SOIL QUALITY PROGRAM
RESEARCH FACTSHEET CSQ02

CAESA

Effects of Long-term Cultivation on a Morainal Landscape

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Problem

Agriculture and Agri-Food Canada established a benchmark site network in the early 1990s to monitor soil quality change over time on reference agricultural landscapes. This approach assumes that monitoring selected soil variables for 10 or more years will show changes in soil conditions. An alternative approach is to compare cultivated and uncultivated (native) soils in a landscape. This approach requires less research time and provides an estimate of changes in soil characteristics over the entire cultivation period. Opportunities for such research are rare in the agricultural parts of western Canada. An opportunity presented itself in conjunction with work at the Provost (05-AB) benchmark site. A parcel of native land only 1.6 km away was studied and sampled using the same methodology. The similarity of the two sites provided an opportunity to examine soil attributes that approximated conditions prior to cultivation, and, by comparison, to assess changes brought about by 80 years of cultivation.

Literature Review

The impact of soil erosion on soil quality has been investigated using long-term cropping system studies[1,2,7] and retrospective views of management-induced soil changes by comparing cultivated with uncultivated soils in the same landscape[6,7]. Differences in organic C content are commonly studied in both approaches. Analysis of cesium-137 (^{137}Cs) redistribution in landscapes is a tool that can be used to estimate erosion rates[3,4,6,8,9,10] in either approach.

Study Description

The Provost benchmark site was set up in 1990[11]. A parcel of uncultivated land located 1.6 km from the benchmark site was characterized and sampled in 1991, using the same methodology[5,11,13].

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Site characterization, sampling design, sample collection and preparation, and analytical methods have been described previously[11,13]. A stratified random sampling design using transects[12] was used to measure variability along a slope from crest to depression. Topsoil and subsoil samples were collected at each sampling point (10-m interval) along each transect. The cultivated site had nine transects with 64 sampling points, and the native site had seven transects with 61 sampling points. Thickness of topsoil, organic C content, and ^{137}Cs activity, all analyzed according to slope position, are featured here.

Cesium-137, from radioactive fallout deposited mainly in the mid-1960s, was used as a tracer to estimate soil movement[3,8,10]. Cesium-137 isotope activity was converted from a weight to an area expression (Bq/m^2) using bulk density and sample depth. (A becquerel (Bq) is the unit of activity of a radioactive source and is defined as one disintegration per second.) Soil redistribution in the cultivated landscape was estimated using the average ^{137}Cs level at the native site (1704 Bq/m^2) as a baseline value to separate erosion from deposition (^{137}Cs depletion vs enrichment)[10]. Net soil erosion rates for the cultivated site were estimated with a model based on the relationship between annual erosion rate and the fraction of ^{137}Cs remaining relative to the number of years of erosion[9]. Modifications to the model account for tillage dilution by mixing of subsoil into the Ap horizon[8] and for increasing thickness in the total A horizon due to deposition[4].

Major Findings

Site Description

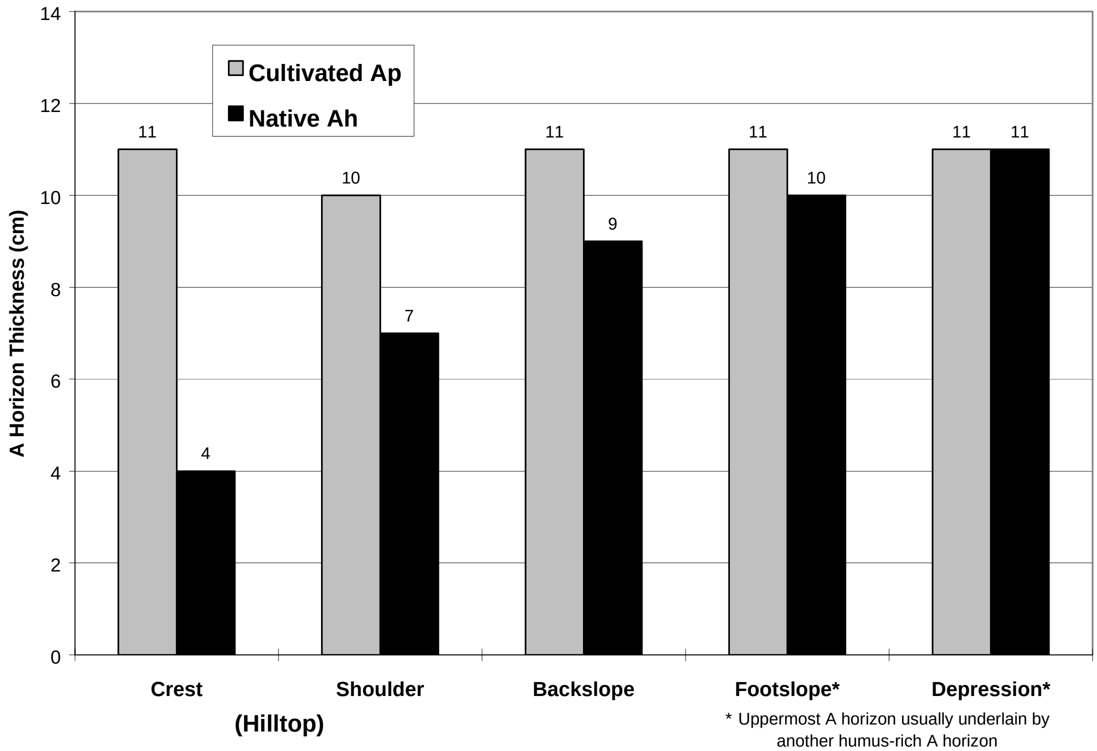
Both sites occur on hummocky to undulating moraine. A veneer of loam textured, waterlaid material caps the clay loam - loam textured till, mostly on lower parts of the terrain. Backslope soils are mainly Orthic Dark Brown Chernozems grading to “eroded” or thin soils on hilltops and Humic Luvic Gleysols in depressions.

The native site was grazed “fairly heavily” (in the words of owner Bill Carter) for about 60 years from 1906, lightly for another decade, not at all since the late 1980s. The cultivated site has been cropped since 1912, primarily in a fallow-wheat rotation. Tillage was mainly by plow until about 1950 and by deep-tillage cultivator since then.

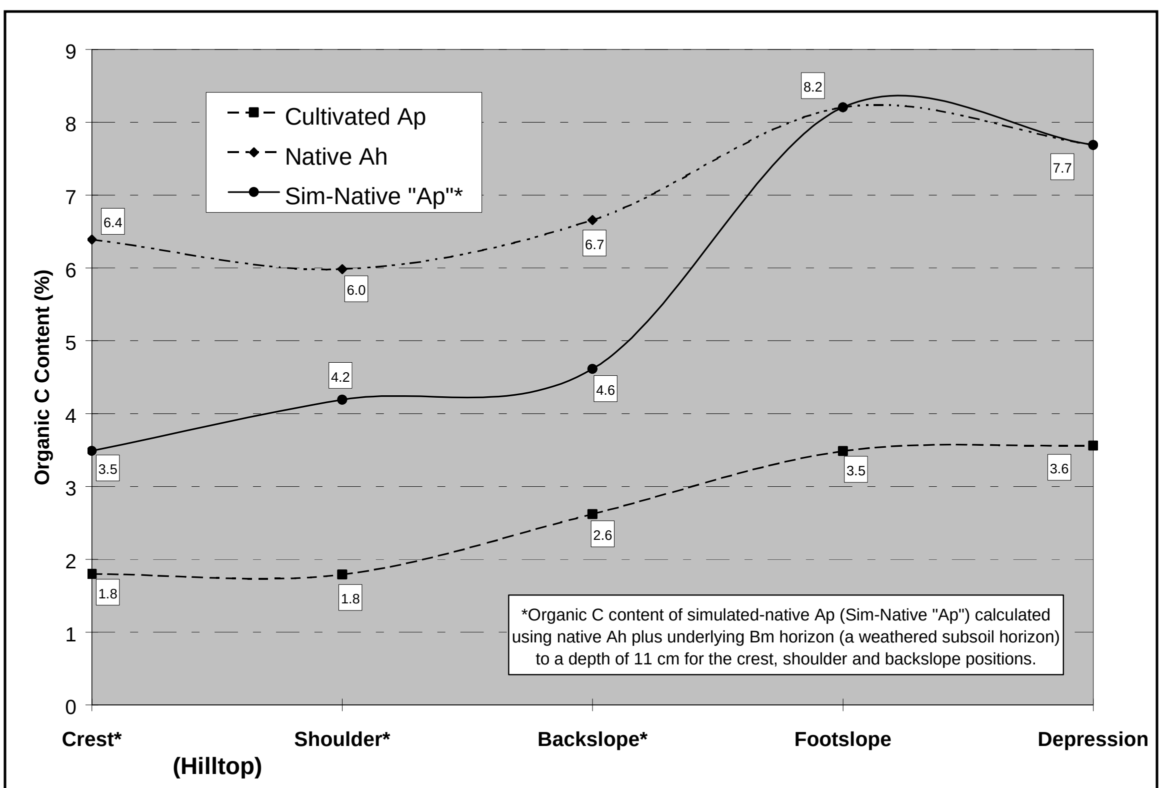
A Horizon (Topsoil) Type and Thickness

One of the most striking differences between the sites is the type and thickness of the uppermost soil horizon. The surface horizon at the cultivated site is mainly Apk (plow layer with calcium carbonates) on hilltops and Ap (plow layer) on backslopes to depressions. Thickness of the plow layer is quite uniform (Figure 1).

An Ah horizon (topsoil enriched with organic matter) of highly variable thickness (Figure 1) dominates the native site. It has significantly more organic C than the Ap (Figure 2). To compare C content in layers of equal thickness, a “simulated plow layer” (simulated Ap) to a total depth of 11 cm was calculated for crest, shoulder and backslope positions at the native site. Bulk density and relative thickness of each layer making up the simulated Ap were used in the calculation. This process also estimated the dilution effect of the subsoil on the organic C content of the “initial” plow layer.



Losses of Soil Organic C and Erosion Rates



sites

The difference in organic C content between the native and cultivated sites is much greater than differences among slope positions within each site (Figure 2). Cultivated Ap horizons have roughly one-third the organic C content of native Ah horizons. A fairer comparison should include the simulated plow layer which estimates the condition of the first Ap in 1912. Results for the simulated Ap (Sim-Native, Figure 2) suggest that the initial Ap horizon on hilltops and backslopes had about half the organic C content of the native Ah due to dilution by the underlying subsoil. So, roughly half the organic C of the initial Ap was lost, when compared to the 1990 cultivated Ap, on these same slope positions (Figure 2).

The initial dilution of soil C is in fact only an apparent loss because the same mass of organic matter was still in the soil system. But as cultivation and cropping continued, processes of erosion and mineralization became important. With the loss of topsoil at a hilltop site, dilution no doubt continued.

Erosion, which includes the downslope movement of soil by cultivation as well as losses by wind and water, was calculated as net soil erosion rate (En, Table 1). Values were greatest on hilltops (crest plus shoulder). Somewhere along the backslopes, deposition from upslope areas became greater than erosion, resulting in net deposition. This likely resulted in another type of dilution that this study did not address – the deposition of upslope material lower in organic C than the material it covered.

Table 1. Estimated organic C losses and net erosion rates on an average toposequence at the cultivated site

Slope position[a]	Perceived C loss (Ah minus Ap) ($kg\ C/m^2$)[b]	Percent[c] of perceived C loss due to:			En (erosion rate) (t/ha/yr)[g]
		tillage dilution[d]	erosion[e]	mineralization[f]	
Crest	4.2	46	61	0	19
Shoulder	3.5	27	58	15	11

Erosional	3.4		30	36	6
Backslope		38			
Depositional	3.0		0	61	-30
Footslope	3.5	0	0	100	-32
Depression	3.0	0	0	100	-43

a The backslope position is most extensive and transitional from erosional hilltops to depositional lower slopes. Backslope sampling points were therefore placed in either erosional or depositional segments based on their individual En values.
b Refers to the difference in organic C (as kg C/m^2) between the native Ah and cultivated Ap, irrespective of thickness.
c The sum of the percentages should be close to but may not equal 100%, and provides a check on the calculations. In this study, erosion may be slightly overestimated in some cases, causing the sum of percentages to exceed 100%.
d Refers to the estimated initial dilution of organic C by mixing of a thin, native, Ah horizon high in organic matter with underlying subsoil much lower in organic matter. This is only an apparent loss since the same mass of organic C is present, but now in a new "Ap" horizon that is thicker than the original Ah. This type of dilution occurred only where the Ah was thin.
e Refers to loss or redistribution of soil material by wind, water and mechanical (tillage) erosion. Calculated in terms of organic C lost in eroded material (En) over 78 years, and expressed as a percentage of the perceived C loss.
f Refers to loss of organic C as atmospheric CO_2 through decomposition of organic matter. Calculated as the remainder, assuming all C losses add up to 100%.
g En = net soil erosion rate (t/ha/yr) calculated from ^{137}Cs data. Positive values mean net erosion, negative values net deposition.

There was no direct way, with our data set, to calculate mineralization. So, it was estimated as the remainder, assuming that values for the three processes (dilution + erosion + mineralization) total 100%. Note that dilution plus erosion for the crest soils totals 107%. We feel that erosion has been slightly overestimated using the ^{137}Cs methodology.

Applied Questions

Do we have to make measurements to show the impact of intensive cultivation or can the effects be seen in some fields?

Cultivation and soil movements have commonly left a visual imprint on hilly landscapes in the Prairie region. Hilltops (knolls) in the cultivated site are clearly visible, when in fallow, by their grayish colours in contrast to darker soils on adjacent slopes. The grayish colours also identify the soils with the lowest organic C content. But the data show that there is lower C content throughout the cultivated landscape (Figure 2).

How did the soil change over time?

The first plowing undoubtedly had a significant impact on the hilltop and many backslope soils in this landscape. Even shallow plowing depths of 3 to 4 inches (personal communication from farmer Bill Carter) probably mixed the native Ah horizon with some of the underlying B horizon at many locations. Carbon, nitrogen and nutrients would have been diluted in the first Ap horizon. This trend likely continued over the ensuing decades, especially with the advent of tractor power and the deep-tillage cultivator, and was probably intensified by erosion and mineralization processes. Within several years, the new Ap horizon likely began to include calcareous C-horizon material in places.

Which type of erosion is most important in this landscape?

According to the landowners, episodes of wind and water erosion have occurred from time to time. But there seems insufficient evidence to suggest that these could account for the relatively high erosion rates determined for the site. Cesium-137 data allow estimates of total movement, and do not differentiate among wind, water and tillage processes. Therefore, in the opinion of the researchers, the mechanical action of tillage implements is the major cause of soil erosion at this site.

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