Management practices for increasing storage of organic C and N in soil in cropping systems in the Canadian Prairies (December 13, 2013)

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Background

The sustainability of agricultural production is linked to soil quality, which in turn is strongly influenced by soil organic carbon (SOC), or more generally, soil organic matter (SOM). Organic matter in soil has many important roles, such as improving soil structure (or tilth) and buffering capacity, making soils more resistant to erosion, aiding air and water movement, influencing pesticide efficacy and decomposition processes, increasing water and nutrient storage, facilitating nutrient cycling, a major source of plant nutrients and energy source for micro-organisms, and acting as both a source and a sink of greenhouse gases (GHG).

In the Canadian Prairies, soils contain large reserves of organic matter. The cultivation of native grassland and forest land has caused substantial decreases in SOC and soil organic nitrogen (SON) in all soil-climatic zones. The quality of organic matter declined more than the quantity; for example, there was a faster decline of mineralizable N than total N. The loss of organic C and N from soil varied with the duration of cultivation, frequency of summerfallow, slope position, and many other factors. This report summarizes research information from field experiments concerning the impact of tillage, crop residue management, balanced fertilization, manure, crop rotation and diversity, cropping frequency and land use on storage of organic C and N in soil across different agro-ecological regions in the Canadian Prairies.

Summary of Research Findings (Tables 1 to 12)

- Soils in the Canadian Prairies have lost a substantial amount of their original organic carbon (C) and nitrogen (N) reserves in the last 100 or more years, mainly due to tilled summer fallow (range of loss from 16.2 to 62.1% of native organic C, or 4.2 to 51.4 Mg C ha^{-1}, or 0.105 to 0.734 Mg C ha^{-1} yr^{-1}). Currently, many soils in the Canadian Prairies represent a potential sink for atmospheric CO_2.

- **Adopting no tillage (NT) increased C sequestration** by up to 1.170 Mg C ha^{-1} yr^{-1} compared to conventional tillage (CT) and up to 0.227 Mg C ha^{-1} yr^{-1} when compared to minimum tillage (MT).
- **Retaining straw added** an additional 1.068 Mg C ha^{-1} yr^{-1} or 0.400 g C kg^{-1} soil yr^{-1} over straw burning and up to 0.695 Mg C ha^{-1} yr^{-1} or 0.405 g C kg^{-1} soil yr^{-1} compared to straw removal practices.
- **Annual application of N, P, or other nutrients increased C sequestration** by 0.906 Mg C ha^{-1} yr^{-1} at 56 kg N ha^{-1} under NT and by 1.620 Mg C ha^{-1} yr^{-1} at 150 kg N ha^{-1} under CT.
- In long-term perennial grassland studies where grass was harvested for hay each year and soil was deficient in both N and sulfur (S), **annual application of S fertilizer in a combination with N** was required to store additional soil organic C (SOC - by up to 1.275 Mg C ha^{-1} yr^{-1} with 120 kg N plus 11 kg S ha^{-1} yr^{-1}), demonstrating the importance of **balanced fertilization**.
- Compared to fertilized cropping systems, **addition of manure had greater improvement in SOC**, which was maintained at a higher level in the long-term (e.g., 33.7 Mg C ha^{-1} for NPKS fertilized vs. 43.2 Mg C ha^{-1} for manure cropping system after 60 yr).
- **Integrated or combined use of manure and fertilizers resulted in much higher SOC** (3.888 Mg C ha^{-1} yr^{-1}) compared to the application of manure (3.140 Mg C ha^{-1} yr^{-1}) or fertilizers alone (1.534 Mg C ha^{-1} yr^{-1}); this effect was particularly notable in eroded soils.
- The adoption of **continuous annual cropping systems or mixed crop rotations** of annual grain and perennial forage crops usually resulted in **higher SOC** than crop rotations with summer fallow.
- Compared to total organic matter in soil, **young or labile fractions** of soil organic matter (i.e., light fraction organic C [LFOC] or light fraction organic N [LFON]) were much more responsive to changes in management practices.
- **Conversion of annually cultivated lands to perennial grassland** resulted in a significant **increase in SOC** when compared to cultivated soils.
- The **gains and losses in SOC** due to changes in management practices are of some finite

duration and magnitude, i.e., these **will not occur indefinitely**.

- **Economic and energy input costs of C sequestration** in agroecosystems, along with the negative impacts, if any, of C sequestration on total greenhouse gas (i.e., CO_2, N_2O and CH_4) emissions **should be considered** in the calculation of net C change.
- **In summary**, **storage of organic C and N can be increased in cultivated soils by implementing proper soil** (elimination of tillage and minimizing summer fallow frequency), **crop residue** (returning residue), **nutrient management** (balanced fertilization, and combined use of organic amendments and mineral fertilizers) and **land use** (conversion of marginal lands to perennial grassland) practices **that prevent loss of C from soil and/or increase C input**. Furthermore, C and N storage in soil also provides the accompanying benefits of more sustainable crop production (due to an improvement in soil quality and nutrient supplying power), and reducing the potential for greenhouse gas (GHG) emissions.

Conclusions

- The findings indicate that under most environmental conditions, **soils under minimal disturbance**, receiving annual **inputs of crop residues** and/or other **organic amendments**, and with **proper/integrated nutrient management** under diversified cropping systems have the greatest potential to store organic C and N in soil.
- The findings suggest that reduction of **summerfallow frequency** and **adoption of no-till** may be the **most effective** techniques/practices to increase storage of organic C and N in soil, as long as **crop residues** are returned to soil and **nutrient deficiencies** in crops are properly prevented.
- The findings also suggest that storage of additional organic C and N in soil can provide **accompanying benefits** of increased sustainable crop productivity due to improvement in **soil quality** and **nutrient supplying power**, while also reducing the potential for environmental damage by GHG emissions.

Research Gaps and Future Research Needs

- The main factors involved in the storage of C and N in cultivated and grassland soils are the reduction of C loss from soil and the increase of C input to soil. Summer fallow on cultivated agricultural lands has caused substantial loss of C from soil through the oxidation of organic matter and possibly soil erosion. It is projected that soil erosion can constitute a dominant portion of the long-term loss of organic C from particular fields after long-term cultivation. Quantitative research information is needed on the **actual contribution of erosion in the loss of C from cultivated fields**, especially during summer fallow. There is also a **need for research related to various mechanisms of organic C decline in soil**, as it is important to distinguish the fate of C lost through various methods (erosion, CO_2, leaching). For example, biologically oxidized C is presumed to be emitted to the atmosphere, while eroded C may be buried deep in soil where further decomposition and turnover of C can be much slower.
- In annually cultivated lands, there was a general increase in SOC when continuously cropped. Increases were also noted when crop residues were retained rather than removed. The inclusion of perennial forages into crop rotations increased more SOC compared to rotations containing only annual grain crops. The amount of organic C sequestered in soil was highest when retention of crop residue was combined with the elimination of tillage under proper nutrient management. This indicates that adoption of no-till may be the most effective technique/practice to increase storage of C and N in soil, as long as crop residues are returned to soil and nutrient deficiencies in crops are properly prevented, high crop yields can be sustained. In only a few studies, soils were analyzed for C and N fractions other than total organic C and N. Because young/dynamic fractions in organic matter are much more sensitive to management practices, soil samples should also be analyzed for LFOC, LFON, C_{min}, N_{min} and microbial biomass C. Future research is **needed on the fate of sequestered C in soil over the long term after the management practices are altered**. Research information is also needed regarding the mechanisms involved in the sequestration of C into more stable organic C pools.
- The findings of long-term perennial grassland experiments suggest proper/appropriate annual applications of fertilizers, designed to supply N, P, S or other nutrients, are required to store additional organic C and N in soil. This shows the importance of

balanced fertilization in improving soil quality, while also sustaining high forage yield. In addition, the increase in SOC through better crop production/yield, particularly on grassland, is also associated with vigorous root growth, which contributes significantly to the build-up of SOC. However, there is little research information on the **contribution of roots and stubble in increasing the storage of organic C in soil**.

- Few studies have reported the **C sequestration efficiency** (defined as: Mass of C sequestered in soil/Mass of C input to soil x 100) of management practices. There has been no report on the **economic benefits** (Net $ returns = Added $ returns from increased crop yield due to C sequestration with improved management practices as a result in improved soil moisture and reduced soil erosion – Additional input costs of C sequestration) from sequestered C in soil. Future reports/research should **include calculations on C sequestration efficiency (%) and economic return ratio for various C enhancing management practices** under various cropping systems.
- Because the majority of C is sequestered in the surface soil layers, soil samples were rarely collected below 30 cm. Future C sequestration studies should also address changes in **organic C below 30 cm**, especially in cropping systems that include perennial forages in the rotation.

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Table 1. Soil organic C (SOC) loss after conversion of native grass/forest land to cultivated crops at various locations in the Northern Great Plains of North America

Location (soil zone or region)[z]	Years of cultivation	Soil horizon or Soil layer depth (cm)[y]	Concentration (g C kg^{-1}) or mass (Mg C ha^{-1}) of SOC in soil horizons/layers		Change or loss of SOC (Mg C ha^{-1} or % change)	Reference
			Ah	Ap		
Alberta			Mg C ha^{-1}			
Brown	70	Ah/Ap	27.0	16.6	10.4 (38.5)	McGill et al. 1981
Dark Brown	70	Ah/Ap	35.0	20.3	14.7 (42.0)	
Black	60	Ah/Ap	67.0	35.7	21.3 (46.7)	
Dark Gray	50	Ah/Ap	53.0	31.5	22.5 (40.6)	
Gray Luvisol	40	Ah/Ap	12.0	7.8	4.2 (35.0)	
Brown	38	Ah/Ap	38.1	26.0	12.1 (31.2)	Reinl 1984
Dark Brown	61	Ah/Ap	62.4	44.6	27.8 (28.5)	
Black	60	Ah/Ap	99.5	83.0	16.5 (15.8)	
Dark Gray	50[x]	Ah/Ap	88.5	63.2	25.5 (28.6)	
Gray Luvisol	40	Ah/Ap	68.8	50.0	18.8 (27.3)	
Peace River	50	Ah/Ap	70.6	59.0	11.6 (16.6)	
Brown	38	Soil profile	68.7	44.0	24.7 (36.0)	
Dark Brown	61	Soil profile	106.8	79.7	27.1 (25.4)	
Black	60	Soil profile	162.3	127.8	34.5 (21.1)	
Dark Gray	50[z]	Soil profile	127.7	99.1	28.6 (22.4)	
Gray Luvisol	40	Soil profile	108.4	66.1	42.3 (39.0)	
Peace River	50	Soil profile	128.6	93.0	35.6 (26.1)	
Gray Luvisol – Breton L	84	0-20	46.2	36.8	9.4 (20.3)	Plante et al. 2006
			g C kg^{-1}			
Brown	20	Ah/Ap	27.9	14.1	13.8 (49.5)	Dormaar 1979
Dark Brown	65	Ah/Ap	33.6	14.4	19.2 (57.1)	
Black	16	Ah/Ap	55.8	32.6	23.2 (41.6)	
Dark Brown	65	Ah/Ap (Cont. W)	31.4	19.8	11.6 (36.9)	Dormaar and Pittman 1980
		Ap (F-W-W)		15.3	16.1 (51.2)	
		Ap (F-W)		13.8	17.6 (56.1)	
Saskatchewan						
Black – Indian Head CL	22	0-20	74	62	12.0 (16.2)	Shutt 1925
Brown - Haverhill L	14	0-30	19.9	14.6	5.3 (26.6)	
Brown - Wood Mountain L	14	0-30	21.5	16.4	5.1 (24.2)	
Brown - Wood Mountain CL	12	0-30	29.1	24.1	5.0 (17.2)	
Brown	65-100	0-15	19.4	11.3	8.1 (41.7)	Campbell and Souster 1982

Dark Brown	65-100	0-15	35.8	19.0	16.8 (46.9)	
Black	65-100	0-15	36.9	19.1	17.8 (48.2)	
Gray Luvisol	40-50	0-15	25.3	11.9	13.4 (53.0)	
Black – SiL	60	A horizon	48	33	15.0 (31.3)	Thiessen et al. 1982
		B horizon	16	15	1.0 (6.3)	
	90	A horizon	48	20	28.0 (58.3)	
		B horizon	16	11	5.0 (31.3)	
Dark Brown – SL	65	A horizon	32	17	15.0 (46.9)	
		B horizon	13	11	2.0 (15.4)	
Dark Brown – C	70	A horizon	38	24	14.0 (36.8)	
		B horizon	23	20	3.0 (13.0)	
			Mg C ha^{-1}			
Dark Brown – Scott (Elstow L)[w]	70	0-30	90.0 (15.34)[v]	51.4 (2.34)		Malhi et al. 2003a
Oxbow – L	70	US (A horizon)	63.6	26.4	37.2 (58.5)	Voroney et al. 1981
		MS (A horizon)	94.1	40.2	53.9 (57.5)	
		LS (A horizon)	83.3	49.2	34.1 (40.9)	
		US (soil profile)	94.2	56.6	37.6 (39.9)	
		MS (soil profile)	132.1	80.7	51.4 (38.9)	
		LS (soil profile)	136.3	97.0	39.3 (28.8)	
Manitoba			g C kg^{-1}			
Black – Portage la Prairie LS	20	0-20	113	86	27.0 (23.9)	Shutt 1925
Black – Winnipeg C	37 – Cont. W	0-15	58	42	16.0 (27.6)	Ridley and Hedlin 1968
	37 – F-W	0-15	58	22	36.0 (62.1)	
Montana						
Brown	35	0-15.2	25.0	15.1	9.9 (39.6)	Haas et al. 1957
North Dakota						
Dark Brown	43	0-15	38.6	22.5	16.1 (49.2)	Haas et al. 1957
		15-30	17.7	11.7	6.0 (33.9)	
		30-45	11.1	8.3	2.8 (20.7)	

[z]Brown, Dark Brown, Black, Dark Gray, and Gray Luvisol soils according to the Canadian System of Soil Classification refer to Aridic Boroll, Typic Boroll, Udic Boroll, Boralfic Boroll, and Cryoboralfs under USDA Soil Classification System, respectively. LS, SL, L, SiL, Cl and C refer to loamy sand, sandy loam, loam, silt loam, clay loam and clay soil texture, respectively.

[y]Cont. = continuous, F = summer fallow, w = spring wheat, US = upper slope, MS = middle slope, LS = lower slope.

[x]Estimated, based on McGill et al. 1981.

[w]The values for light fraction organic C in the 0-30 cm soil depth were 15.34 Mg C ha^{-1} in native grassland and 2.34 Mg C ha^{-1} in cultivated land.

Table 2. Relationship of soil organic C (SOC), soil organic N (SON), light fraction organic matter (LFOM), light fraction organic C (LFOC), mineralizable C (C_{min}), mineralizable N (N_{min}) or water stable aggregates (WSA), with input of crop residue, residue C, residue N, LFOC or clay content in various annual grain crop field experiments conducted in the Northern Great Plains of North America

Location	Soil zone[w]	Soil type or texture[y]	Years	Depth (cm)	Regression	Coefficient of determination	Reference
Alberta							
Breton	Gray Luvisol	Breton L	11	0-15	Increase in SOC (Mg C ha^{-1}) = 0.606 + 0.336 Residue C (Mg C ha^{-1})	0.76*	Nyborg et al. 1995b
Ellerslie	Black	Malmo SiCL					
Lethbridge	Dark Brown	Lethbridge CL	4	0-15	SOC related to surface residue	$0.54^{0.15}$	Larney et al. 1997
					LFOC related to surface residue	$0.72^{0.07}$	
Lethbridge	Dark Brown	Lethbridge CL	42	0-15	C_{min} (g C kg^{-1}) = 0.52 + 0.14 LFOC (g C kg^{-1})	0.31**	Bremer et al. 1994
Saskatchewan							
Indian Head	Thin Black	Indian Head C	30	0-15	SOC (Mg C ha^{-1}) = 23.4 + 0.083 Residue (Mg ha^{-1});	0.85**	Campbell et al. 1997b
					SOC (Mg C ha^{-1}) = 23.3 + 0.187 Residue C (Mg C ha^{-1})	0.81*	
					SOC (Mg C ha^{-1}) = 26.8 + 5.59 Residue N (Mg N ha^{-1})	0.72**	
					SON (Mg N ha^{-1}) = 2.55 + 0.007 Residue (Mg ha^{-1})	0.74**	
					SON (Mg N ha^{-1}) = 2.56 + 0.016 Residue C (Mg C ha^{-1})	0.68**	
					SON (Mg N ha^{-1}) = 2.80 + 0.056 Residue N (Mg N ha^{-1})	0.83**	
Melfort	Black	Melfort SiCL	31	0-15	SOC (Mg C ha^{-1}) = 61.8 + 0.013 Residue (Mg ha^{-1});	0.02^{ns}	
Swift Current	Brown	Swinton L	12	0-15	SOC (Mg C ha^{-1}) = 4.84 + 0.84 Residue C (Mg C ha^{-1})	0.99**	Campbell et al. 1997a
					LFOM (Mg C ha^{-1}) = -4.0 + 0.41 Residue C (Mg C ha^{-1})	0.99**	
					N_{min} (kg C ha^{-1}) = -46.4 + 9.6 Residue C (Mg C ha^{-1})	0.99**	
					WSA (%) = -48.3 + 5.5 Residue C (Mg C ha^{-1})		
Cantuar	Brown	Hatton FSL	11	0-15	[z]RAISOC (%) = -0.37 + 0.026 Clay (%)	0.89**	McConkey et al. 2003
Cantuar	Brown	Hatton FSL	11	0-15	[z]RAISON (kg N ha^{-1}) = 11.1 + 0.53 Clay (%)	0.74*	Liang et al. 2003a
Cantuar	Brown	Hatton FSL	11	0-15	C_{min} (mg C kg^{-1}) related to LFOC (mg C kg^{-1})	0.27**	Liang et al. 2003b
Swift Current	Brown	Swinton SiL	12	0-15		0.88**	
Stewart Valley	Brown	Sceptre C	11	0-15		0.82**	
Scott	Dark Brown	Elstow CL	16	0-15		0.56**	
Indian Head	Thin Black	Indian Head C	8	0-15		0.55**	
Melfort	Black	Melfort SiCL	25	0-15		0.56**	

[z]RAI = relative annual increase. [y]*, ** and ns refer to significant at $P < 0.05$, $P < 0.01$ and not significant, respectively.
[x]FSL, L, SiL, SiCL, Cl and C refer to fine sandy loam, loam, silt loam, silty clay loam, clay loam and clay soil texture, respectively.
[w]Brown, Dark Brown, Black, and Gray Luvisol soils according to the Canadian System of Soil Classification refer to Aridic Boroll, Typic Boroll, Udic Boroll, and Cryoboralfs under USDA Soil

Classification System, respectively.

Table 3. Decrease in soil organic C (SOC) and light fraction organic C (LFOC) removing or burning straw compared to its retention or return to land in various annual grain crop field experiments conducted in the Northern Great Plains of North America

Location	Soil zone[u]	Soil type or texture[v]	Year	Soil depth (cm)	Straw treatment	Loss in SOC (Mg C ha^{-1}/g C kg^{-1})	Loss in LFOC (kg C ha^{-1})	Reference
Alberta								
Lethbridge	Dark Brown	Lethbridge CL	48	Ap horizon	[x]Ret. Vs Burnt	No loss		Dormaar et al. 1979
Indian Head	Thin Black	Indian Head C	20	Ap horizon	[x]Ret. Vs Burnt (Expt I)	4.6 g C kg^{-1}		
Indian Head	Thin Black	Indian Head C	21	Ap horizon	[x]Ret. Vs Burnt (Expt II)	8.5 g C kg^{-1}		
Breton	Gray Luvisol	Breton L	13	0-30, 0-15	Ret. Vs Rem. (CT, 50 kg N ha^{-1})	4.20	210	Solberg et al. 1998
Ellerslie	Black	Malmo SiCL	13	0-30, 0-15	Ret. Vs Rem. (CT, 50 kg N ha^{-1})	1.23	160	
Saskatchewan								
Star City-1	Gray Luvisol	SCL	8	0-15	[y]Ret. Vs Rem.	No loss	1275	Malhi and Lemke (2007)
Star City -2	Dark Gray	CL	5	0-15	[x]Ret. Vs Burnt	4.49	926	Malhi and Kutcher (2007)
Birch Hills	Gray Luvisol	SL	5	0-15	[x]Ret. Vs Burnt	5.34	710	
Melfort	Black	Melfort SiC	20	0-15	[x]Ret. Vs Burnt	8.0 g C kg^{-1}		Biederbeck et al. 1980
Indian Head	Thin Black	Indian Head C	21	0-15	[x]Ret. Vs Burnt	3.0 g C kg^{-1}		
Indian Head	Thin Black	Indian Head C	30	0-15	[w]Ret. Vs Rem.	1.15		Campbell et al. 1998
Indian Head	Thin Black	Indian Head C	40	0-15	[w]Ret. Vs Rem.	1.56	133	Campbell et al. 2001a
North Dakota	Dark Brown	Temvik-Wilton SiL	8	0-7.5	Ret. Vs. Rem.	No loss		Liebig et al. 2004

[z] NT = no-till; CT = conventional tillage; Breton and Ellerslie sites also received adequate amounts of P, K and S fertilizers at seeding.
[y]Average of NT and CT treatments receiving N fertilizer at 0, 40, 80 and 120 kg N ha^{-1} plus adequate amounts of P, K and S fertilizers at seeding.
[x]Average of NT and CT treatments receiving fertilizers to supply 74 kg N, 9 kg P, 8 kg K and 10 kg S ha^{-1} at seeding.
[w]Received N and P fertilizers at seeding.
[v]SL, L, SiL, SCL, Cl and C refer to sandy loam, loam, silt loam, sandy clay loam, clay loam and clay soil texture, respectively.
[u]Brown, Dark Brown, Black, Dark Gray, and Gray Luvisol soils according to the Canadian System of Soil Classification refer to Aridic Boroll, Typic Boroll, Udic Boroll, Boralfic Boroll, and Cryoboralfs under USDA Soil Classification System, respectively.

Table 4. Increase in soil organic C (SOC) and light fraction organic C (LFOC) due to adoption of no-till or minimum tillage (MT), compared to corresponding conventional tillage (CT) in various field experiments conducted in the Northern Great Plains of North America

Location	Soil zone[v]	Soil type or texture[x]	Years	Soil depth (cm)	Tillage treatment[z]	Gain in SOC	Gain in LFOC mass or concentration	Reference
Alberta						Mg C ha^{-1}	kg C ha^{-1}	
Breton	Gray Luvisol	Breton L	11	0-15	No-till	7.50		Nyborg et al. 1995b
Ellerslie	Black	Malmo SiCL	11	0-15	No-till	1.75		
Breton	Gray Luvisol	Breton L	23	0-20	No-till	1.5	390	Plante et al. 2006
Lethbridge	Dark Brown	Lethbridge CL	16	0-15	No-till (F-W)	2.1	184	Larney et al. 1997
Lethbridge	Dark Brown	Lethbridge CL	8	0-15	No till (Cont. W)	2.0	716	
Saskatchewan								
Stewart Valley	Rego Brown	Scetre C	11	0-15	No-till (Cont. W)	3.02		Campbell et al. 1996b
Cantuar	Brown	Hatton FSL	11	0-15	No-till (Cont. W)	No gain		Campbell et al. 1996c
Swift Current	Brown	Swinton SiL	12	0-15	No-till (Cont. W)	1.60		Campbell et al. 1995
			12	0-15	No-till (F-W)	No gain		
Star City-1	Gray Luvisol	SCL	8	0-15	No-till	No gain	563	Malhi and Lemke (2007)
Star City -2	Dark Gray	CL	5	0-15	No-till[y]	4.38	144	Malhi and Kutcher (2007)
Birch Hills	Gray Luvisol	SL	5	0-15	No-till[y]	8.85	1325	
Melfort	Black	Melfort SiCL	8	0-15	No-till	4.51	898	Malhi et al. (2008)
							g C kg^{-1}	
Scott	Dark Brown	Elstow CL	16	0-15	No-till	4.4	0.3	McConkey et al. 2003 for SOC;
Melfort	Black	Melfort SiCL	25	0-15	No-till	12.0	1.1	Liang et al. 2003 for LFOC
					MT	7.1		
Indian Head	Thin Black	Indian Head C	8	0-15	No-till	4.1	0.6	
					MT	4.1		
Cantuar	Brown	Hatton FSL	11	0-15	No-till vs MT	2.0	0.2	
Swift Current	Brown	Swinton SiL	12	0-15	No-till vs MT	0.8	0.1	
Stewart Valley	Brown	Sceptre C	11	0-15	No-till vs MT	2.5	0.2	
Montana	Brown	Hillon CL	9	0-20	No-till	3.3		Bricklemyer et al. 2007
		Ethridge CL	10	0-20	No-till	4.0		
		Kobase C/CL	6	0-20	No-till	5.1		
		Telstad L	8	0-20	No-till	1.3		
		Telstad SiL/L	7	0-20	No-till	2.5		

	Brown	Dooley SL	9	0-9	No-till	2.0	Pikul and Aase 1995
North Dakota	Dark Brown	Temvik-Wilton SiL	12	0-15	No-till	2.8	Halvorson et al. 2002
					MT	0.3	

[z]W = spring wheat; F = summer fallow, Cont. = continuous. No-till versus CT except where MT indicated. [y]Crop residue was burnt or returned to soil.

[x]SL, FSL, L, SiL, SiCL, SCL, Cl and C refer to sandy loam, fine sandy loam, loam, silt loam, silty clay loam, sandy clay loam, clay loam and clay soil texture, respectively.

[z]Brown, Dark Brown, Black, Dark Gray, and Gray Luvisol soils according to the Canadian System of Soil Classification refer to Aridic Boroll, Typic Boroll, Udic Boroll, Boralfic Boroll, and Cryoboralfs under USDA Soil Classification System, respectively.

Table 5. Increase in soil organic C (SOC) and light fraction organic C (LFOC) as affected by fertilizers in various annual grain crop field experiments conducted in the Northern Great Plains of North America

Location	Soil zone[v]	Soil type or texture[x]	Years	Depth (cm)[w]	Tillage treatment[z]	Fertilizer N and/or P[y]	Gain in SOC (Mg C ha-	Gain in LFOC (kg C ha-	Reference
Alberta									
Breton	Gray Luvisol	Breton L	11	0-15	NT	56 kg N ha^{-1}	9.96		Nyborg et al. 1995b
					CT	56 kg N ha^{-1}	5.82		
Ellerslie	Black	Malmo SiCL	11	0-15	NT	56 kg N ha^{-1}	No gain		
					CT	56 kg N ha^{-1}	2.18		
Breton	Gray Luvisol	Breton L	23	0-20	NT	56 kg N ha^{-1}	10.0	578	Plante et al. 2006
Breton[z]	Gray Luvisol	Breton L	13	0-30,	CT	50 kg N ha^{-1}	7.7	560	Solberg et al. 1998
Ellerslie[z]	Black	Malmo SiCL	13	0-15	CT	50 kg N ha^{-1}	4.1	390	
Breton	Gray Luvisol	Breton L	60	0-15	CT	N (F-W)	3.2		Izaurralde et al. 2001
						N (W-O-B-H-H)	4.6		
Cooking Lake	Gray Luvisol	Cooking Lake CL	5	0-30	CT	150 kg N ha^{-1}	8.1		Izaurralde et al. 1998
Josephburg	Black	Angus Ridge SiL	5			150 kg N ha^{-1}	No gain		
Saskatchewan									
Star City-1	Gray Luvisol	SCL	8	0-15	NT/CT	80 kg N ha^{-1}	No gain	1375	Malhi and Lemke 2007
Melfort	Black	Melfort SiCL	25	0-15	CT	NP	No gain		Nuttall et al. 1986
Melfort	Black	Melfort SiCL	31	0-15	CT	NP	No gain		Campbell et al. 1991b
Indian Head	Thin Black	Indian Head C	30	0-15	CT	NP (F-W)	1.6		Campbell et al. 1991a
						NP (F-W-W)	2.1		
						NP (Cont. W)	2.3		
Indian Head	Thin Black	Indian Head C	40	0-15	CT30+NT10	NP (F-W)	1.6	180	Campbell et al. 2001a
						NP (F-W-W)	7.1	270	
						NP (Cont. W)	5.6	648	

Indian Head	Thin Black	Indian Head C	42	0-15	CT	NP (F-W)	No gain	No gain	Campbell et al. 1997
						NP (F-W-W)	0.9	No gain	
						NP (Cont. W)	5.8	515	
Swift Current	Brown	Swinton L	24	0-15	CT	NP vs P (F-W-W)	1.2		Campbell and Zentner 1993
						NP vs N (F-W-W)	2.7		
						NP vs P (Cont. W)	2.9		
Swift Current	Brown	Swinton L	17	0-7.5	CT	NP vs P (Cont. W)	2.3	1200	Biederbeck et al. 1994
Swift Current	Brown	Swinton L	24	0-7.5	CT	NP vs P (Cont. W)	2.0	1030	Campbell et al. 1997
Swift Current	Brown	Swinton L	33	0-15	CT	NP vs N (F-W-W)	6.7		Campbell et al. 2001b
						NP vs P (F-W-W)	4.9		
						NP vs P (Cont. W)	4.3		
Swift Current	Brown	Swinton L	37	0-15	CT	NP vs N (F-W-W)	1.76		Campbell et al. 2007a
						NP vs P (F-W-W)	2.11		
North Dakota	Dark Brown	Temvik-Wilton SiL	12	0-15	NT/MT/CT	34, 67, 101 kg N ha^{-1} (Cont. W)	No gain		Halvorson et al. 2002
						0, 22, 45 kg N ha^{-1} (F-W)	No gain		

[z]NT = no-till, CT = conventional tillage.

[y]Fertilized versus no N, or as indicated otherwise. F = summer fallow, W = spring wheat, Cont. = continuous, O = oat, B = barley, H = hay.

[x]L, SiL, SiCL, SCL, Cl and C refer to loam, silt loam, silty clay loam, sandy clay loam, clay loam and clay soil texture, respectively.

[w]Soil depth 0-30 for SOC and 0-15 for LFOC.

[v]Brown, Dark Brown, Black, and Gray Luvisol soils according to the Canadian System of Soil Classification refer to Aridic Boroll, Typic Boroll, Udic Boroll, and Cryoboralfs under USDA Soil Classification System, respectively.

Table 6. Increase in soil organic C (SOC) and light fraction organic C (LFOC) as affected by fertilizers in various grassland[z] field experiments conducted in the Northern Great Plains of North America

Location	Soil zone[v]	Soil type or texture[x]	Years	Depth (cm)	Fertilizer	Gain in SOC (Mg C ha^{-1})	Gain in LFOC (Mg C ha^{-1})	Reference
Alberta								
Crossfield[y]	Thin Black	L	27	0-30	56 kg N ha^{-1}	16.56	4.46	Malhi et al. 2003c
					112 kg N ha^{-1}	24.00	8.97	
					168 kg N ha^{-1}	27.08	12.91	
Saskatchewan								
Canwood	Dark Gray	Canwood L	11	0-37.5	112 kg N + 11 kg S ha^{-1}	6.0	8.4	Nyborg et al. 1998
Canwood	Dark Gray	Canwood L	13	0-30	112 kg N + 11 kg S ha^{-1}	3.88	9.50	Nyborg et al. 1999
Canwood	Dark Gray	Canwood L	21	0-37.5	112 kg N + 11 kg S ha^{-1}	26.77	10.33	Malhi et al. 2005
North Dakota[w]	Dark Brown	Temvik-Wilton SiL	71 ??	0-100	45 kg N ha^{-1} (since 1963)	18.0		Liebig et al. 2006b

[z]Grassland was smooth bromegrass at Crossfield, Alberta, mixture of smooth bromegrass, Kentucky bluegrass and rough hairgrass.

[y]Relationship between SOC and applied N rate: SOC (Mg C ha^{-1}) = 87.95 + 0.304N – 0.000656N^2; r^2 + 0.91**; N = kg N ha^{-1};
Relationship between LFOC and applied N rate: LFOC (Mg C ha^{-1}) = 3.074 + 0.114N – 0.000197N^2; r^2 + 0.99**; N = kg N ha^{-1}.

[x]L refers to loam.

[w]Crested wheatgrass.

[v]Dark Brown, Black, and Dark Gray soils according to the Canadian System of Soil Classification refer to Typic Boroll, Udic Boroll, and Boralfic Boroll, under USDA Soil Classification System, respectively.

Table 7. Effect of manure addition on soil organic C (SOC), light fraction organic C (LFOC) and mineralizable C (Cmin) in various field experiments conducted in the Northern Great Plains of North America

Location	Soil zone[w]	Soil type or texture[y]	Years	Depth (cm)	Rotations[z]	Concentration or mass of C SOC	LFOC	Cmin	Reference
Alberta						Mg C ha^{-1}			
Breton	Gray Luvisol	Breton L	60	0-15	F-W	18.1			Izaurralde et al. 2001
					F-W (M)	31.1			
					W-O-B-H-H	29.1			
					W-O-B-H-H (NPKS)	33.7			
					W-O-B-H-H (M)	43.2			
Lethbridge	Dark Brown	Lethbridge CL	42	0-15	F-W-W	29.7			Bremer et al. 1994
					F-W-W (M)	34.9			
						g C kg^{-1}	g C kg^{-1}	mg C kg^{-1}	
Lethbridge	Dark Brown	Lethbridge CL	42	0-7.5	F-W-W	17.0	2.15	795	Bremer et al. 1994
					F-W-W (M)	21.7	3.56	983	
Lethbridge	Dark Brown	Lethbridge CL	20	0-15	F-W-W	13.6			Pittman 1977
					F-W-W (M)	14.9			
Breton	Gray Luvisol	Breton L	20	0-15	F-W	11			
					F-W (M)	16			
					G/L mixture	14			
					G/L mixture (M)	17			
Saskatchewan									
Humboldt	Black	Cudworth L	4	0-30	LHM vs. control	No gain			Assefa et al. 2004
Humboldt	Black	Cudworth L	6	0-15	[x]LHM vs. control	No gain	0.2 Mg C ha^{-1} gain		King 2007
Plenty	Brown	Regina C	4	0-15	LHM vs. control	3 Mg C ha^{-1} gain	0.7 Mg C ha^{-1} gain		
Star City	Dark Gray Luvisol	Kamsack L	3	0-15	LHM vs. control	No gain	1.3 Mg C ha^{-1} gain		
Manitoba						Mg C ha^{-1}			Ridley et al. 1968
Winnipeg	Black	Red River C	37	0-15	F-W	38.7			
					F-W (M)	42.8			
					F-W-W	51.1			
					F-W-W (M)	57.4			
					F-W-W-W	49.1			
					F-W-W-W (M)	57.4			

Cont. W	78.4
Cont. W (M)	79.4

[z]F = summerfallow, W = spring wheat, Cont. = continuous, O = oat, B = barley, H = hay, G = grass, L = legume, A = alfalfa, Fx = flax, wW = winter wheat, C = canola, Sf = sunflower, N = N fertilized, P = P fertilized, NP = N and P fertilized, NPKS = N, P, K and S fertilized, NT = no-till, CT = conventional tillage, M = manure, GM = green manure.

[y]L, CL and C refer to loam, clay loam and clay, respectively.

[x]LHM = Liquid hog manure applied annually at about 80 kg N ha^{-1} compared to unfertilized control.

[w]Brown, Dark Brown, Black, Dark Gray, and Gray Luvisol soils according to the Canadian System of Soil Classification refer to Aridic Boroll, Typic Boroll, Udic Boroll, Boralfic Boroll, and Cryoboralfs under USDA Soil Classification System, respectively.

Table 8. Increase in soil organic C (SOC) and/or light fraction organic C (LFOC) from the integrated use of chemical fertilizers (F) and manure (M) on eroded and non-eroded soils in field experiments at two locations in Alberta, Canada

Location	Soil zone	Soil type or texture[x]	Years	Depth (cm)	Tillage	F and/or M in eroded treatments[z]	Gain in SOC (Mg C ha^{-1})	Gain in LFOC (Mg C ha^{-1})	Reference
Alberta									
Cooking Lake	Gray Luvisol	Cooking Lake L	5	0-30, 0-15[y]	CT	F in 0 cm removal	8.11	0.53	Izaurralde et al. 1998
						M in 0 cm removal	8.62	1.68	
						F + M in 0 cm removal	15.20	2.81	
						F in 10 cm removal	7.67	0.95	
						M in 10 cm removal	15.70	2.09	
						F + M in 10 cm removal	19.34	3.47	
						F in 20 cm removal	1.31	0.43	
						M in 20 cm removal	11.20	1.08	
						F + M in 20 cm removal	14.94	1.22	
Josephburg	Black	Angus Ridge SiCL	5	0-30, 0-15[y]	CT	F in 0 cm removal	No gain	0.83	
						M in 0 cm removal	9.95	1.58	
						F + M in 0 cm removal	13.57	5.60	
						F in 10 cm removal	4.45	1.56	
						M in 10 cm removal	9.95	2.11	
						F + M in 10 cm removal	11.31	5.32	
						F in 20 cm removal	15.45	1.05	
						M in 20 cm removal	20.52	1.46	
						F + M in 20 cm removal	28.48	5.71	

[z]In eroded treatments, surface soil (cm depth) was removed artificially.
[y]Soil depth 0-30 for SOC and 0-15 for LFOC.
[x]L and SiCL refer to loam and silty clay loam, respetively.
[w]Black, and Gray Luvisol soils according to the Canadian System of Soil Classification refer to Udic Boroll, and Cryoboralfs under USDA Soil Classification System, respectively.

Table 9. Effect of cropping frequency (CF) or summer fallow frequency (SFF) in a crop rotation on soil organic C (SOC), light fraction organic C (LFOC) and mineralizable C (C_{min}) in various field experiments conducted in the Northern Great Plains of North America

Location	Soil zone[v]	Soil type or texture[w]	Years	Depth (cm)	[z]Rotations with Different CF or SFF	Concentration or mass of C			Reference
						SOC	LFOC	C_{min}	
Alberta						Mg C ha^{-1}	g C kg^{-1}	mg C kg^{-1}	
Breton	Gray Luvisol	Breton L	60	0-15	F-W (none)	18.1			Izaurralde et al. 2001
					W-O-B-H-H (none)	29.1			
					F-W (NPKS)	21.3			
					W-O-B-H-H (NPKS)	33.7			
					F-W (manure)	31.1			
					W-O-B-H-H (manure)	43.2			
						g C kg^{-1}			
Bow Island	Dark Brown	Chin CL	6	0-15	F-W	20.2			Bremer et al. 2002
					F-W-W	20.9			
					Cont. W	21.7			
Lethbridge	Dark Brown	Lethbridge CL	9	0-15	F-W	35.7			Larney et al. 1997
					Cont. W	38.5			
Lethbridge	Dark Brown	Lethbridge CL	42	0-7.5	F-W	15.9	1.60	622	Bremer et al. 1994
					F-W-W	17.0	2.15	795	
					Cont. W	18.7	3.27	939	
					F-W (N)	16.4	1.77	727	
					F-W-W (N)	16.6	1.92	739	
					Cont. W (N)	18.5	2.67	956	
Lethbridge	Dark Brown	Lethbridge CL	20	0-15	F-W-W	13.6			Pittman 1977
					Cont. W	14.9			
Saskatchewan									
Swift Current	Brown	Swinton L	17	0-7.5	F-W (NP)	17.2	1.2	160	Biederbeck et al. 1994
					F-W-W (NP)	18.9	1.6	180	
					Cont. W (NP)	21.3	3.2	370	
Swift Current	Brown	Swinton L	24	0-7.5	F-W (NP)	14.8	1.01	136	Campbell et al. 1997
					F-W-W (NP)	16.3	1.34	159	
					Cont. W (NP)	18.4	2.72	320	

						Mg C ha^{-1}	Mg C ha^{-1}		
Swift Current	Brown	Swinton L	12	0-7.5 (0-15)	F-W (CT)	13.85 (30.1)			Campbell et al. 1995
					Cont. W (CT)	14.60 (30.1)			
					F-W (NT)	14.78 (30.6)			
					Cont. W (NT)	15.91 (32.7)			
Swift Current	Brown	Swinton L	11	0-15	F-W (CT)	25.5			Campbell et al. 1996b
					Cont. W (CT)	27.5			
					F-W (NT)	30.7			
					Cont. W (NT)	30.5			
Swift Current	Brown	Swinton L	24	0-15	F-W (NP)	30.9			Campbell and Zentner 1993
					F-W-W (NP)	31.4			
					Cont. W (NP)	34.3			
Swift Current	Brown	Swinton L	10	0-15 (0-30)	F-W-W	33.7 (50.3)			Campbell et al. 2000b
					F-W-W-W	33.5 (50.8)			
					Cont. W	38.5 (56.7)			
Swift Current	Brown	Swinton L	33	0-15	F-W (NP)	36.5			Campbell et al. 2000a
					F-W-W (NP)	38.3			
					F-W-W-W-W-W (NP)	39.7			
					Cont. W (NP)	42.2			
Swift Current	Brown	Swinton L	30	0-15	F-W-W (NP)	34.65			Campbell et al. 2007a
					F-W-W-W-W-W (NP)	37.34			
					Cont. W (NP)	39.97			
			37	0-15	F-W-W (NP)	35.65			
					F-W-W-W-W-W (NP)	39.71			
					Cont. W (NP)	39.25			
Cantanar	Brown	Hatton FSL	11	0-15	F-W	17.2	0.81	56	McConkey et al. 2003
					Cont. W	19.2	1.52	90	for TOC
									Liang et al. 2003b
Swift Current	Brown	Swinton SiL	12	0-15	F-W	27.1	0.85	110	for LFOC and Min C
					Cont. W	29.6	1.30	135	
Stewart Valley	Brown	Sceptre C	11	0-15	F-W	27.1	0.79	135	
					Cont. W	26.7	1.32	215	
Scott	Dark Brown	Elstow CL	16	0-15	F-Fx-W-F-C-W	50.9	2.2	199	
					W-Fx-W-W-C-W-	57.8	3.6	269	

Indian Head	Thin Black	Indian Head C	8	0-15	F-W-W-wW	40.4	1.5	296	
					W-W-Fx-wW	43.3	2.1	364	
Indian Head[y]	Thin Black	Indian Head C	30	0-15	F-W (NP)	37.9		178	Campbell et al. 1991a
					F-W-W (NP)	38.5		193	
					Cont. W (NP)	41.9		230	
Indian Head	Thin Black	Indian Head C	30	0-15	F-W (NP)	29.06			Campbell et al. 2001a
					F-W-W (NP)	29.85			
					Cont. W (NP)	34.47			
			40	0-15	F-W (NP)	33.99	0.619		
					F-W-W (NP)	35.06	0.742		
					Cont. W (NP)	36.42	1.238		
Indian Head	Thin Black	Indian Head C	42	0-15	F-W (NP)	30.1	0.627	178	Campbell et al. 1997
					F-W-W (NP)	31.9	0.687	193	
					Cont. W (NP)	37.4	1.315	230	
Swift Current[x]	Brown	Swinton SiL	33	0-15	F-W	36.5			Campbell et al. 2001b
					F-W-W	38.3			
					F-W-W-W-W-W	39.7			
					Cont. W	42.2			
Melfort	Black	Melfort SiCL	31	0-15	F-W-W	61.3		132	Campbell et al. 1991b
					Cont. W	65.4		254	
Manitoba									
Winnipeg		Red River C	37	0-15	F-W	38.7			Ridley et al. 1968 (estimated by using soil bulk density of 1.20 Mg m^{-3} for the 0-15 cm depth, as cited by Campbell et al. 2005)
					F-W-W	51.1			
					F-W-W-W	49.1			
					Cont. W	78.4			
					F-W (P)	37.6			
					F-W-W (P)	52.2			
					F-W-W-W (P)	48.1			
					Cont. W (P)	65.7			
					F-W (M)	42.8			
					F-W-W (M)	57.4			
					F-W-W-W (M)	57.4			
					Cont. W (M)	79.4			
North Dakota									

Mandan	Dark Brown	Temvik-Wilton SiL	12	0-15	F-W (NP, CT)	36.2	Halvorson et al. 2002
					W-wW-Sf (NP, CT)	37.7	
					F-W (NP, MT)	37.6	
					W-wW-Sf (NP, MT)	39.7	
					F-W (NP, NT)	35.6	
					W-wW-Sf (NP, NT)	42.2	

[z]F = summer fallow, W = spring wheat, Cont. = continuous, O = oat; B = barley, H = hay, Fx = flax, wW = winter wheat, C = canola, Sf = sunflower, N = N fertilized, NP = N and P fertilized, NPKS = N, P, K and S fertilized, NT = no-till, CT = conventional tillage, M = manure.

[y]Relationship between soil organic C (SOC) and cropping frequency (CF): SOC (Mg C ha^{-1}) = 33.2 + 7.5 CF (CF was 0.33, 0.50 or 1.00).

[x]Relationship between relative annual increase of soil organic C (RAISOC) and summer fallow frequency (SFF): RAISOC (kg C ha^{-1} yr^{-1}) = 303.8 -412.4 SFF (SFF 0, 0.17, 0.33 or 0.50), r^2 = 0.973;

Relationship between light fraction organic C (LFOC) in soil and summer fallow frequency (SFF): LFOC (Mg C ha^{-1}) = 2.1 – 1.8 SFF (SFF was 0, 0.25 or 0.50), r^2 = 0.95, 4 years, 0-7.5 cm depth (Source for LFOC - Liang et al. 2002).

[w]FSL, L, SiL, SiCL, Cl and C refer to fine sandy loam, loam, silt loam, silty clay loam, clay loam and clay soil texture, respectively.

[v]Brown, Dark Brown, Black, and Gray Luvisol soils according to the Canadian System of Soil Classification refer to Aridic Boroll, Typic Boroll, Udic Boroll, and Cryoboralfs under USDA Soil Classification System, respectively.

Table 10. Effect of crop type, green manure and other crop management practices in a crop rotation on soil organic C (SOC), light fraction organic C (LFOC) and mineralizable C (C_{min}) in various field experiments conducted in the Northern Great Plains of North America

Location	Soil zone[x]	Soil type or texture[y]	Years	Depth (cm)	Crop rotations[z]	Concentration or mass of C SOC	LFOC	C_{min}	Reference
Alberta						Mg C ha^{-1}			
Lethbridge	Dark Brown	Lethbridge CL	42	0-15	F-W-W (P)	30.1			Bremer et al. 1994
					F-W-W-H-H-H (P)	33.4			
						g C kg^{-1}	g C kg^{-1}	mg C kg^{-1}	
Lethbridge	Dark Brown	Lethbridge CL	42	0-7.5	F-W-W (N)	16.6	1.92	739	Bremer et al. 1994
					F-W-W-H-H-H	18.6	2.78	984	
					Cont. G	19.9	4.75	1451	
					Cont. W (N)	18.5	2.67	956	
Lethbridge	Dark Brown	Lethbridge CL	20	0-15	F-W-W	13.6			Pittman 1977
					F-W-W-A-A-A	15.0			
					Cont. W	14.9			
Breton	Gray Luvisol	Breton L	20	0-15	F-W	11			
					G/L mixture	14			
Saskatchewan									
Swift Current	Brown	Swinton L	17	0-7.5	Cont. W (NP)	21.3	3.2	370	Biederbeck et al. 1994
					W-Lentil (NP)	20.3	2.2	280	
Swift Current	Brown	Swinton L	24	0-7.5	Cont. W (NP)	18.4	2.72	320	Campbell et al. 1997
					W-Lentil (NP)	17.4	1.90	239	
					F-W-W (NP)	16.3	1.34	159	
					F-Fx-W (NP)	15.4	1.71	182	
Swift Current	Brown	Swinton L	33	0-15	F-W-W	38.3			Campbell et al. 2001b
					F-Fx-W	36.6			
					F-Rye-W	42.0			
						Mg C ha^{-1}	Mg C ha^{-1}	mg C kg^{-1}	
Indian Head	Thin Black	Indian Head C	8	0-15	P-W-Fx-wW	43.0	1.9	356	McConkey et al. 2003 for TOC;
					W-W-Fx-wW	43.3	2.1	364	Liang et al. 2003b for LFOC and Cmin
Indian Head	Thin Black	Indian Head C	11	0-15	Cont. W (NP)	41.9		230	Campbell et al. 1991a
					F-W-W (NP)	38.5		193	
					GM-W-W	39.7		207	
					F-W-W-H-H-H	41.9		217	

Indian Head	Thin Black	Indian Head C	42	0-15	Cont. W (NP)	37.9	1.315	230	Campbell et al. 1997
					F-W-W (NP)	31.9	0.687	193	
					GM-W-W	36.5	0.811	214	
					F-W-W-H-H-H	36.0	1.390	227	
						Mg C ha^{-1}			
North Dakota	Dark Brown	Temvik-Wilton SiL	8	0-7.5	W-M	20.9			Liebig et al. 2004
					W-Sa-F	19.3			
					W-Sa-R	18.3			
					W-F	18.8			

[z]F = summer fallow, W = spring wheat, Cont. = continuous, O = oat, B = barley, H = hay, G = grass, L = legume, A = alfalfa, Fx = flax, wW = winter wheat, C = canola, Sf = sunflower, N = N fertilized, P = P fertilized, NP = N and P fertilized, NPKS = N, P, K and S fertilized, NT = no-till, CT = conventional tillage, M = manure, GM = green manure.

[y]L, Cl and C refer to loam, clay loam and clay, respectively.

[x]Brown, Dark Brown, Black, and Gray Luvisol soils according to the Canadian System of Soil Classification refer to Aridic Boroll, Typic Boroll, Udic Boroll, and Cryoboralfs under USDA Soil Classification System, respectively.

Table 11. Soil organic C (SOC) and light fraction organic C (LFOC) as affected by land use (conversion to grassland versus cultivated land) at various locations in Saskatchewan, Canada

Location	Soil zone[x]	Soil type or texture[y]	Depth (cm)	Land use	Mass of SOC (Mg C ha^{-1})	Mass of LFOC (Mg C ha^{-1})	Reference
Scott	Dark Brown	Elstow L	0-30	Converted to grass 60 yr	76.2	11.31	Malhi et al. 2003a
				Cultivated	52.6	1.86	
				Converted to [z]G-L mix 30 yr	107.4	14.99	
				Cultivated	65.0	2.36	
Hanuschak	Dark Brown	Weyburn L	0-5	Converted to grass 7 yr	22.7		Mensah et al. 2003
				Cultivated Cereal-Fallow-Canola	15.2		
Bergren	Gray Luvisol	Shellbrook SL	0-5	Converted to grass 6 yr	21.3		
				Cultivated Canola-Barley-Flax	5.8		
Fontaine	Dark Brown	Elstow SiL	0-5	Converted to grass 9 yr	14.8	2.29	
				Cultivated Cereal-Fallow	10.7	1.64	
Totzke	Dark Brown	Oxbow L	0-5	Converted to grass 7 yr	13.9	1.31	
				Cultivated Canola-Fallow	12.8	1.06	
Gayowoski	Dark Brown	Weyburn L	0-5	Converted to grass 4 yr	14.8	2.10	
				Cultivated Cereal-Oilseed	12.8	1.36	
Meacham	Dark Brown	Weyburn L	0-15	Converted to grass 8 yr	59.4		Mensah. 2000
				Cultivated Cereal-Pea	52.9		
Dana	Black	Oxbow L	0-15	Converted to grass 4 yr	43.1		
				Cultivated	36.1		
Gronlid	Black	Shellbrook CL	0-15	Converted to grass 4 yr	44.5		
				Cultivated alfalfa	25.5		
Trembley WL	Dark Brown	Amulet L	0-60	Converted to grass 5 yr	112.8		Nelson et al. 2008
				Cultivated Cereal-Fallow	98.8		
Vermillion WL	Brown	Ardill CL	0-60	Converted to grass 9 yr	174.3		
				Cultivated Cereal-Fallow	84.6		

[z]G-L refers to grass-legume mixture grown for hay.
[y]SL, L, SiL and CL refer sandy loam, loam, silt loam and clay loam, respectively.
[x]Brown, Dark Brown, Black, and Gray Luvisol soils according to the Canadian System of Soil Classification refer to Aridic Boroll, Typic Boroll, Udic Boroll, and Cryoboralfs under USDA Soil Classification System, respectively.

Table 12. Soil organic C (SOC) and light fraction organic C (LFOC) as affected by conversion of land use from cultivated land to grassland on different landscape position (SH – shoulder, MS – middle slope, and FS – foot slope) at various locations in Saskatchewan, Canada

Location	Soil zone[x]	Soil type or texture[y]	Depth (cm)	Land use at SH, MS and FS positions	Mass of SOC (Mg C ha^{-1})	Mass of LFOC (Mg C ha^{-1})	Reference
Trembley	Dark Brown	Amulet CL	0-15, 0-7.5[z]	Converted to grass 5 yr previous - SH	30.1	2.1	[z]Nelson et al. 2008
				Wheat-fallow cultivated equivalent-SH	15.5	0.4	
				Converted to grass 5 yr previous- MS	23.2	0.8	
				Wheat-fallow cultivated equivalent-MS	12.3	0.3	
				Converted to grass 5 yr previous - FS	36.1	1.5	
				Wheat-fallow cultivated equivalent-FS	34.6	0.9	
Vermillion	Brown	Ardill CL	0-15, 0-7.5[z]	Converted to grass 9 yr previous - SH	37.2	6.2	
				Wheat-fallow cultivated equivalent-SH	18.8	0.8	
				Converted to grass 9 yr previous - MS	31.2	3.7	
				Wheat-fallow cultivated equivalent-MS	14.5	0.5	
				Converted to grass 9 yr previous - FS	53.2	3.8	
				Wheat-fallow cultivated equivalent-FS	32.0	0.9	

[z]SOC in 0-15 cm, and LFOC in 0-7.5 cm depth.
[y]SL and CL refer to sandy loam and clay loam, respectively.
[x]Brown and Dark Brown soils according to the Canadian System of Soil Classification refer to Aridic Boroll and Typic Boroll, under USDA Soil Classification System, respectively.