EROSION AND CULTIVATION EFFECTS ON THE LOSS OF ORGANIC MATTER FROM PRAIRIE SOILS

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The deterioration of the quality of cultivated soils in Western Canada due to organic matter loss and erosion has been a concern since the early days of agriculture in this region. There have been several studies that essentially agree with the tabulations of McGill et al. (1981) that the organic matter content of many of our soils has been reduced by 50% with cultivation. There is, however, only limited information on the relative contribution of erosion and mineralization to the decline in organic matter, to the magnitude of losses on an amount (weight per unit area), or the redistribution or displacement of soil and organic matter by erosion. The objective of this study was to use a landscape or soil catena approach to study the effect of cultivation on the organic matter content and degree of erosion of Saskatchewan soils.

MATERIALS AND METHODS

This study include 17 sites in the different soil zones, with each site consisting of a cultivated hillslope or catena, and a control or native catena as nearly similar to the cultivated catena as possible. Data from three sites will be presented in detail, with an overall summary describing the organic matter status of all sites. A more detailed report is available from the Saskatchewan Institute of Pedology (Anderson et al., 1985). The three detailed sites include:

ASSINIBOIA.... in the Brown zone, with Haverhill soils on loam-textured glacial till. Relatively short slopes were compared. The native catena was 12 m long with a slope of 7%; the cultivated catena was 18 m long with a slope of 12%.

HEPBURN.... in the Black soil zone, with Oxbow soils on loam-textured glacial till. The native catena was 24 m long with a 7% slope; the cultivated catena was 27.5 m long with a 7% slope.

MIDDLE LAKE.... in the Gray soil zone, with Meeting Lake (Waitville-like) soils on loam-textured glacial till. The native and cultivated catenas were both 50 m long with slopes of 6%.

Sites were sampled on a hillslope or catena basis, with individual sample locations spaced equally from the crest of the slope to the lowest point in the hillslope system, usually a local depression. Five or six locations were sampled on each catena. Three replicate cores of A and B horizons were taken with a sampler of known volume. After drying, these samples were weighed and bulk density calculated. The three replicates for each horizon were combined, and a representative sample taken for cesium-137 and organic C analyses.

Organic C analyses were by dry combustion (Tiessen et al., 1981). Cesium analyses utilized the facilities at the Saskatchewan Institute of Pedology (de Jong et al., 1982).

RESULTS

The native catena at the Assiniboia site has a typical downslope increase in Ah and solum (Ah + Bm) depths, and in concentration and amount of organic C (Table 1). These downslope trends are magnified on the cultivated catena, primarily because of downslope displacement of soil by erosion and cultivation. Organic C contents are about 50% less in Ap horizons than in native Ah horizons, and bulk density values are 1.30 to 1.40 in the Ap's, compared to about 1.0 in the Ah horizons. On a weight basis, organic C is much reduced in the upper slope, where solum depth is much less than on the native catena. These soil and organic C losses from upper slopes are generally balanced by gains in lower slopes, although some of these data indicate that detailed comparisons for each slope position should not be made, because of slight differences in the shape of the slope. Erosion losses and displacement by cultivation from the crest and upper slopes are estimated at 48 and 56 kg/m², respectively. This is an average erosion rate of about 20 t/ha/yr.

The Hepburn site in the Black zone shows the typical downslope increase in solum depth and organic C on the native catena (Table 3). The cultivated catena generally has about 50% less organic C in Ap horizons than Ah horizons of comparable slope positions. Bulk density values are similar, probably because of the difficulty in obtaining good estimates of the bulk density of Ap horizons. On a weight per unit area basis, marked losses of organic C from upper slope (convex) areas, coupled with a gain in the depression at the bottom of the slope indicate substantial downslope

Table 1. Characteristics of soils at the Assiniboia site.

Slope position	Horizon thickness (cm)	Bulk density g/cm³	Organic C %	Organic C in solum t/ha	Estimated soil loss since 1960 kg/m²
		Haverhill loam, native			
Crest	Ah, 0-7	1.02	2.0	59.8	
	Bm, 7-23	1.31	2.1		
Upper	Ah, 0-9	1.08	3.3	60.6	
	Bm, 9-23	1.21	1.7		
Mid	Ah, 0-11	1.05	3.2	62.7	
	Bm, 11-23	1.21	1.8		
Lower	Ah, 0-14	0.96	3.7	71.1	
	Bm, 14-32	1.30	0.9		
Depression	Ah, 0-13	0.90	4.0	90.7	
	Bm, 13-36	1.44	1.3		
		Haverhill loam, cultivated			
Crest	Ap, 0-7	1.38	1.2	12.1	48
Upper	Ap, 0-10	1.30	1.2	44.8	56
	Bm, 10-37	1.40	0.8		
Mid	Ap, 0-15	1.40	2.0	81.6	12
	Bm, 15-51	1.30	0.8		
Lower	Ap, 0-22	1.35	2.2	153.9	Gain
	B, 22-100	1.22	0.9		
Depression	Ap, 0-27	1.32	2.3	177.6	Gain
	B, 27-100	1.16	1.2		

Table 2. Characteristics of soils at the Hepburn site.

Slope position	Horizon thickness (cm)	Bulk density g/cm³	Organic C %	Organic C in solum t/ha	Estimated soil loss since 1960 kg/m²
		Oxbow, native			
Crest	Ah, 0-15	1.27	3.7	70.2	
Upper	Ah, 0-18	0.95	4.6	78.2	
Middle	Ah, 0-28	1.15	3.8	128.8	
	Bm, 28-37	1.40	0.9		
Lower-Mid	Ah, 0-18	1.08	5.9	138.9	
	Bm, 18-37	1.15	1.1		
Lower	Ah, 0-15	1.20	4.9	113.4	
	Bm, 15-23	1.34	1.1		
Depression	Ah, 0-10	0.92	7.2	93.9	
	Bt, 10-46	1.42	0.5		
		Oxbow, cultivated			
Crest	Ap, 0-8	1.26	2.5	25.6	75
Upper	Ap, 0-8	1.15	2.3	21.5	71
Middle	Ap, 0-13	0.89	3.5	101.8	48
	Bm, 13-48	1.28	1.4		
Lower-Mid	Ap, 0-12	1.07	4.1	85.2	6
	Bm, 12-37	1.32	1.0		
Lower	Ap, 0-18	0.97	2.7	96.3	Gain
	B, 18-87	1.68	0.4		
Depression	Ap, 0-25	1.29	3.1	191.7	
	B, 25-100	1.53	0.8		

displacement of soil and organic matter. Losses from convex parts of the cultivated hillslope are estimated at 25 to 30 t/ha/yr, with gains in the toe slope and depression.

The Middle Lake site has Gray Luvisol soils and involves a comparison of a field cultivated for 40 to 50 years with native aspen forest. Well mixed samples of the 0-15 cm depths in the native catena (LH-Ah-Ae horizons) indicate organic C contents of 2.2 to more than 5%, and total amounts on a 0-30 cm depth basis of 50 to 80 t/ha. The cultivated catena has markedly less organic C, with concentrations down about 75%, and total amounts reduced by about one-third. In these soils with relatively thick Ap horizons and high bulk densities (1.3 to 1.5 g/cm^3), low organic C concentrations do not indicate low total amounts of organic C. Losses by erosion are primarily from the crest of the slope.

Our study of three sites in the Gray zone indicates that there is considerable variation in present day organic C levels in these soils. We think this is mostly a consequence of the manner in which the land was broken and management since cultivation began. Gray soils appear particularly sensitive to management. It was also evident that organic C contents and total amounts of organic C in cultivated Gray soils are often as high or higher than in Brown or Dark Brown soils, even though soil structural problems are most common in the Gray zone. This suggests that the qualitative nature of the organic matter, soil properties such as the high silt content of Gray soils, and particular weather conditions contribute to the poor tilth of Gray soils.

CONCLUDING DISCUSSION

An overall summary of the data from all 17 sites (Table 4) indicates that our sites generally fit in with well-known ideas about organic matter in the soil zones, along catenas and the effects of cultivation. Organic C increases in the Brown to Thick Black sequence, decreasing again in the Gray zone. Unusually high organic C levels in the native Dark Brown soils reflects the sampling of thin Ah horizons from prairie sites that appear to have been neither grazed nor burned for several decades. Organic C contents of cultivated soils are consistently about 50% of comparable native soils, in agreement with earlier estimates (Rennie and Ellis, 1978). On a total amount basis, our data indicate substantial losses from convex (upper and some mid-slopes) areas, coupled with gains in lower slope or concave areas. Overall, this study showed that organic matter losses are a serious problem, in that contents are down in Ap horizons to the extent that they are adversely affecting nutrient supplying capability and, in some cases, soil tilth. However, much of the lost organic matter has been displaced from convex parts of landscapes to concave or lower slope areas. Erosion and displacement by cultivation are probably responsible for the downslope movement of soil.

Many individual sites where cesium content indicated a gain of soil had low organic C contents in Ap horizons, and low total amounts of organic C on a weight basis. This indicates that losses by mineralization from lower slope soils are substantial. Estimates based on a similar but more detailed study (Gregorich and Anderson, 1985) indicated organic C losses by mineralization of 1 to 1.5 t/ha/yr on lower slopes, compared to about 0.5 t/ha/yr on upper slopes. Lower slopes have more organic C to lose, and the moist environment to promote microbial activity, particularly during summerfallow periods when soil temperatures are also increased because of the absence of a plant cover.

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Table 3. Characteristics of soils at the Middle Lake site.

Slope position	Horizon thickness (cm)		Bulk density g/cm³	Organic C %	Organic C in solum t/ha	Estimated soil loss since 1960 kg/m²
			Meeting Lake, native			
Crest	L-H,Ae	0-15	0.97	2.2	56.4	
	Ae-Bt	15-30				
Upper	LH-Ae	0-15	0.76	4.1	73.1	
	Ae-Bt	15-30				
Middle	LH-Ae	0-15	0.85	2.5	50.5	
	Ae-Bt	15-30				
Lower	LH-Ae	0-15	0.61	5.3	63.4	
	Ae	15-30				
Toe	LH-Ae	0-15	0.75	4.7	79.1	
	Ae	15-30				
			Meeting Lake, cultivated			
Crest	Ap	0-4	1.5	0.8	--	159
		4-30				
Upper	Ap	0-15	1.5	1.2	40.6	Gain
	Ap-Bt	15-30				
Middle	Ap	0-15	1.3	1.5	39.4	Gain
	Bt	15-30				
Lower	Ap	0-15	1.3	1.3	34.6	Gain
	Bt	15-30				
Toe	Ap	0-15	1.3	1.9	52.3	Gain
		15-30				

Table 4 A horizon depth, bulk density and concentration and amount of organic carbon (mean ± S.D.) in native and cultivated catenas in the different soil zones.

BROWN SOILS

Field	Slope area	A horizon depth (cm)	A horizon Org. C (mg/g)	A horizon B.D. (g/cm^3)	A horizon Org. C (Mg/ha)	Solum Org. C (Mg/ha)
Native	upper	9±4	27±10	1.23±0.45	25±7	47±14
	mid	12±5	29±14	1.07±0.07	33±9	82±17
	lower	14±4	42±14	0.95±0.16	53±10	158±51
Cult.	upper	10±5	14±2	1.29±0.10	18±6	23±12
	mid	15±3	17±6	1.30±0.12	34±17	89±56
	lower	32±10	25±7	1.20±0.12	94±45	188±49

DARK BROWN SOILS

Field	Slope area	A horizon depth (cm)	A horizon Org. C (mg/g)	A horizon B.D. (g/cm^3)	A horizon Org. C (Mg/ha)	Solum Org. C (Mg/ha)
Native	upper	7±4	63±26	1.00±0.17	43±28	85±47
	mid	10±3	49±15	1.02±0.10	46±15	87±34
	lower	13±4	50±18	0.99±0.13	60±15	129±73
Cult.	upper	9±3	17±5	1.25±0.11	20±9	25±14
	mid	11±4	18±5	1.36±0.27	28±15	50±46
	lower	20±9	22±7	1.22±0.12	53±20	98±40

BLACK SOILS

Field	Slope area	A horizon depth (cm)	A horizon Org. C (mg/g)	A horizon B.D. (g/cm^3)	A horizon Org. C (Mg/ha)	Solum Org. C (Mg/ha)
Native	upper	15±8	46±7	1.00±0.18	64±25	78±29
	mid	21±11	44±12	1.02±0.14	82±28	129±28
	lower	19±13	49±11	1.05±0.11	100±32	149±42
Cult.	upper	11±6	22±9	1.21±0.14	32±29	46±59
	mid	17±14	29±9	1.22±0.29	60±54	99±63
	lower	29±12	31±8	1.19±0.15	108±60	164±60

THICK BLACK SOILS

Field	Slope area	A horizon depth (cm)	A horizon Org. C (mg/g)	A horizon B.D. (g/cm^3)	A horizon Org. C (Mg/ha)*	Solum Org. C (Mg/ha)**
Native	upper	34±6	67±22	0.76±0.16	73±10	136±33
	mid	43±4	60±22	0.85±0.31	71±0	125±18
	lower	69±25	74±25	0.75±0.11	81±19	163±38
Cult.	upper	28±10	42±6	1.14±0.03	71±12	95±25
	mid	27±4	43±17	1.12±0.03	72±27	106±44
	lower	55±24	54±16	1.09±0.09	87±18	136±64

LUVISOLIC SOILS

Field	Slope area	A horizon depth (cm)	A horizon Org. C (mg/g)	A horizon B.D. (g/cm^3)	A horizon Org. C (Mg/ha)*	Solum Org. C (Mg/ha)**
Native	upper	19±6	42±15	0.79±0.16	47±8	69±8
	mid	24±11	32±6	0.82±0.06	39±6	65±19
	lower	26±11	62±36	0.68±0.14	57±16	79±22
Cult.	upper	15±6	17±8	1.35±0.15	32±12	53±19
	mid	20±9	24±16	1.27±0.12	45±25	62±35
	lower	27±14	26±17	1.22±0.17	45±22	60±26

upper = crest and upper slope positions

mid = middle slope positions

lower = lower, toe and depression slope positions

* denotes 0-15 cm depth; ** denotes 0-30 cm depth