Tillage Impact on Carbon Sequestration on Rolling Landscapes of Farm Fields in Saskatchewan

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Introduction

Long term (10 to 25 years) rotation studies on the Canadian prairies have shown that conservation tillage and reduced fallow have, depending upon clay content and soil moisture deficits, sequestered from 0.3 to 0.7 Mg C $ha^{-1}yr^{-1}$ soil organic C (Liang et al., 1999a,b). However, since these studies were conducted on replicated and relative level research plots, it is questionable whether they reflect the reality of actual farm fields where landscapes and management practices often differ markedly from that on research plots. Therefore, the objective of this study was to quantify carbon sequestration as a function of conservation tillage on a range of typical soil-landscapes throughout Saskatchewan by comparing neighboring farmer's fields with and without conservation tillage.

Site Selection

Paired sites representing no-till and conventional tillage regimes were selected at Kindersley, Limerick, Biggar, Perdue, Unity, Arberdeen, Indian Head, Prince Albert, and Arbofield in the fall of 1997 and 1998. The no-till fields had been under a reduced tillage regime for a minimum of four years and were located in hummocky or ridged landscapes with slopes ranging from 5 to 10% (Fig. 1). At each location, a conventional-tilled field with similar soil and landscape characteristics to those of the no-till field was located nearby for comparison.

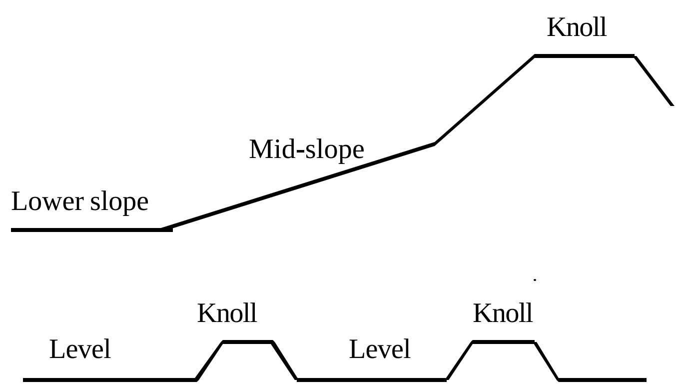

Fig. 1. Typical landscape positions defined in this study

Soil sampling sites were located on the knoll, mid-slope and where possible, on lower slope positions in both the no-till and conventional-tillage fields. To ensure, as much as possible, comparability between the conventional and no-tillage sites, considerable care was taken to ensure that the soil profile characteristics were reasonably similar, particularly with respect to the depth of the Ap horizon and to the depth of solum. This was particular critical at the mid-slope positions, where soil organic carbon content is strongly influenced by the slope position (e.g. distance from the knoll) and by subtle differences in the shape of the slope, as well as on the lower slopes where deposition of organic-rich erosional sediments is often chaotic and unpredictable and can result in significant differences in soil organic carbon content from field to field. Nonetheless, it is important to remember that while considerable care was taken to ensure comparability between the no-tillage and conventional tillage fields, it is virtually impossible to know for sure if the soil conditions were in fact similar prior to the implementation of the no-till regime.

Soil Sampling and Analysis

Four sampling sites, or replicates, were located approximately 10 to 20 m apart at each landscape position. At each site, three individual soil profiles, each within approximately 1 m, were sampled using a hydraulically operated sampling tube of 5.5-cm diam. The samples from each or the three profiles were subdivided at 0-10, 10-20, 20-30, and 30-40 cm depth increments and bulked according to depth. Soil bulk density for each soil layer was calculated using the gross fresh weight and moisture content. Surface crop residues were collected from six 0.5 m^2 plots at each landscape position of no-till and conventional tillage fields at Limerick, Biggar, Unity, Indian Head, and Prince Albert. The residues were washed, dried, and weighed in the laboratory. Organic C content of soil samples and surface crop residue were analyzed using an automated combustion technique (Carlo Erba™, Milan, Italy). Soil organic C in the 0-10-cm and 10-20-cm layers was calculated using soil organic C concentration and bulk density values. Soil organic C in the 0-20-cm layer was also calculated based on an equivalent mass for the same landscape position of no-till and conventional tillage systems at each site (Ellert and Bettany, 1995) and is presented in this paper.

Statistical Analysis

For each site, the tillage system was treated as an experimental factor, and statistically analyzed using t-test for each of the landscape positions. Since it is assumed that the soil carbon content at comparable landscape positions at each site was similar prior to the adoption of no-till, the annual carbon gains/losses at each landscape position were calculated by taking the difference in the organic C between no-till and conventional tillage, divided by the number of years under no-till.

Cropping Systems

In general under conventional tillage, traditional crop rotations across Saskatchewan can be related to long term climate conditions and in particular to the incidence and frequency of drought. For example in the drier regions, or Brown soil zone, wheat fallow is the predominant rotation. In the slightly more moist Dark Brown soil zone, crop rotations commonly include one fallow in two or three years, whereas the frequency of fallow in the Black and Grey soil zones, where inadequate soil moisture is rarely a concern, fallow is seldom part of the rotation. Moreover, over the past decade or more, there has been a general trend in reduction of fallow frequency throughout the Province.

Results and Discussion

The difference in the amount of surface crop residue-C between no-till and conventional tillage was relatively small at Biggar, Unity, and Limerick, compared to Prince Albert and Indian Head where surface crop residues accounted for approximately 1 Mg C ha^{-1} for no-tillage (Table 1). The higher amount of surface residue C under no-till at Prince Albert and Indian Head may have resulted from higher crop productivity along with the environment that favored the formation of mulch layer on the surface of no-till soil. On the other hand, the formation of mulch layer on the surface of the no-till sites in the Dark Brown and Brown soil zones was less obvious. It should be recognized that the amount of surface residue-C under no-till is highly variable and dynamic, depending upon the type of crop grown, the yield and in particular upon amount of disturbance associated with the direct seeding operation. In a study of tillage on surface residue C, McConkey et al. measured annual changes in surface crop residues on three different-textured soils for more than 10 years at Swift Current, and found that the medium-textured soil under no-till accumulated more surface residue C than the coarse- or fine-textured soil, but the amount of surface residue C under no-tillage was mainly dependent of previous years of weather and crop yields (unpublished data). It should be noted that the accumulation of surface residue-C associated with no-tillage is important for erosion protection and C sequestration.

There were large differences in gains of soil organic C between no-till and conventional tillage not only between sites but within the landscape positions of the same site. Gains of soil organic C under no-till compared with conventional tillage varied from 1 to 16 Mg ha^{-1}, and from 0.1 to 1.4 Mg $ha^{-1}yr^{-1}$ for the various soil zones in Saskatchewan. It should be noted that these C gains were due to the combined effects of reduced tillage and less fallow, and to the extent that fallow was a part of crop rotations under conventional tillage. Unknown removal or redistribution of soil assumed to be greater on the conventionally tilled fields also affected the difference. In addition, since it is impossible to know in this study if soil conditions were similar prior to the implementation of the no-till regime for each site, we will not discuss the results for each site individually, but an overall impact of tillage on soil organic C with similar landscapes of all sites. Considering these inherent problems with these comparisons, the results were remarkably consistent. Average

C gains for all sites were 0.7 Mg $ha^{-1}yr^{-1}$ for the knoll, 0.5 Mg $ha^{-1}yr^{-1}$ for the mid-slope, and 0.6 Mg $ha^{-1}yr^{-1}$ for the lower slope and level. These values are generally comparable with the results obtained from research plots for the Dark Brown, Black and Gray soil zones, but higher than those obtained from research plots for the Brown soil zone (Liang et al., 1999a; McConkey et al., 1999).

Because of the differences in the duration of no-till and amounts of soil organic C presented in the soil under conventional tillage at the different landscape positions of each site, the relative annual increase in soil organic C due to no-till was calculated as the difference of the amount of soil organic C between no-tillage and conventional tillage divided by the amount of soil organic C under conventional tillage, and further divided by the number of years under no-tillage. The relative annual increase in soil organic C due to no-tillage varied from 0.2 to 5.7 % yr^{-1} among different sites and landscape positions (Table 2). On an average, the relative annual increase in soil organic C due to no-tillage was approximately 2 % yr^{-1} for the knoll and mid-slope positions, and 1.2 % yr^{-1} for the lower slope and level areas. This greater increase in soil organic C associated with the knoll and mid-slope positions compared with the lower slope and level under no-tillage may have due mainly to reduced erosion such as wind, water or tillage.

Conclusions

The accumulation of surface crop residue-C under no-tillage compared with conventional tillage was generally small for the drier regions of the prairies and up to approximately 1 Mg C ha^{-1} for the more moist regions of the prairies. The amount of "sequestered" soil organic C estimated under no-tillage along with continuous cropping compared to conventional tillage, using direct comparisons of neighboring farmer's fields across various soil zones and landscape positions in Saskatchewan, varied from 0.5 to 0.7 Mg C ha^{-1} yr^{-1} with a higher value associated with more eroded areas. The relative annual increase in soil organic C due to no-tillage was approximately 2% yr^{-1} for the more eroded areas such as knoll, and 1.2% yr^{-1} for the non-eroded area, indicating an additional benefit of conservation tillage in sequestering soil organic C on more eroded areas. In addition, the results obtained from this study were generally consistent with those of long-term research plots established on the Canadian prairies, suggesting that the extrapolation of results of carbon sequestration due to no-till from research plots to the real world is valid, provided that carbon sequestration resulting from reduced erosion under no-tillage should be accounted for.

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Table 1. Surface crop residue-C on various landscape positions as influenced by tillage systems

Location	Landscape position	Tillage[1]	
		CT	NT
		------------- Mg C ha^{-1} ---------	
Biggar	Knoll	0.63[a]	1.29[a]
	Lower slope	1.09[a]	1.35[a]
Unity	Knoll	0.68[a]	0.92[a]
	Level	1.38[a]	1.35[a]
Limerick	Knoll	0.96[a]	1.42[a]
	Lower slope	1.13[a]	1.23[a]
Indian Head	Knoll	0.68[b]	1.96[a]
	Level	1.22[b]	2.49[a]
Prince Albert	Knoll	0.96[b]	2.23[a]
	Level	0.58[b]	1.46[a]

[1] Means associated with different letters within the same row indicate statistical significance at $P=0.05$

Table 2. Amounts of soil organic C at various landscape positions of several Saskatchewan soils as influenced by tillage systems

Soil zones	Nearby town	Years of no-tillage	Landscape position	SOC		C gains		Relative annual increase in SOC due to no-tillage
				NT	CT			
				Mg C ha^{-1}		Mg C ha^{-1}	Mg C ha^{-1} yr^{-1}	% yr^{-1}
Brown	Kindersley	6	Knoll	19.9[a]	19.2[a]	0.7	0.1	0.6
			Mid-slope	22.9[a]	18.7[b]	4.2	0.7	3.7
			Lower slope	33.4[a]	32.8[a]	1.6	0.3	0.8
	Limerick	6	Knoll	32.7[a]	24.4[b]	8.3	1.4	5.7
			Mid-slope	39.1[a]	33.1[b]	6.0	1.0	3.0
Dark Brown	Biggar	7	Knoll	35.9[a]	28.1[b]	7.8	1.1	4.0
			Mid-slope	45.3[a]	43.8[a]	1.5	0.2	0.5
			Lower slope	64.1[a]	63.1[a]	1.0	0.1	0.2
	Perdue	10	Knoll	42.0[a]	37.6[a]	4.4	0.4	1.2
			Level	48.5[a]	41.4[b]	7.1	0.7	1.7
	Unity	4	Knoll	41.4[a]	38.4[a]	3.0	0.8	2.0
			Level	69.8[a]	69.0[a]	0.8	0.2	0.3
Black	Indian Head (I)	20	Knoll	61.8[a]	49.8[b]	12.0	0.6	1.2
			Level	73.5[a]	57.3[b]	16.2	0.8	1.4
	Indian Head (II)	13	Knoll	55.1[a]	49.8[a]	5.3	0.4	0.8
			Level	65.2[a]	57.3[b]	7.9	0.8	1.1
Gray	Prince Albert	7	Knoll	42.2[a]	40.3[a]	1.9	0.3	0.7
			Level	42.0[a]	36.6[b]	5.4	0.8	2.1
	Arbofield	9	Knoll	58.9[a]	46.6[b]	12.3	1.4	2.9
			Mid-slope	53.0[a]	49.5[b]	3.5	0.4	0.8
			Lower slope	58.3[a]	49.6[b]	8.7	1.0	2.0

For each site different letters associated with CT and NT within the same landscape position indicate significant difference at *$P<0.05$*