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Effects of Short-term Tillage of a Long-term No-Till Land on Quantity and Quality of Organic C and N in Two Contrasting Soil Types

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Abstract

Pre-seeding tillage of long-term no-till soil may alter soil quality by changing some properties, but the magnitude of change depends on soil type and climatic conditions. Effects of short-term (2 or 3 years) tillage (hereafter called reverse tillage [RT]) of land previously under long-term no-till (NT, 29 or 30 years), with straw management (straw removed [S_{Rem}] and straw retained [S_{Ret}]) and N fertilizer rate (0, 50 and 100 kg N ha^{-1} in S_{Ret}, and 0 kg N ha^{-1} in S_{Rem} plots) were determined in autumn 2011 on total organic C (TOC) and N (TON), light fraction organic C (LFOC) and N (LFON), and mineralizable N (N_{min}) in the 0-7.5, 7.5-15, or 15-20 cm soil layers at Breton (Gray Luvisol [Typic Cryoboralf] loam) and Ellerslie (Black Chernozem [Albic Argicryoll] loam), Alberta, Canada. Short-term RT following long-term NT had no significant negative effect on TOC and TON in soil at both sites, although these parameters tended to be slightly lower in the 0-7.5 cm soil layer with RT compared to NT. For the zero-N treatment, S_{Ret} had greater TOC and TON compared to S_{Rem} in both soil layers at both sites. On average, over both sites, TOC and TON in the 0-15 cm soil increased by 2.08 Mg C ha^{-1} and 0.216 Mg N ha^{-1}, respectively. Application of N fertilizer increased TOC and TON in both soil layers, up to the 50 kg N ha^{-1} rate at Breton (by 7.96 Mg C ha^{-1} and 0.702 Mg N ha^{-1} in the 0-15 cm soil) and up to the 100 kg N ha^{-1} rate at Ellerslie (by 5.11 Mg C ha^{-1} and 0.439 Mg N ha^{-1} in the 0-15 cm soil). In both RT and NT treatments, the effects of N rate on TOC and TON were similar for S_{Ret} and $S_{Rem.}$ There was greater LFOC and LFON in the 7.5-15 cm soil layer with RT than NT at both sites. In the 0-15 cm soil layer, averaged over both sites, RT increased LFOC by 66 kg C ha^{-1} and LFON by 4.0 kg N ha^{-1}. In both 0-7.5 and 7.5-15 cm soil layers, LFOC and LFON increased with S_{Ret} compared to $S_{Rem.}$ Averaged over both sites, the increase in LFOC and LFON in the 0-15 cm soil was 97 kg C ha^{-1} and 3.5 kg N ha^{-1}, respectively. Mass of LFOC and LFON increased dramatically in both soil layers with application of N fertilizer up to the 100 kg N ha^{-1} rate at both sites, with an average increase of 866 kg C ha^{-1} and 45.5 kg N ha^{-1}. In the zero-N treatment, LFOC and LFON increased with S_{Ret} compared to S_{Rem} under RT at Breton and under NT at Ellerslie. On average, tillage had no effect on N_{min} in soil, but S_{Ret} increased N_{min} in soil in both RT and NT, with an average increase of 4.8 kg N ha^{-1}. Application of N fertilizer increased N_{min} in the 0-20 cm soil up to 50 kg N ha^{-1} rate at Breton (by 13.7 kg N ha^{-1}) and up to 100 kg N ha^{-1} rate at Ellerslie (by 18.6 kg N ha^{-1}). In conclusion, RT had no effect on TOC, TON and N_{min} in soil, but LFOC and LFON increased with RT compared to NT in the 7.5-15 cm layer at one site. S_{Ret} and N fertilization usually had dramatic positive effects on TOC, TON, LFOC, LFON and N_{min} in soil compared to the corresponding treatments.

Keywords: Dynamic organic fractions, N fertilizer, organic C and N, pre-seeding tillage, reverse tillage, soil quality, straw management

1. Introduction

In the Prairie Provinces of Canada, farmers traditionally used tillage for seedbed preparation to facilitate seeding operations, seed germination and weed control. Previous research has shown that tillage, especially along with summer fallow, can deteriorate soil quality by diminishing organic C, aggregation, water storing capacity and nutrient supplying capacity/power (or capacity of soil to release/supply available nutrients for crop use), and increasing the potential for soil erosion (McGill et al., 1988; Lal et al., 1990). In the past several decades, no-tillage (NT, also called zero-tillage, or direct seeding) has gained popularity, because of its potential to enhance storage of water in soil by proper snow management/conservation, improvement in soil fertility/productivity, aggregation/tilth, lower requirement for labour, fuel and machinery, and increase in economic returns compared to conventional tillage (CT) (Malhi et al., 1988; Singh & Singh, 1994; Larney et al., 1997). However, long-term NT can increase: 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). In addition, in areas where large amounts of crop residue/straw are produced and accumulate on soil surface, it may be difficult to place the crop seeds properly into the soil, resulting in poor/sporadic germination, especially when proper direct-seeding drills are not available to facilitate seeding.

Because of the above-mentioned undesirable characteristics of long-term NT and for economic reasons, many producers are interested to introduce tillage occasionally. Tillage is expected to expose some of the protected soil organic C (SOC) by breaking the aggregates through physical action and making it more accessible to soil microorganisms for faster decomposition. This information 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., 1988, 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. The objectives of this study were to examine the effects of short-term (2 or 3 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 (N_{min}) in the 0-7.5 and 7.5-15 cm soil layers]; and soil fertility [nitrate-N, ammonium-N, extractable P, exchangeable K and sulphate-S 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; Dyck et al., 2015, 2016). This paper discusses the effects of RT on soil quality parameters, related to quantity and quality of soil organic C and N.

2. Methods

2.1 Location and Experimentation

The 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 Breton area belongs to agro-ecological region Peace Lowland/Boreal Transition with a rolling landscape. The soil was an Orthic Gray Luvisol (Typic Cryoboralf), with loam texture, pH of 6.6 and initial total C concentration of 13.75 g C kg^{-1}. The mean annual precipitation of the area is 475 mm and the growing season is from May to August. This area has 2356 growing degree days (GDD) at >0^{o}C and 1335 GDD at >5^{o}C, 118 days 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 area belongs to the Aspen Parkland ecological region, which is characterized by a flat glacio-lacustrine landscape. The 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}. The mean annual precipitation of the area is about 450 mm and the growing season is from May to August, with GSP of 335 mm (range of 190 to 440 mm). This area has growing degree days (GDD) of 2419 at >0^{o}C and GDD of 1402 at >5^{o}C, a 120 day frost free period, and a mean daily temperature of 14^{o}C (8^{o}C to 21^{o}C) in the growing season.

The original experiments with NT and CT with various straw management (removed [S_{Rem}] and retained [S_{Ret}]) and N rate (0, 50 and 100 kg N ha^{-1}) treatments were established in autumn 1979 (with the first growing season in 1980) at the University of Alberta Experimental Farms Breton and Ellerslie, Alberta 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.) 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}) (Nyborg et al., 1995). However in 1991, another N treatment was added (100 kg N ha^{-1}) and the 56 kg N ha^{-1} was reduced to 50 kg N ha^{-1} (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 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 2011 for seed, straw or whole plant yield. In autumn 2011, soil samples were taken from each plot in 8 treatments (Table 1) after crop harvest. The soil samples were then analyzed for various organic C and N fractions including mineralizable N (N_{min}).

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]		Tillage system	Straw management	Annual
No.	ID			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.

2.2 Soil Sampling and Sample Preparation

Soil cores from 8 locations in each plot were collected from the 0-7.5, 7.5-15 and 15-20 cm layers using a 2.4 cm diameter coring tube. Bulk density of the soil was determined by the core method (Culley, 1993). The soil samples were air dried at room temperature after removing any coarse roots and easily detectable crop residues, and ground to pass a 2-mm sieve. Sub-samples were pulverized in a vibrating-ball mill (Retsch, Type MM2, Brinkman Instruments Co., Toronto, Ontario) for determination of organic C and N in various fractions.

2.3 Organic C and N, and Mineralizable N Analysis

The method of Technicon Industrial Systems (1977) was used to determine TON in the soil. Light fraction organic matter (LFOM) was separated using a NaI solution of 1.7 Mg m^{-3} specific gravity, following the method described by Janzen et al. (1992) and modified by Izaurralde et al. (1997). The TOC, and C and N in LFOM (LFOC, LFON) were measured by Dumas combustion using a Carlo Erba instrument (Model NA 1500, Carlo Erba Strumentazione, Italy). Mineralizable N in soil for the 0-7.5, 7.5-15 and 15-20 cm layer was estimated from the quantities of ammonium-N + nitrate-N that were mineralized from an unfumigated sample during 10-dincubation at 25 ^oC and a soil water potential of -30 J kg-1 (Campbell et al., 1991). The concentrations of ammonium-N and nitrate-N were measured with a Technicon Analyzer II (Technicon Industrial Systems 1973a, 1973b. Soil samples of all layers for organic C and N analyses were also tested to detect any inorganic C using dilute HCl, but none was found. The data on TOC, TON, LFOC and LFON were calculated using the equivalent soil mass (ESM) technique (Ellert & Bettany, 1995).

2.4 Statistical Analysis

The calculated data on TOC, TON, LFOC, LFON and N_{min} in soil 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 $p > 0.05$ not significant) differences between each treatment were determined using LSmeans (Proc GLM, SAS 6.1 for windows). Least significant difference test ($LSD_{0.05}$, or $LSD_{0.10}$ when $LSD_{0.05}$ not significant) for various parameters was used to compare all treatment means, and tillage (NT vs. RT), straw management (S_{Rem} vs. S_{Ret} for the zero-N treatment) and N fertilizer rate (0 kg N ha^{-1} , 50 kg N ha^{-1} and 100 kg N ha^{-1}) treatments.

3. Results

Short-term RT following long-term NT had no significant negative effect on the amounts of TOC and TON in the 0-15 cm soil at both sites, although these parameters tended to be slightly lower in the 0-7.5 cm soil layer with RT compared to NT (Tables 2 and 3). For the zero-N treatment, S_{Ret} had greater TOC and TON compared to

Table 2. Effect of long-term tillage, straw and N rate on mass of soil total organic C (TOC) and total organic N (TON) in soil in autumn 2011 at Breton, Alberta, Canada (Gray Luvisol soil, experiment established in autumn 1979)

Treatmenta	TOC mass (Mg C ha-1) in soil layers (cm)			TON mass (Mg N ha-1) in soil layers (cm)		
(tillage/straw/kg N ha-1)	0-7.5	7.5-15	0-15	0-7.5	7.5-15	0-15
Treatment mean						
$NTS_{Rem}0$	13.79by	10.46c	24.25b	1.256b	0.998b	2.254b
$RTS_{Rem}0$	12.53b	10.73c	23.26b	1.155b	0.987b	2.143b
$NTS_{Ret}0$	14.42b	12.35bc	26.77b	1.330b	1.154b	2.484b
$RTS_{Ret}0$	13.10b	12.38bc	25.48b	1.217b	1.161b	2.379b
$NTS_{Ret}50$	19.38a	15.33ab	37.72a	1.715a	1.475a	3.191a
$RTS_{Ret}50$	17.32a	16.12a	33.44a	1.568a	1.507a	3.075a
$NTS_{Ret}100$	19.10a	15.43ab	34.53a	1.688a	1.445a	3.133a
$RTS_{Ret}100$	18.76a	16.02a	34.78a	1.674a	1.533a	3.207a
$LSD_{0.05}$	2.63a	3.30	5.53	0.202	0.229	0.403
SEM (Prob)	0.866***	1.087**	1.824***	0.0664***	0.0754***	0.1330***
Tillage effect						
NT mean	16.67a	13.39a	30.07a	1.497a	1.268a	2.765a
RT mean	15.43a	13.81a	29.24a	1.404a	1.297a	2.701a
$LSD_{0.05}$	2.67	2.47	5.01	0.216	0.222	0.432
SEM (Prob)	0.906ns	0.836ns	1.699ns	0.0732ns	0.0753ns	0.1464ns
Straw effect at 0 N						
S_{Rem} mean	13.16a	10.59a	23.75a	1.206a	0.993a	2.198a
S_{Ret} mean	13.76a	12.36a	26.12a	1.274a	1.158a	2.431a
$LSD_{0.05}$	2.49	2.54	4.58	0.191	0.169	0.334
SEM (Prob)	0.764ns	0.779ns	1.403ns	0.0586ns	0.0519•	0.1025ns
N rate effect with S_{Ret}						
0 mean	13.76b	12.36b	26.12b	1.274b	1.158b	2.431b
50 mean	18.35a	15.73a	34.08a	1.642a	1.491a	3.133a
100 mean	18.93a	15.72a	34.66a	1.681a	1.489a	3.170a
$LSD_{0.05}$	1.88	1.64	3.05	0.137	0.126	0.230
SEM (Prob)	0.615***	0.535***	0.998***	0.0447***	0.0412***	0.0751***

[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 $P \leq 0.10$, $P \leq 0.01$, $P \leq 0.001$ and not significant, respectively.

[y]In each column, the values (numbers) separately for each parameter (variable), followed by the same letter are not significantly different at $P \leq 0.05$.

Table 3. Effect of long-term tillage, straw and N rate on mass of soil total organic C (TOC) and total organic N (TON) in soil in autumn 2011 at Ellerslie, Alberta, Canada (Black Chernozem soil, experiment established in autumn 1979)

Treatment[a] (tillage/straw/kg N ha^{-1})	TOC mass (Mg C ha^{-1}) in soil layers (cm)			TON mass (Mg N ha^{-1}) in soil layers (cm)		
	0-7.5	7.5-15	0-15	0-7.5	7.5-15	0-15
Treatment mean						
$NTS_{Rem}0$	39.49c[y]	40.50a	79.99a	3.400c	3.438a	6.838a
$RTS_{Rem}0$	39.02c	41.25a	80.27a	3.347c	3.534a	6.881a
$NTS_{Ret}0$	40.05bc	41.85a	81.90a	3.469bc	3.602a	7.071a
$RTS_{Ret}0$	39.41c	42.49a	81.90a	3.419bc	3.624a	7.043a
$NTS_{Ret}50$	42.94ab	42.54a	85.48a	3.710ab	3.653a	7.363a
$RTS_{Ret}50$	40.01b	42.90a	82.91a	3.438bc	3.664a	7.102a
$NTS_{Ret}100$	44.34a	42.47a	86.81a	3.821a	3.671a	7.492a
$RTS_{Ret}100$	43.65a	43.56a	87.21a	3.766a	3.734a	7.500a
$LSD_{0.05}$	3.45	3.43	6.31	0.292	0.297	0.523
SEM (Prob)	1.173*	1.168^{ns}	1.265^{ns}	0.0991*	0.1010^{ns}	0.1777•
Tillage effect						
NT mean	41.70a	41.84a	83.54a	3.600a	3.591a	7.191a
RT mean	40.52a	42.55a	83.07a	3.492a	3.639a	7.131a
$LSD_{0.05}$	2.14	1.63	3.45	0.183	0.145	0.297
SEM (Prob)	0.737^{ns}	0.562^{ns}	1.189^{ns}	0.0630^{ns}	0.0499^{ns}	0.1023^{ns}
Straw effect at 0 N						
S_{Rem} mean	39.25a	40.87a	80.12a	3.373a	3.486b	6.859b
S_{Ret} mean	39.73a	42.17a	81.90a	3.444a	3.613a	7.057a
$LSD_{0.05}$	1.66	1.45	2.51	0.141	0.117	0.181
SEM (Prob)	0.533^{ns}	0.467•	0.807^{ns}	0.0453^{ns}	0.0375*	0.0580*
N rate effect with S_{Ret}						
0 mean	39.73b	42.17a	81.90b	3.444b	3.613a	7.057b
50 mean	41.48ab	42.72a	84.20ab	3.574ab	3.658a	7.232ab
100 mean	43.99a	43.02a	87.01a	3.794a	3.702a	7.496a
$LSD_{0.05}$	2.66	2.34	4.42	0.232	0.193	0.370
SEM (Prob)	0.897*	0.788^{ns}	1.489•	0.0781*	0.0648^{ns}	0.1244•

[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 $P \leq 0.10$, $P \leq 0.05$ and not significant, respectively.

[y]In each column, the values (numbers) separately for each parameter (variable), followed by the same letter are not significantly different at $P \leq 0.05$.

S_{Rem} in both soil layers at both sites (but significant in 7.5-15 cm layer at Breton for TON, and in 7.5-15 cm layer for TOC [$P \leq 0.10$] and in 7.5-15 and 0-15 cm layers for TON at Ellerslie). In the 0-15 cm soil, TOC and TON increased by 2.37 Mg C ha^{-1} and 0.233 Mg N ha^{-1} at Breton, and by 1.78 Mg C ha^{-1} and 0.198 Mg N ha^{-1} at Ellerslie due to S_{Ret}. Application of N fertilizer increased TOC and TON in both soil layers, mainly up to the 50 kg N ha^{-1} rate at both sites (by 8.54 Mg C ha^{-1} and 0.739 Mg N ha^{-1} at Breton and by 5.11 Mg C ha^{-1} and 0.439 Mg N ha^{-1} at Ellerslie in the 0-15 cm soil at 100 kg N ha^{-1} rate). In both RT and NT treatments under S_{Ret} or $S_{Rem,}$ the effects of N rate on TOC and TON were usually similar for S_{Ret}.

The amounts of LFOC and LFON were greater with RT than NT in the 7.5-15 cm soil layer at both sites, although not significant for LFOC and significant at $P \leq 0.10$ for LFON at Breton (Tables 4 and 5). In the 0-15 cm soil, RT had greater LFOC by 64 kg C ha^{-1} and LFON by 4.2 kg N ha^{-1} at Breton, and by 67 kg C ha^{-1} and LFON by 3.8 kg N ha^{-1} at Ellerslie than NT. In both 0-7.5 and 7.5-15 cm soil layers, LFOC and LFON tended to increase with S_{Ret} compared to S_{Rem} at both sites, but significant in a few cases only at Ellerslie. In the 0-15 cm soil, the increase in LFOC and LFON due to S_{Ret} was 27 kg C ha^{-1} and 2.7 kg N ha^{-1} at Breton, and 166 kg C ha^{-1} and 4.4 kg N ha^{-1} at Ellerslie. The amount of LFOC and LFON increased dramatically in both soil layers with application of N fertilizer up to the 100 kg N ha^{-1} rate at both sites, by 1164 kg C ha^{-1} and 53.5 kg N ha^{-1} at Breton and by 567 kg C ha^{-1} and 37.4 kg N ha^{-1} at Ellerslie. In the zero-N treatment, LFOC and LFON increased with S_{Ret} compared to S_{Rem} under RT at Breton and under NT at Ellerslie.

Tillage had no significant effect on N_{min} in soil, although N_{min} in soil tended to decrease in the 0-7.5 cm layer and tended to increase in subsoil layers (Table 6). S_{Ret} had greater N_{min} in both soil layers under both RT and NT compared to S_{Rem} in most cases at both sites but the differences between S_{Ret} and S_{Rem} were much greater and significant in many cases at Ellerslie compared to at Breton. The increase N_{min} in the 0-20 cm soil due to S_{Ret} was 1.6 kg N ha^{-1} at Breton and 7.9 kg N ha^{-1} at Ellerslie. Application of N fertilizer increased N_{min} in the 0-20 cm soil up to 50 kg N ha^{-1} rate at Breton (by 14.7 kg N ha^{-1}) and up to 100 kg N ha^{-1} rate at Ellerslie (by 18.6 kg N ha^{-1}).

4. Discussion

Previous studies have shown that the quantity and/or quality of organic matter in soil can be altered by tillage, residue management and fertilization (Havlin et al., 1990; Nyborg et al., 1995). Tillage (CT or RT) increases oxidation of soil organic matter (Doran and Scott-Smith 1987), while NT reduces its oxidation because of less oxygen due to less mixing of organic matter with the soil (Doran, 1980). Therefore, one would expect a decrease of total organic C in soil under RT compared to NT, especially in soils with relatively low initial organic matter content. However, in our study, short-term tillage (RT after 32 years of NT) had no influence on the amounts of TOC and TON in soil compared to NT, but the amounts of LFOC and LFON in soil were greater under RT than NT. The greater amounts of LFOC and LFON in the 7.5-15 soil layer with RT compared to NT in our study could be due to burying, mixing and decomposition of crop residues (both fresh and previously added/accumulated crop residues on the soil surface over 32 years under NT), into the subsoil by RT, resulting in greater LFOC and LFON in the 7.5-15 cm soil layer.

Crop residues provide a source of organic matter, so when returned to soil the residues increase the storage of organic C and N in soil, whereas their removal results in a substantial loss of organic C and N from the soil system (Nuttall et al., 1986; Campbell et al., 1991, 1998; Nyborg et al., 1995; Solberg et al., 1997; Malhi et al., 2006; Malhi & Lemke, 2007). Similarly in our study after 32 years, the amounts of TOC, TON, LFOC and LFON in the 0-15 cm soil layer were greater with S_{Ret} than S_{Rem} treatments. Because of the combined effects of RT in increasing oxidation of organic matter or output/emission of C from soil to the atmosphere and of S_{Rem} in decreasing input of C to soil, the amounts of TOC, TON, LFOC and LFON in soil in our study were usually lowest in the combination treatments of the RT and S_{Rem} compared to the NT and S_{Ret} in most cases, with only a few exceptions at Ellerslie where LFOC and LFON were lowest in the NT-S_{Rem} combination treatment.

Previous results in the Canadian prairies show an increase in organic C and/or N from N fertilization (Janzen et al., 1998; Nyborg et al., 1995). Similarly, in our study, annual applications of N fertilizer significantly increased TOC, TON, LFOC and LFON in soil, and the amount of organic C and N stored in the soil usually increased with N rate under both RT and NT systems. The soil at both sites, particularly at Breton, was considered to be deficient in plant-available N for optimum crop growth and yield. Yield response of crops to N at these sites would support these statements, and therefore, the increase organic in C and N in soil, especially LFOC and LFON, was most likely due to the increase in crop yield with N fertilization, returning more organic C and/or N to the soil at higher N rates through crop residue including straw, chaff (Campbell et al., 1991; Nyborg et al., 1995; Malhi et al., 2006; Malhi & Lemke, 2007) and root mass (Lorenz, 1977; Malhi & Gill, 2002). The lower mass of soil C and N with S_{Rem} than S_{Ret} suggests that the practice of removing straw from fields for on-farm and industrial uses or to facilitate seeding operations may, in the long run, result in soil degradation or deterioration related to physical, chemical or biological properties, especially under CT (Campbell et al., 1998; Singh & Malhi, 2006). In the present study, the comparisons between S_{Rem} and S_{Ret} treatments were made only at the zero-N rate, and probably the increase in organic C and N may have been much greater if N fertilizer was used in these treatments.

The effect of soil, crop residue and fertilizer management practices on C sequestration in soil is additive. So, the total amount of organic C stored in the soil is the difference between C input (crop residues) and C output (C loss through gases from decomposition of crop residues, with few exceptions such as soil erosion). Therefore, one would expect a dramatic increase in organic C in soil from a combination of NT, straw retention and proper/balanced fertilization. However, in our study, there was no significant difference in the amount of TOC and TON between NT and RT, while the amount of LFOC and LFON in soil was greater with RT compared to NT, with the highest amount of organic C and N, especially LFOC and LFON in the 0-15 cm soil at the 100 kg N ha^{-1} rate under $S_{Ret.}$ As explained earlier, the greater amounts of organic C and N, especially LFOC and LFON in the 7.5-15 cm soil layer, under RT than NT were most likely associated with the burying, mixing and decomposition of the accumulated crop residue by RT.

Table 4. Effect of long-term tillage, straw and N rate on mass of light fraction organic C (LFOC) and N (LFON) in soil in autumn 2011 at Breton, Alberta, Canada (Gray Luvisol soil, experiment established in autumn 1979)

Treatmenta		LFOC mass (kg C ha-1) in soil layers (cm)			LFON mass (kg N ha-1) in soil layers (cm)		
(tillage/straw/kg N ha-1)		0-7.5	7.5-15	0-15	0-7.5	7.5-15	0-15
Treatment mean							
$NTS_{Rem}0$	1	734cy	239c	973c	27.1c	7.7c	34.7c
$RTS_{Rem}0$	4	631c	214c	845c	22.6c	5.5c	28.2c
$NTS_{Ret}0$	3	723c	258c	981c	27.1c	7.0c	34.0c
$RTS_{Ret}0$	6	667c	224c	891c	24.9c	9.2c	34.1c
$NTS_{Ret}50$	2	1211b	362b	1573b	53.3b	12.3bc	65.5b
$RTS_{Ret}50$	5	1423ab	513a	1936ab	63.0ab	25.1a	88.2a
$NTS_{Ret}100$	8	1672a	374b	2046a	75.0a	12.3bc	87.3a
$RTS_{Ret}100$	7	1613a	541a	2154a	67.5a	20.4ab	87.9a
$LSD_{0.05}$		341	101	385	13.2	8.3	18.4
SEM (Prob)		112.6***	33.2***	127.0***	4.35***	2.75**	6.08***
Tillage effect							
NT mean		1085a	308a	1393a	45.6a	9.8a	55.4a
RT mean		1083a	373a	1457a	44.5a	15.1a	59.6a
$LSD_{0.05}$		413	117	515	19.8	6.5	25.1
SEM (Prob)		140.0ns	39.6ns	174.7ns	6.72ns	2.20•	8.50ns
Straw effect at 0 N							
S_{Rem} mean		682a	227a	909a	24.9a	6.6a	31.5a
S_{Ret} mean		695a	241a	936a	26.0a	8.1a	34.1a
$LSD_{0.05}$		235	81	304	8.0	2.8	9.7
SEM (Prob)		71.9ns	24.3ns	93.1ns	2.45ns	0.86ns	2.97ns
N rate effect with S_{Ret}							
0 mean		695c	241b	936c	26.0c	8.1b	34.1b
50 mean		1317b	438a	1755b	58.1b	18.7a	76.9a
100 mean		1642a	458a	2100a	71.3a	16.3ab	87.6a
$LSD_{0.05}$		224	112	267	9.8	8.8	15.2
SEM (Prob)		73.2***	36.7**	87.3***	3.21***	2.88*	4.96***

[z]NT = No-tillage, CT = conventional 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.

[y]In each column, the values (numbers) separately for each parameter (variable), followed by the same letter are not significantly different at $P \leq 0.05$.

Table 5. Effect of long-term tillage, straw and N rate on mass of light fraction organic C (LFOC) and N (LFON) in soil in autumn 2011 at Ellerslie, Alberta, Canada (Black Chernozem soil, experiment established in autumn 1979)

Treatmenta		LFOC mass (kg C ha-1) in soil layers (cm)			LFON mass (kg N ha-1) in soil layers (cm)		
(tillage/straw/kg N ha-1)		0-7.5	7.5-15	0-15	0-7.5	7.5-15	0-15
Treatment mean							
$NTS_{Rem}0$	1	600dy	168d	768e	29.2c	8.3c	37.5e
$RTS_{Rem}0$	4	666d	329abc	995de	29.4c	15.8abc	45.2e
$NTS_{Ret}0$	3	866c	229cd	1095cd	37.1c	10.6bc	47.7de
$RTS_{Ret}0$	6	723cd	280bc	1003de	32.5c	11.3bc	43.8e
$NTS_{Ret}50$	2	1066b	274bc	1340bc	49.2b	11.6bc	60.8cd
$RTS_{Ret}50$	5	1106ab	376ab	1482ab	51.1b	18.3ab	69.4bc
$NTS_{Ret}100$	8	1273a	349abc	1622a	64.6a	17.0ab	81.7ab
$RTS_{Ret}100$	7	1183ab	425a	1608a	62.7a	21.9a	84.6a
$LSD_{0.05}$		182	140	267	8.6	8.3	14.2
SEM (Prob)		61.9***	47.5*	90.7***	2.91***	2.83*	4.82***
Tillage effect							
NT mean		951a	255b	1206a	45.0a	11.9b	56.9a
RT mean		920a	353a	1273a	43.9a	16.8a	60.7a
$LSD_{0.05}$		204	77	261	11.3	4.6	14.6
SEM (Prob)		70.4ns	26.6*	90.0ns	3.90ns	1.58*	5.04ns
Straw effect at 0 N							
S_{Rem} mean		633b	249a	882a	29.3b	12.1a	41.4a
S_{Ret} mean		794a	254a	1048a	34.8a	11.0a	45.8a
$LSD_{0.05}$		129	108	200	4.3	5.1	7.2
SEM (Prob)		41.4*	34.6ns	64.3•	1.37*	1.64ns	2.31ns
N rate effect with S_{Ret}							
0 mean		794b	254b	1048c	34.8c	11.0b	45.8c
50 mean		935b	292ab	1227bc	43.4b	14.2ab	57.6b
100 mean		1228a	387a	1615a	63.7a	19.5a	83.2a
$LSD_{0.05}$		143	110	199	6.5	6.4	10.6
SEM (Prob)		48.1***	37.6•	67.0***	2.19***	2.15*	3.58***

[z]NT = No-tillage, CT = conventional 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.

[y]In each column, the values (numbers) separately for each parameter (variable), followed by the same letter are not significantly different at $P \leq 0.05$.

Light fraction organic matter (LFOM) in soil reflects a balance between crop residues input, and their decomposition and persistence, depending on the soil-climatic conditions (Gregorich & Janzen, 1995; Carter et al., 2003; Gulde et al., 2008). The decomposition of LFOM is relatively faster than total organic matter in soil (Sollins et al., 1984; Bonde et al., 1992), and this could provide an increased supply of plant-available N and other nutrients to plants (Carter et al., 1994), maintain high microbial populations, enzyme activity (Kanazawa & Filip, 1986) and soil respiration rate (Janzen et al., 1992), and improve soil physical properties or overall soil quality/health (Singh & Malhi, 2006). Research has shown that LFOC and LFON are more sensitive to management practices than TOC and TON (Malhi et al., 2003a, b, c). Other researchers have observed larger responses of LFOC and LFON to elimination of tillage, straw retention and N fertilization than responses of TOC and TON (Bremer et al., 1994; Solberg et al., 1997; Malhi & Lemke, 2007). In our present study, the changes in LFOC and LFON were more pronounced than TOC and TON, as suggested by other researchers, but the positive responses of LFOC and LFON were greater under RT than NT. The changes in LFOC and LFON cannot be considered negative indicators of changes in soil C and N as a result of short term tillage (RT0 of long-term NT. This also suggests that monitoring the changes in LFOC and LFON in the surface soil appears to be a good strategy to determine the potential of long-term RT on N supplying power and other changes in soil quality/health over a number of years in the long term. The higher organic C and N in light organic fractions than their total organic fractions in the S_{Ret} treatment was most likely due to greater input of C and N to soil through straw and chaff in the S_{Ret} treatment (Malhi & Lemke, 2007) plus increased root mass from fertilization (Malhi & Gill, 2002). The reduction in soil C and N in the S_{Rem} treatments suggests that the practice of straw removal to facilitate the seeding operation may degrade/deteriorate soil quality in the long term (Dalal, 1989, 1992).

Among the other dynamic fractions, N_{min} was higher with S_{Ret} than S_{Rem}. Mineralizable N increased with N fertilization and rate, but decreased with soil depth. Other studies have also shown an increase in N_{min} in soil due to N fertilization rate, and its decrease with soil depth (Patra et al., 1999). Soil N availability is usually the most limiting factor for crop production (Pastor et al., 1984). Because the majority of the available N used for the synthesis of plant biomass is produced by mineralization from native soil organic N, this source of N should be considered when determining nutrient requirements of crops (Uri et al., 2003). In our study, the increase in N_{min} in soil suggests that the N-supplying power of soil can be improved by returning straw to the soil and proper/adequate/balanced application of fertilizers. These data also suggest the possibility of increase in greenhouse gas (GHG) emissions, after soil is tilled and crop residues are mixed into the soil, resulting increased decomposition of crop residues with RT.

Overall, our results did not show any negative effects of short-term RT on soil organic C and N, and N-supplying power of soil. In fact, LFOC and LFON in soil improved with RT. In addition to improving TOC and TON, higher amounts of crop residue may also improve soil aggregation and water infiltration as well as decrease water runoff and soil erosion, thereby increasing sustainability of crop production (Singh & Malhi, 2006; Malhi & Lemke, 2007).

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