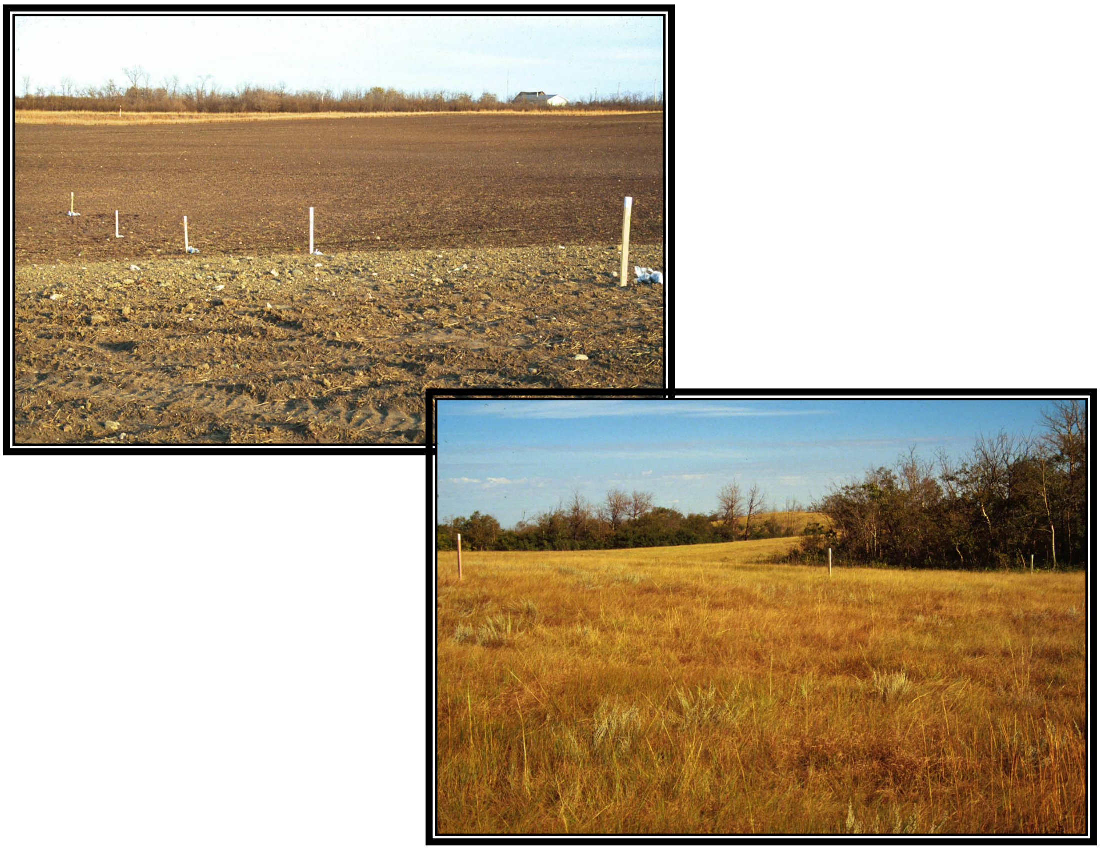
Soil Quality Evaluation Program

Comparison of Cultivated and Native Soils in a Morainal Landscape in East Central Alberta



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COMPARISON OF CULTIVATED AND NATIVE SOILS IN A MORAINAL LANDSCAPE IN EAST CENTRAL ALBERTA

BENCHMARK SITE COMPARISON REPORT

05-AB vs. 55-AB (PROVOST, ALBERTA)

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PROVOST BENCHMARK SITE COMPARISON STUDY

INTRODUCTION

The Soil Quality Benchmark Site Study was adopted as part of the National Soil Conservation Program, in 1990, to monitor soil quality change in agricultural areas across Canada. The study became part of the Soil Quality Evaluation Program (Acton 1994) managed by Agriculture and Agri-Food Canada's Centre for Land and Biological Resources Research (CLBRR).

By 1992, twenty-three benchmark monitoring sites, representative of several major agro-ecosystems and agricultural landscapes in Canada, were established (Wang *et al.* 1994).

Several land, soil and air characteristics are being monitored regularly at these sites for at least a 10-year period. Monitoring of the benchmark sites serves the dual purpose of:

1. establishing baseline data sets for soil quality assessment, and

2. enabling researchers to monitor changes in soil quality over time.

The sites may also be used for testing and validation of mechanistic models and for the development of integrated research projects (Wang *et al.* 1994).

The Provost Benchmark Site, coded 05-AB, was established in September, 1990. The selection of the site was based on a number of criteria that were met at its east central Alberta location (Walker and Wang 1994). Primarily, the site is representative of the northern Dark Brown soil zone under the Prairie - Parkland Transition Ecoregion. Its undulating to hummocky glacial terrain, composed mainly of medium textured till, is a common landscape in this region. Further, the site was managed under a wheat – oilseed or barley – fallow rotation with conventional tillage, a widespread cropping practice in the area for decades (Walker and Wang 1994). Parts of the landscape showed signs of soil degradation, a feature also common to such terrain throughout the Prairies.

The occurrence of similar but uncultivated land only one km away was a compelling feature that ensured choosing the Provost Benchmark Site. Opportunity to compare the two sites awaited only financial support.

The Canada-Alberta Agreement on Environmental Sustainability Initiative (ESI) helped turn the opportunity into reality. This short-term (one year) program enabled the agri-food industry to evaluate resource management in terms of environmental issues. With ESI support, the native site was characterized and sampled using the same methodology as for the cultivated benchmark site.

The native site (coded 55-AB) was characterized and sampled in 1991 and 1992. Fieldwork and preliminary analysis of early results were undertaken by Land Resources Network Ltd., Edmonton, AB[1]. Laboratory analyses were performed by the soil laboratories of the Alberta Research Council, Edmonton, and the Centre for Land and Biological Resources Research, Ottawa, ON. Cesium^{137} tracer analysis was conducted by the Department of Land Resource Science, University of Guelph, ON.

Results from these measurements were analyzed to assess changes in soil characteristics attributed to nearly 80 years of cultivation. In particular, a picture of soil redistribution within the complex landscape emerged, and provided some clues as to changes in soil quality.

OBJECTIVES

The primary purpose of this study was to examine the effects of 80 years of cultivation on a morainal landscape in east central Alberta. Specific objectives were to:

1. determine the relationship between landscape position and erosion on cultivated slopes in complex terrain;

2. examine the influence of landscape position on selected soil properties thought to be indicators of changes in soil quality; and

3. evaluate the overall effects of long-term cultivation on slope processes and soil quality in this landscape and region.

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[1] Finlayson, N.M. 1992. Provost Benchmark Site – Native Site monitoring. Unpublished draft report for Agriculture Canada. Land Resources Network Ltd., Edmonton, AB. 21 pp.

SITE DESCRIPTION AND HISTORY

SITE LOCATION

The Provost Benchmark and Native sites are located in east central Alberta, about 300 km southeast of Edmonton, and 8-10 km from the Saskatchewan border. From Provost, the sites can be reached by traveling 10 km east, along Highway No. 13, to the village of Hayter, and about 8 km north along a gravel road. Figure 1 shows their locations in the area and their proximity. Geographic coordinates are as follows:

Benchmark (or "cultivated") Site: LSD 8, SE quarter of Section 7, Township 40, Range 1, west of the 4th Meridian; approximately 52°25′35″ N latitude and 110°07′35″ W longitude; UTM coordinates Zone 12, Northing 5808781.38 m, Easting 559403.13 m (corrected from Walker and Wang 1994); elevation about 677 m ASL.

Native (or "native") Site: LSD 3-4, SW quarter of Section 18, Township 40, Range 1, west of the 4th Meridian; approximately 52°26′08″ N latitude and 110°08′39″ W longitude; UTM coordinates Zone 12, Northing 5809826.07 m, Easting 558187.34 m; elevation about 689 m ASL.

ECOLOGY AND CLIMATE

The Provost sites occur in the southern fringe of the Aspen Parkland Ecoregion, within the Prairies Ecozone (ESWG 1995). The general climate is marked by short, warm summers and long, cold winters with continuous snow cover. The nearest long-term climate station, located at Macklin, SK (52°20′N 109°57′W), has a mean annual temperature of 1.7°C (from AES N.d. normals as tabulated in Walker and Wang 1994). The mean summer temperature is 15.0°C and mean winter temperature is -12.5°C. The moisture regime is semiarid; mean annual precipitation is 394 mm, and is characterized by a distinct summer maximum.

From an agro-ecological perspective, the sites are located in Agroecological Resource Area (ARA) I1, Provost (Pettapiece 1989). The agro-climate is classed as 2AH, which signifies slight moisture and heat limitations for spring-seeded small grains (AIWG 1995). Selected climate indices, computed from climate normals (AES N.d.) and generalized for the ARA (Kirkwood *et al.* 1993), are:

- Seasonal growing degree days >5 °C: 1419.
- Growing season start (date that mean daily air temp. is ≥5 °C in spring): Apr. 21.
- Growing season end (date that mean daily air temperature is ≤5 °C in fall): Oct. 14.
- Potential evapotranspiration: 630 mm annually with over 80% occurring in May through August.

Ecologically, the area is transitional between the drier treeless grassland to the south and aspen-dominated parkland to the north. It was once aptly termed "aspen groveland" (Strong and Leggat 1981). The native site is typical of the groveland area as described by Strong (1992). Grassland plant communities are dominant and associated with the driest segments of the landscape. Groves of aspen (*Populus tremuloides*) occur in moister sites such as shallow depressions, north-facing slopes, creek banks, and seepage sites, and account for about 15% of the land cover. Upland shrub communities, developed in localities where snow commonly accumulates, account for another 10-15% cover. Slough-like depressions, usually ringed with willows and dominated by wetland vegetation such as sedges, account for another 15% of the land cover. Although they rarely contain permanent water, many of the largest and wettest depressions remain uncultivated in surrounding fields. The Dark Brown soil group is characteristic of the area (ALRU 1995); Black and Gleysolic soils are also common.

Native landscapes like the one described here are rare in this region. The vast majority of the land has been cultivated for several decades; native vegetation has been replaced with cereal and oilseed crops.

Wind is likely an important part of the regional climate, based on data from AES climate stations at Coronation A, AB, and Scott CDA, SK (AES 1993). Mean yearly wind speeds are 16 and 14 km/h respectively, with very little variation month to month. The most frequent direction is NW. Extreme hourly wind speeds are often in the 60 to 80 km/h range with no clear seasonal patterns. Extreme gust speeds of 100 km/h or more were recorded in six of 12 months during the 1944-90 measurement period at Coronation A.

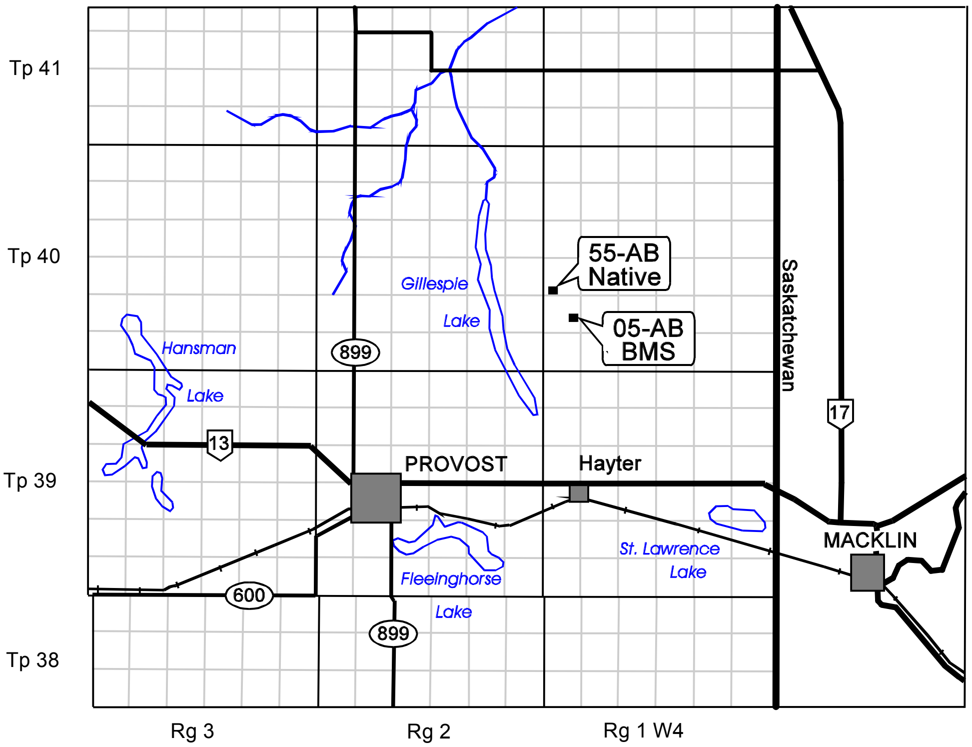

Figure 1. Location of the cultivated benchmark (05-AB) and native (55-AB) sites in east central Alberta.

TERRAIN DESCRIPTION

The Provost sites are located on the Provost Upland District, one of several upland areas found in eastern Alberta and western Saskatchewan (Acton *et al.* 1960, Pettapiece 1986). Like most of these uplands, the terrain is characterized by undulating to hummocky moraine dotted with small wetland depressions. The Provost Upland is situated within the Neutral Hills Uplands Section of the Eastern Alberta Plains Region (Pettapiece 1986).

The undulating to hummocky moraine of both sites has distinct internal relief. The contour maps (Fig. 2 and 3) show this complex terrain in plan view. The hillier parts, or hummocks, have complex slope patterns, mostly of class 3 and 4 topography (ECSS 1987b) at the cultivated site, class 4 topography at the native site. A few hummocks at both sites have steep sides with class 5 to 6 slopes. Hilltops commonly have class 2 to 3 slopes. Lower lying areas usually have level to very gentle slopes, mostly of class 2 to 3 topography. Bowl-shaped wetland depressions with surprisingly sharp steep margins are common.

Topography at the native site is a bit steeper and rougher than at the cultivated site. However, slopes at the native site tend to be a bit longer, leaving an impression that the terrain is very similar. Also, the long-term cultivation at the 05-AB site has likely smoothed the terrain. Averages derived from transect point location data show that the overall slope gradient is 3% steeper, local relief is 1.3m greater, and slope length is 15m longer at the native site (refer to Fig. 6).

The moraine is composed of moderately calcareous, CL-L textured, continental till. Underlying and principal source bedrock is the nonmarine Belly River Formation, which consists of sandstone, siltstone and mudstone (Green 1972). Salinity in upper till layers is minimal (E.C. <1 dS m^{-1}). Weakly saline subsoil (E.C. about 4 dS m^{-1}) was found at a few sampling points. A thin (<1 m) discontinuous capping of SiL-L textured, local slopewash or glaciolacustrine sediment covers the till. It is nearly continuous in the level to gently sloping, low lying segments of the landscape, less extensive on the hummocky parts.

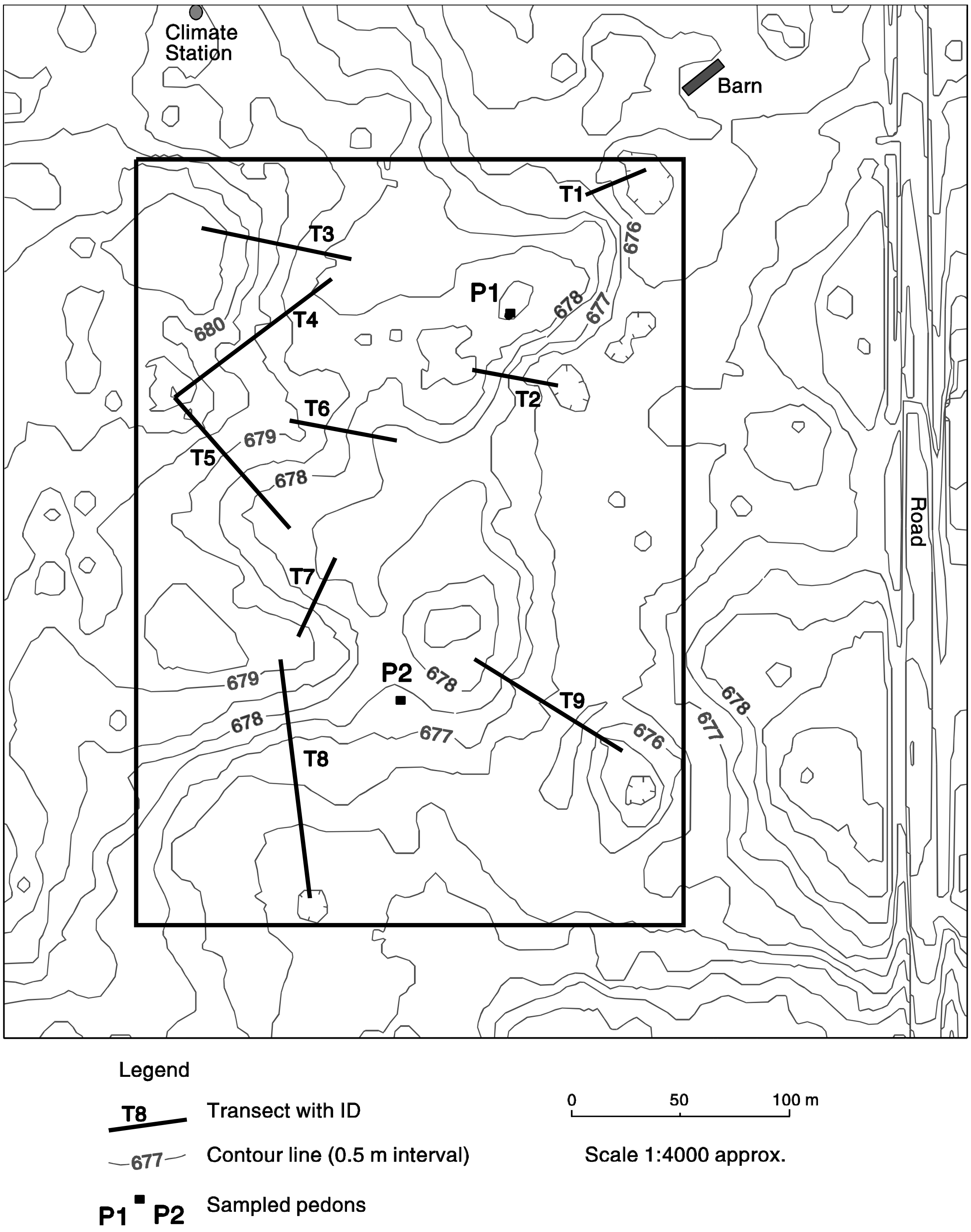

Figure 2. Contour map of the cultivated benchmark site, with transect and pedon locations.

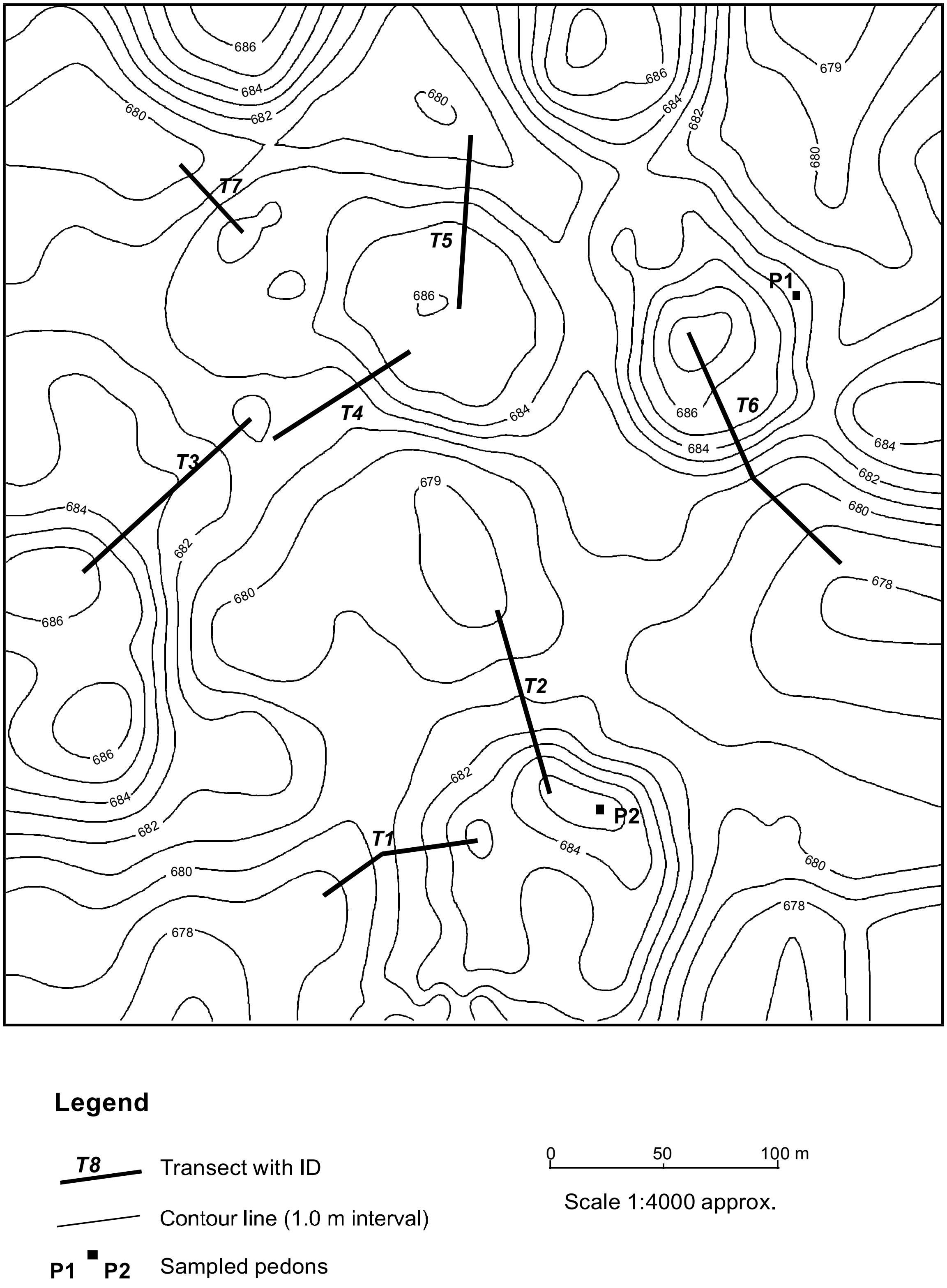

Figure 3. Contour map of the native site with transect and pedon sampling locations.

GENERAL SOIL PATTERNS

The following discussion provides a generalized, terrain-oriented description of the soil distribution. For more detail, refer to Figures 4 and 5 that show the complex soil patterns of the cultivated and native sites, respectively. Mapping units that describe the soil patterns are listed in adjoining legends. All sampling points are listed, with landscape and soil features, in Appendix A.

Hummocks

The hillier, well drained, "upland" parts of both landscapes are dominated by soils developed in glacial till. Slopes of these hummocks (slope classes ranging from 3 to 6) are dominated by Orthic Dark Brown (O.DB) Chernozemic soils developed on till (Hughenden series, HND), often with thin Ah horizons. Soils developed on medium-textured veneer overlying till (Provost series, PRO) are also common. Map units prefaced with "HNPR" identify areas with co-dominant HND and PRO soils. Orthic Black soils occur sporadically, mostly at the native site in moist, unexposed segments of the landscape.

Crests and upper slopes, i.e. hilltops, in the hummocky terrain exhibit the most visible signs of erosion. Most cultivated hilltops are dominated by Rego Dark Brown (R.DB) soils on till (Neutral series, NUT). The associated map unit is NUT1 on 3-4 topography. Hilltops at the native site have Orthic Dark Brown soils on till, but typically with thin (<10cm) Ah horizons (thin Hughenden variant, HNDta). The map unit is HND4 on 3 topography.

Pedons representing the HND and NUT soils series are described in Walker and Wang (1994). Appendix B contains pedon descriptions and selected data for the PRO and HNDta soils from the native site.

Lower-slope "Plain"

A large, broad, undulating area with very gentle slopes encircles the hummocky upland at the native site. Similar landscape dominates the south and east sides of the cultivated site. Moderately well drained Orthic Dark Brown soils developed on veneer over till (Provost series, PRO) dominate this low-lying terrain. Small wetland depressions and troughs are also common. These contain a variety of imperfectly to poorly drained soils, including gleyed Blacks and Dark Browns (e.g. Hansman series, HAS) and Humic Gleysols. The map units are PRO2 on 3-2 or 3 topography. Black soils also occur in this segment of the landscape, and are fairly common at the native site in moister localities.

Depressions

Depressions, or basins, contain some form of wetland with poorly to imperfectly drained soils. The dominant soils are Gleysols, mainly Humic Luvic Gleysols. A variety of gleyed soils were also occur. The parent materials, whether slopewash, glaciolacustrine or till deposits, tend to be slightly finer textured than on surrounding parts of the terrain. Most of these depressions are wet early in the season but dry out in most years. The larger depressions were identified by map unit ZGL at both sites.

CULTIVATED (05-AB) SITE HISTORY

Information on the agronomic history of both sites was obtained by interviewing the owners/operators, son Dennis Carter and father Bill Carter. Following is a summary of the information documented in Walker and Wang (1994) for the cultivated site.

Cropping History

The land was broken for cropping in 1912. The crop rotation was mainly cereal (wheat) - fallow (clover grown in 1935). The plow was the principal tillage tool, drawn by horses until 1940. Harvesting (until 1947) involved removal of the crop material, bound in sheaves, to a threshing site. Deep-tillage cultivators replaced the plow as the main tillage implement in about 1950. Use of chemical fertilizers (11-48-0) and herbicides (2-4-D ester) also began *circa* 1950. Use of fertilizers high in nitrogen (e.g. 34-0-0) began in 1977. Fertilizer use has decreased slightly in recent years due to soil testing. Pre-emergent herbicide usage (e.g. Treflan and Avadex) began in 1980. In recent years, herbicides have replaced some tillage operations. Harvesting changed in 1947 with the introduction of the combine, at which time, crop residue has been left on the field and tilled into the soil. In 1991, the crop rotation was extended to include canola.

Current Management Practices

A canola-cereal-fallow rotation, common in the area, has been used since the introduction of canola in 1991. The crop in 1991 was canola, wheat in 1992, fallow in 1993. Management procedures used in the rotation were documented (Walker and Wang 1994).

NATIVE (55-AB) SITE HISTORY

The native site had been grazed, beginning in 1906, until the early 1970's. The grazing intensity during that period was described as "fairly heavy" by owner/operator Bill Carter. As surrounding land was brought into production, the intensity of grazing on the shrinking native range increased towards the latter end of that period. Between the mid 1970's to mid 80's, the grazing was described as "light"; no grazing has occurred since the late 1980's. In the opinion of Bill Carter, the land "has recovered almost to 1906 conditions". A gas pipeline was installed (approximately 8 feet wide) across the southern end of the site in the early 1980's, causing minimal disturbance.

SAMPLING DESIGN AND METHODOLOGY

FIELD SAMPLING DESIGN

The Provost sites are characterized by undulating to hummocky terrain with distinct internal relief. Soil patterns repeat in such landscapes. With the repetition comes a degree of predictability about many soil attributes.

A stratified random sampling method using transects (Wang 1982) was designed to sample the repeating landscape patterns. Orientation of each transect was perpendicular to the contour, or nearly so, stretching from the apex of a "hill" to the bottom of an adjacent depression. Samples were taken at 10m intervals along each transect. Figure 6 shows a schematic landscape profile, with a model transect, on which transect length, rise and slope gradient are compared between the two sites.

Cultivated (05-AB) Site Layout: An area 250m E-W by 350m N-S, totalling 8.8 ha, was selected to represent the cultivated landscape. Nine transects, T1 to T9, were laid out in this area. Sampling points under cultivation totalled 64 after excluding three in an uncultivated depression. Figures 2 and 4 show transect locations on the contour and soil maps of the cultivated site. More details are provided by Walker and Wang (1994).

Native (55-AB) Site Layout: An area roughly 360m E-W by 405m N-S, covering nearly 13.5 ha, was selected to represent the bit of native landscape remaining in the area. Seven transects, T1 to T7, encompassing 61 sampling points, were laid out to capture the landscape variability[2]. Figures 3 and 5 show transect locations relative to topographic and soil features at the native site.

Each transect point was described, during sampling activities, in terms of slope position, slope shape, soil taxonomy, and other pertinent landscape features. Slope position was reported as one of five classes: 1) crest, 2) upper slope, 3) mid slope, 4) lower slope, and 5) depression. Slope shape was classed as: 1) convex, 2) concave, or 3) straight.

Two pedons were selected to characterize and sample, in detail, two of the major soils of each site. At the native site, Pedon 1 (P1, Fig. 3) represented Orthic Dark Browns (Provost, PRO) of mid-slope areas; Pedon 2 (P2, Fig. 3) represented very thin Orthic Dark Browns (Hughenden-ta, HNDta) of the hummock crests. They are described in Appendix B. Similar pedons representing soils of the cultivated site can be found in Walker and Wang (1994).

Soil and Topographic Characterization

Topographic Data and Contour Map: A detailed contour map, with a 0.5m interval, was created for both sites (Fig. 2 and 3). Photogrammetric and total station data were "merged" to create the X-Y-Z digital database for the contour mapping at the cultivated site (Walker and Wang 1994). Total station data alone was collected to generate the contour map for the native site. In 1995, both data sets were corrected to "real world" accuracy using differential global positioning system techniques (Hoffmann-Wellenhof *et al.* 1993).

Detailed Soil Map: The soils of each site were mapped at a scale of roughly 1:3000 (Fig. 4 and 5). The complex landscape was subdivided into repeating areas with similar patterns of terrain and soils. These repeating landscapes are identified by mapping units based on the series (or variant) and phase levels of classification (ECSS 1987a, 1987b). Delineation and mapping unit decisions were based on sampling point inspections, additional soil and terrain inspections, traverses of the site, aerial photo interpretation, and topography.

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[2] Finlayson, N.M. 1992. Provost Benchmark Site – Native Site monitoring. Unpublished draft report for Agriculture Canada. Land Resources Network Ltd., Edmonton, AB. 21 pp.

PROVOST CULTIVATED SITE (05-AB)
SOIL MAP LEGEND

MAP UNIT[1]	DESCRIPTION
HAS1/2-3	**Landscape**: Small basins within the hummocky "upland" that consist of nearly level to very gentle lower slopes. **Major Soils**: Imperfectly drained GLSZ.DB[2] (Hansman series, HAS) and GLE.DB (HASze) on SiL-L[3] slopewash or glaciolacustrine veneer overlying CL-L till. **Inclusions**: Veneer thickens to over 1m in places. Several gleyed Blacks, e.g. GLSZ.BL, and some Gleysols, mostly HU.LG can be found.
HND4/3	**Landscape**: Very gently sloping, broad hilltops in the hummocky terrain. **Major Soils**: Mainly well drained O.DB on CL-L till (Hughenden series, HND), commonly with a thin (<10 cm) Ap horizon (Hughenden-ta variant, HNDta). Significant CA.DB and R.DB (Hughenden-ca & Neutral, HNDca & NUT) “eroded” soils.
HNPR4/3-4	**Landscape**: Majority of the hummocky "upland" areas; consists of very gentle to gentle mid slopes and small hilltops. **Major Soils**: Well drained. Mainly O.DB on CL-L till (Hughenden, HND) with significant O.DB on SiL-L slopewash or glaciolacustrine veneer overlying till (Provost, PRO). Significant CA.DB and R.DB (Hughenden-ca & Neutral, HNDca & NUT) “eroded” soils on most small hilltops and other exposed sites. **Inclusions**: In places hummock foreslopes are moderate to strong (class 5 to 6).
NUT1/3-4	**Landscape**: Prominent, very gently to gently sloping, “eroded” hilltops in hummocky areas. **Major Soils**: Mainly well to rapidly drained R.DB (Neutral, NUT) developed on CL-L till; some CA.DB (Hughenden-ca, HNDca). Calcareous to the surface. **Inclusions**: In places hummock foreslopes are moderate to strong (class 5 to 6).
PRO2/3-2	**Landscape**: Large low-lying area with very gentle to nearly level slopes. **Major Soils**: Mainly moderately well drained O.DB developed on SiL-L slopewash or glaciolacustrine veneer overlying CL-L till (Provost, PRO). Significant imperfectly to poorly drained, gleyed Dark Browns and Blacks; e.g. GL.DB (PROgl), GLSZ.DB (HAS), and Gleysols, mostly HU.LG, in small shallow depressions. Profiles with carbonated B horizons are common. **Inclusions**: Veneer thickens to over 1m (a blanket) in some places.
ZGL	**Landscape**: Nearly level to gentle depressions; wetlands. **Major Soils**: Variety of poorly to imperfectly drained Gleysolic and related soils, best represented by HU.LG developed on SiL slopewash or glaciolacustrine veneer overlying CL till (Fleet-zlxt variant, FLTzlxt). **Inclusions**: Veneer extends to over 1m thick occasionally. Other Gleysols, e.g. O.HG and SZ.LG. Various gleyed Dark Browns, e.g. HAS and HASze, and Blacks occupy margins and better drained sites.

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[1] Numerator consists of series code(s) plus number signifying typical for series (1), significant wet soils (2), or significant “eroded” profiles (4). Denominator signifies slope classes per ECSS (1987b) with slope gradients, in percent slope (%), as follows: 2 = 0-2% (level to nearly level), 3 = 2-5% (very gentle), 4 = 6-9% (gentle), 5 = 9-15% (moderate), 6 = 15-30% (strong). Map unit “ZGL” signifies undifferentiated Gleysolic and gleyed soils, and is used without slope classes..

[2] Soil Subgroup symbols (ECSS 1987b) used in tables and text are defined as follows:

Dark Brown Chernozemic – O.DB (Orthic Dark Brown), CA.DB (Calcareous Dark Brown), R.DB (Rego Dark Brown), GL.DB (Gleyed Dark Brown), GLSZ.DB (Gleyed Solonetzic Dark Brown), GLE.DB (Gleyed Eluviated Dark Brown), GLR.DB (Gleyed Rego Dark Brown)

Black Chernozemic – SZ.BL (Solonetzic Black), GLSZ.BL (Gleyed Solonetzic Black), O.BL (Orthic Black)

Gleysolic – HU.LG (Humic Luvic Gleysol), O.HG (Orthic Humic Gleysol), SZ.LG (Solonetzic Luvic Gleysol)

[3] Texture class symbols (ECSS 1987b) used in tables and text are defined as follows: SiL = Silt Loam; L = Loam; CL = Clay Loam

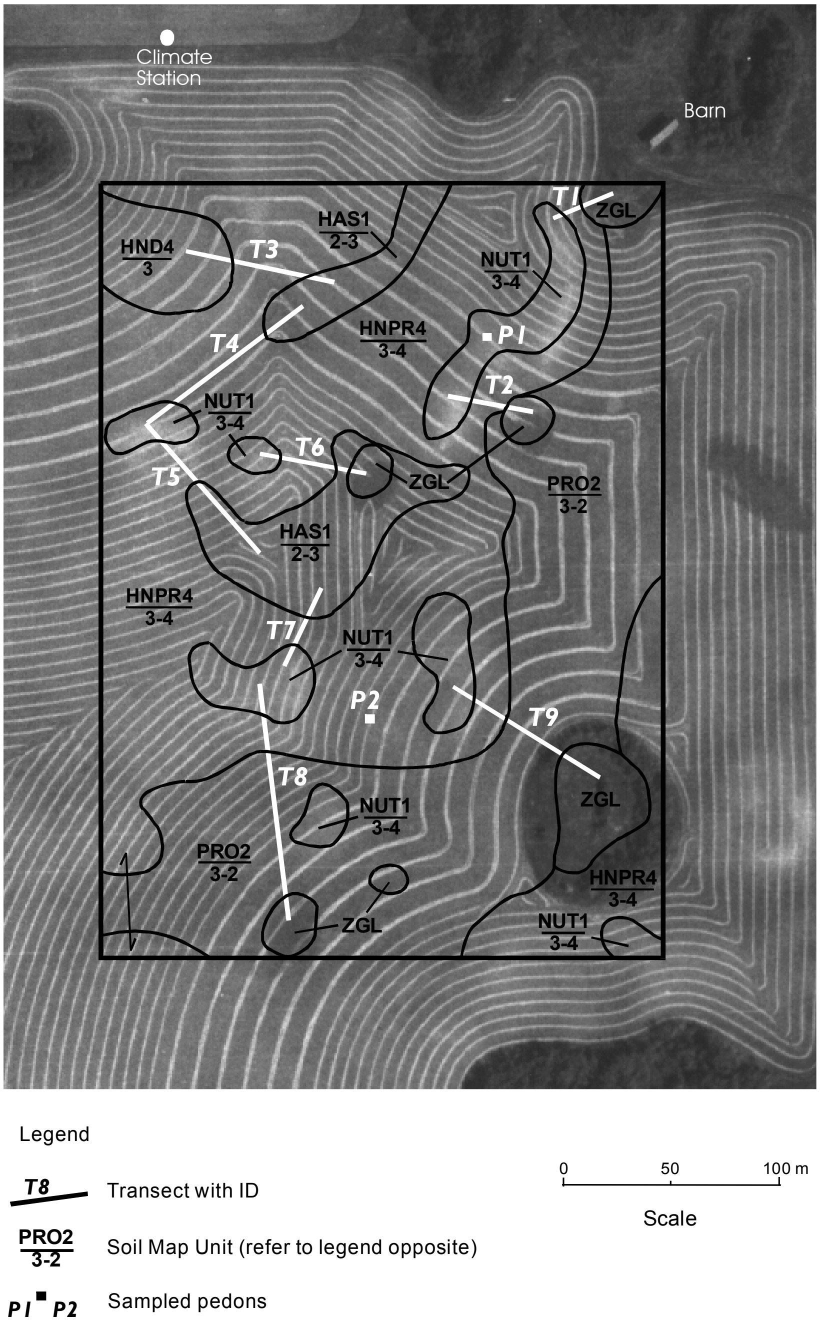

Figure 4. Detailed soil map of the cultivated site with transect and pedon sampling locations.

PROVOST NATIVE SITE (55-AB)
SOIL MAP LEGEND

MAP UNIT[1]	DESCRIPTION
HND4/3	**Landscape**: Very gently sloping, broad hilltops (crests plus upper slopes) in the hummocky terrain. **Major Soils**: Well drained O.DB[2] on CL-L[3] till, but with very thin (mean 6±2 cm) Ah horizon (Hughenden-ta variant, HNDta).
HND4/5-6	**Landscape**: Moderate to strong, usually short slopes that form the sides of some larger hummocks. **Major Soils**: Well drained O.DB on CL-L till, usually with thin (<10 cm) Ah horizon (Hughenden-ta, HNDta). **Inclusions**: Well drained O.DB on SiL-L, slopewash or glaciolacustrine veneer overlying the till (Provost series, PRO).
HNPR1/3	**Landscape**: Very gently sloping, somewhat inclined (bench-like), lower-slope segments of the hummocky terrain. **Major Soils**: Well drained. Mainly O.DB on CL-L till (Hughenden series, HND), with significant O.DB on SiL-L slopewash or glaciolacustrine veneer overlying till (Provost series, PRO). Similar soils except for thin (<10 cm) Ah horizons (HNDta, PROta) are also common. **Inclusions**: Where the veneer thickens to a blanket, O.DB on SiL-L material (Coronation, CNN). Black soils often replace Dark Brown in protected, moist localities. SZ.BL may sometimes occur on lower slopes.
HNPR1/4	**Landscape**: Gentle side slopes of many hummocks. **Major Soils**: Well drained. Mainly O.DB on CL-L till (Hughenden, HND), with significant O.DB on SiL-L slopewash or glaciolacustrine veneer overlying till (Provost, PRO). Similar soils except for thin (<10 cm) Ah horizons (HNDta, PROta) are also common. **Inclusions**: Calcareous R.DB soils, with upper horizons composed of loose drift from up-slope positions and often disturbed by burrowing animals, occur on some mid to lower slopes. Black soils often replace Dark Brown counterparts in some protected, lower- to mid-slope localities, e.g. northerly aspects. In places, slopes are moderate to strong (class 5 to 6).
PRO2/3	**Landscape**: Low-lying, very gently sloping, undulating terrain amongst the hummocks. **Major Soils**: Mainly moderately well drained O.DB developed on SiL-L slopewash or glaciolacustrine veneer overlying CL-L till (Provost, PRO). Significant poorly to imperfectly drained HU.LG and gleyed soils in small depressions. **Inclusions**: Where the veneer thickens to a blanket, O.DB on SiL-L material (Coronation, CNN). Where the veneer is absent, O.DB on till (HND). Calcareous R.DB soils, with upper horizons composed of loose drift from up-slope positions and often disturbed by burrowing animals, occur on some mid to lower slopes, often near aspen grove margins. Black soils often replace Dark Brown counterparts in some protected localities. SZ.BL may occur occasionally on lower slopes.
ZGL	**Landscape**: Nearly level to gentle depressions; wetlands. **Major Soils**: Variety of poorly to imperfectly drained Gleysolic and related soils, best represented by HU.LG developed on SiL slopewash or glaciolacustrine veneer overlying CL till (Fleet-zlxt variant, FLTzlxt). **Inclusions**: Other Gleysols, e.g. O.HG. Imperfectly drained, gleyed soils, e.g. GLR.DB and GLE.DB, and others can be found along depression margins.

[1] Numerator consists of series code(s) plus number signifying typical for series (1), significant wet soils (2), or significant "eroded" profiles (4). Denominator signifies slope classes per ECSS (1987b) with slope gradients, in percent slope (%), as follows: 2 = 0-2% (level to nearly level), 3 = 2-5% (very gentle), 4 = 6-9% (gentle), 5 = 9-15% (moderate), 6 = 15-30% (strong). Map unit "ZGL" signifies undifferentiated Gleysolic and gleyed soils, and is used without slope classes.

[2] Soil Subgroup symbols (ECSS 1987b) used in tables and text are defined as follows:

Dark Brown Chernozemic – O.DB (Orthic Dark Brown), CA.DB (Calcareous Dark Brown), R.DB (Rego Dark Brown), GL.DB (Gleyed Dark Brown), GLE.DB (Gleyed Eluviated Dark Brown), GLR.DB (Gleyed Rego Dark Brown)

Black Chernozemic – SZ.BL (Solonetzic Black), GLSZ.BL (Gleyed Solonetzic Black), O.BL (Orthic Black)

Gleysolic – HU.LG (Humic Luvic Gleysol), O.HG (Orthic Humic Gleysol), SZ.LG (Solonetzic Luvic Gleysol)

[3] Texture class symbols (ECSS 1987b) used in tables and text are defined as follows: SiL = Silt Loam; L = Loam; CL = Clay Loam

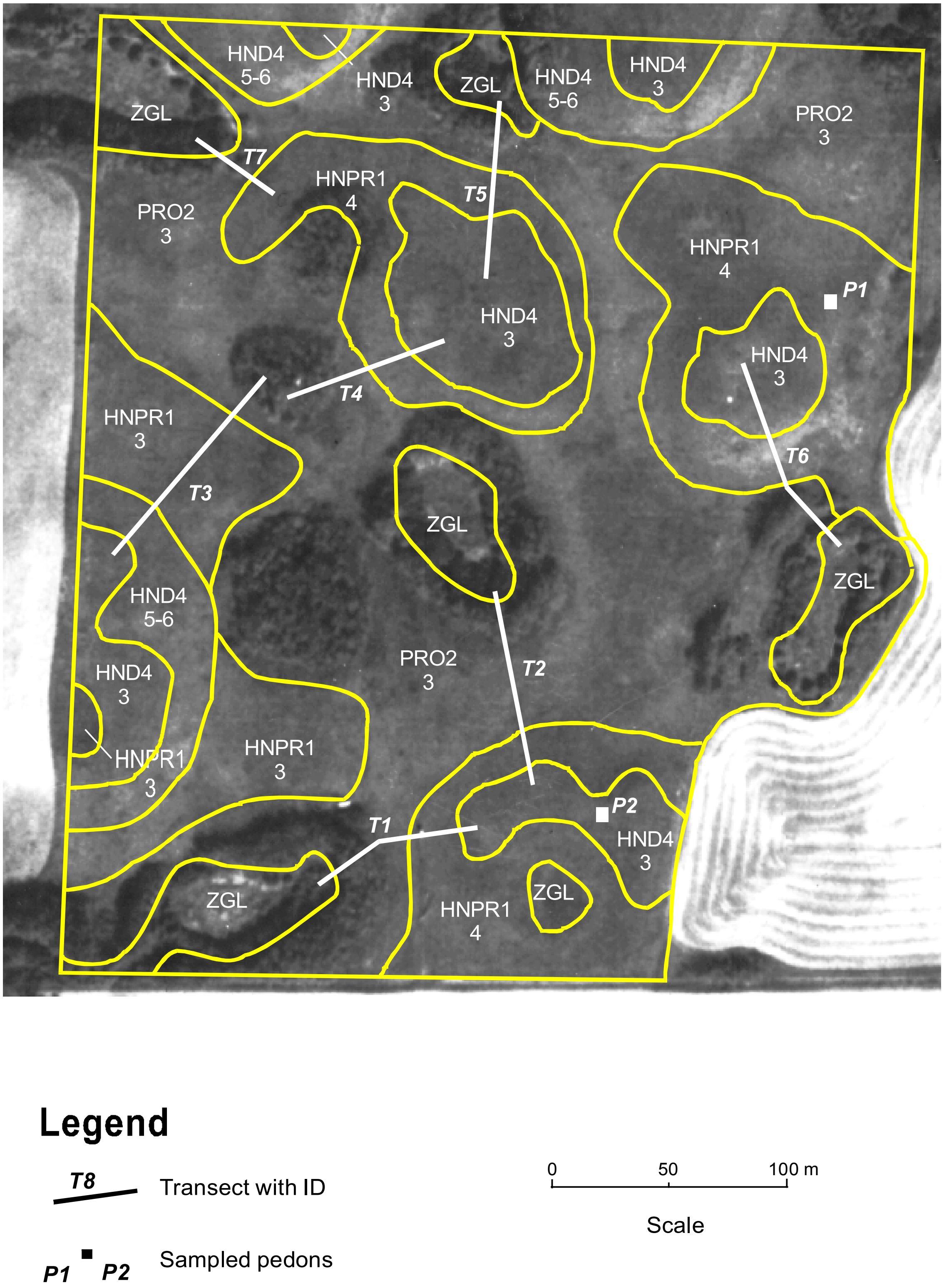

Figure 5. Detailed soil map of the native site with transect and sampling point locations.

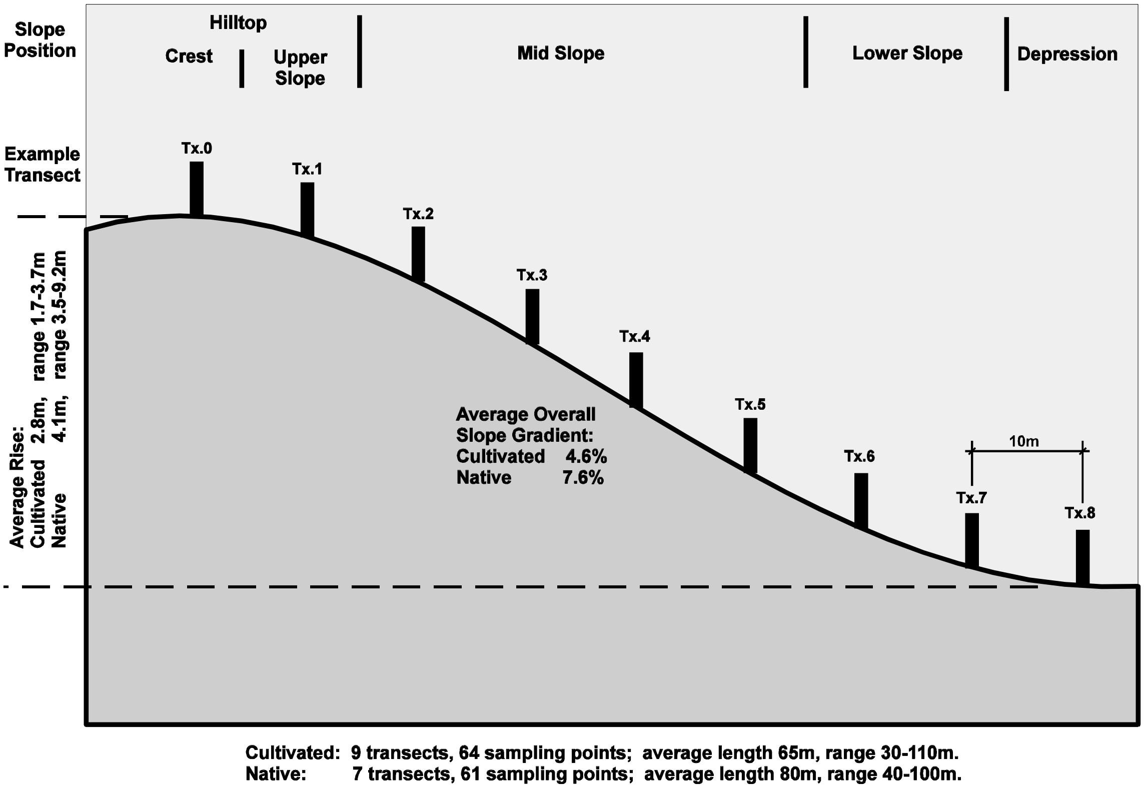

Figure 6. Schematic of transect layout with average topographic features for both sites.

Sampling Activities

The sampling methods used to characterize the native site were the same as those used for the cultivated site (Walker and Wang 1994). Sampling for dry aggregate size distribution, however, was not appropriate for the "turfy" Ah horizons of the native site. Thus, three main sampling activities remained as an important part of the comparison:

1. transect point sampling for chemical and physical analyses,
2. pedon sampling, and
3. transect point sampling for ^{137}Cs analysis.

At the cultivated site, sampling activities were conducted in the late fall of 1990. Sampling followed the final fall cultivation in the fallow year of a wheat-fallow rotation. At the native site, sampling began in the fall of 1991. Preliminary analysis of the data showed a need to collect upper B horizon samples in order to assess subsoil dilution effects[3]. These were collected at the native site in the spring of 1992. Bulk densities of these B horizons were measured by the Kubiena box method (refer to sampling for ^{137}Cs).

Transect Point Sampling: A loose sample (bulk as opposed to core sample) of the contemporary (in 1990) Ap or Apk at the cultivated site, Ah1 horizon at the native site, was taken at every sampling point. Loose samples of the underlying (and presumably older) Ap2 and/or Ap3 horizon were collected at 15 transect points at the cultivated site. In addition, a loose sample at roughly 50-60 cm depth (B or C horizon) was collected at every 4th transect point. At 16 locations on the native site, a loose sample of B horizon from immediately below thin (<10cm) Ah horizons was collected at crest, upper-, and mid-slope points. Horizon type and depth, color, structure, field texture, consistence, landscape position, soil classification, and other morphological and site information were recorded for each sampling point and sample.

Pedon Sampling: Pits about 1m by 2m by 1.5m deep were opened by backhoe at the P1 and P2 locations (Fig. 2 through 5). The soil horizons of the exposed pedons were identified and described according to Day (1983). About 1 kg of loose soil

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[3] Finlayson, N.M. 1992. Provost Benchmark Site – Native Site monitoring. Unpublished draft report for Agriculture Canada. Land Resources Network Ltd., Edmonton, AB. 21 pp.

was collected from each horizon. Cores from several horizons were obtained at the cultivated site (Walker and Wang 1994); coring was hindered by very dry conditions at the native site.

Transect Point Sampling for ^{137}Cs Analysis: At the cultivated site, a loose bulk sample (1-2 kg) of the contemporary Ap horizon was taken at every sampling point. In addition, an underlying Ap or Ah, if present, was sampled at some points. The thickness of each sampled layer was recorded. At the native site, a block of soil from the mineral surface to the 10 cm depth was extricated. A bulk density sample, collected in a 7.5 x 5 cm Kubiena box, was taken next to each ^{137}Cs sample, at about the mid-point of the sampled layer. A thin layer of surface litter was removed at native site points to expose the underlying Ah for sampling. Where shrubby vegetation flourished, a fibrous network of roots infused the Ah horizon. Use of the Kubiena box at these points was difficult, and occasionally impossible, due to the mass of roots.

Field Measurements

The baseline set of *in situ* field measurements was begun prior to spring tillage in 1991 at the cultivated site. Monitoring of the various attributes continues. Measurements were made at the native site in the fall of 1991, under very dry conditions. To improve the data set, penetrometer and moisture measurements were repeated in the spring of 1992 under improved moisture conditions. No further monitoring activities were conducted at the native site since it was sampled specifically for this comparison study.

Hydraulic Conductivity (Ksat): Saturated hydraulic conductivity was measured by Guelph Permeameter, initially at 3 depths (5-10, 15-25 and 30-40 cm), using procedure 56.2.1 by Reynolds (1993). As monitoring continued at the cultivated site, measurements at the 5-10 cm depth (Ap) were discontinued due to highly variable results, probably due in part to tillage. For the same reason, comparison of Ksat values for this depth was inappropriate. Sufficient transect points were selected, in a stratified random manner, to ensure proportional representation of slope positions. Over 30% of all points were selected at both sites, with a minimum of 3 per landscape position (Walker and Wang 1994).

Penetration Resistance and Soil Moisture: Resistance to penetration was measured for 3 depths (0-10, 10-20 and 20-30 cm) using the Centre-Cone Penetrometer, operated manually per the user's manual (Star Quality Samplers 1990). Reported results, in MPa, are the averages of 5 readings per depth per sampling point. Measurements at both sites were made on approximately 50% of the transect points, selected in a stratified random manner, with a minimum of 3 per landscape position. Small samples, one from each depth at each sampling point, were collected in moisture tins for gravimetric determination of soil moisture. Measurements at the 0-10 cm depth (Ap) were discontinued due to highly variable results. Although measurements were less variable at the native site, comparison of the results from the 0-10 cm depth was not appropriate.

Climate: A climate monitoring station, based on the Campbell Scientific CR10 measurement and control module, was installed in May, 1991, along a fenceline about 70 m north of the cultivated site, on an east-facing mid slope. Air temperature; relative humidity; global solar radiation; wind speed; soil temperatures at 20, 50 and 100 cm; total rainfall; 15-minute rainfall intensity; and snow depth have been recorded. Refer to Walker and Wang (1994) for a more detailed description of equipment and monitoring frequencies.

ANALYTICAL METHODS

Laboratory Methods

The methods for the handling, preparation, and analyses were identical for samples from both sites. A spectrum of analyses was conducted to establish baseline characteristics of the sites (Walker and Wang 1994), but only procedures relevant to descriptions and comparisons in this report are included below.

Sample Handling and Preparation: Loose samples for chemical, physical and ^{137}Cs analyses were air-dried and roller-ground to separate the fine earth fraction (<2mm) from coarse fragments as per procedure 1.2 (McKeague 1978). The prepared ^{137}Cs samples were shipped to the Univ. of Guelph's Dept. of Land Resource Science for analysis. Pedon and field samples prepared for detailed laboratory characterization were split into two equal parts, one part for analysis and the other for future use. Core samples from the pedons were stored at about 4ºC until processing.

Soil Reaction ($CaCl_2$ pH): Determined with a pH meter using a 1:2 soil to 0.01 M $CaCl_2$ solution, per procedure 84-001 in Sheldrick (1984).

Total Carbon: LECO induction furnace, per procedure 84-013 in Sheldrick (1984).

Organic Carbon: Total carbon minus inorganic carbon as determined in the $CaCO_3$ procedure.

Total Nitrogen: Samples digested using a semi-micro version of the Kjeldahl-Wilforth-Gunning method (A.O.A.C. 1955) with Se-K_2SO_4 (Keltabs) as the catalyst. Ammonium-N in the distillate was detected colorimetrically with a Kjeltec nitrogen analyzer.

$CaCO_3$ Carbonate Equivalent: Determined by the inorganic carbon manometric (calcimeter) method of Bascombe (1961), similar to procedure 84-008 of Sheldrick (1984), on samples with $CaCl_2$ pH of 6.5 and greater.

Cesium^{137} Analysis: Samples analyzed using high-resolution, Gamma-spectroscopy methods described by de Jong *et al.* (1982).

Particle Size Distribution: The fine earth fraction of all pedon and 10% of field samples was separated into particle size groups using a pipette or filter candle system, per procedure 84-026 in Sheldrick (1984). Samples were pretreated to remove soluble salts, carbonates and organic matter as required.

Bulk Density: Two sets of oven-dry, bulk density values, uncorrected for coarse fragment content, were obtained: 1) on core samples from the pedons, per procedure 2.211 in McKeague (1978), and 2) on the Kubiena box samples, collected in conjunction with sampling for ^{137}Cs analysis.

Data Selection and Calculations

Hydraulic Conductivity (Ksat): Ksat data sets collected in the spring (cultivated site) and fall (native site) of 1991 were compared for this report.

Penetration Resistance: Soil strength values for each depth are the average of five replicate readings per transect point. A few readings were off-scale (>11 MPa), especially at the native site. If only 1 or 2 of the replicates were >11 MPa, those readings were assigned a value of 12 MPa, and all 5 replicates were averaged to get the resistance value. If 3 or more replicates were off-scale, the resistance value was designated as 11.5 MPa. Resistance data collected in the spring of 1991 (cultivated site) and spring of 1992 (native site) were compared.

Simulated Ap Calculation: The first noticeable difference between the sites was thickness of the uppermost A horizon. Cultivated Ap's averaged 11 cm across the landscape; Ah's at the native site averaged 4-7 cm on hilltops, 9 cm on mid slopes, and 11cm on lower slopes and in depressions. A "simulated plow layer" (simulated Ap) was calculated for crest, upper- and mid-slope positions at the native site in order to estimate the dilution effect of subsoil materials in the primordial plow layer, and to compare carbon and nitrogen contents in layers of equal depth between the two sites. The mass of organic C (g $m^{-2.}$) was calculated for each thin Ah horizon plus underlying Bm to a total depth of 11 cm using Equation 1. Mass of total N was done in the same way, substituting total N content (%) for organic C content. Mass values for organic C and total N in the simulated Ap were then converted back to proportional content (%) of the total dry soil mass.

$$\textbf{Mass of organic C (g m}^{-2}\textbf{) in 11-cm simulated Ap} = \frac{(Ta*D_b a*100^2*Ca)}{100} + \frac{((11-Ta)*D_b b*100^2*Cb)}{100} \quad (1)$$

Where:
Ta = Thickness (cm) of the A horizon.
$D_b a$, $D_b b$ = Bulk density (g cm^{-3}) of A, B horizons.
Ca, Cb = Organic C content (%) of A, B horizons.

Cesium^{137} Calculations: ^{137}Cs isotope activity in the soil was determined on a weight basis (Bq kg^{-1} soil), and converted to an area expression (Bq m^{-2}) by multiplying by the bulk density and sampling depth. Only the uppermost A horizon data were compared for this report.

Cesium^{137} Redistribution Calculation

To estimate soil redistribution in the cultivated landscape, the average ^{137}Cs level at the native site (1704 Bq m^{-2}, standard deviation of 765) was used as a baseline value for separation of erosion (^{137}Cs depletion) and deposition (^{137}Cs enrichment) using the following equation (Kiss *et al.*, 1986):

$$^{137}Cs_r = \frac{(^{137}Cs_c - {}^{137}Cs_n)}{^{137}Cs_n} \quad (2)$$

Where:
$^{137}Cs_r$ = ^{137}Cs redistribution at the site (expressed as % loss when the quotient is multiplied by 100); a negative value indicating deposition and a positive value indicating soil loss.
$^{137}Cs_c$ = ^{137}Cs present at the cultivated site.
$^{137}Cs_n$ = baseline value of ^{137}Cs at the native site.

Net Erosion Rate Calculation

Net soil erosion rates for the cultivated site were estimated with a theoretical model developed by Kachanoski *et al.* (1992). This model is based on the relationship between annual erosion rate and the fraction of ^{137}Cs remaining as a function of the number of years of erosion. It assumes that current ^{137}Cs levels are equal to the initial input (either atmospheric fallout or native non-eroded baseline values) minus ^{137}Cs removed through erosion, taking into account radioactive decay (^{137}Cs inputs must be corrected before using the model) and the period of time over which soil loss occurred. The equation accounts for tillage dilution by mixing of subsoil into the Ap. This results in a power-function relationship between soil loss and ^{137}Cs loss (Kachanoski 1993).

Mathematically, the relationship is represented by:

$$\mathbf{C_n = C_o\,(1 - (E_n/(D_b{*}D_p))^n)} \qquad (3)$$

Where:

C_n = ^{137}Cs activity (Bq m^{-2}) for each sampling point in year n.

C_o = atmospheric input of ^{137}Cs (Bq m^{-2}) after decay.

E_n = net average soil erosion (kg m^{-2} yr^{-1}) in n years.

D_b = bulk density (kg m^{-3}) of the layer in which ^{137}Cs was measured.

D_p = cultivated layer (Ap) thickness (m) in which ^{137}Cs was measured.

n = number of years over which soil loss occurred.

Equation 3 is solved for net erosion (Kachanoski *et al.* 1992, Cao *et al.* 1993) resulting in the following equation:

$$\mathbf{E_n = D_b{*}D_p\,(1 - (C_n/C_o)^{1/n})} \qquad (4)$$

A positive E_n value (kg m^{-2} y^{-1} = mean annual net soil erosion rate) indicates soil loss exceeded soil gain, and erosion took place at that sampling point. A negative E_n value indicates that soil gain exceeded soil loss, resulting in deposition.

The value of the C_o term in Equation 4 was based on the average ^{137}Cs content of the native site (1704 Bq m^{-2}). This level of ^{137}Cs activity would presumably occur at sites where no erosion or deposition had taken place.

Erosion was assumed to have occurred over 30 years (1960 to 1990), parameter 'n' in equations 3 and 4. This method under predicts actual soil gain in cultivated depositional sites, especially where a constant depth of A (i.e. the plow layer) was sampled for ^{137}Cs across all points in the landscape. This is due to the upward migration of the plow layer over time as soil materials accumulate, assuming depth of cultivation doesn't change. A fourth equation (de Jong *et al.* 1983, Cao *et al.* 1993) compensates for this fact, and also estimates net deposition:

$$\mathbf{E_n = -D_b(D_e - D_p)} \qquad (5)$$

Where:

D_e = the effective depth (m) in which ^{137}Cs is present.

In this case, D_e was estimated as the total thickness of the contemporary plus underlying Ap horizons. Equation 5 was applied where ^{137}Cs values were greater than baseline, indicating deposition (i.e. accumulation of ^{137}Cs over that of the native site average). The outcome of Equation 5 resulted in an adjusted E_n value calculated for depositional areas. This outcome was divided by 30 yr. to achieve a mean annual rate of soil gain since 1960.

Statistical Methods

The descriptive statistics of measured soil variables are presented by slope position for each site in Table 1. The distribution of soil properties in eroded fields tend to be skewed and non-normal (Rogowski *et al.* 1990). The variability of soil properties in landscapes of complex terrain usually does not occur randomly. This nonrandom variability is a reflection of the varying degree of intensity in slope processes occurring at eroded sites (Daniels *et al.* 1985). Statistical methods that use commonly pooled error terms and assume homogeneity of variance, like multiple comparison of means or analysis of variance, do not apply. Consequently, means of dependent variables were analyzed through individual t-tests ($P<0.05$). Data were grouped by slope position for analysis. Two types of t-test comparisons were made:

1. Between site comparison, made within each slope position, where significance is indicated by uppercase letters from A through C.
2. Within site comparison, made between each slope position along the transect, where significance is indicated by lowercase letters from x through z.

Regression Analysis

Nonlinear regression (Procedure NLIN, SAS® 1990) was used to analyze the relationship between selected soil properties and proportional distance downslope.

Several models were run for each dependent variable, with the model best describing the relationship presented in this report.

Transect length varied considerably at both sites. In order to examine the effects of slope position on dependent variables, regressions were run against the proportional distance downslope, a method used by Verity and Anderson (1990) for evaluating the effects of soil erosion on slopes. In this procedure, the location of sampling points along each transect were converted to a relative distance from the crest down-slope to the depression. The highest point, or crest position, was assigned a value of zero; the lowest point in the depression was assigned a value of one. All other points in between were given values between 0 and 1 in proportion to their distance, in m, from 0, divided by the total length of the transect.

RESULTS AND DISCUSSION

SOIL – LANDSCAPE PATTERNS COMPARED

The landscapes of both sites, including their complex soil distribution patterns, were described in a previous section. Much of their complexity is shown in the contour (Fig. 2 and 3) and soil (Fig. 4 and 5) maps, and in the “typical” transect diagram (Fig. 6), which compares slope features between the two sites. Table 1 lists the statistical variability of selected soil properties for both sites. Table 2 summarizes some landscape features by slope position for the sites. All this information conveys the considerable similarities as well as some differences between the sites.

Both sites have the same overall landscape pattern with distinctive hummocky upland areas encircled by a gentler sloping “plain” that is dotted with wetland depressions. However, the native site has slightly steeper slopes with greater internal relief than the cultivated landscape (Fig. 6). This rougher topography likely did not deter its use for crop production because identical land in adjacent fields has been cultivated for many decades.

On the other hand, long-term cultivation probably “smoothed” the slopes somewhat at the cultivated site. Exactly how much can no longer be determined. A crude estimate, based on average bulk densities and calculated rates of erosion on crests and deposition in depressions, is 0.5 m in nearly 80 years. This is equivalent to reducing the current 4.1 m relief at the native site by 13% to 3.6 m. Morphological evidence of the estimated deposition is rare; thus, the estimated value is likely the maximum change in relief. Further, the calculated erosion rates tend to be overestimated (see below) and were assumed constant over the 78 years of cultivation.

Some interesting observations also emerge from the summary of selected soil and landscape attributes in Table 2. At both sites, attributes of hilltops (crest and upper-slope positions) are predictable. Slope shape is predominantly convex, and the soils tend to be thin and developed exclusively on till. The very thin soils of the native hilltops “became” the predominantly Rego and Calcareous Dark Brown Chernozemic soils of cultivated hilltops through cultivation.

Soil complexity tends to increase downslope at both sites (Table 2). The most complex pattern of soils occurs on lower slopes. However, lower slopes at the native site have a substantially higher proportion of wet soils. Perhaps these areas are better defined in the slightly steeper, native landscape. Certainly, most depressions in the native landscape are well defined (note Fig. 5). The predominance of Humic Luvic Gleysols in depressions at the native site confirms this observation. One possible conclusion based on these qualitative observations is that long-term cultivation may have blurred the distinction between landscape segments.

EROSION AND SLOPE POSITION

Distribution of ^{137}Cs Activity in the Landscape

The residual ^{137}Cs activity at the cultivated site varied from 818 to 3578 Bq m^{-2}, with an overall mean of 2029 and a standard deviation of 650 Bq m^{-2} (Table 1 and Figure 7). These ^{137}Cs levels lie within the common range of activity for cultivated Dark Brown soils on the Canadian prairies (Verity and Anderson 1990; Moulin *et al*., 1994).

Table 1. Descriptive statistics for selected soil attributes of the cultivated and native sites.

Slope Position: Variable	n	Mean	Std. Dev.	Range	Median	n	Mean	Std. Dev.	Range	Median
Crest:			***Cultivated Site***					***Native Site***		
A horizon: Thickness (cm)	9	11	2	8 - 16	11	8	4	1	3 - 6	5
pH ($CaCl_2$)	9	7.5	0.4	6.5 - 7.8	7.6	8	5.9	0.3	5.6 - 6.3	5.9
Organic C (%)	9	1.80	0.30	1.38 - 2.33	1.84	8	6.39	1.98	4.73 - 10.17	5.65
Total N (%)	9	0.18	0.03	0.12 - 0.23	0.18	8	0.53	0.11	0.40 - 0.70	0.49
C:N Ratio	9	10.1	0.7	9.5 - 11.5	10.1	8	11.9	1.6	10.3 - 14.5	11.5
Available K (ug g soil^{-1})	9	283	66	216 - 374	253	8	625	113	515 - 885	605
Bulk Density (Mg m^{-3})	8	1.12	0.06	1.03 - 1.22	1.13	7	0.94	0.09	0.81 - 1.03	0.96
^{137}Cs (Bq m^{-2})	6	1093	324	604 - 1463	1135	7	1425	361	939 - 1982	1535
Ksat (cm h^{-1}): 15-25 cm depth	3	0.60	0.34	0.21 - 0.85	0.75	3	4.29	1.62	2.83 - 6.04	4.01
30-40 cm depth	3	1.05	0.95	0.13 - 2.03	1.80	3	3.00	1.12	2.10 - 4.26	2.64
Resistance (MPa): 10-20 cm	3	14	4	11 - 19	12	4	48	21	27 - 76	43
20-30 cm	3	16	5	13 - 22	13	4	72	35	30 - 115	72
Upper slope:			***Cultivated Site***					***Native Site***		
A horizon: Thickness (cm)	7	10	2	9 - 13	10	9	7	2	4 - 9	7
pH ($CaCl_2$)	7	7.4	0.3	6.9 - 7.7	7.6	9	6.1	0.7	5.3 - 7.2	6.2
Organic C (%)	7	1.79	0.27	1.33 - 2.09	1.90	9	5.98	1.89	3.72 - 8.50	5.66
Total N (%)	7	0.18	0.03	0.14 - 0.21	0.19	9	0.46	0.12	0.27 - 0.64	0.42
C:N Ratio	7	9.9	0.3	9.5 - 10.4	10.0	9	13.1	2.0	9.9 - 16.6	13.5
Available K (ug g soil^{-1})	7	275	51	183 - 350	281	9	496	136	298 - 679	525
Bulk Density (Mg m^{-3})	7	1.17	0.07	1.11 - 1.30	1.15	9	0.90	0.16	0.69 - 1.24	0.87
^{137}Cs (Bq m^{-2})	6	1327	349	818 - 1737	1322	9	1748	743	891 - 2974	1427
Ksat (cm h^{-1}): 15-25 cm depth	3	1.43	1.00	0.38 - 2.38	1.53	3	3.78	2.23	2.25 - 6.34	2.75
30-40 cm depth	3	1.85	2.36	0.44 - 4.57	0.54	3	5.05	2.09	3.58 - 7.45	4.13
Resistance (MPa): 10-20 cm	3	14	6	8 - 20	13	5	40	5	34 - 44	40
20-30 cm	3	20	6	14 - 25	19	5	55	15	39 - 77	58
Mid slope:			***Cultivated Site***					***Native Site***		
A horizon: Thickness (cm)	25	11	1	9 - 13	11	28	9	4	3 - 23	9
pH ($CaCl_2$)	25	6.2	1.1	4.8 - 7.7	6.0	28	5.8	0.6	4.8 - 7.3	5.6
Organic C (%)	25	2.62	0.56	1.76 - 3.59	2.62	28	6.66	2.02	3.10 - 11.82	6.62
Total N (%)	25	0.23	0.04	0.17 - 0.31	0.23	28	0.54	0.16	0.28 - 1.05	0.54
C:N Ratio	25	11.1	0.8	9.7 - 12.8	11.2	28	12.4	1.1	9.5 - 14.4	12.5
Available K (ug g soil^{-1})	25	450	185	193 - 974	393	28	509	138	211 - 774	474

Table 1 continued.

***Slope Position:* Variable**	**n**	**Mean**	**Std. Dev.**	**Range**	**Median**	**n**	**Mean**	**Std. Dev.**	**Range**	**Median**
***Mid slope:* cont'd**			***Cultivated Site***					***Native Site***		
Bulk Density (Mg m^{-3})	24	1.05	0.07	0.94 - 1.15	1.05	26	0.88	0.15	0.57 - 1.19	0.86
^{137}Cs (Bq m^{-2})	24	1988	422	818 - 2625	2059	27	1862	828	421 - 4247	1728
Ksat (cm h^{-1}): 15-25 cm depth	8	1.54	1.30	039 - 4.32	0.94	7	2.31	0.73	0.91 - 3.25	2.57
30-40 cm depth	8	1.34	1.20	023 - 3.76	1.07	7	2.38	1.23	0.53 - 4.57	2.35
Resistance (MPa): 10-20 cm	5	15	4	10 - 20	14	8	27	6	20 - 38	27
20-30 cm	5	18	6	11 - 28	16	8	37	11	22 - 52	37
Lower slope:			***Cultivated Site***					***Native Site***		
A horizon: Thickness (cm)	18	11	2	10 - 18	11	11	10	2	7 - 14	10
pH ($CaCl_2$)	18	5.2	0.4	4.6 - 6.2	5.1	11	5.8	1.1	4.6 - 7.7	5.4
Organic C (%)	18	3.49	0.46	2.81 - 4.25	3.49	11	8.21	2.17	5.04 - 12.53	7.72
Total N (%)	18	0.31	0.04	0.19 - 0.40	0.31	11	0.65	0.15	0.40 - 0.92	0.64
C:N Ratio	18	11.4	1.3	10.4 - 16.2	11.2	11	12.7	0.9	10.7 - 13.6	12.6
Available K (ug g $soil^{-1}$)	18	559	198	201 - 980	550	11	615	194	298 - 924	563
Bulk Density (Mg m^{-3})	18	0.97	0.05	0.83 - 1.05	0.99	11	0.81	0.15	0.60 - 1.19	0.80
^{137}Cs (Bq m^{-2})	18	2419	364	2032 - 3578	2366	10	1663	925	124 - 3639	1517
Ksat (cm h^{-1}): 15-25 cm depth	6	0.64	0.60	0.15 - 1.75	0.49	4	2.03	0.56	1.56 - 2.80	1.89
30-40 cm depth	6	0.42	0.34	0.12 - 1.00	0.26	4	2.66	1.36	0.88 - 4.06	2.85
Resistance (MPa): 10-20 cm	4	12	6	5 - 17	13	5	17	4	12 - 23	18
20-30 cm	4	14	5	8 - 19	15	5	24	10	12 - 33	27
Depression:			***Cultivated Site***					***Native Site***		
A horizon: Thickness (cm)	7	12	1	10 - 13	13	7	11	2	8 - 13	10
pH ($CaCl_2$)	7	5.1	0.2	4.9 - 5.4	5.0	7	5.0	0.2	4.8 - 5.5	5.0
Organic C (%)	7	3.56	0.19	3.32 - 3.83	3.57	7	7.69	1.22	6.02 - 9.38	7.96
Total N (%)	7	0.33	0.01	0.31 - 0.34	0.34	7	0.65	0.07	0.56 - 0.75	0.66
C:N Ratio	7	10.8	0.4	10.3 - 11.3	10.7	7	11.8	1.2	10.6 - 14.0	11.5
Available K (ug g $soil^{-1}$)	7	753	124	518 - 860	794	7	695	149	561 - 997	628
Bulk Density (Mg m^{-3})	7	0.95	0.07	0.80 - 1.02	0.96	6	0.79	0.13	0.59 - 0.94	0.80
^{137}Cs (Bq m^{-2})	7	2683	607	1734 - 3415	2907	7	1375	552	646 - 2096	1637
Ksat (cm h^{-1}): 15-25 cm depth	3	0.68	0.58	0.31 - 1.35	0.37	3	3.68	1.50	2.13 - 5.13	3.79
30-40 cm depth	3	0.38	0.43	0.10 - 0.88	0.17	3	1.19	0.44	0.75 - 1.63	1.19
Resistance (MPa): 10-20 cm	3	8	3	4 - 11	8.6	4	17	6	10 - 22	18
20-30 cm	3	10	8	4 - 19	7.6	4	22	5	15 - 28	22

Table 2. A summary of selected landscape features by slope position for the Provost sites.

Slope Position (n)[1]	Slope Shape	Soil Groupings and Their Distribution[2]	Topsoil[3] (cm, mean and σ)
Cultivated Site:			
Crest (9)	Convex – 89% Straight – 11%	Rego Dark Brown on till – 89% Orthic Dark Brown on till – 11%	13 (4)
Upper slope (7)	Convex – 100%	Calcareous Dark Brown on till – 43% Rego Dark Brown on till – 29% Thin Orthic Dark Brown on till – 29%	11 (3)
Mid slope (25)	Straight – 76% Concave – 16% Convex – 8%	Orthic Dark Brown on till or veneer/till – 88% Calcareous Dark Brown on till or veneer/till – 8% Eluviated Dark Brown on veneer/till – 4%	17 (7)
Lower slope (19)	Straight – 53% Concave – 42% Convex – 5%	Gleyed Solonetzic Dark Brown on veneer/till – 26% Orthic Dark Brown on veneer/till – 26% Gleyed Eluviated Dark Brown on veneer/till – 26% Gleyed Dark Brown on veneer/till – 11% Humic Luvic Gleysol on veneer/till – 5% Solonetzic Black on veneer/till – 5%	21 (8)
Depression (9)	Concave or straight	Humic Luvic Gleysol on veneer/till – 45% Orthic Humic Gleysol on veneer/till – 22% Various gleyed Dark Brown soils on veneer /till – 22% Solonetzic Luvic Gleysol on veneer/till – 11%	26 (12)
Native Site:			
Crest (8)	Convex – 63% Straight – 37%	Thin Orthic Dark Brown on till – 100%	4 (1)
Upper slope (9)	Convex – 89% Concave – 11%	Thin Orthic Dark Brown or Black on till – 56% Orthic Dark Brown or Black on till – 33% Rego Dark Brown on till – 11%	7 (2)
Mid slope (28)	Straight – 68% Concave – 18% Convex – 14%	Thin Orthic Dark Brown or Black on till or veneer/till – 46% Orthic Dark Brown or Black on till or veneer/till – 32% Rego Dark Brown or Black on till or veneer/till – 14% Other Dark Brown or Black soils on veneer/till – 8%	10 (8)
Lower slope (11)	Straight – 73% Concave – 18% Convex – 9%	Humic Luvic Gleysol on veneer/till – 27% Various gleyed Black soils on veneer/till – 27% Orthic Black on veneer/till – 18% Rego Dark Brown on veneer/till – 18% Solonetzic Black on veneer/till – 9%	11 (2) [n = 6]
Depression (7)	Concave or straight	Humic Luvic Gleysol on veneer/till – 100%	20 (4) [n = 2]

[1] All sampling points (n) are included in this table – not all were used in other analyses, and three that occur in the cultivated site weren't actually cultivated until the mid-1990's.

[2] Soil groupings are based on subgroups (E.C.S.S. 1987b) and combinations of similar parent materials. A few Black soils are included with the Dark Browns on mid and lower slopes at the cultivated site. Blacks are far more common at the native site, and are listed.

[3] The mean thickness of humus-rich topsoil, and standard deviation, is listed in cm. This includes the current Ap or Apk plus any underlying older Ap, uncultivated Ah or AB horizon at the cultivated site; and the uppermost Ah or Ahe plus any underlying Ah, Ahe or AB horizon at the native site. Strongly eluviated (Ae) horizons were excluded. In two cases, the observations of topsoil thickness, indicated by [n number], are less than the total number of sampling points as indicated in the Slope Position column.

The ^{137}Cs content at the native site showed a greater range, with a maximum of 4247, a minimum of 124 Bq m^{-2} and an overall average of 1704 Bq m^{-2} (standard deviation of 765 Bq m^{-2}). The greater variability present in the native site is not an uncommon phenomenon, and was reported for similar soils on the prairies (Pennock *et al*. 1994). However, the average ^{137}Cs content at the native site is unusually low. Common values reported for Dark Brown and Black Chernozemic soils at non-eroded native sites in Saskatchewan range from 3204 to 2001 Bq m^{-2}. Reported averages range from 2989 to 2231 Bq m^{-2} (Kiss *et al*. 1986, Pennock *et al*. 1994). Further, the typical pattern in comparison studies is for the native sites to be about 20-30% higher in ^{137}Cs activity than cultivated sites (Cao *et al*. 1993, Moulin *et al*. 1994, Kachanoski and de Jong 1984). In this study, ^{137}Cs levels at the cultivated site exceeded those of the native site by 20%.

One of the key assumptions in ^{137}Cs redistribution analysis, where ^{137}Cs concentrations are compared to levels in adjacent uncultivated sites, is that a uniform deposition pattern of ^{137}Cs occurred across the landscape under natural conditions (i.e. there should be no relationship between slope position and ^{137}Cs levels at the native site). Several studies on similar soils in prairie landscapes have shown that ^{137}Cs levels are not related to landscape position (Lance *et al*. 1986, de Jong *et al*. 1983, Pennock *et al*. 1994). This study was no exception; Figure 7 shows no significant differences in ^{137}Cs levels between slope positions at the native site ($P<0.05$, x-z comparison).

Conversely, the cultivated site showed a distinct increase in ^{137}Cs levels from the crests to the bottom of the slopes (Fig. 7). The relationship between slope position and ^{137}Cs content was best described, through nonlinear regression analysis, by a second order polynomial equation (Fig. 8). Cesium levels on the crests of the transects averaged less than half of the ^{137}Cs content of depressions, indicating a downslope movement of soil materials and ^{137}Cs by erosional processes.

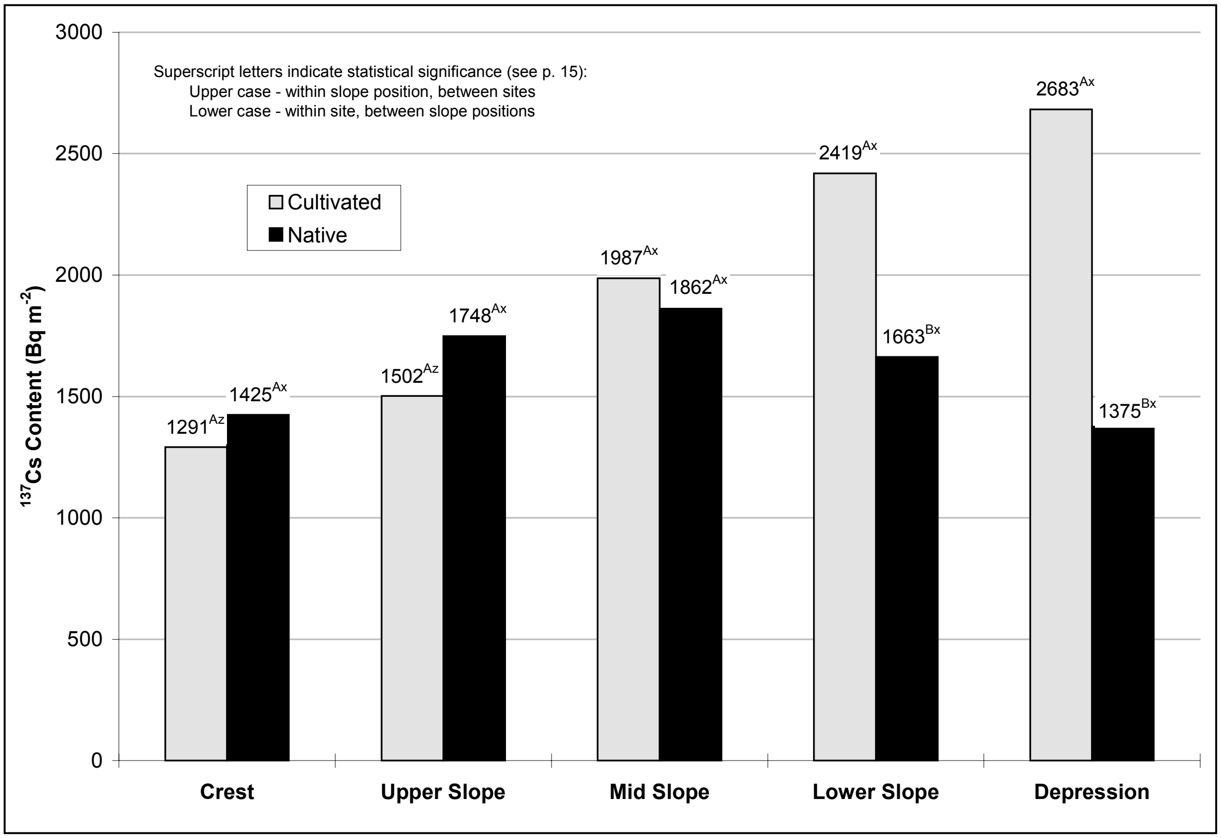


Figure 7. Cesium^{137} content (Bq m^{-2}) in the uppermost layer of topsoil at both sites.

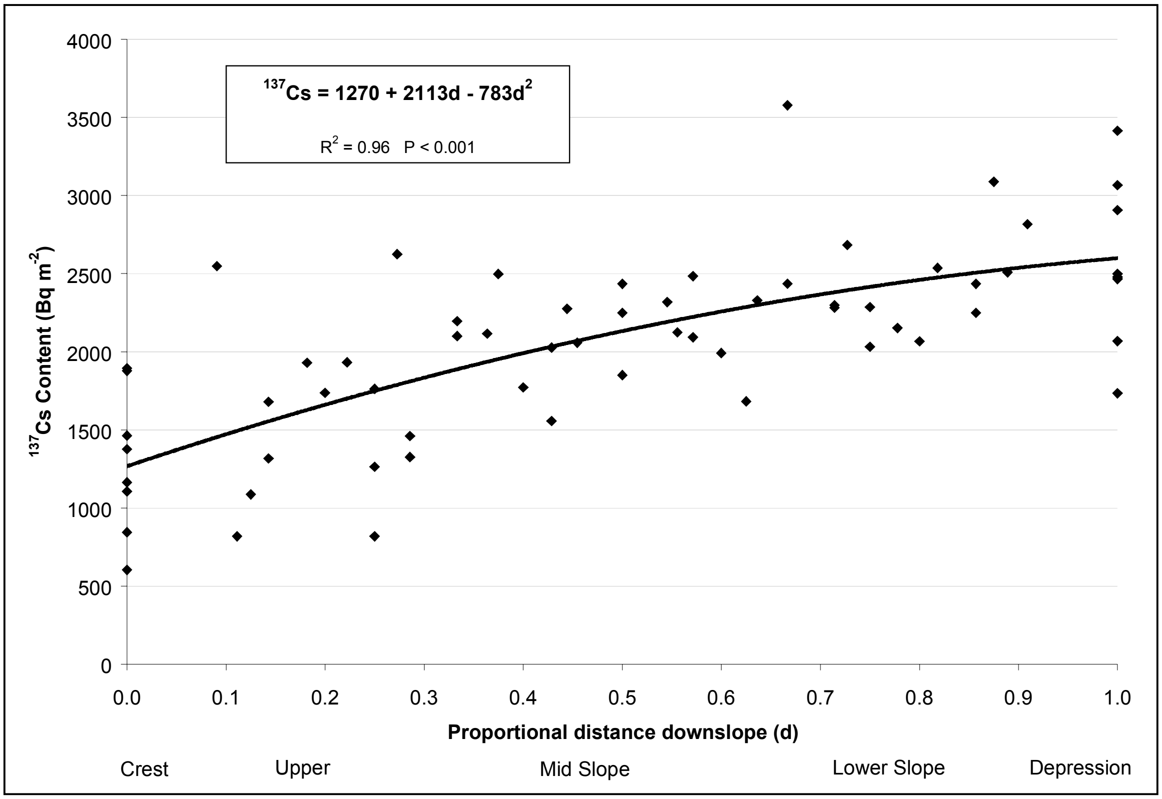


Figure 8. Relationship between ^{137}Cs content and proportional distance downslope at the cultivated site.

Figure 9 shows the frequency of ^{137}Cs redistribution (loss versus gain) for the sampling points. The distribution is positively skewed indicating more gain than loss: approximately 65% of the transect points incurred a ^{137}Cs gain, 8% had no change, and 27% lost ^{137}Cs.

The ^{137}Cs distribution for the cultivated site indicates the concomitant loss of soil across the hilltops and deposition on mid to lower slopes (Fig. 10). This pattern of ^{137}Cs activity down the slope indicates a close relationship between topography and soil erosion. Water erosion processes, exacerbated by tillage disturbance, were likely more significant than wind erosion due to the pattern of soil loss and deposition, and the absence of a net soil loss for the site (de Jong *et al.* 1983).

A balance of ^{137}Cs could not be calculated for the cultivated site due to the nature of the sampling design. The stratified random transect layout, used in this study, may not have captured all the contributing sites of soil loss and soil deposition in the surrounding landscape. Further, the length of the selected transects were not uniform (ranged from 40m to 110m). In addition, the areas occupied by various slope positions are not equal, which is the expected result. Crests and upper slopes occupy 22% of the sampled landscape, mid slopes 36%, lower slopes 28%, and depressions 13%. Presumably, the intensity of slope processes occurring between transects (and thus slopes) of different lengths would vary. Individual transect analysis may provide a better indication of soil redistribution and loss.

Another factor contributing to the incomplete accounting of ^{137}Cs is the effect of snow redistribution at the time of atmospheric ^{137}Cs deposition (de Jong *et al.* 1982). The probable accumulation of snow on lower slopes and depressions may indicate ^{137}Cs movement that is not accompanied by soil erosion. This situation may contribute to overestimates of deposition.

A Horizon Thickness and ^{137}Cs Distribution

The mixing of subsoil into the Ap through cultivation on hilltops (crests and upper slopes) affects the ^{137}Cs concentration of this uppermost topsoil layer. The comparison of hilltop ^{137}Cs concentrations for the two sites (Fig. 7) indicates a tendency towards lower ^{137}Cs levels at the cultivated site, although the difference is not statistically significant (P<0.05).

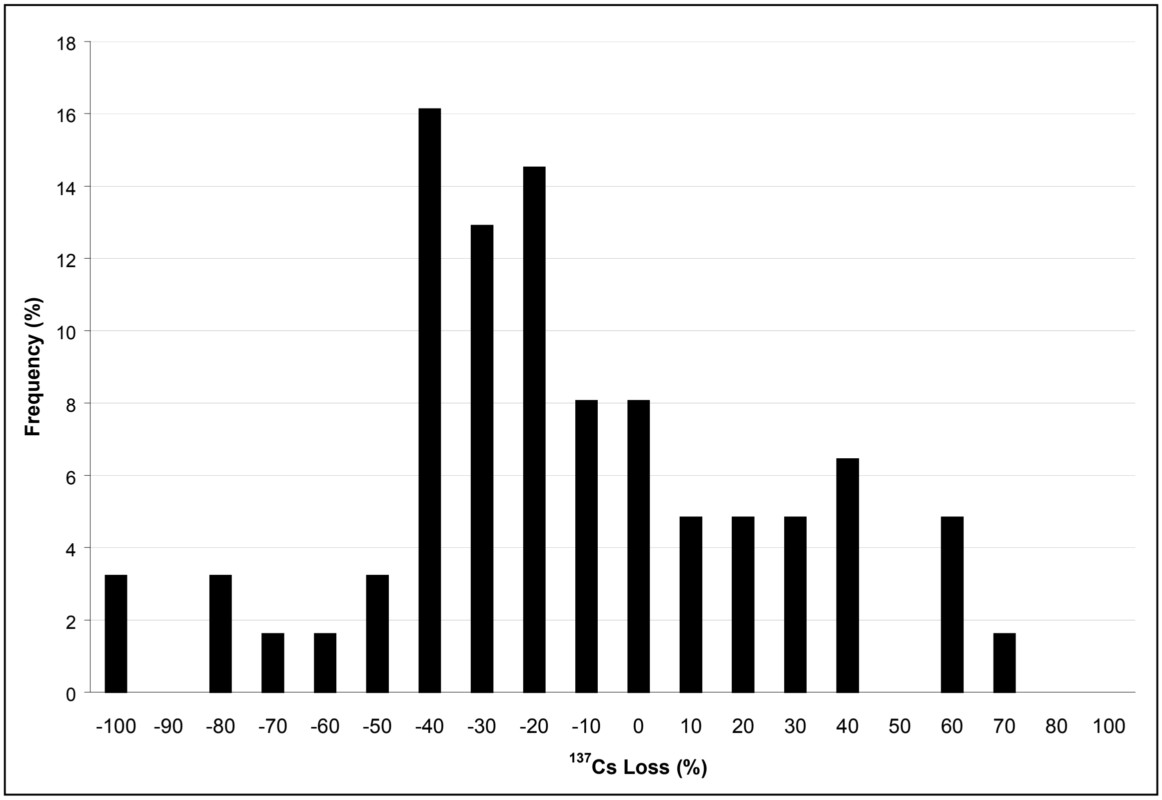


Figure 9. Frequency distribution of ^{137}Cs loss at the cultivated site.

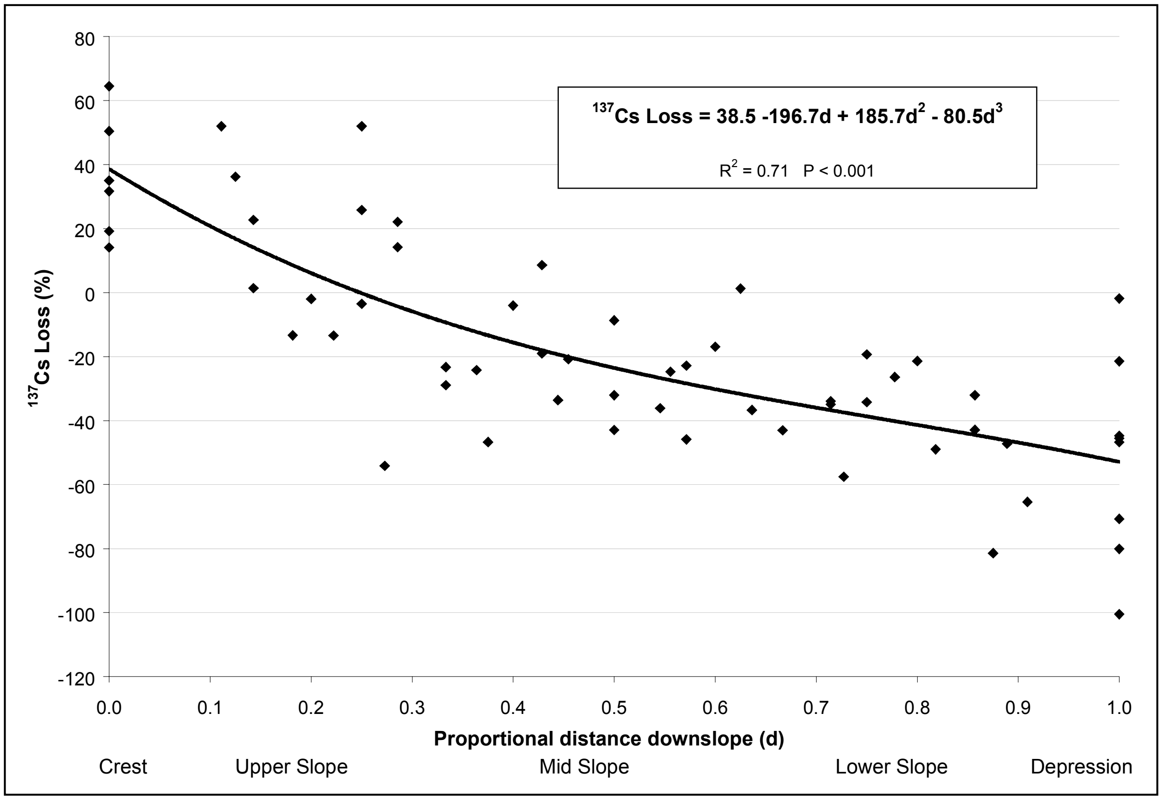


Figure 10. The relationship between ^{137}Cs loss (redistribution) and proportional distance downslope.

Figure 11 shows the average thickness of the uppermost A horizons found across both sites. Based on their very thin Ah horizons on the native site, hilltop soils would have been impacted most by cultivation. We can speculate at changes in the topsoil over the decades. Initial plowing (circa 1912, to a depth of 3-4 inches; pers. comm., Bill Carter) likely incorporated approximately 3 to 6 cm of B horizon with the Ah on the hilltops. As cultivation continued and the hilltops eroded, more and more of the subsoil materials became mixed into the Ap. Over time, the B horizon disappeared on most hilltops, becoming incorporated into the Ap through annual soil cultivation. After the B disappeared, underlying calcareous C material (Ck or Cca) was incorporated into the Ap. At some point, the cultivated topsoil became an Apk horizon, as is commonly found on the cultivated hilltops today.

Our results indicate that most of the material eroded from hilltops and some mid-slope sites over this time was likely deposited downslope. In fact, buried Ap or Ah horizons were common at some mid-slope and many lower-slope sites. The ^{137}Cs analysis should have captured the subsoil dilution and topsoil movement over the last 30-year period. After each erosion event, the dilution action of cultivation on topsoil (by incorporating subsoil) would lower the ^{137}Cs concentration. Over time, ensuing erosion events would exhibit less and less ^{137}Cs loss, even though similar or greater amounts of soil may be moving each time (de Jong *et al*. 1983, Kachanoski and de Jong 1984).

Net Soil Loss Estimates for the Cultivated Site

Methods that calculate soil losses assuming a direct link between ^{137}Cs levels and erosion (known as proportional methods, de Jong *et al*. 1983), without factoring in a temporal relationship, underestimate actual soil losses (Kachanoski and de Jong 1984, Kachanoski 1993). Equation 4 used here (power-function method, Kachanoski *et al*. 1992), takes into account tillage dilution by the mixing of underlying soil into the Ap, resulting in a power-function relationship between soil loss and ^{137}Cs loss that is dependent on time (Kachanoski 1993).

Estimates of net soil loss varied from 3.21 to -10.24 kg m^{-2} y^{-1}, with a mean loss rate of -1.87 kg m^{-2} y^{-1}. Figure 12 shows the relationship between rate of net soil loss and topography, expressed as proportional distance downslope. Note that sampling points with inordinately thick A horizons (total A depth ≥30 cm) appear as outliers. The hilltop slope positions incurred soil loss, while the lower slopes and depressional areas were sites of net soil gain. Other work on similar landscapes showed that soil erosion upslope results in deposition downslope, with overall net soil losses being minimal for the drainage basin (de Jong *et al*. 1983, Gregorich and Anderson 1985, Martz and de Jong 1987).

Mid slopes of the cultivated site were most variable, exhibiting features of both hilltops and lower slopes. The data indicate that the cultivated site experienced net soil gain overall. A few factors, linked to the methods used in this study, likely contributed to this apparent anomaly.

Equation 5, which corrects the underestimation of rates of deposition by Equation 4, may have actually overestimated deposition at some sampling points. Time is one factor here. The underlying assumption in Equation 5 is that the deposition of soil materials from upslope occurred within the last 30 years. In reality, a good deal of the deposition probably occurred prior to 1960.

De Jong and Kachanoski (1988) found that erosion estimates based on a comparison of total profile ^{137}Cs values from 1960 to 1980 were highly correlated with erosion estimates calculated from an equation like Equation 4. They also found that estimates based on comparing 1980's ^{137}Cs levels with nearby native sites were less well correlated. The authors attributed this to the degree of erosion and deposition that had occurred by the mid-1960s.

Morphological evidence at the native site (increasing Ah thickness downslope [Fig. 11] and the occurrence of buried Ah horizons) suggests that some deposition occurs naturally. This is likely another factor. Although Equation 5 is not based on ^{137}Cs levels, when used in conjunction with estimates from Equation 4, the results could become skewed.

Slope shape is another possible factor that contributed to the variability observed at the mid slope positions. As noted previously, the ^{137}Cs redistribution data showed a greater number of depositional sites than loss sites (Fig. 9). Pennock and de Jong (1990) caution that complete erosional assessments of an area need to consider both net soil loss from and mean soil loss within the study area. In this study, given the sampling design, there was no way to quantify the contributions of soil to depositional sites from surrounding slopes that were not monitored by transects. In fact, deposition of soil material from upslope, both parallel with and perpendicular to the transect, may have occurred on concave segments of four transects.

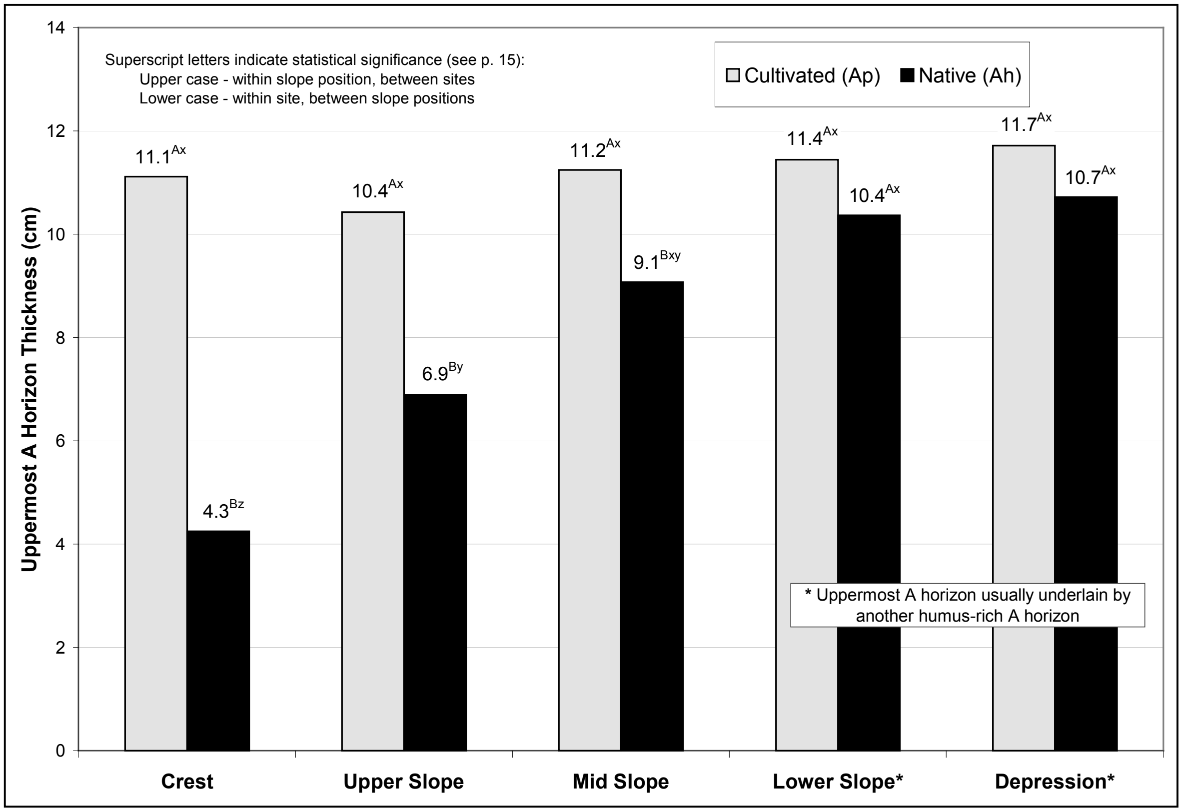


Figure 11. Comparison of the uppermost A horizon thickness at the native and cultivated sites.

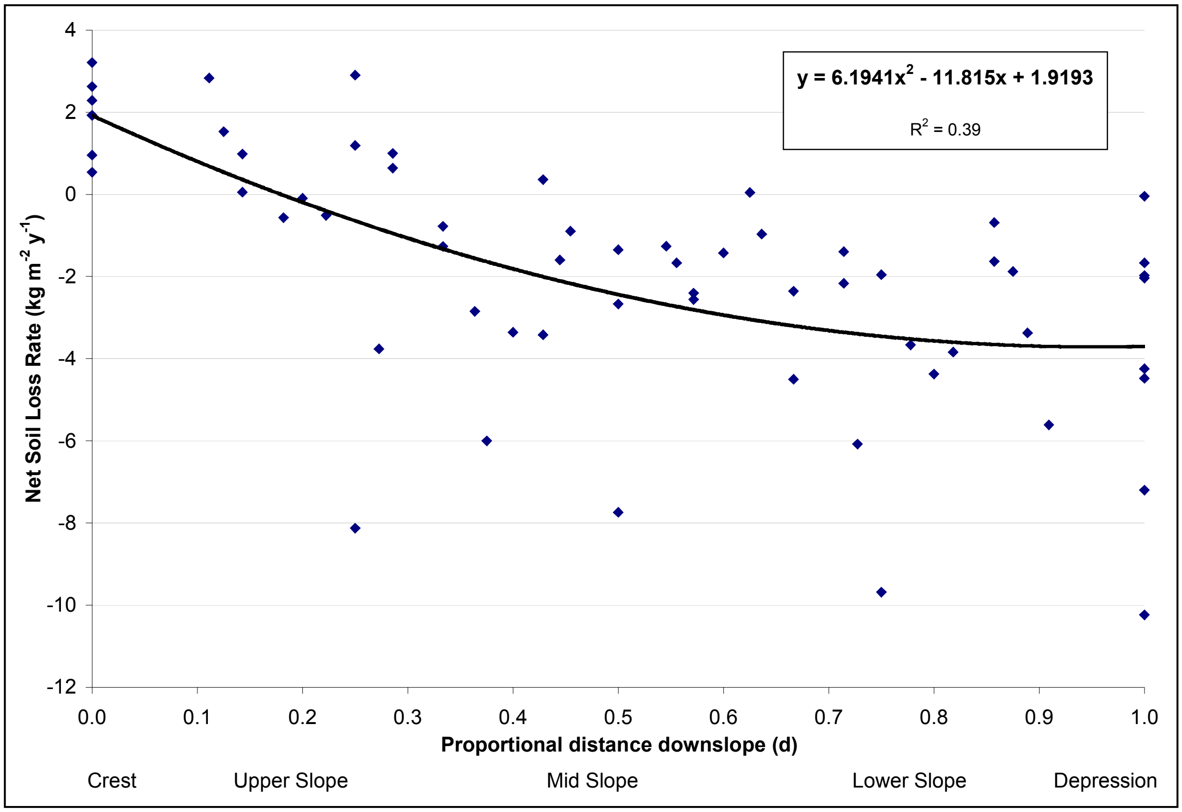


Figure 12. Relationship between net soil loss rate (E_n) and proportional distance downslope, cultivated site.

SOIL PROPERTIES AND SLOPE POSITION

A Horizon Thickness

One of the most striking differences between the sites is the type and thickness of the uppermost soil horizon i.e., the currently cultivated Ap or Apk horizon at the cultivated site and the Ah1 horizon at the native site (Fig. 11). The surface horizon at the cultivated site was mainly Apk on hilltops and Ap on mid slopes to depressions. Thickness of the plow layer was uniform. Hilltops at the cultivated site were clearly visible, when in fallow, by their grayish colors in contrast to darker soils on adjacent slopes.

The uppermost Ah horizons at the native site varied substantially in thickness from 4 cm on crests to 11 cm in depressions (Fig. 11). This systematic variability reflects the long-term impacts of different moisture regimes, plant communities, plant residue supply and entrapment, and natural erosion. Subsurface A horizons (Ah2, Ahe, or AB) were common at the native site, mainly in lower-slope and depressional areas. Unfortunately, too few of these were measured.

Even more variable was thickness of the entire humus-rich A horizon, or topsoil. Table 2 lists mean topsoil depth for all slope positions at both sites. Figure 13 shows the relative contributions of the 1990 Ap plus underlying A horizons to total A horizon thickness at the cultivated site. Ap contribution to topsoil thickness decreased from about 88% at the hilltop (mean topsoil thickness 11cm) to less than 50% at the bottom of the slope (mean topsoil thickness 26cm). This trend was consistent with ^{137}Cs findings and clearly showed the "upward migration" of the Ap as deposition occurred in the mid-, lower- and depressional slope positions. Moulin *et al.* (1994) and Gregorich and Anderson (1985) reported similar patterns in A horizon thickness. They concluded that erosion was the main factor responsible for thin A horizons on eroded knolls and thick A horizons in concave slope positions.

A Horizon pH

Dramatic differences in pH of cultivated Ap versus native Ah horizons emphasize the impact of cultivation across the landscape (Fig. 14). The pH of cultivated hilltops averaged almost 2.5 units more than in lower slopes and depressions. In the native landscape, there was only about 1.0 unit difference. These higher pH values reflect the incorporation of calcareous subsoil into the Ap. With carbonate contents of 1 to 11%, pH values averaging 7.5 are not surprising in such soils. While the alkaline soil reaction and the presence of carbonates are not intrinsically detrimental to crop growth, interactions with nutrients like P may reduce P availability.

In contrast, the acidic pH's that dominate the lower slope and depressional locations are borderline for optimum crop growth, and may become an issue if acidification progresses. Acidification in lower-slope positions may have been enhanced by management activities, but the trend does not hold in depressions (Fig. 14).

The wide range in pH at the cultivated site affects herbicide management for weed control. Herbicides belonging to the chemical family Sulfonylurea (e.g. GLEAN®) degrade slowly at pH 7.5 and greater, and can leave residues that are harmful to some crops for several years after application in high pH soils (Ahrens 1994). Further, the Sulfonylurea herbicides tend to be moderately mobile at high pH. In contrast, herbicides of the Imidazolinone family (e.g. PURSUIT®) bind more readily to organic matter and clay below pH 6.5, decreasing their degradation (Ahrens 1994). Anaerobic conditions will exacerbate the situation, severely hampering degradation of Imidazolinone herbicides. Some of the low pH soils at the cultivated site are also occasionally inundated, and experience anaerobic conditions for at least part of the growing season.

Organic C and Total N

The difference in organic C and total N contents between native and cultivated sites is much greater than differences among slope positions within each site (Fig. 15 and 16). Cultivated Ap horizons have roughly one-third the organic C content of native Ah horizons. These findings are consistent with previous studies which estimated that for the Canadian and American prairie, the last 80-90 years of cropping have resulted in an approximate decrease of 40-60% (wt:wt basis) of original soil organic matter content (Campbell *et al.* 1976, McGill *et al.* 1981).

A fairer comparison would consider layers of about equal thickness – the primordial Ap with today's Ap. This was accomplished by calculating organic C and total N content in a "simulated plow layer" 11 cm thick, using native site data for crest, upper-slope and mid-slope positions. Results for this simulated Ap (Fig. 15 and 16) suggest that the primordial Ap horizon on hilltops and mid slopes had 40-60% the organic C and total N content of the native Ah.

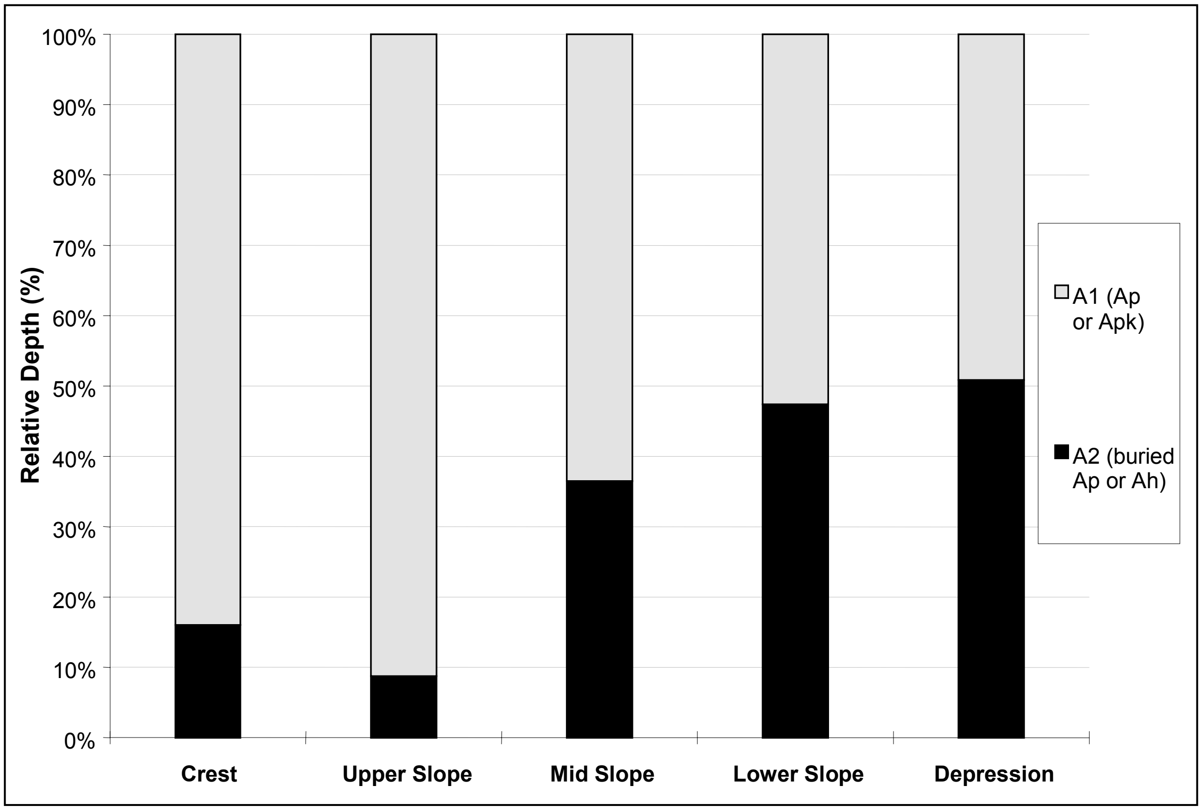


Figure 13. Relative contributions of Ap and underlying A horizons to total topsoil depth at the cultivated site.

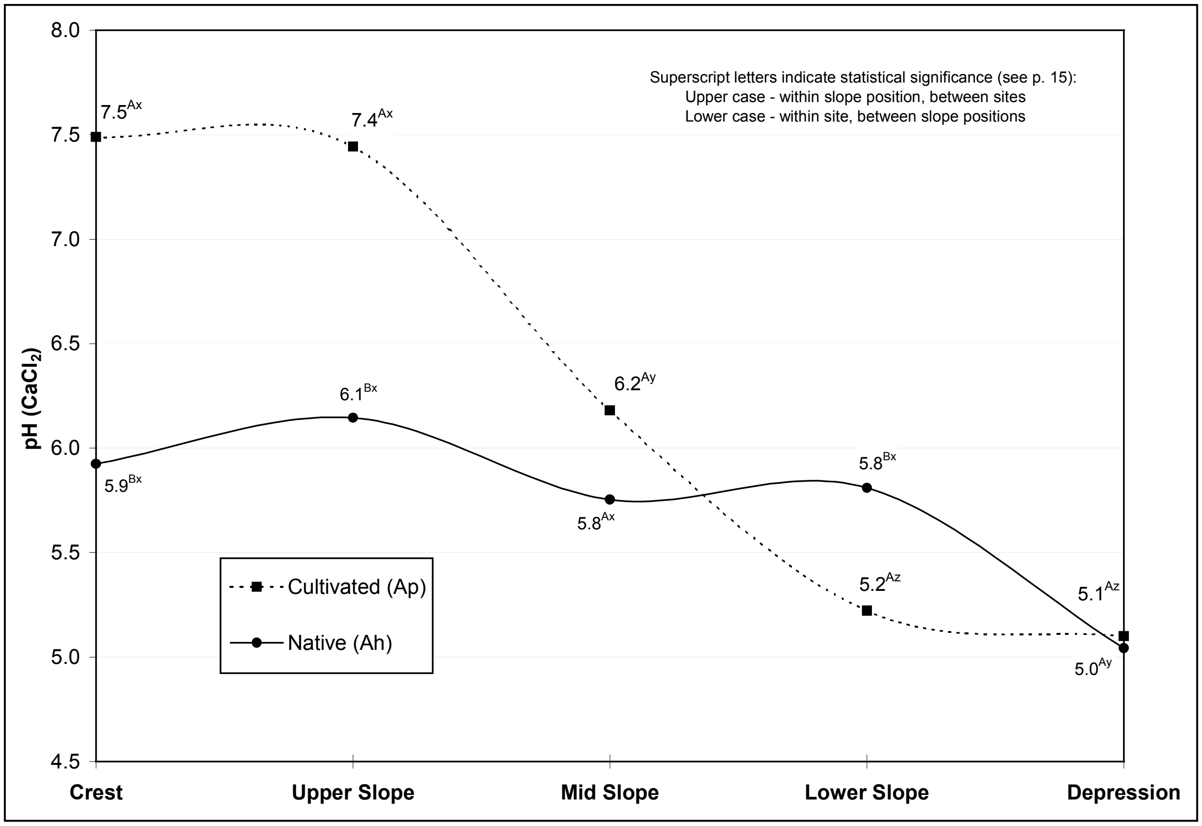


Figure 14. Comparison of pH in cultivated and native horizons.

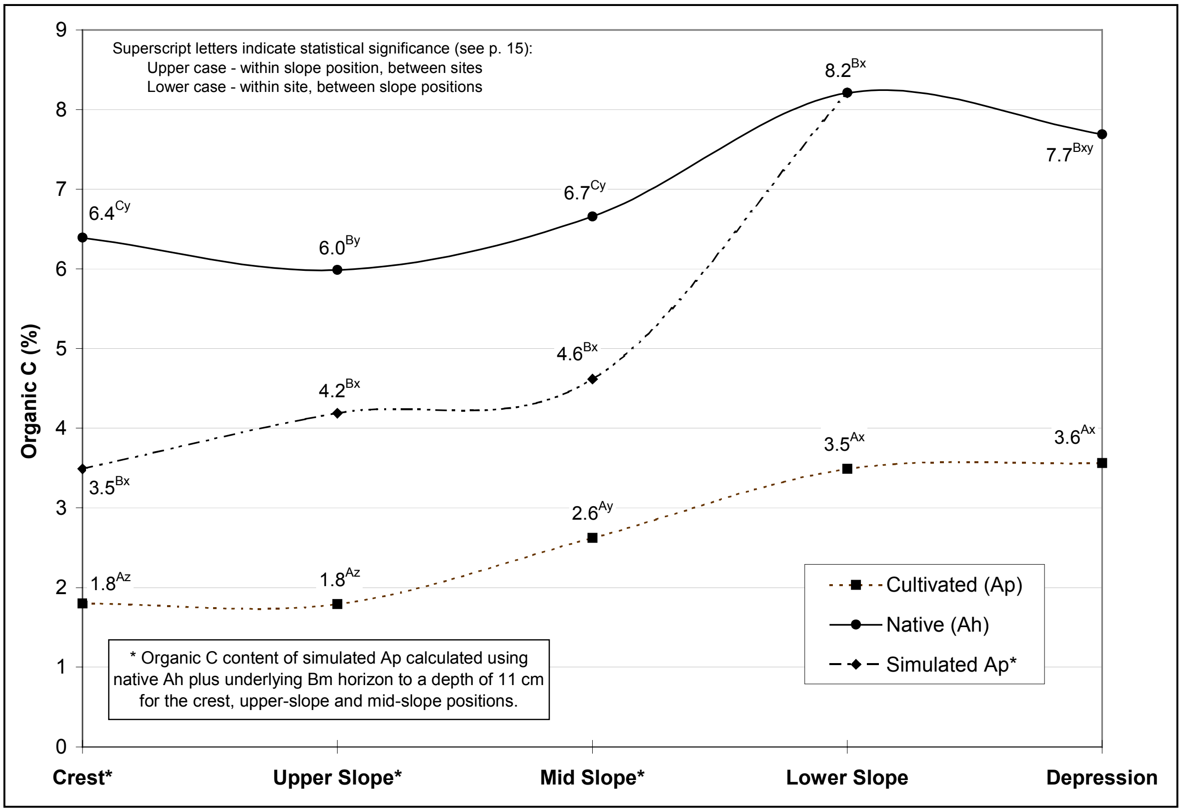


Figure 15. Comparison of the organic C content in the cultivated Ap, simulated Ap and native Ah horizons.

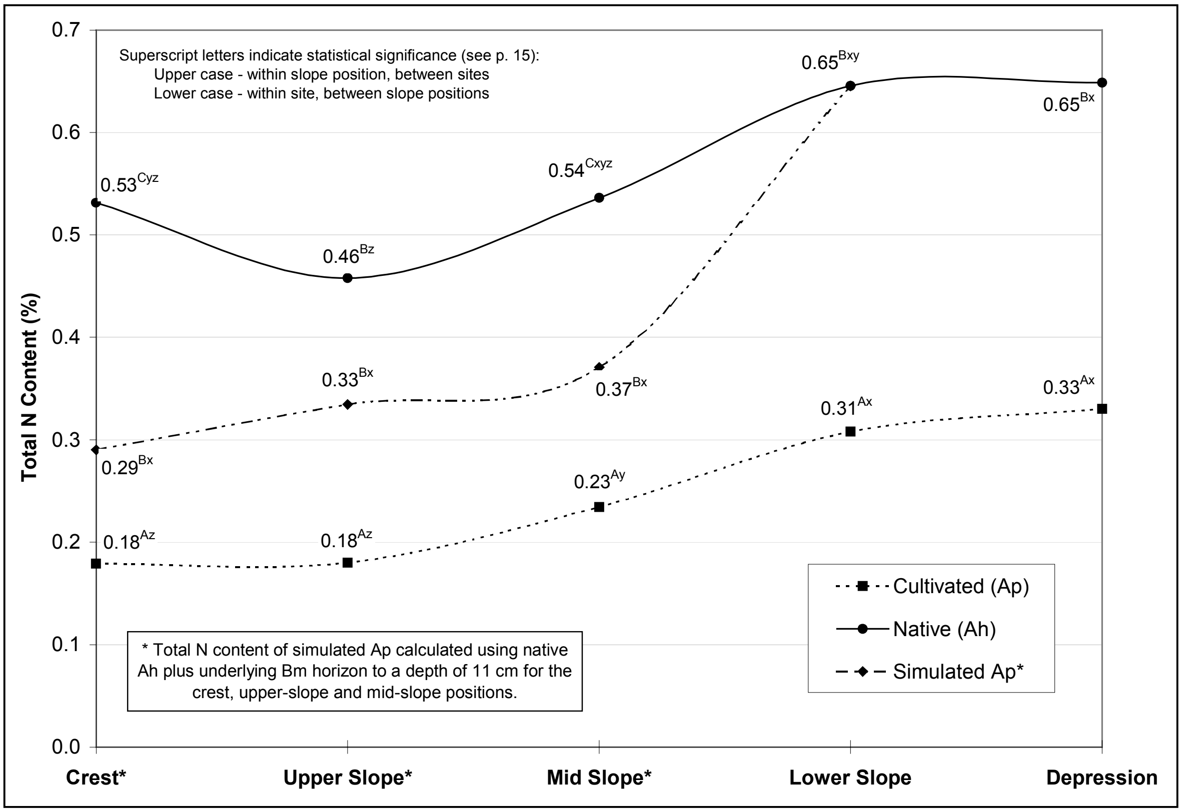


Figure 16. Comparison of the total N content of the cultivated Ap, simulated Ap and Native Ah horizons.

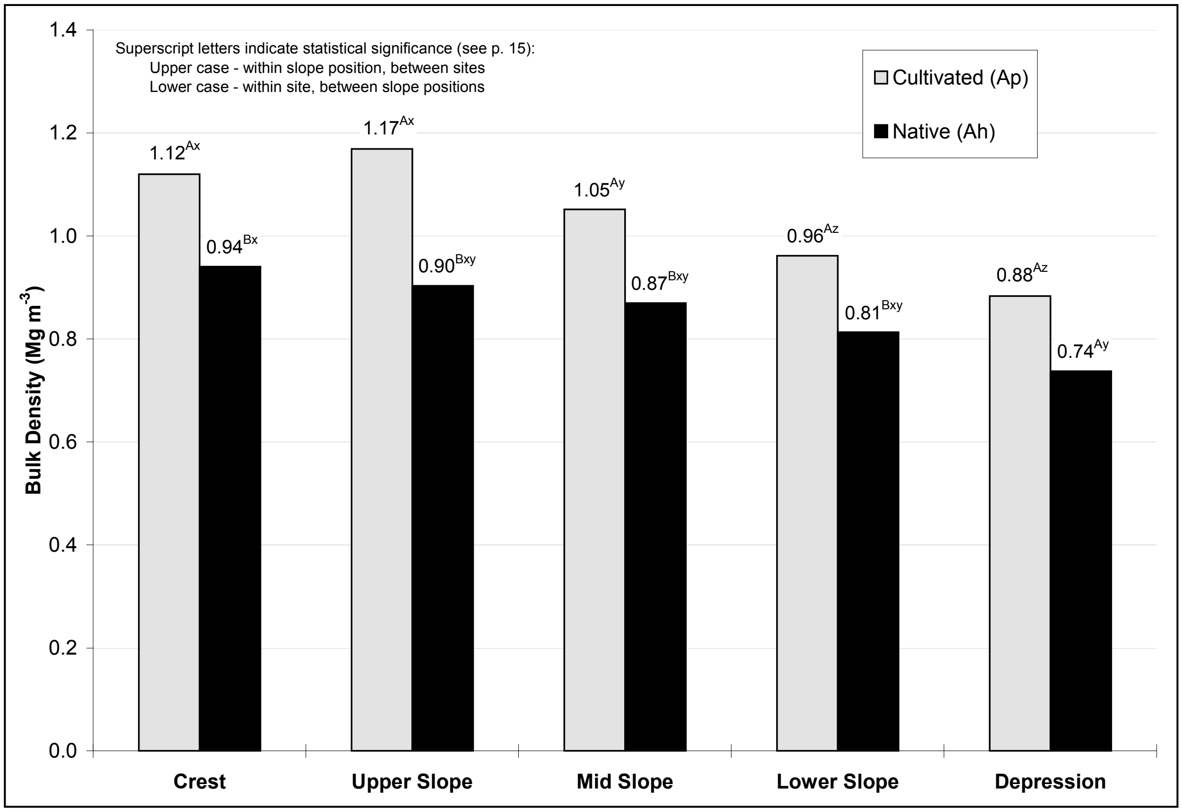


Figure 17. Bulk density comparison of the uppermost A horizons at the native and cultivated sites.

In other terms, roughly half of the perceived “loss” of organic C and total N may be attributed to an initial “dilution effect” caused by cultivation where the native topsoil was thin. Results were similar when expressed on a mass basis. Organic C and total N of the cultivated Ap were 44% and 36% lower, respectively, than levels in the simulated Ap. Bulk density and thickness data for the A and underlying horizons were used in these calculations. Note that the A horizon bulk densities were significantly lower ($P<0.05$) at the native site than the cultivated site (0.85 and 1.04 Mg m^{-3}, respectively, Fig. 17).

Loss of organic C in cultivated agroecosystems occurs through three main processes: reduced C inputs, increased rates of organic matter mineralization, and increased soil erosion (Juma and McGill 1986, Campbell and Souster 1982). From studies comparing zero and conventional tillage systems, there is evidence that tillage alters soil physical properties, substrate availability and/or accessibility to decomposers, and soil organism habitat (Doran *et al.* 1987, Hendrix *et al.* 1986, House *et al.* 1984). Through disruption of aggregates and relocation of substrates and decomposers, organic C and N previously hidden become mineralized to CO_2 (lost to the system) and mineral N (NO_3^- and NH_4^+) after cultivation. Consequently, cultivated systems exhibit increased rates of mineralization and soil organic matter degradation.

This loss of organic C and total N impacts the quality of soil organic matter and influences the erodibility of the soil, potentially increasing its susceptibility to further losses. During the first 35 years, harvesting operations at the cultivated site removed most of the above ground plant material. This practice, in combination with plowing, would have contributed to the decline in C and N levels. Crop residues have been returned to the soils since the combine was introduced in 1947.

Inputs of N are increased in managed systems, emphasizing the mineral N pool. Losses of N occur not only through increased mineralization and erosion, but also with the export of grain from the system. Studies examining the N balance between N input in fertilizers and N export in grain have shown that there has been large net deficits in N across the prairies due to farming (Doyle and Cowell 1993, Curtin *et al.* 1993). Campbell and Zentner (1995) noted that in the 1940s and 1950s the effects of farming had not noticeably impacted N-supplying power of soils. The selective decrease in potentially mineralizable N over other forms of soil N due to crop production has resulted in N being the dominant nutrient applied by prairie farmers today.

At the cultivated site, the early (1912 to ~1950) practices of removing crop residues with no addition of exogenous N would have depleted the N-supplying reserves of the soils. Decline in soil N might have been mitigated with the retention of straw in 1947 and the introduction of 11-48-0 fertilizer in 1950 (Walker and Wang 1994). Introduction of fertilizer high in N (34-0-0) at the cultivated site in 1977 indicates that the depletion of available N reserves was likely beginning to limit production. Based on annual soil testing, the need for fertilizer N has decreased slightly in recent years, possibly signifying a buildup of N reserves.

The amount of N lost in managed systems is a function of the timing and rates of N application, cropping system, period of cultivation, and moisture regime (Juma and McGill 1986, Tiessen *et al.* 1982). In well-managed systems, losses can be as little as 1-5% of added N (Juma and McGill 1986). The Carter's, owners and managers of the sites, have now developed a flexible, well-considered set of management practices for their area (Walker and Wang 1994). The operational procedures consider plant nutrient demand (banding 12-51-0 with seed), moisture regimes (anhydrous N applications), residue management, and annual soil testing to adjust fertilizer application rates. Considering the decreased need for fertilizer N at the cultivated site, the current suite of management practices appears to be maintaining or possibly improving soil N levels.

Soil Loss Estimates

Organic C and total N content of the contemporary Ap horizon clearly increase as proportional distance downslope increases (Figs. 18 and 19) at the cultivated site. Trends for these soil elements were not observed for the native site ($R^2 \approx 0.20$).

The downslope increase in organic matter components can be attributed to several factors. Two of these include downslope moisture redistribution resulting in increased biomass production and soil organic matter accumulation (Roberts *et al.* 1989), and deposition of materials eroded from upslope (Gregorich and Anderson 1985, Verity and Anderson 1990, Pierson and Mulla 1990). The relative contribution of either process is unclear and confounded by the fact that increased organic C levels cause increased moisture retention.

De Jong and Kachanoski (1988) compared 1960 and 1980 ^{137}Cs and organic C levels on upper- and mid-slope soils, cultivated since the early 1940's. They concluded that erosion and deposition were largely responsible for observed organic C changes over the 20-year period. Further, their results indicated that as the period of cultivation increased, the dominant mechanism of C loss changes from net mineralization to erosion.

Similar results were obtained by Gregorich and Anderson (1985), who examined C loss from soils on four Orthic Black Chernozemic toposequences. Three had been cultivated since 1910, 1930 and 1961; and the fourth was a native toposequence. They concluded that of C lost on upper slopes, the greatest proportion could be attributed to mineralization in the early years of cultivation, while erosion predominated in the later years. Their results showed that, after 20 years of cultivation, 20% of the loss was due to erosion, and after 50+ years of cultivation, over 70% of the loss could be attributed to erosion. They attributed the greater total losses and rates of mineralization seen in the older toposequences (1910 and 1930) mainly to inclusion of summerfallow in crop rotations and to harvesting methods used prior to 1948 when combine harvesters were introduced. Very similar management activities were followed at the cultivated site in this study.

Tables 3 and 4 show estimated carbon losses. In this study, we estimated that 46, 27 and 38% of the perceived C loss on crest, upper-slope and erosional parts of mid-slope positions, respectively, can be attributed to tillage dilution. Tillage dilution involves the incorporation of subsoil materials, which have lower C content, into the plow layer. Tillage dilution was not considered to be a factor in C content reduction for lower and depressional slope areas due to the occurrence of naturally thicker A horizons (Fig. 11).

The proportion of organic C loss due to erosion was over 60% for hilltops and about 30% for the erosional segments of mid-slope positions. Thus, erosion and tillage dilution were the two dominant factors for depletion of organic C at the crest and upper-slope positions (hilltops).

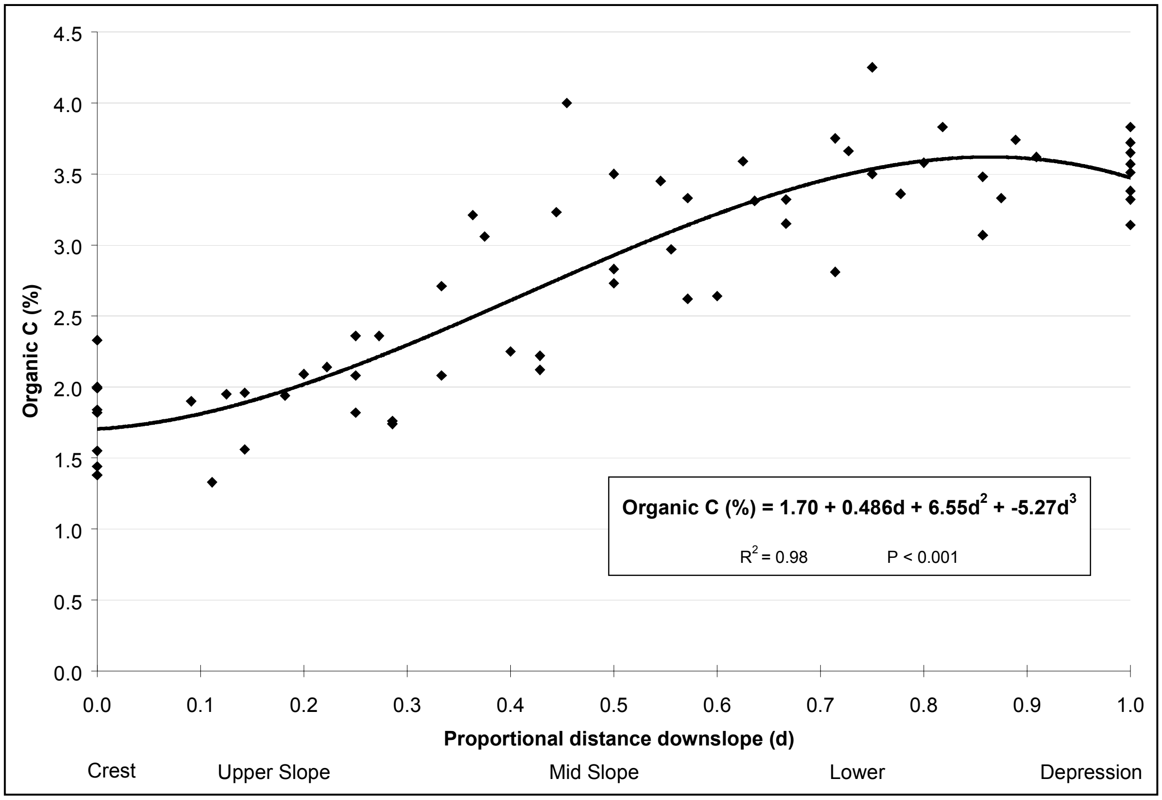


Figure 18. Relationship between organic C content and proportional distance downslope at the cultivated site.

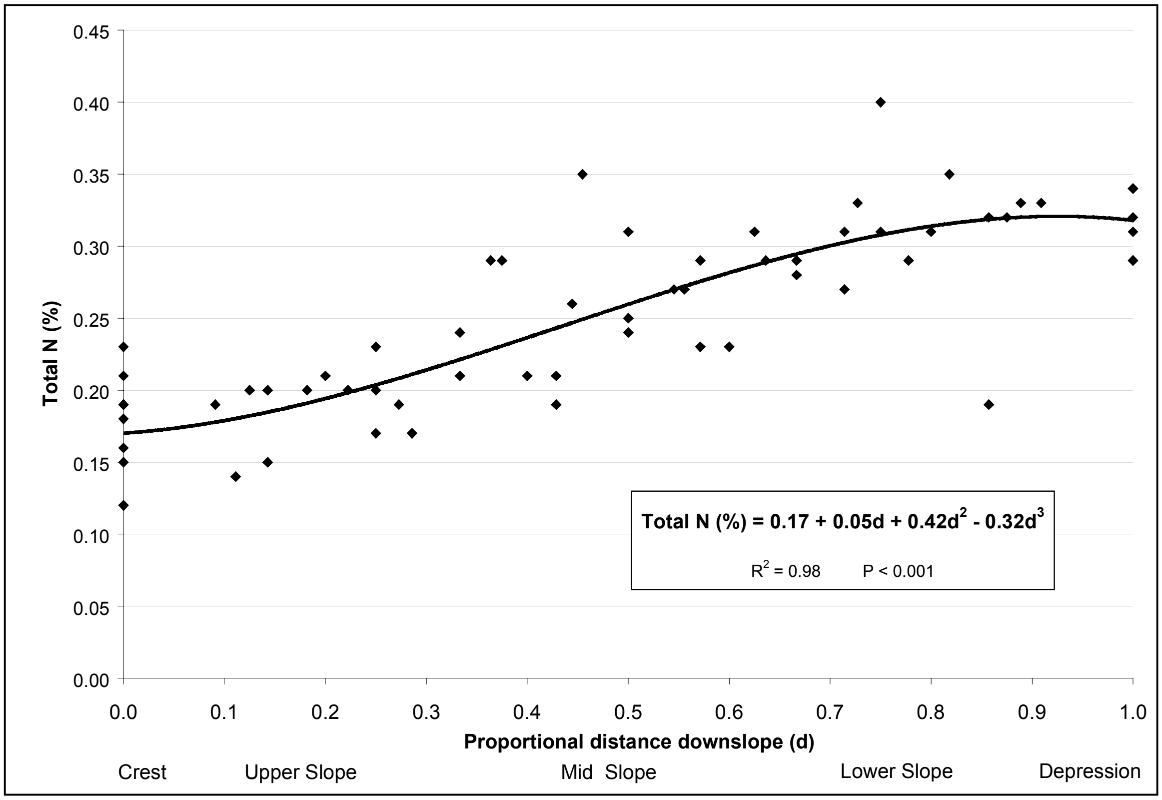


Figure 19. Relationship between total N content and proportional distance downslope at the cultivated site.

In the erosion calculations; it was assumed that the net erosion rate (E_n in kg m^{-2} y^{-1}) calculated from the ^{137}Cs data (last 30 y period), was constant for the entire 80 year period of cultivation. This assumption likely overestimated the contribution of erosion to C loss, since decreases in organic C due to mineralization (over the first 20 to 30 years of cultivation) would have increased soil erodibility (de Jong and Kachanoski 1988, Pierson and Mulla 1990).

The proportion of organic C lost through mineralization increased downslope: 0, 15, 36, 61, 100 and 100% for crest, upper-, erosional mid-, depositional mid-, lower-, and depressional slope positions, respectively (Table 4). Estimates of mineralization for the depositional slope positions are very conservative since additions from the eroded upper-slope positions were not considered in the calculations. It is difficult to quantify the amount of soil redistribution along the transects and determine the eventual sites of deposition of soil from upslope soils. If we assume that eroded materials are largely deposited on lower- and depressional slope areas, we can add the average amount of organic C lost by erosion on the hilltops (2.31 kg m^{-2}) to the average lower- slope total loss estimates (3.25 kg m^{-2} + 2.31 kg m^{-2}). Consequently, the average amount of organic C lost to mineralization on lower slopes (roughly 5.60 kg m^{-2}) is twice the amount lost to erosion on hilltops (2.31 kg m^{-2}). These findings are consistent with Gregorich and Anderson (1985) who demonstrated that in the lower-slope areas, organic matter losses are higher due to high rates of mineralization, despite gains of upper-slope materials.

Losses of total N at each slope position are similar to the relative magnitude of organic C loss on a percent basis (Fig. 19). Assuming losses on a mass basis are also similar to the C patterns, and taking into account the effects of tillage dilution for upper-slope soils, the lower-slope and depression areas show the greatest losses of total N (over 50%).

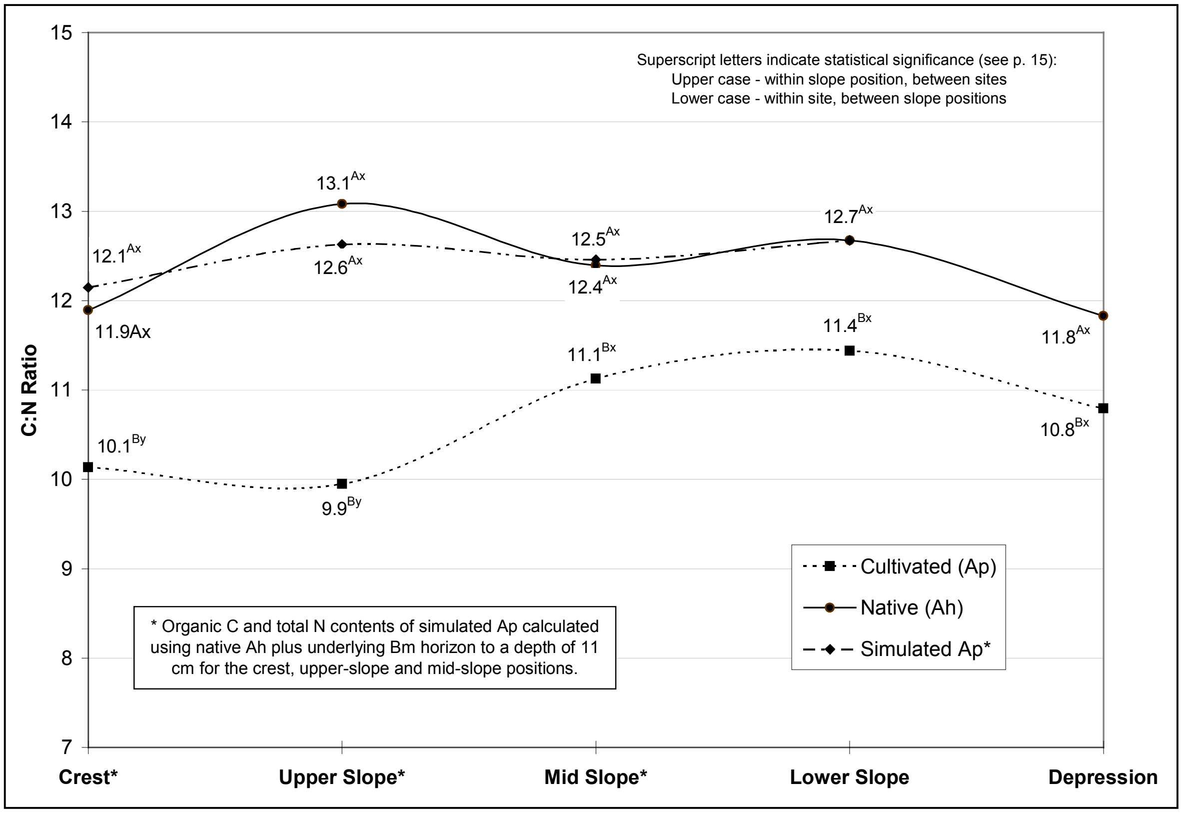
C:N ratios augment the carbon picture. The overall difference between native (including simulated Ap) and cultivated sites (Fig. 20) affirms faster organic matter mineralization under cultivation. Most affected by cultivation and the amount and characteristics of C inputs is the light fraction (LF) organic matter, which normally has a wide C:N ratio (Gregorich and Ellert 1993). Plant residue returned in the cropping system is likely lower than in the native system, resulting in little light-fraction organic matter in the cultivated soils.

The difference in C:N ratios on the hilltops illustrates the role of plant residue. Under cultivation, return of crop residue to the soil has likely been the least on hilltops due to lower yields over the long term. In addition, fresh plant residue and light-fraction organic matter were likely more susceptible to erosion from hilltops. In the native landscape, well established grass communities and minimal erosion on hilltops promoted entrapment and accumulation of plant residue for decay.

Gregorich *et al.* (1994) suggest that the soil C:N ratio may provide insight into the capacity for recycling and storing energy. In short, native grassland soils tend to have wider C:N ratios, whereas agricultural soils, due to the effects of practices like cultivation, fertilization and residue management, tend to have narrower C:N ratios with less variability.

This study was no exception. Figure 20 depicts the C:N ratio of soils at each slope position for the cultivated and native sites. On average, the native site had wider C:N ratios than the cultivated site ($P<0.05$). Further, the C:N ratio did not vary across slope positions at the native site. The narrower C:N ratios at the cultivated site are in part due to greater losses of C (CO_2 evolved through respiration) relative to N and the effects of fertilization (Verity and Anderson 1990).

The crest and upper-slope soils of the cultivated site had significantly lower C:N ratios than the mid- and lower-slope positions. These results are common for soils of this kind, where ratios typically widen downslope due to increased moisture and biomass production. Roberts *et al.* (1989) noted that the increased biological activity in soils at the lower-slope positions would likely have decomposition and humification processes similar to Black Chernozems; hence, the wider C:N ratios. The lower C:N ratios of soils on the hilltops reflect the incorporation of subsoil materials with lower C:N ratios into the plow layer (Roberts *et al.* 1989, Stevenson 1959).



Superscript letters indicate statistical significance (see p. 15):
Upper case - within slope position, between sites
Lower case - within site, between slope positions

* Organic C and total N contents of simulated Ap calculated using native Ah plus underlying Bm horizon to a depth of 11 cm for the crest, upper-slope and mid-slope positions.

Figure 20. Comparison of C:N ratio in the cultivated Ap, simulated Ap and native Ah horizons.

Table 3. Calculation of organic C losses in the landscape (values in kg C m^{-2} unless otherwise stated).

Slope Position	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**
	1990 Organic C			**OC Diff.**[b]	**E_n**[c]	**Organic C Loss Due to:**[f]			
	Ap	Simulated Ap[a] (kg C m^{-2})	Ah	Sim. Ap - Ap (kg C kg $soil^{-1}$)	Erosion Rate (kg m^{-2} y^{-1})	Tillage Dilution **(Col. 3-2)**	Erosion + Mineralization[d] **(Col. 2-1)**	Erosion[e] **78(Col. 4x5)**	Mineralization **(Col. 7-8)**
Crest	2.2	4.5	6.4	0.017	1.9	1.9	2.3	2.6	0.0
Upper-Slope	2.3	4.8	5.7	0.024	1.1	0.9	2.5	2.0	0.5
Erosional	2.7			0.023	0.6		2.3	1.0	1.2
Mid-Slope[g]		5.0	6.2			1.2			
Depositional	3.2			0.028	-3.0		1.8	0.0	1.8[i]
Lower-Slope	3.7	7.2	7.2	0.047	-3.2	0.0[h]	3.5	0.0	3.5[i]
Depression	3.7	6.7	6.7	0.042	-4.3	0.0[h]	3.0	0.0	3.0[i]

a Simulated Ap calculated using C (%), thickness and bulk density estimates for the native Ah and underlying B to 11 cm total depth for crest, upper- and mid-slope positions. Assumed no dilution of topsoil at lower-slope and depressional positions.

b Organic C difference (kg C per kg of soil) = difference in organic C levels between simulated Ap and cultivated Ap. Assumed no significant dilution effects at lower-slope and depressional positions.

c E_n = net soil erosion rate (kg soil m^{-2} y^{-1}) calculated from ^{137}Cs data. Positive values indicate erosion; negative values mean deposition.

d Erosion does not apply to depositional positions (mid-slope depositional, lower slope and depression).

e Organic C loss due to erosion = 78y x absolute values of E_n (kg m^{-2} y^{-1}) x kg organic C kg $soil^{-1}$. E_n rate assumed constant over the 78-y period of cultivation.

f Displayed values have been rounded; mathematical sums and products of these numbers may therefore appear imprecise.

g Mid-slope positions are transitional, and were separated into depositional and erosional segments (based on E_n values).

h Average horizon thickness for lower-slope and depressional positions was over 11 cm, therefore tillage dilution was not a factor.

i Mineralization estimates assumed no soil losses beyond the hillslope, and are modest because upslope additions were not considered.

Table 4. 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:**			**E_n (Erosion Rate)** (t ha^{-1} yr^{-1})[g]
		Tillage Dilution[d]	**Erosion**[e]	**Mineralization**[f]	
Crest	4.2	46	61	0	19
Upper-Slope	3.5	27	58	15	11
Mid-Slope Erosional	3.4	38	30	36	6
Mid-Slope Depositional	3.0		0	61	-30
Lower-Slope	3.5	0	0	100	-32
Depression	3.0	0	0	100	-43

a The mid-slope position is most extensive and transitional from erosional hilltops to depositional lower slopes. Mid-slope sampling points were therefore placed in either erosional or depositional segments based on their individual E_n 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 over-estimated 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 was only an apparent loss since the same mass of organic C was present, but now in a new "Ap" horizon that was 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 (E_n) 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 E_n = net soil erosion rate (t ha^{-1} yr^{-1}) calculated from ^{137}Cs data. Positive values mean net erosion, negative values net deposition.

Soil Physical Properties

On average, the bulk density (Fig. 17, see page 28) of the uppermost A horizon at the cultivated site was greater ($P<0.05$) than at the native site (1.04 and 0.85 Mg m^{-3}, respectively, Table 1, pp. 17-18). Given the large differences in organic matter between the two sites, these findings are not unexpected.

There was a slight, albeit significant ($P<0.05$), decline in bulk density from hilltops to depressions at both sites. This response in bulk density downslope is consistent with the erosion/deposition patterns and the organic C and total N results shown earlier. Average total porosity, calculated from bulk density values (assuming a particle density of 2.65 Mg m^{-3}), was higher at the native site (68%) compared to the cultivated site (61%). It can be assumed that total porosity would increase downslope at both sites, following the bulk density trends.

On average, the saturated hydraulic conductivity (Ksat) for the 15-25 cm depth interval was greater ($P<0.05$) at the native site (Fig. 21). The greatest differences were seen on hilltop and depressional slope positions. Slope position had no effect on saturated hydraulic conductivity at the cultivated site. Studies comparing the soil physical structure under zero-till and conventional tillage demonstrate that less disturbance of the soil creates an open and continuous network of pores (Francis *et al.* 1987). Sequi *et al.* (1985) observed a greater proportion of elongated pores between the sizes of 30 to 500 µm with reduced tillage, and thus greater pore continuity. These phenomena, in conjunction with the increased porosity and lower bulk density observed at the native site, are likely responsible for the higher hydraulic conductivity values.

A general decline in saturated hydraulic conductivity (Ksat) was evident for the 15-25 cm depth, from the crest to the lower slopes at the native site, with resurgence in conductivity in the depressions. Edwards (1988) observed a similar trend with slope for the 0-15 cm depth interval of cultivated soils of Prince Edward Island; hydraulic conductivity was greater on hilltops than mid- or lower-slope positions, regardless of the cropping pattern.

The relationship with slope was less evident for the 30-40 cm depth interval at the native site (Fig. 22). Further, at this depth the two sites were similar in hydraulic conductivity, with the exception of the lower-slope position. Results from the 5-10 cm depth interval at the cultivated site were highly variable and changed with tillage; hence, measurements at this depth were discontinued.

Average maximum penetration resistance in the 10-20 cm depth interval of soils at the native site was over twice that of the cultivated site (2.9 vs. 1.3 MPa, respectively), indicating more stable soil structures, e.g., strong aggregation, at the native site ($P<0.05$). Further, resistance decreased downslope at the native site (Fig. 23), while at the cultivated site there was little relationship with slope position. Gravimetric moisture content of the 10-20 cm depth, measured at the same time as penetration resistance, was similar, on average, for the two sites (Fig. 24).

Variation in penetrometer resistance is largely related to soil water content and bulk density. However, Carter (1988) notes that other factors such as pore size distribution, particle size, organic C content and soil structure can affect penetrometer resistance. Presumably, the differences seen in penetration resistance at the 10-20 cm depth are related to differences in total porosity, bulk density, structural stability, and organic C rather than moisture. Moisture contents increased downslope at both sites for the 10-20 cm depth interval, in part explaining the decreased resistance with slope position at the native site (Coote and Ramsay 1983).

Maximum penetrometer resistance over the 20-30 cm depth interval was almost 3 times greater at the native site, on average, than at the cultivated site (Fig. 25). In this case, the hilltop's (i.e. crest and upper-slope positions) 20-30 cm depth interval had nearly twice the water content at the cultivated site as compared to the native site (Fig. 26). This may account for the large differences in penetrometer resistance seen between the two sites for these higher slope positions.

Like the 10-20 cm depth interval at the cultivated site, maximum penetration resistance for the 20-30 cm depth interval did not vary appreciably with slope position. At the native site on the other hand, penetration resistance showed a distinctive decrease downslope. Toposequence patterns in soil water content at this depth interval explain in part the decrease in resistance at the native site.

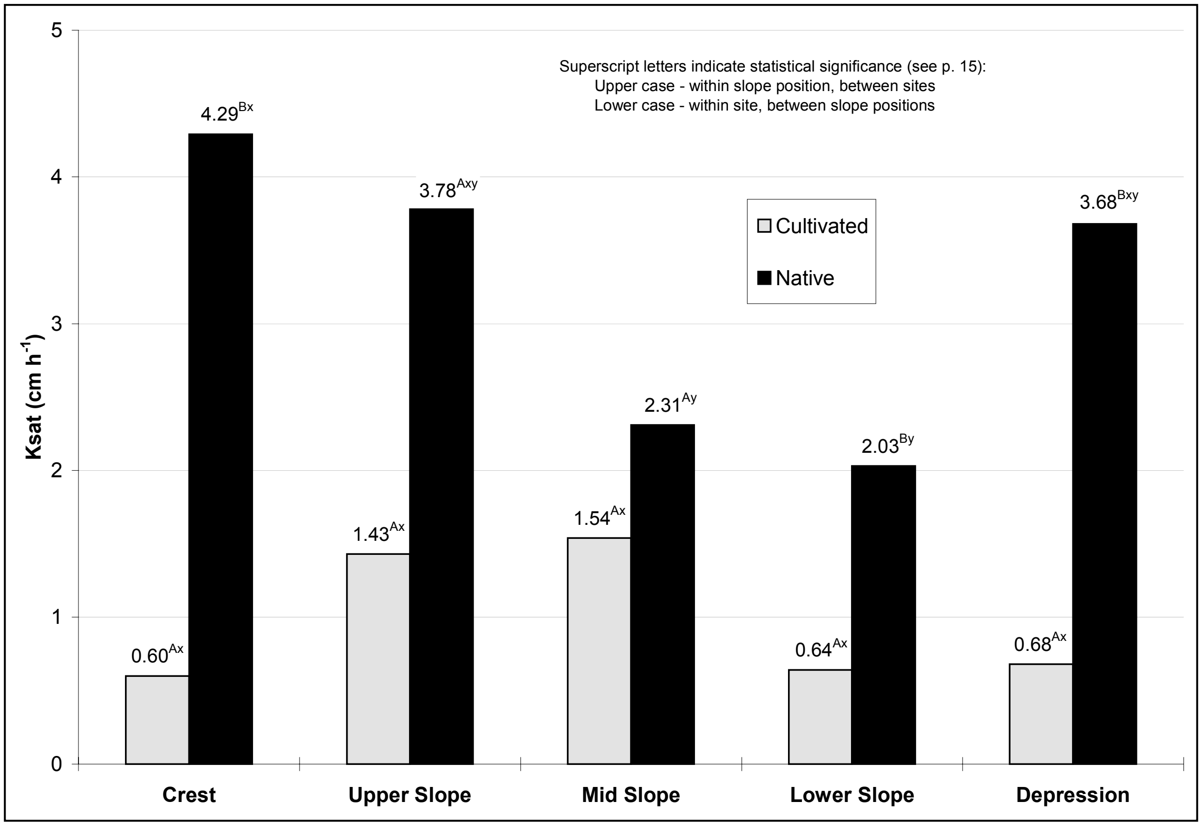


Figure 21. Saturated hydraulic conductivity at the 15-25 cm depth interval for both sites.

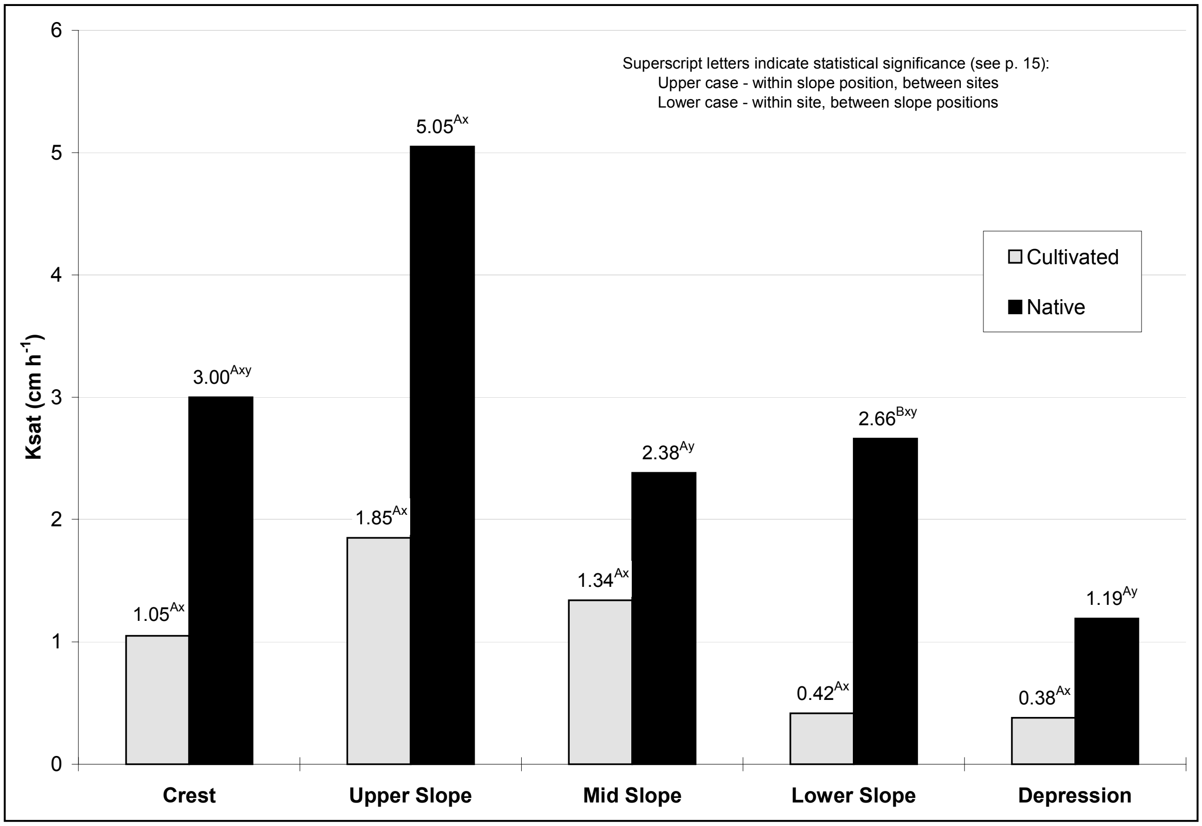


Figure 22. Saturated hydraulic conductivity at the 30-40 cm depth interval for both sites.

When averaged across all slope positions, there was a significant increase ($P<0.05$) in maximum penetration resistance from the 10-20 cm to the 20-30 cm depth intervals at the native site only (2.9 and 4.1 MPa, respectively). Moisture may have been a minor factor since soil water content was similar for both depth intervals (site averages of 25 vs. 21% for the 10-20 and 20-30 cm depths, respectively). Although no supporting measurements were made, other potential factors include higher bulk density and stronger, more competent, soil structure at depth. Another factor in the increased penetration resistance with depth may be the grazing that occurred on the native site until the late 1980's. Naeth *et al.* (1990) observed increases in penetrometer resistance with grazing intensity on Orthic Black Chernozems developed on glacial till. The heaviest intensity of grazing had the most compacting effect, which was observed to be the greatest at the 30-cm depth.

SUMMARY – CULTIVATION EFFECTS ON SLOPE PROCESSES

The impact of cultivation must be assessed over the entire landscape, due to the influence of topography, or slope position, on the distribution of soil properties. Through comparisons with a similar nearby native site, we were able to discern the degree to which nearly 80 years of cultivation intensified natural slope processes, resulting in an altered distribution of soil properties in the landscape.

In general, cultivation caused an increase in susceptibility to erosion, indicated by loss of soil on hilltops and subsequent accumulations on lower slopes and depressions. Analysis of original A horizon thickness indicated that natural slope processes resulted in thin Ah horizons on hilltops (4 cm) and thicker Ah1 horizons in depressions (11 cm).

The initial cultivation of the thinner Ah horizons on hilltops incorporated substantial amounts of subsoil into the surface layer. Over time, as erosion depleted hilltop soils, more and more subsoil material was incorporated into the plow layer (Ap horizon). After nearly 80 years, this process has resulted in calcareous hilltop soils that are classified as either Rego or Calcareous Dark Brown Chernozemic (ECSS 1987b) where Orthic Dark Browns were once the norm.

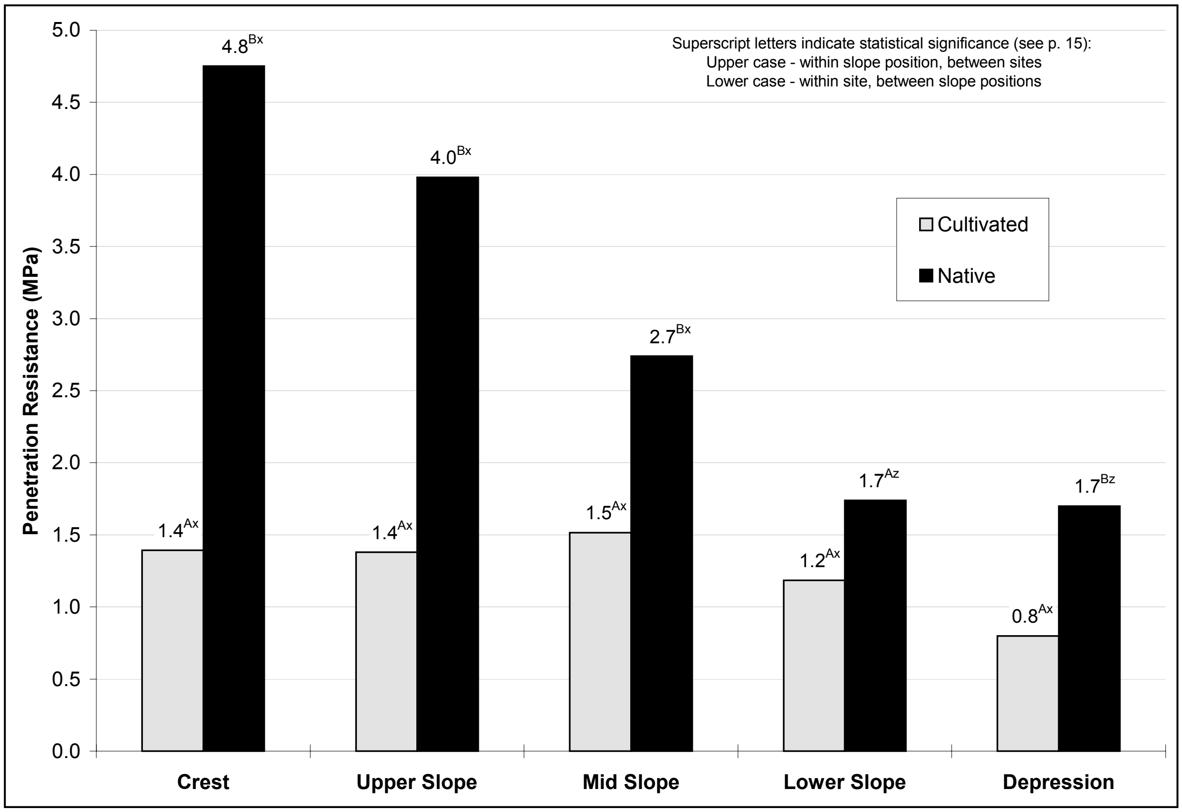


Figure 23. Penetration resistance for the 10-20 cm depth interval at both sites.

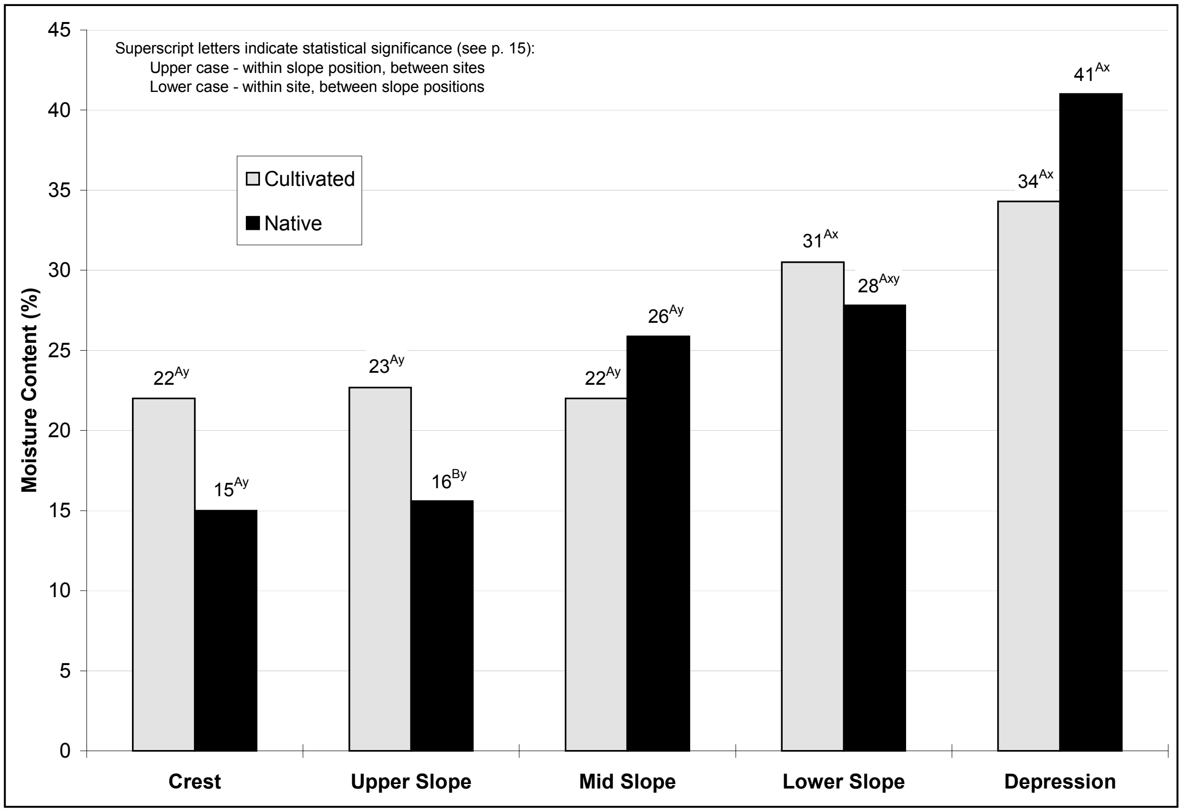


Figure 24. Gravimetric moisture content at the 10-20 cm depth interval for both sites.

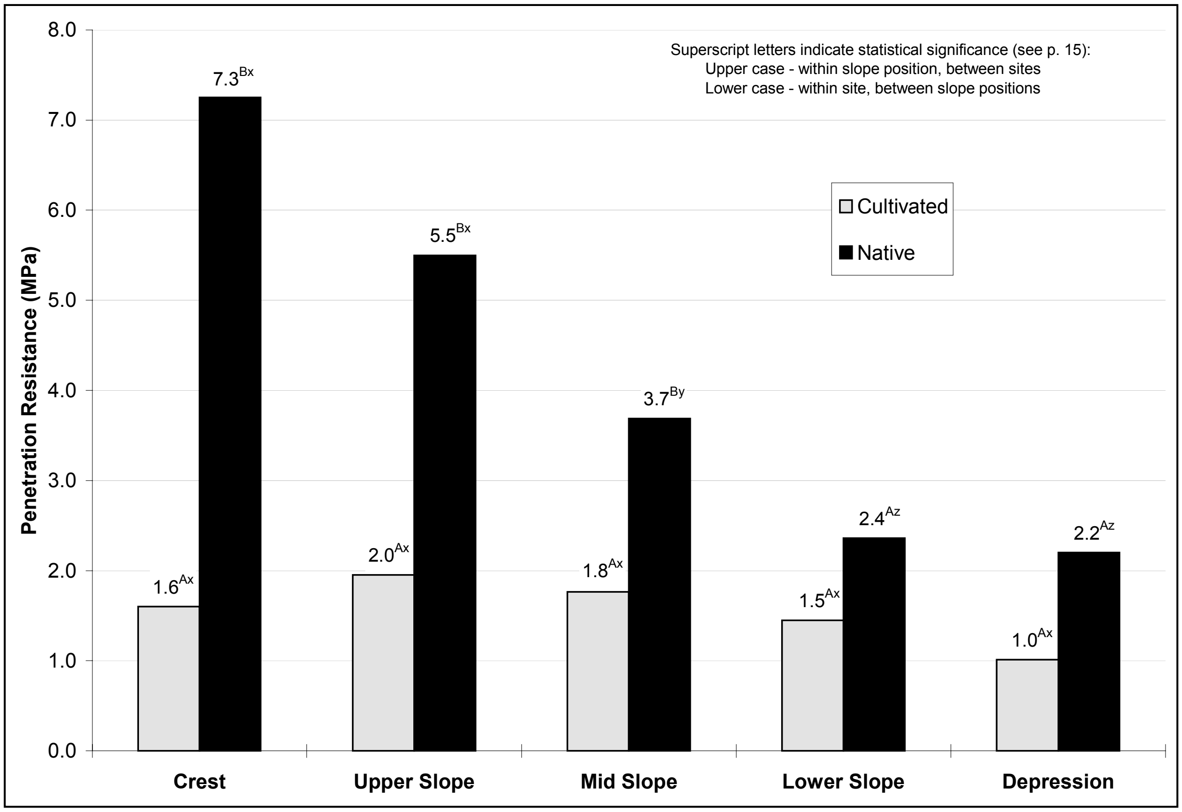


Figure 25. Penetration resistance at the 20-30 cm depth interval for both sites.

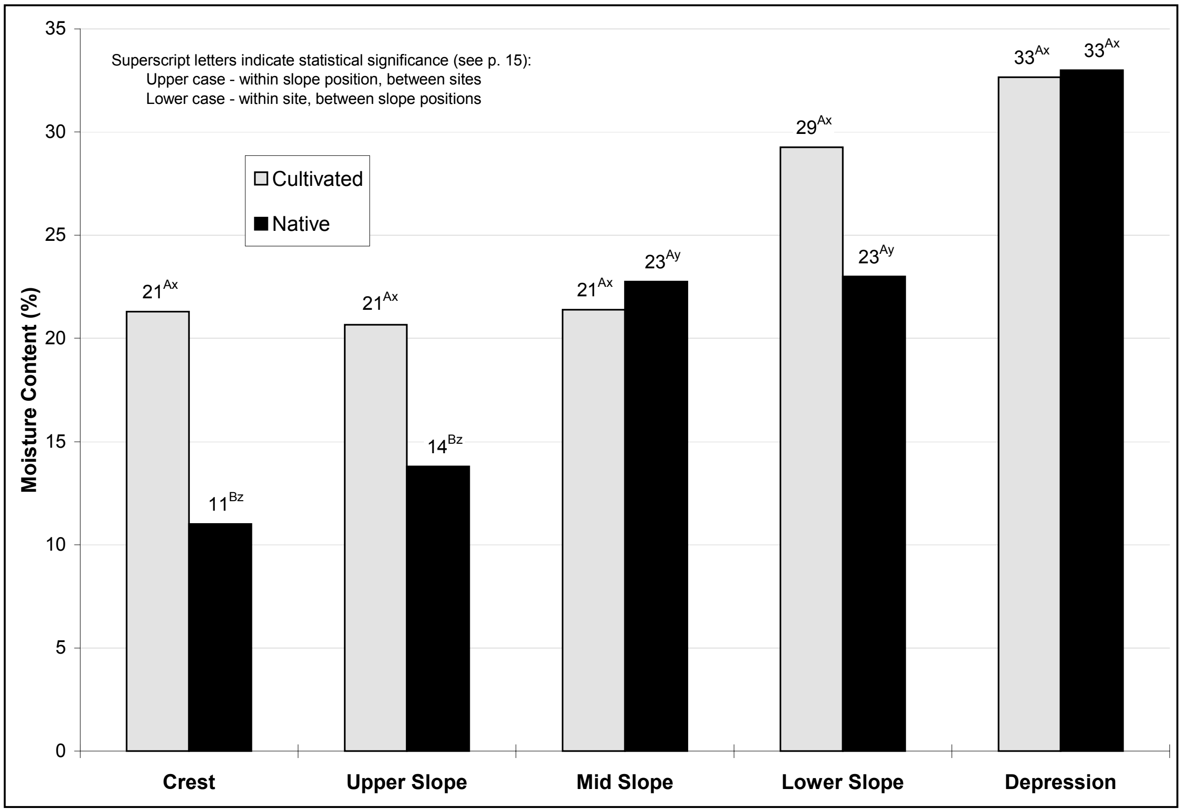


Figure 26. Gravimetric moisture content for the 20-30 cm depth interval at both sites.

How much soil has eroded over the nearly 80 years of cultivation can no longer be determined. However, a crude estimate of the change in topographic relief gives some clues. Based on average bulk densities and calculated rates of erosion on crests and deposition in depressions, the estimated net change in relief is 0.5 m in nearly 80 years. This is equivalent to reducing average relief at the native site by 13%.

This estimate relies on Cs^{137} data, which permits calculations from *circa* 1960. Perhaps erosion was greater during the first 40 years of cultivation; perhaps it is negligible under the current cropping system. While part of this question may never be answered, the soil quality benchmark study at Provost was established to determine the magnitude of change that could be detected in about 10 years.

Evidence of erosion is visible at the cultivated site. When in fallow, hilltops (knolls) have grayish colors, in contrast to darker soils on adjacent slopes. The grayish colors also identify soils with the lowest organic C content. However, the data show that organic C content is lower throughout the cultivated landscape. The 78 years of cultivation has decreased soil organic matter by approximately 40% overall. Further, the results show a redistribution of organic materials downslope, presumably coincident with erosion of soil. For each slope position, the loss/gain of C was apportioned to several causes, based on ^{137}Cs net loss estimates and native site comparisons.

It is important to note that on "erosive" slope positions – crest, upper- and erosional mid-slope positions – 46, 27 and 38% of the perceived C loss was due to a tillage dilution effect. This effect involves the incorporation of subsoil material with low organic C content into the topsoil rather than an actual loss of C.

Loss of C through erosion was the major mechanism of loss for hilltop positions – approximately 60%. For erosional mid-slope positions, erosion still accounted for almost 30% of the C loss; however, mineralization was also a major cause of C loss.

According to the landowners, episodes of wind and water erosion have occurred from time to time. However, 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.

Loss of C through mineralization increased proportionally downslope, and became the dominant mechanism for C loss at lower-slope positions. If the additions of C from upper slopes are accounted for, losses through mineralization in the lower-slope and depressional sites are almost double the amount of C lost through erosion at hilltop positions. Other researchers have drawn similar conclusions – in lower-slope areas organic matter losses are higher, despite gains from upper slopes, due to high rates of mineralization (Gregorich and Anderson 1985).

Cultivation caused an alteration in soil physical properties. Overall, the bulk density of the uppermost A horizon (Ap, Ap1, Ah or Ah1), regardless of slope position, was lowered by the nearly 80 years of cultivation compared to the native conditions. Further, the soil bulk density decreased downslope – a phenomenon not seen in the native soil. This change in the value and distribution of soil bulk density in the landscape is consistent with the erosion, deposition, organic C and total N patterns seen earlier.

Saturated hydraulic conductivity (Ksat) at the two measured depth intervals – 15-25 and 30-40 cm – was considerably slower at the cultivated site compared to the native site. Higher porosity and more abundant rooting at the native site are offered as explanations. While not evident in the pore descriptions, root numbers are certainly higher in the native site pedons (see descriptions in Appendix B).

In contrast to the Ksat measurements, maximum penetration resistance, measured in the 10-20 and 20-30 cm depth intervals, was lower at the cultivated site. Part of the difference was due to the complex relationship between moisture content and resistance to penetration. Other factors may include porosity, bulk density, and soil structure, although these were not measured relative to penetration resistance. Grazing in the past may also have been a contributing factor to subsurface compaction (Naeth *et al.* 1990).

It is interesting to note that for both saturated hydraulic conductivity and penetration resistance, toposequence differences are negligible, if not absent, after cultivation for nearly 80 years. This is particularly true of the depth intervals closest to the surface (see Figs. 21, 23 and 25).

Cultivation and management of the site for the last 80 years have exacerbated natural slope processes resulting in alteration of soil properties that may eventually have an impact on production, or the ability to sustain production.

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APPENDIX A: SELECTED SOIL AND LANDSCAPE FEATURES OF SAMPLING POINTS

Selected physical soil features and landscape position information is presented in the following tables. The data is sorted by slope shape (3 classes) within slope position (5 classes; see methods). Soil subgroup codes are standard (ECSS 1987b). Soil series and variant codes are from the recently developed Generation 2 Alberta Soil Names File (Alberta Soil Series Working Group 1993). The last column lists total depth of humus-rich topsoil. The current Ap or Apk plus any underlying older Ap or uncultivated Ah or AB horizon were summed; strongly eluviated (Ae) horizons were excluded.

CULTIVATED SITE

SLOPE POSITON	**SAMPLING POINT ID**	**SLOPE SHAPE**	**SOIL SUBGROUP[1]**	**SOIL SERIES[2]**	**TOTAL Ap/Ah THICKNESS (cm)**
Crest:	05T4.00	Convex	R.DB	Neutral (NUT)	12
	05T1.00	Convex	R.DB	NUT	8
	05T6.00	Convex	R.DB	NUT	16
	05T7.00	Convex	R.DB	NUT	11
	05T2.00	Convex	R.DB	NUT	11
	05T9.00	Convex	R.DB	NUT	10
	05T8.00	Convex	R.DB	NUT	20
	05P1	Convex	R.DB	NUT	11
	05T3.00	Straight	O.DB	Hughenden (HND)	18
	Average:				**13**
	Std. Dev.:				**4**
Upper Slope:	05T9.01	Convex	R.DB	NUT	9
	05T5.01	Convex	CA.DB	Hughenden-calcareous (HNDca)	12
	05T3.02	Convex	O.DB	HND	10
	05T8.01	Convex	R.DB	NUT	17
	05T4.01	Convex	CA.DB	HNDca	9
	05T3.01	Convex	O.DB	Provost (PRO)	10
	05T6.01	Convex	CA.DB	HNDca	13
	Average:				**11**
	Std. Dev.:				**3**
Depression:	05T6.05	--	HU.LG	Fleet-luvic, till <1m (FLTzlxt)	45
	05T7.04	--	GLE.DB	Coronation-fine, gleyed (CNNfigl)	27
	05T8.11	--	HU.LG	FLTzlxt	19
	05T2.04	--	HU.LG	FLTzlxt	38
	05T1.03	--	GL.DB	Hughenden-gleyed (HNDgl)	8
	05T3.07	--	O.HG	FLTxt	25
	05T9.07[3]	--	HU.LG	FLTzlxt	30
	05T9.08[3]	--	SZ.LG	Fleet-luvic, solonetzic (FLTzlzt)	25
	05T4.09	--	GLSZ.DB	Hansman (HAS)	16
	Average:				**26**
	Std. Dev.:				**11**

[1] Refer to the Canadian System of Soil Classification (ECSS 1987b) for explanation of soil subgroup codes; see also pages 8 & 10.

[2] Soil series and variant codes and formatting as used in the Generation 2 Alberta Soil Names File (Alberta Soils Series Working Group 1993). Several codes have been written out to provide a preliminary guideline into the references should follow-up be an option.

[3] Large depression containing these sampling points was never cultivated until it was cleared in 1995.

SLOPE POSITON	SAMPLING POINT ID	SLOPE SHAPE	SOIL SUBGROUP[1]	SOIL SERIES[2]	TOTAL Ap/Ah THICKNESS (cm)
Mid Slope:	05T4.04	Concave	O.DB	Provost (PRO)	16
	05T4.03	Concave	O.DB	Hughenden (HND)	15
	05T3.04	Concave	O.DB	PRO	20
	05T4.05	Concave	O.DB	PRO	16
	05T8.02	Convex	CA.DB	Provost-calcareous (PROca)	12
	05T5.02	Convex	CA.DB	Hughenden-calcareous (HNDca)	11
	05T7.02	Straight	O.DB	HND	13
	05T6.03	Straight	E.DB	Lanfine (LFE)	15
	05T3.03	Straight	O.DB	HND	11
	05T4.06	Straight	O.DB	HND	18
	05T1.01	Straight	O.DB	HNDca	20
	05T5.03	Straight	O.DB	HND	20
	05T2.01	Straight	O.DB	HNDca	30
	05T5.04	Straight	O.DB	PRO	20
	05T8.03	Straight	O.DB	HND	22
	05T6.02	Straight	O.DB	PRO	20
	05T2.02	Straight	O.DB	PRO	35
	05T8.07	Straight	O.DB	HND	14
	05T7.01	Straight	O.DB	HND	11
	05T4.02	Straight	O.DB	PRO	11
	05T8.06	Straight	O.DB	HND	12
	05P2	Straight	O.DB	HND	11
	05T9.02	Straight	O.DB	HND	33
	05T9.04	Straight	O.DB	PRO	20
	05T9.05	Straight	O.BL	Blaine Lake (BLL)	17
	Average:				**18**
	Std. Dev.:				**7**
Lower Slope:	05T2.03	Concave	GLSZ.DB	Hansman (HAS)	45
	05T5.08	Concave	GLSZ.DB	HAS	17
	05T9.03	Concave	GLE.DB	Hasman-eluviated (HASze)	30
	05T8.08	Concave	GLSZ.BL?	BLL-solonetzic, gleyed (BLLztgl)	30
	05T8.04	Concave	O.DB	PRO	19
	05T4.07	Concave	O.DB	HND	23
	05T4.08	Concave	GL.DB	Provost-gleyed (PROgl)	23
	05T5.06	Concave	SZ.BL	Blaine Lake-solonetzic (BLLzt)	13
	05T8.09	Convex	GLE.BL?	BLL-eluviated, gleyed (BLLzegl)	23
	05T7.03	Straight	GLE.DB	CNN-gleyed, eluviated (CNNglze)	17
	05T5.07	Straight	GL.DB	Provost-gleyed (PROgl)	16
	05T1.02	Straight	GLE.DB	HND-gleyed, eluviated (HNDglze)	18
	05T9.06[3]	Straight	GLSZ.BL	BLLztgl	20
	05T5.05	Straight	O.DB	PRO	15
	05T8.10	Straight	GLSZ.DB	HAS	30
	05T3.05	Straight	O.DB	PRO	18
	05T3.06	Straight	GLE.DB	HASze	15
	05T8.05	Straight	O.DB	PRO	14
	05T6.04	Straight	HU.LG	Fleet-luvic, till <1m (FLTzlxt)	22
	Average:				**21**
	Std. Dev.:				**8**

[1] Refer to the Canadian System of Soil Classification (ECSS 1987b) for explanation of soil subgroup codes; see also pages 8 & 10.

[2] Soil series and variant codes and formatting as used in the Generation 2 Alberta Soil Names File (Alberta Soils Series Working Group 1993). Several codes have been written out to provide a preliminary guideline into the references should follow-up be an option.

[3] Sampling point likely never cultivated until 1995, but topsoil includes substantial drift from the cultivated field only meters away.

NATIVE SITE

SLOPE POSITION	SAMPLING POINT ID	SLOPE SHAPE	SOIL SUBGROUP[1]	SOIL SERIES[2]	TOTAL Ap/Ah DEPTH (cm)
Crest:	55T1.00	Convex	O.DB	Hughenden-thin A (HNDta)	6
	55T3.00	Convex	O.DB	HNDta	3
	55T4.00	Convex	O.DB	HNDta	5
	55T6.00	Convex	O.DB	HNDta	3
	55P2	Convex	O.DB	HNDta	4
	55T2.00	Strait	O.DB	HNDta	3
	55T5.00	Strait	O.DB	HNDta	5
	55T7.00	Strait	O.DB	HNDta	5
	Average:				**4**
	Std. Dev.:				**1**
Upper Slope:	55T5.01	Concave	O.DB	HNDta	7
	55T2.01	Convex	O.DB	HNDta	6
	55T3.01	Convex	O.BL	Elnora-thin A (EORta)	5
	55T4.01	Convex	O.BL	Elnora (EOR)	9
	55T5.02	Convex	O.DB	HNDta	7
	55T6.01	Convex	R.DB	Neutral (NUT)	9
	55T6.04	Convex	O.DB	HNDta	4
	55T7.01	Convex	O.DB	HND	7
	55T5.03	--	O.DB	HND	8
	Average:				**7**
	Std. Dev.:				**2**
Mid Slope:	55T4.05	Concave	GL.DB	Provost-gleyed (PROgl)	-
	55T5.05	Concave	O.DB	PRO	14
	55T6.02	Concave	O.DB	HNDta	5
	55T6.06	Concave	O.BL	BLL	12
	55T7.02	Concave	R.BL	BLL-rego, overblown (BLLzrob)	45
	55T3.04	Convex	O.DB	HNDta	6
	55T3.05	Convex	O.BL	EORta	5
	55T3.06	Convex	O.DB	HNDta	5
	55T5.04	Convex	O.DB	Hughenden-disturbed (HNDdl)	10
	55T1.01	Strait	O.DB	HND	10
	55T1.02	Strait	O.BL	BLL	10
	55T1.03	Strait	O.BL	BLL	9
	55T1.04	Strait	O.BL	EOR	9
	55T2.02	Strait	O.DB	HNDta	9
	55T2.03	Strait	O.DB	PRO	13
	55T2.04	Strait	O.BL	EOR	13
	55T2.05	Strait	R.DB	Neutral-disturbed (NUTdl)	--
	55T2.06	Strait	R.BL	Elnora-rego, disturbed (EORzrdl)	3
	55T3.02	Strait	O.BL	Blaine Lake (BLL)	9
	55T3.07	Strait	O.BL	BLL	8
	55T3.08	Strait	SZ.BL	Blaine Lake-solonetzic (BLLzt)	8
	55T4.02	Strait	O.BL	EOR	8
	55T4.03	Strait	O.BL	BLL	9
	55T5.06	Strait	R.BL	EORzrdl	12
	55T6.03	Strait	O.DB	HNDta	5
	55T6.05	Strait	O.DB	HND	10
	55T6.07	Strait	O.BL	BLL	10
	55P1	Strait	O.DB	PRO	8
	Average:				**10**
	Std. Dev.:				**8**

SLOPE POSITION	SAMPLING POINT ID	SLOPE SHAPE	SOIL SUBGROUP[1]	SOIL SERIES[2]	TOTAL Ap/Ah DEPTH (cm)
Lower Slope:	55T3.03	Concave	O.BL	Blaine Lake (BLL)	9
	55T7.03	Convex	GLR.BL	Blaine Lake-rego, gleyed (BLLzrgl)	12
	55T1.05	Strait	SZ.BL	Blaine Lake-solonetzic (BLLzt)	9
	55T1.06	Strait	GLSZ.BL	BLL-solonetzic, gleyed (BLLztgl)	--
	55T2.07	Strait	HU.LG	Fleet-luvic, till <1m (FLTzlxt)	--
	55T3.09	Strait	GLE.BL	BLL-gleyed, eluviated (BLLglze)	9
	55T4.04	Strait	O.BL	BLL	--
	55T4.06	Strait	HU.LG	FLTzlxt	--
	55T6.08	Strait	R.DB	Coronation-rego (CNNzr)	14
	55T6.09	Strait	R.DB	Provost-rego (PROzr)	12
	55T5.07	--	HU.LG	FLTzlxt	--
	Average:				**11**
	Std. Dev.:				**2**
Depression:	55T1.07	--	HU.LG	Fleet-luvic, fine (FLTzlfi)	--
	55T2.08	--	HU.LG	Fleet-luvic, till <1m (FLTzlxt)	--
	55T3.10	--	HU.LG	FLTzlxt	--
	55T4.07	--	HU.LG	FLTzlxt	--
	55T5.08	--	HU.LG	FLTzlxt	22
	55T6.10	--	HU.LG	FLTzlxt	--
	55T7.04	--	HU.LG	FLTzlxt	17
	Average:				**20**
	Std. Dev.:				**4**

[1] Refer to the Canadian System of Soil Classification (ECSS 1987b) for explanation of soil subgroup codes; see also pages 8 & 10.

[2] Soil series and variant codes and formatting as used in the Generation 2 Alberta Soil Names File (Alberta Soils Series Working Group 1993). Several codes have been written out to provide a preliminary guideline into the references should follow-up be an option.

APPENDIX B: PEDON DESCRIPTIONS

Pedons representing the major soils of both sites were described and sampled in detail when the sites were established. The descriptions and selected analytical data follow. Other available data for some or all horizons include cation exchange capacity, exchangeable cations (Na, Ca, Mg, and K), available P and K, electrical conductivity and soluble salts, mineralogical analysis, and soil moisture retention and bulk density from core samples. Descriptions of pedons from the cultivated site are reprinted from Walker and Wang (1994).

CULTIVATED SITE, PEDON 1: NEUTRAL SERIES (NUT)

Identification:	05-AB, Pedon 1 (P1); Rego Dark Brown
Location:	SE7-40-1-W4; north central part of benchmark site (see Fig. 2 and 4)
Described by:	B.D. Walker; October 15, 1990
Parent material:	Moderately fine textured (fine loamy), moderately calcareous till
Landscape:	Crest (1.5% convex slope) of an eroded knoll in undulating to hummocky terrain
Drainage:	Well drained
Land use:	Cropland; canola - wheat - fallow rotation

Horizon	Depth cm	Description
Apk	0-11	Very dark brown to very dark grayish brown (10YR 2.5/2 m), dark grayish brown (10YR 4/2 d); loam; very weak, very fine, subangular blocky; loose; plentiful, micro to very fine, random roots; weakly calcareous; 2% gravels & cobbles; abrupt, smooth boundary; 7-12 cm thick; alkaline.
Cca	11-31	Light olive brown (2.5Y 5/4 m); clay loam; weak to moderate, medium to coarse, subangular blocky; friable; plentiful, micro to very fine, vertical roots; many, micro to very fine, random pores; moderately calcareous; many, medium, friable, light yellowish brown (2.5Y 6/3), horizontal carbonate streaks; 2% gravels & cobbles; gradual, wavy boundary; 15-30 cm thick; alkaline.
Ck1	31-51	Dark grayish brown (2.5Y 4/2 m) & light olive brown (2.5Y 5/4 m); clay loam; weak to moderate, medium to coarse, subangular blocky; friable; plentiful, micro to very fine, random roots; many, micro to very fine, random pores; moderately calcareous; common, fine, friable, light brownish gray (2.5Y 6/3), horizontal carbonate streaks; 5% gravels & cobbles; abrupt, smooth boundary; 12-25 cm thick; alkaline.
Ck2	51-150	Very dark grayish brown to dark grayish brown (2.5Y 3.5/2 m); loam; massive breaking to weak, coarse, subangular blocky; friable; plentiful, micro to very fine, random roots; common, very fine, vertical pores; moderately calcareous; 10% gravels, cobbles & stones; alkaline.

Selected chemical and physical characteristics of cultivated site Pedon 1 are listed in the table below.

Horizon	pH $CaCl_2$	Organic C %	Total N %	$CaCO_3$ Eqiv. %	Sand %	Silt %	Clay %
Apk	7.6	1.89	0.18	3.48	36	38	26
Cca	7.9	1.02	0.07	14.22	24	38	38
Ck1	8.0	0.35	0.04	11.28	33	36	31
Ck2	8.2	0.23	0.02	8.26	41	32	27

CULTIVATED SITE, PEDON 2: HUGHENDEN SERIES (HND)

Identification: 05-AB, Pedon 2 (P2); Orthic Dark Brown with thin Ap
Location: SE7-40-1-W4; south central part of benchmark site (see Fig. 2 and 4)
Described by: B.D. Walker; October 15, 1990
Parent material: Moderately fine textured (fine loamy), moderately calcareous till
Landscape: Southwest facing mid slope (6% slope) in undulating to hummocky terrain
Drainage: Well drained
Land use: Cropland; canola - wheat - fallow rotation

Horizon	Depth cm	Description
Ap	0-11	Very dark grayish brown (10YR 3/2 m), dark grayish brown (10YR 4/2 d); loam; very weak, very fine, granular; loose; plentiful, micro to very fine, random roots; 2% gravels & cobbles; abrupt, smooth boundary; 7-13 cm thick; acid.
Bt	11-30	Dark brown to brown (7.5YR 4/4 matrix m) & dark brown (10YR 3/3 exped m); clay loam; strong, medium to coarse, subangular blocky; friable; plentiful, micro to very fine, vertical roots; many, micro to very fine, vertical & horizontal pores; continuous, very thin, dark brown (10YR 3/3) clay films in many voids & channels and on some ped faces; 2% gravels & cobbles; clear, wavy boundary; 13-24 cm thick; neutral.
BC	30-50	Dark brown (10YR 3.5/3 matrix m, 10YR 3/3 exped m); clay loam; very weak, coarse prismatic breaking to weak, medium to coarse, subangular blocky; friable; plentiful, micro to very fine, random roots; many, micro to very fine, vertical & horizontal pores; common, thin, dark brown (10YR 3/3) clay films in many voids & channels and on some ped faces; moderately calcareous; many, fine, friable, light yellowish brown (2.5Y 6/4), random & irregular, carbonate streaks and spots; 5% gravels & cobbles; gradual, wavy boundary; 15-25 cm thick; alkaline.
Ck1	50-75	Olive brown to light olive brown (2.5Y 4.5/4 m) & grayish brown (2.5Y 5/2 m); clay loam; massive breaking to very weak, medium to coarse, subangular blocky; friable; few, micro to very fine, random roots; many, micro to very fine, vertical pores; moderately calcareous; many, medium, friable, light yellowish brown (2.5Y 6/4), horizontal streaks and irregular spots of secondary carbonate; 15% gravels, cobbles & stones; abrupt, wavy boundary; 23-45 cm thick; alkaline.
Ck2	75-150	Very dark grayish brown to dark grayish brown (2.5Y 3.5/2 m); clay loam; massive; firm; few, micro to very fine, random roots; common, very fine, vertical pores; moderately calcareous; 10% gravels, cobbles & stones; alkaline

Selected chemical and physical characteristics of Pedon 2 are listed in the table below.

Horizon	pH $CaCl_2$	Organic C %	Total N %	$CaCO_3$ Eqiv. %	Sand %	Silt %	Clay %
Ap	5.2	2.35	0.21	--	32	42	26
Bt	6.8	1.01	0.11	0.59	32	34	34
BC	7.9	0.70	0.06	10.59	27	37	36
Ck1	8.1	0.39	0.04	10.82	27	44	29
Ck2	8.1	0.41	0.03	7.28	30	36	34

NATIVE SITE, PEDON 1: PROVOST SERIES (PRO)

Identification:	55-AB, Pedon 1 (P1); Orthic Dark Brown
Location:	SW18-40-1-W4; northeast part of native site (see Fig. 3 and 5)
Described by:	B.D. Walker; September 1991
Parent material:	Glaciolacustrine material overlying moderately calcareous till, both medium textured (L, SiL)
Landscape:	Northeast facing mid slope (8% slope) in hummocky terrain
Drainage:	Well drained
Land use:	Parkland-grassland; light grazing (last used for livestock grazing in late 1980s)

Horizon	Depth cm	Description
Ah	0-8	Very dark grayish brown (10YR 3/2 d) loam; weak, fine to medium, subangular blocky; slightly hard; abundant, micro to very fine, random roots; many, micro to very fine pores; abrupt, irregular boundary; 5-32 cm thick; neutral.
Bm1	8-18	Very dark brown to dark brown (10YR 2.3/3 & 3/3 d) loam; moderate, medium prismatic breaking to moderate, medium to coarse, subangular blocky; hard; plentiful, very fine, random roots; many, micro pores; abrupt, irregular boundary; 5-15 cm thick; acid.
Bm2	18-30	Dark yellowish brown to yellowish brown (10YR 4/4 & 5/4 d); silt loam; moderate, medium to coarse prismatic breaking to weak, medium to coarse, subangular blocky; hard; plentiful, very fine, vertical roots; common, micro to very fine pores; 5% gravels & cobbles; abrupt, wavy boundary; 10-20 cm thick; neutral.
Ck	30-50	Brown (10YR 5/3 d); silt loam; weak, medium to coarse prismatic breaking to weak, medium, subangular blocky; slightly hard; plentiful, very fine, vertical roots; many, micro to very fine pores; moderately calcareous; many, fine, soft, light gray (10YR 7/2), irregular, carbonate spots; clear, wavy boundary; 15-25 cm thick;
2Ck1	50-74	Brown (10YR 5/3 d); loam; very weak, coarse prismatic breaking to very weak, medium to coarse, subangular blocky; hard; plentiful, very fine, vertical roots; many, micro to very fine pores; moderately calcareous; many, medium, soft, light gray (10YR 7/2), irregular, carbonate spots; 2-5% gravels, 1% cobbles; clear, wavy boundary; 17-38 cm thick;
2Ck2	74-125	Dark brown (10YR 3.5/3 d); loam; very weak, medium to coarse, subangular blocky; very hard; few, very fine, vertical roots; common, micro to very fine pores; few, very thin, clay films in voids &/or channels only; weakly calcareous; common, medium to coarse, slightly hard, light gray (10YR 7/2), irregular, carbonate spots and random streaks; 2-5% gravels, 1% cobbles; alkaline.

Selected chemical and physical characteristics of native site Pedon 1 are listed in the table below.

Horizon	pH $CaCl_2$	Organic C %	Total N %	$CaCO_3$ Eqiv. %	Sand %	Silt %	Clay %
Ah	5.8	7.87	0.59	--	30	48	22
Bm1	5.4	1.77	0.20	--	29	47	24
Bm2	6.1	1.34	0.15	--	17	59	24
Ck	7.9	0.90	0.06	10.09	17	64	19
2Ck1	8.1	0.63	0.08	7.83	38	42	20
2Ck2	8.2	0.41	0.08	6.50	47	34	19

NATIVE SITE, PEDON 2: HUGHENDEN SERIES, THIN VARIANT (HNDta)

Identification:	55-AB, Pedon 2 (P2); Orthic Dark Brown (thin)
Location:	SW18-40-1-W4; northeast part of native site (see Fig. 3 and 5)
Described by:	B.D. Walker; September 1991
Parent material:	Medium textured (fine loamy), moderately calcareous till
Landscape:	Crest (4% convex slope) of a hill in hummocky terrain
Drainage:	Well drained
Land use:	Parkland-grassland; light grazing (last used for livestock grazing in late 1980s)

Horizon	Depth cm	Description
Ah	0-4	Very dark grayish brown to dark brown (10YR 3.5/2.5 d), very dark brown (10YR 2/1.5 m); clay loam; weak, medium to coarse, subangular blocky; slightly hard; abundant, micro to very fine, random roots; many, micro to very fine pores; weakly calcareous; abrupt, wavy boundary; 2-6 cm thick; neutral.
Bm	4-14	Very dark grayish brown to dark brown (10YR 3/2 & 3/3 d); clay loam; moderate, medium to coarse prismatic breaking to weak, medium to coarse, subangular blocky; hard; plentiful, micro to very fine, random roots; common, micro to very fine pores; weakly calcareous; 2% gravels & cobbles; abrupt, wavy boundary; 7-17 cm thick; neutral.
Cca	14-40	Brown to dark brown (10YR 4/3 d); clay loam; very weak, coarse prismatic breaking to weak, medium, subangular blocky; slightly hard; plentiful, very fine, vertical roots; common, micro to very fine pores; moderately calcareous; many, coarse, slightly hard, light gray (10YR 7/2), irregular, carbonate spots; 2-5% gravels, 1% cobbles; clear, wavy boundary; 19-30 cm thick; alkaline.
Ck1	40-92	Dark grayish brown (2.5Y 4/2 d); loam; weak, fine to medium, subangular blocky; hard; plentiful, very fine, vertical roots; common, micro to very fine pores; moderately calcareous; common, medium, hard, light gray (10YR 7/2), random, carbonate streaks; 2-5% gravels, 1% cobbles; abrupt, smooth boundary; 50-60 cm thick; alkaline.
Ck2	92-125	Very dark grayish brown to dark grayish brown (2.5Y 3.5/2 m); loam; very weak, medium to coarse, subangular blocky; hard; plentiful, very fine, vertical roots; common, micro to very fine pores; moderately calcareous; few, fine, hard, light gray (10YR 7/2), irregular, carbonate spots; 2-5% gravels, 1% cobbles; alkaline.

Selected chemical and physical characteristics of native site Pedon 2 are listed in the table below.

Horizon	pH $CaCl_2$	Organic C %	Total N %	$CaCO_3$ Eqiv. %	Sand %	Silt %	Clay %
Ah	6.1	6.80	0.66	--	30	41	29
Bm	6.9	2.56	0.31	1.75	36	29	35
Cca	8.0	1.37	0.17	13.60	35	26	39
Ck1	8.5	0.28	0.08	7.56	40	35	25
Ck2	8.2	0.35	0.07	6.45	41	35	24