in two contrasting soil types. *Commun. Soil Sci. Plant Anal., 42*, 2548-2560. http://dx.doi.org/10.1080/00103624.2011.609262.

McGill, W. B., Dormaar, J. F., & Reinl-Dwyer, E. (1988). New perspectives on soil organic matter quality, quantity, and dynamics on the Canadian Prairies. In: P*roc. Canadian Society of Soil Science and Canadian Society of Extension Joint Symposium, Land degradation: Assessment and insight into a western Canadian problem* (pp. 30-48). August 23, 1988, Agricultural Institute of Canada, Calgary, Alberta, Canada.

Noel, R. J., & Hambleton, L. G. (1976). Collaborative study of a semi-automated method for the determination of crude protein in animal feeds. *J. Assoc. Offic. Anal. Chem., 59*, 134-140.

Nyborg, M., Solberg, E. D., Malhi, S. S., & Izaurralde, R. C. (1995). Fertilizer N, crop residue, and tillage after soil C and N content in a decade. In R. Lal, J .Kimble, E. Levine & B. A. Stewart (eds.), *Soil management and greenhouse effect* (pp. 93-99). Adv. Soil Sci., Lewis Publishers, CRC Press, Boca Raton, FL, U.S.A.

Pennock, D. J., Anderson, D. W., & de Jong, E. (1994). Landscape-scale changes in indicatros of soil quality due to cultivation in Saskatchewan, *Canada. Geoderma, 64*, 1-19. http://dx.doi.org/10.1016/0016-7061(94)90086-8

Richter, D., Callaham, M. A., Powlson, D. S., & Smith, P. (2007). Long-term soil experiments: Keys to managing earth's rapidly changing ecosystems. *Soil Sci. Soc. Am. J., 71*, 266-279. http://dx.doi.org/10.2136/sssaj2006.0181

SAS Institute. (2004). *SAS product documentation* (Version 8). Retrieved July 17, 2009, from http://support.sas.com/documentation/onlinedoc/index.html

Singh, B., & Malhi, S. S. (2006). Response of soil physical properties to tillage and straw management on two contrasting soils in a cryoboreal environment. *Soil Tillage Res., 85*, 143-153. http://dx.doi.org/10.3923/ajps.2006.613.618

Singh, B., Chanasyk, D. S., & McGill, W. B. (1998). Soil water regime under barley with long-term tillage-residue systems. *Soil Tillage Res., 45*, 59-74. http://dx.doi.org/10.1016/S0167-1987(97)00067-6

Singh, H., & Singh, K. P. (1994). Nitrogen and phosphorus availability and mineralization in dryland reduced tillage cultivation – effects of residue placement and chemical fertilizer. *Soil Biol. Biochem., 26*, 695-702. http://dx.doi.org/10.1016/0038-0717(94)90261-5

Six, J., Feller, C., Denef, K., Ogle, S. M., de Moraes Sa, J. C., & Albrecht, A. (2002).Soil organic matter, biota, and aggregation in temperate and tropical soils – Effects of no-tillage. *Agronomie, 22*, 755-775. http://dx.doi.org/10.1051/agro:2002043

Tessier, S., Peru, M., Dyck, F. B., Zentner, R. P., & Campbell, C. A. (1990). Conservation tillage for spring wheat production in semiarid Saskatchewan. *Soil Tillage Res., 18*, 73-79. http://dx.doi.org/10.1016/0167-1987(90)90094-T

Vanderbygaart, A. J., & Kay, B. D. (2004). Persistence of soil organic carbon after plowing a long-term no-till field in southern Ontario, Canada. *Soil Sci. Soc. Am. J., 68*, 1394-1402. http://dx.doi.org/10.2136/sssaj2004.1394

Wolfe, A. M., & Eckert, D. J. (1999). crop sequence and surface residue effects on the performance of no-till corn grown on a poorly drained soil. *Agron. J., 91*, 363-367. http://dx.doi.org/10.2134/agronj1999.00021962009100030002x

Yang, X. M., & Kay, B. D. (2001). Rotation and tillage effects on soil organic carbon sequestration in a Typic Hapludalf in southern Ontario. *Soil Tillage Res., 59*, 107-114. http://dx.doi.org/10.1016/S0167-1987(01)00162-3

Zibilske, L. M., Bradford, J. M., & Smart, J. R. (2002). Conservation tillage induced changes in organic carbon, total nitrogen and available phosphorus in a semi-arid alkaline subtropical soil. *Soil Tillage Res., 66*, 153-163. http://dx.doi.org/10.1016/S0167-1987(02)00023-5