Long-term Tillage, Straw and N Rate Effects on Quantity and Quality of Organic C and N in a Gray Luvisol Soil

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Background

- With recent developments, such as the Kyoto protocol, there is a desire to identify best management practices to enhance carbon (C) sequestration.
- Soil organic matter is the primary source and temporary sink for plant nutrients and it maintains soil tilth, aids air and water movement, promotes water retention and reduces soil erosion.
- Soil organic carbon (SOC) reserves in western Canada have diminished considerably since the initial cultivation of native prairie grasslands 100 or more years ago, especially with tilled summer fallow.
- Adoption of better management strategies such as continuous cropping, reduced tillage, improved fertilization, application of organic amendments and crop rotations including perennial forage can increase the amount of organic C and/or N stored in the soil.
- Soil, crop and fertilizer management practices alter soil properties, but the magnitude of change depends on soil type and climatic conditions.

Objective

- To determine the long-term (19 or 27 years – 1980 to 1998 or 2006) effects of tillage, straw management and N fertilizer on total organic C (TOC) and N (TON), light fraction organic C (LFOC) and N (LFON), macro organic matter C (MOM-C) and N (MOM-N), microbial biomass C (MB-C), and mineralizable C (C_{min}) and N (N_{min}), pH, extractable P, ammonium-N and nitrate-N in a Gray Luvisol (Typic Cryoboralf) loam soil.

Materials and Methods

- A field experiment conducted from 1980 to 1998 or 2006 with barley-wheat-canola rotation on a Gray Luvisol (Typic Cryoboralf) loam (pH 6.6 and initial TOC 13.75 g C kg^{-1}) at Breton, Alberta, Canada.
- Treatments (Table 1) included two tillages (zero tillage [ZT] and conventional tillage [CT]), two straw managements (straw removed [S_{Rem}] and straw retained [S_{Ret}]) and four N fertilizer rates (0, 50 and 100 kg N ha^{-1} in S_{Ret}, and 0 kg N ha^{-1} in S_{Rem} plots).

- Individual plots were 2.8 m x 6.9 m. Plots under CT were tilled twice, once in autumn and once in spring (chisel cultivator). The ZT plots did not undergo any disturbance, except for seeding drill.
- Crop was harvested from 1980 to 2006 for seed and straw yield.
- In autumn 1998, and in spring 2007, soil samples were taken from each plot after growing wheat. The soil samples were then analyzed for various organic C and N fractions and some chemical properties.
- Total organic C (TOC) and N (TON), light fraction organic C (LFOC) and N (LFON), macro organic matter C (MOM-C) and N (MOM-N), microbial biomass C (MB-C), and mineralizable C (C_{min}) and N (N_{min}) measured in 0-7.5 and 7.5-15 cm or 0-5, 5-10 and 10-15 cm layers.
- pH, extractable P, ammonium-N and nitrate-N in 0-7.5, 7.5-15, 15-30 and 30-40 cm or 0-15, 15-30, 30-60, 60-90 and 90-120 cm layers.

Summary

- Zero tillage, S_{Ret} and N fertilizer treatments usually had higher mass of TOC, TON, LFOC, LFON, C_{min} and N_{min} compared to the corresponding CT, S_{Rem} and zero-N control treatment, especially in the surface soil layers, but no consistent effect of these treatments on MB-C (Tables 2 and 3).
- MOM-C in both 0-7.5 and 7.5-15 cm layers and MOM-N in 0-7.5 cm layer generally higher with S_{Ret} than S_{Rem}, also higher with N fertilizer than zero-N, and tended to be higher under ZT than CT treatments (Table 3).
- There were close and significant correlations among most soil organic C or N fractions in most cases, except MB-C which correlated only with MOM-N at $P \leq 0.10$, and N_{min} did not correlate with MOM-C (Table 4). Linear regressions between crop residue or C input and soil organic C or N were significant in most cases, except for MB-C, or N_{min} ($P \leq 0.16$) (Tables 5 and 6).
- In the 0-15 cm soil layer, pH was depressed slightly with N application, and extractable P was higher with S_{Ret} than S_{Rem} and under ZT than CT, but decreased with N application ((Table 7).
- In this layer, nitrate-N (though quite low) increased with application of N, but no effect of treatments on ammonium-N (Table 7). There was usually no effect of treatments on any soil parameters at depths below 15 cm.
- Compared to the 1979, the TOC concentrations in the 0-15 cm layer indicated a loss in the $CTS_{Rem}0$ treatment in 1998, and in the $CTS_{Rem}0$, $CTS_{Ret}0$ and $ZTS_{Rem}0$ treatments in 2007 (Table 8).

Conclusion

- Elimination of tillage, straw retention and N application all improved organic C and N in soil, and generally differences were more pronounced for light fraction organic C and N, and between the most extreme treatments ($CTS_{Rem}0$ vs. $ZTS_{Ret}100$) for each dynamic organic fraction. This will be better for the long-term sustainability of soil quality, fertility, and productivity.

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Table 1. Description of treatments sampled in autumn 1998 and spring 2007 at Breton, Alberta, Canada (Gray Luvisol soil, experiment established in autumn 1979)

Treatment		Tillage system	Straw management	Rate of N (kg N ha^{-1})
No.	ID			
1	$ZTS_{Rem}0$	Zero	Straw removed	0
4	$ZTS_{Ret}0$	Zero	Straw retained	0
3	$ZTS_{Ret}50$	Zero	Straw retained	50
6	$ZTS_{Ret}100$	Zero	Straw retained	100
2	$CTS_{Rem}0$	Conventional	Straw removed	0
5	$CTS_{Ret}0$	Conventional	Straw retained	0
8	$CTS_{Ret}50$	Conventional	Straw retained	50
7	$CTS_{Ret}100$	Conventional	Straw retained	100

Table 2. Effect of long-term tillage, straw and N rate on mass of total organic C (TOC), total organic N (TON), light fraction organic C (LFOC) and light fraction organic N (LFON) in soil depth 0-15 cm, spring 2007 at Breton, Alberta, Canada (Gray Luvisol soil, experiment established in autumn 1979)

Treatment (tillage/straw/kg N ha^{-1})	(Mg ha^{-1})		(kg C ha^{-1})	
	TOC	TON	LFOC	LFON
$ZTS_{Rem}0$	21.95	2.476	936	29.6
$ZTS_{Ret}0$	25.49	2.799	977	31.4
$ZTS_{Ret}50$	31.80	3.229	1456	49.9
$ZTS_{Ret}100$	32.47	3.352	2335	92.3
$CTS_{Rem}0$	20.11	2.390	756	23.6
$CTS_{Ret}0$	21.09	2.582	865	27.4
$CTS_{Ret}50$	25.44	2.804	1508	49.4
$CTS_{Ret}100$	30.57	3.143	1436	53.0
$LSD_{0.05}$	8.03	0.578	374	16.3
SEM^{y}	2.647^{*}	0.1906^{*}	123.3^{***}	5.4^{***}

Table 3. Effect of long-term tillage, straw and N rate on mass of mineralizable and microbial biomass C and N in soil depth 0-15 cm, autumn 1998 at Breton, Alberta, Canada (Gray Luvisol soil, experiment established in autumn 1979)

Treatment (tillage/straw/kg N ha^{-1})	Mineralizable mass		Microbial biomass		
	Cmin	Nmin	MB-C	MOM-C	MOM-N
	(kg C ha^{-1})	(kg N ha^{-1})	(kg C ha^{-1})	(kg C ha^{-1})	(kg N ha^{-1})
$ZTS_{Rem}0$	303	25.2	917	267	11.1
$ZTS_{Ret}0$	367	30.7	1063	464	18.9
$ZTS_{Ret}50$	424	37.5	888	595	20.7
$ZTS_{Ret}100$	416	37.6	1002	377	15.7
$CTS_{Rem}0$	259	14.7	943	316	8.1
$CTS_{Ret}0$	261	17.9	997	299	10.8
$CTS_{Ret}50$	349	23.8	1089	591	23.1
$CTS_{Ret}100$	390	28.4	1085	762	27.4
$LSD_{0.05}$	129	12.0	268	290	12.6
SEM^{y}	42.4$^{\bullet}$	3.95**	88.4^{ns}	95.7*	4.14*

Table 4. Relationships among soil organic C or N fractions (TOC, TON, LFOC, LFON, MOM-C, MOM-N, MB-C, mineralizable C [C_{min}] and mineralizable N [N_{min}]) in autumn 1998 and in spring 2007at Breton, Alberta, Canada (Gray Luvisol soil, experiment established in autumn, 1979)

Parameter	Correlation coefficients								
Relationships among soil organic C or N fractions									
1998	***TOC***	***TON***	***LFOC***	***LFON***	***MOM-C***	***MOM-N***	***MB-C***	***Cmin***	***Nmin***
TOC		0.997***	0.806*	0.810*	0.595•	0.635•	-0.017^{ns}	0.932***	0.893**
TON			0.813*	0.827*	0.612•	0.661•	0.049^{ns}	0.940***	0.890**
LFOC				0.986***	0.934***	0.941***	0.310^{ns}	0.817*	0.643•
LFON					0.930***	0.965***	0.427^{ns}	0.843**	0.662•
MOM-C						0.961***	0.493^{ns}	0.656•	0.403^{ns}
MOM-N							0.590•	0.736*	0.519^{ns}
MB-C								0.156^{ns}	-0.047^{ns}
Cmin									0.946***
Nmin									
2007	***TOC***	***TON***	***LFOC***	***LFON***					
TOC		0.990***	0.840**	0.835*					
TON			0.863**	0.860**					
LFOC				0.994***					
LFON									

Table 5. Relationships between crop residue or crop residue C input from 1980 to 1998 or 2006 growing seasons and soil organic C or N stored in soil sampled in autumn 1998 and in spring 2007at Breton, Alberta, Canada (Gray Luvisol soil, experiment established in autumn, 1979)

Parameter	Correlation coefficients								
Relationships between crop residue or crop residue C input and soil organic C or N fractions									
1980 to 1998	***TOC***	***TON***	***LFOC***	***LFON***	***MOM-C***	***MOM-N***	***MB-C***	***Cmin***	***Nmin***
Crop residue or C input	0.813*	0.832*	0.851**	0.885**	0.797*	0.797*	0.348^{ns}	0.744*	$0.541^{0.16}$
1980 to 2006	***TOC***	***TON***	***LFOC***	***LFON***					
Crop residue or C input	0.820*	0.815*	0.772*	0.744*					

Table 6. Linear regressions for relationships between crop residue or crop residue C input from 1980 to 1998 or 2006 growing seasons and soil organic C or N (TOC, TON, LFOC, LFON, MOM-C, MOM-N, MB-C, mineralizable C [C_{min}] and mineralizable N [N_{min}]) stored in soil sampled in autumn 1998 and in spring 2007at Breton, Alberta, Canada (Gray Luvisol soil, experiment established in autumn, 1979)

Crop parameter (X)	Soil C or N parameter (Y)	Linear regression (Y = a + bX)	R^2
1980 to 1998			
Crop residue C input	TOC	Y = 22.17 + 0.4204X	0.6609*
	TON	Y = 2.287 + 0.0358X	0.6930*
	LFOC	Y = 385.6 + 30.893X	0.7244**
	LFON	Y = 15.41 + 1.2000X	0.7828**
	MOM-C	Y = 174.9 + 14.220X	0.6347*
	MOM-N	Y = 6.128 + 0.5431X	0.6354*
	MB-C	Y = 943.6 + 2.7222X	0.1210^{ns}
	Cmin	Y = 247.5 + 4.9361X	0.5539*
	Nmin	Y = 17.85 + 0.4570X	$0.2934^{0.16}$
1980 to 2006			
Crop residue C input	TOC	Y = 17.47 + 0.2704X	0.6726*
	TON	Y = 2.222 + 0.0195X	0.6648*
	LFOC	Y = 432.8 + 22.596X	0.5964*
	LFON	Y = 8.977 + 1.1128X	0.5447*

Table 7 Effect of long-term tillage, straw and N rate on nitrate-N, extractable P and pH in soil in spring 2007 at Breton, Alberta, Canada (Gray Luvisol soil, experiment established in autumn, 1979)

Treatment[z] (tillage/straw/kg N ha^{-1})	Nitrate-N (kg N ha^{-1})		Extractable P (kg P ha^{-1})	pH	
	0-15 cm	15-30 cm	0-15 cm	0-5 cm	5-10 cm
$ZTS_{Rem}0$	2.0	2.0	35.6	5.94	5.80
$ZTS_{Ret}0$	2.7	2.5	44.1	6.08	5.90
$ZTS_{Ret}50$	6.2	2.2	41.9	5.55	5.48
$ZTS_{Ret}100$	7.1	3.1	28.1	5.44	5.34
$CTS_{Rem}0$	2.6	2.0	41.7	6.92	5.86
$CTS_{Ret}0$	3.4	2.3	48.8	6.03	5.96
$CTS_{Ret}50$	3.5	3.1	16.5	5.55	5.48
$CTS_{Ret}100$	5.7	3.8	27.7	5.49	5.40
$LSD_{0.05}$	3.5	1.29	20.7	0.21	0.28
SEM[y]	1.14*	0.39*	6.81•	0.068***	0.091***

Table 8 Total organic C (TOC) concentration in 0-15 cm soil in1979, 1990, 1998 and spring 2007 for each treatment at Breton, Alberta, Canada (Gray Luvisol soil, experiment established in autumn 1979 - mean total organic C concentration was 13.75 g C kg-1 in 1979)

	TOC concentration (g C kg^{-1})			
Treatment	1979	1990	1998	2007
$ZTS_{Rem}0$	13.75	12.59	12.22	10.51
$ZTS_{Ret}0$	13.75	13.92	13.72	12.18
$ZTS_{Ret}50$	13.75	17.89	16.76	15.80
$ZTS_{Ret}100$	13.75	17.39	16.49	15.22
$CTS_{Rem}0$	13.75	13.41	10.17	9.57
$CTS_{Ret}0$	13.75	13.41	11.96	10.06
$CTS_{Ret}50$	13.75	16.46	12.99	12.27
$CTS_{Ret}100$	13.75	16.58	15.62	13.37