Long-term Tillage, Straw and N Rate Effects on Quantity and Quality of Organic C and N in a Black Chernozem 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 (Cmin) and N (Nmin), pH, extractable P, ammonium-N and nitrate-N in a Black Chernozem (Albic Argicryoll) loam soil.

Materials and Methods

- A field experiment was conducted from 1980 to 1998 or 2006 with barley-wheat-canola rotation on a Black Chernozem (Albic Argicryoll) loam (pH 6.0 and initial TOC 5.645%). at Ellerslie, 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 (Cmin) and N (Nmin) 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

- The mass of TOC and TON in soil was usually higher in S_{Ret} than S_{Rem} plots, and tended to increase with ZT and N fertilizer application (Table 2).
- The mass of LFOC and LFON in soil increased with straw retention and N fertilizer application, but LFOC and LFON were higher under CT than ZT especially in the 5-10 cm layer (Table 2).
- Treatments with S_{Ret} and N fertilizer generally had higher mass of Cmin, Nmin, MOM-C and MOM-N in soil than the corresponding S_{Rem} and zero-N control treatments (Table 3). Tillage, straw and N fertilizer had no consistent effect on MB-C in soil.
- There were close and significant correlations among most soil organic C or N fractions in most cases, except MB-C which correlated with TOC and TON, and also with MOM-N at $P \leq 0.10$ (Table 4). Linear regressions between crop residue or C input and soil organic C or N were significant in most cases, except MB-C where it was not significant (Tables 5 and 6).
- Soil pH was depressed with N application in the 0-7.5 or 0-10 cm layer (Table 7).
- Extractable P was higher in ZT than CT plots in the 0-7.5 cm soil layer, but decreased with N fertilizer application after 27 years. Extractable P tended to be higher in S_{Ret} than S_{Rem} plots (Table 7).
- There was no consistent effect of N fertilization on ammonium-N in soil. Nitrate-N increased with N fertilizer application, and also indicated downward movement in the soil profile especially after 27 years (Table 7).
- The effects of tillage, straw management and N fertilizer on soil properties were more pronounced in the surface layers than the deeper layers.

Conclusion

- In conclusion, the findings suggest that elimination of tillage, straw retention and N fertilizer application would improve soil organic C and N, and may be better for the long-term sustainability of soil quality/health/fertility, and subsequently crop production.

Acknowledgements

- The authors would like to thank Z. Zhang and K. Strukoff for technical help, D. Leach for preparing and Erin Cadieu for printing the poster.

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 No.	Treatment ID	Tillage system	Straw management	Rate of N (kg N ha^{-1})
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 soil total organic C (TOC), total organic N (TON), light fraction organic C (LFOC) and light fraction organic N (LFON) in 0-15 cm soil depth in spring 2007 at Ellerslie, Alberta, Canada (Black Chernozem soil, experiment established in autumn 1979)

Treatment (tillage/straw/kg N ha^{-1})	(Mg C ha^{-1})		(kg N ha^{-1})	
	TOC	TON	LFOC	LFON
ZTS$_{Rem}$0	86.74	7.469	1277	59.0
ZTS$_{Ret}$0	89.88	7.720	1523	67.3
ZTS$_{Ret}$50	91.20	7.763	2004	94.0
ZTS$_{Ret}$100	92.17	7.833	1886	93.7
CTS$_{Rem}$0	84.63	7.269	1508	68.4
CTS$_{Ret}$0	88.37	7.514	1831	85.2
CTS$_{Ret}$50	93.19	7.909	2650	130.6
CTS$_{Ret}$100	89.89	7.657	2503	131.0
LSD$_{0.05}$	5.96	0.450	441	24.1
SEM	2.026$^{\bullet}$	0.1529$^{\bullet}$	149.9***	8.2***

Table 3. Effect of long-term tillage, straw and N rate on mass of mineralizable C and N, microbial biomass C (MB-C), MOM-C, MOM-N in 0-15 cm soil depth in autumn 1998 at Ellerslie, Alberta, Canada (Black Chernozem 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}$0	554	64.5	1436	659	25.6
ZTS$_{Ret}$0	561	70.8	1424	656	30.2
ZTS$_{Ret}$50	635	77.2	1395	704	31.8
ZTS$_{Ret}$100	600	78.8	1350	935	46.0
CTS$_{Rem}$0	492	52.8	1244	421	17.4
CTS$_{Ret}$0	573	64.7	1354	733	28.8
CTS$_{Ret}$50	655	84.4	1477	931	41.5
CTS$_{Ret}$100	618	72.3	1421	855	38.1
LSD$_{0.05}$	71	14.9	139	378	14.2
SEM	24.0**	5.06**	47.3$^{\bullet}$	128.5$^{\bullet}$	4.83*

Table 4. Relationships among soil organic C or N fractions (TOC, TON, LFOC, LFON, MOM-C, MOM-N, MB-C, mineralizable C [Cmin] and mineralizable N [Nmin]), or 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 Ellerslie, Alberta, Canada (Black Chernozem soil, experiment established in autumn, 1979)

Parameter	Correlation coefficients								
Relationships among soil organic C or N fractions									
1998 soil samples	*TOC*	*TON*	*LFOC*	*LFON*	*MOM-C*	*MOM-N*	*MB-C*	*Cmin*	*Nmin*
TOC		0.979***	0.759*	0.753*	0.866**	0.891**	0.714*	0.846**	0.956***
TON			0.867**	0.863**	0.936***	0.948***	0.703*	0.897**	0.969***
LFOC				0.988***	0.965***	0.948***	0.494^{ns}	0.775*	0.788*
LFON					0.931***	0.945***	0.463^{ns}	0.756*	0.783*
MOM-C						0.967***	0.611•	0.843**	0.873**
MOM-N							0.511^{ns}	0.806*	0.895**
MB-C								0.709*	0.700*
Cmin									0.932***
Nmin									
2007 soil samples	*TOC*	*TON*	*LFOC*	*LFON*					
TOC		0.991***	0.699*	0.675•					
TON			0.633•	0.610•					
LFOC				0.992***					
LFON									

Table 5. Relationships among soil organic C or N fractions (TOC, TON, LFOC, LFON, MOM-C, MOM-N, MB-C, mineralizable C [Cmin] and mineralizable N [Nmin]), or 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 Ellerslie, Alberta, Canada (Black Chernozem 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	0.535^{ns}	0.670•	0.795*	0.819*	0.720*	0.755*	0.268^{ns}	0.782*	0.713*
1980 to 2006	*TOC*	*TON*	*LFOC*	*LFON*					
Crop residue or C input	0.726*	0.669•	0.889**	0.910**					

Table 6. Linear regressions for relationships between 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 [Cmin] and mineralizable N [Nmin]) stored in soil sampled in autumn 1998 and in spring 2007at Ellerslie, Alberta, Canada (Black Chernozem 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 = 89.74 + 0.1575X	0.2857^{ns}
	TON	Y = 7.834 + 0.0166X	$0.4495^{\bullet}$
	LFOC	Y = 981.3 + 27.301X	0.6321*
	LFON	Y = 39.86 + 1.7065X	0.6710*
	MOM-C	Y = 323.9 + 12.912X	0.5186*
	MOM-N	Y = 9.161 + 0.7276X	0.5707*
	MB-C	Y = 1323 + 2.0163X	0.0718^{ns}
	Cmin	Y = 449.2 + 4.2783X	0.6112*
	Nmin	Y = 46.89 + 0.7444X	0.5083*
1980 to 2006			
Crop residue C input	TOC	Y = 82.13 + 0.0708X	0.5271*
	TON	Y = 7.135 + 0.0110X	$0.4478^{\bullet}$
	LFOC	Y = 365.3 + 33.285X	0.7901**
	LFON	Y = 1.396 + 1.9494X	0.8291**

Table 7. Effect of long-term tillage, straw and N rate on nitrate-N in 0-15 and 15-30 cm soil depths, extractable P in 0-15 cm soil depth and pH in 0-5 and 5-10 cm soil depths in spring 2007 at Ellerslie, Alberta, Canada (Black Chernozem soil, experiment established in autumn, 1979)

Treatment (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
$ZTS_{Rem}0$	6.20	4.04	37.27	5.63	5.42
$ZTS_{Ret}0$	5.01	3.53	39.70	5.50	5.34
$ZTS_{Ret}50$	5.77	5.37	20.90	5.27	5.18
$ZTS_{Ret}100$	8.80	7.35	23.24	5.20	5.13
$CTS_{Rem}0$	5.71	4.71	37.40	5.48	5.50
$CTS_{Ret}0$	6.28	4.49	39.76	5.50	5.46
$CTS_{Ret}50$	5.60	5.66	17.47	5.33	5.26
$CTS_{Ret}100$	6.77	7.99	21.37	5.18	5.06
$LSD_{0.05}$	2.54	2.19	7.37	0.13	0.16
SEM	$0.862^{\bullet}$	0.744**	2.895***	0.044***	0.053***