RESEARCH SUB-PROGRAM

DEVELOPMENT OF STANDARD METHODOLOGIES FOR RESIDENT BIOMASS AND ORGANIC CARBON

January 1997

COESA Report No.: RES/MON-001/95

Prepared by: V. Alder and D. Charlton,
Ecological Services For Planning,
361 Southgate Drive, Guelph, Ontario N1G 3M5

E.G. Gregorich, Agriculture and Agri-Food Canada, Ottawa
D.J. King, Agriculture and Agri-Food Canada, Guelph

On behalf of: Research Branch, Agriculture and Agri-Food Canada,
Pest Management Research Centre (London)
1391 Sandford St.
London, Ontario N5V 4T3

S.S.C. Contract No.: 01689-3-0200/01-XSE

F O R W A R D

This report is one of a series of **COESA** (Canada-Ontario Environmental Sustainability Accord) reports from the Research Sub-Program of the Canada-Ontario Green Plan. The **GREEN PLAN** agreement, signed Sept. 21, 1992, is an equally-shared Canada-Ontario program totalling $64.2 M, to be delivered over a five-year period starting April 1, 1992 and ending March 31, 1997. It is designed to encourage and assist farmers with the implementation of appropriate farm management practices within the framework of environmentally sustainable agriculture. The Federal component will be delivered by Agriculture and Agrifood Canada and the Ontario component will be delivered by the Ontario Ministry of Agriculture and Food and Rural Assistance.

From the 30 recommendations crafted at the Kempenfelt Stakeholders conference (Barrie, October 1991), the Agreement Management Committee (AMC) identified nine program areas for Green Plan activities of which the three comprising research activities are (with Team Leaders):

1. **Manure/Nutrient Management and Utilization of Biodegradable Organic Wastes** through land application, with emphasis on water quality implications
   A. Animal Manure Management (nutrients and bacteria)
   B. Biodegradable organic urban waste application on agricultural lands (closed loop recycling) (Dr. Bruce T. Bowman, Pest Management Research Centre, London, ONT)

2. **On-Farm Research**: Tillage and crop management in a sustainable agriculture system. (Dr. Al Hamill, Harrow Research Station, Harrow, ONT)

3. **Development of an integrated monitoring capability** to track and diagnose aspects of resource quality and sustainability. (Dr. Bruce MacDonald, Centre for Land and Biological Resource Research, Guelph, ONT)

The original level of funding for the research component was $9,700,000 through Mar. 31, 1997. Projects will be carried out by Agriculture and Agri-Food Canada, universities, colleges or private sector agencies including farm groups.

This Research Sub-Program is being managed by the Pest Management Research Centre, Agriculture and Agri-Food Canada, 1391 Sandford St., London, ONT. N5V 4T3.

Dr. Bruce T. Bowman
Scientific Authority

Green Plan Web Address: http://res.agr.ca/lond/gp/gphompag.html

The following report, approved by the Research Management Team, is reproduced in its entirety as received from the contractor, designated on the previous page.

EXECUTIVE SUMMARY

The biologically active carbon fractions represent only a small proportion of the soil organic matter but they are dynamic and respond rapidly to changes in management or environmental conditions. Hence, the soil microbial biomass may be useful in assessing the impacts of management on long term changes in organic matter.

The study examined components of soil carbon - microbial biomass, soluble organic, and total organic C - as well as other soil quality and productivity parameters such as soil strength, carbonates, density and crop yields. The relationship between soil properties and carbon components, and the implications for soil productivity were examined at various agricultural sites in Ontario.

Soil redistribution due to topography and by agricultural practices will influence the distribution of soil properties in a landscape. Hence, soil properties were examined on the basis of landscape position within an agricultural practice. Effects of agricultural practices were examined at one location which consisted of adjacent farm fields under different long term crop and tillage management.

Impacts of soil management and topography were reflected in the carbon components. No-till soils had about 1.5 times more organic carbon and about 2.5 times more microbial biomass carbon than conventionally tilled soils. The impact of landscape position within each management system was smaller than the effects of agricultural practices on carbon.

All sites reflected higher organic carbon levels at lower slope positions but not always higher microbial biomass carbon, though there tended to be more labile organic matter at the lower slope positions.

Soil chemical, physical and productivity parameters were often less sensitive to soil management and landscape than the total and labile carbon components. That is, changes in soil organic carbon may be more readily reflected in the labile carbon components, than in, for example, bulk density.

Seasonal differences in the levels of microbial carbon were not evident at all sites, and where temporal differences occurred, peak MBC levels did not coincide with the sampling date which approximated the initial reproduction stage of crop growth. However, more intensive sampling than was carried out in this study would be needed within a season, to determine when microbial populations are at a maximum.

High variation in microbial biomass carbon underscores the fact that biomass measurements alone do not indicate much about soil quality. In order to characterize soil quality the biomass carbon needs to be compared with other measurements of labile carbon.

SOMMAIRE

Les fractions carbonées bioactives ne représentent qu'une petite partie des matières organiques des sols, mais elles sont dynamiques et réagissent rapidement aux changements apportés à la gestion environnementale. Dès lors, la biomasse microbienne des sols peut être utile pour l'évaluation des effets de cette gestion sur les variations à long terme des matières organiques.

L'étude a permis d'examiner des composantes du carbone du sol (la biomasse microbienne ainsi que le carbone organique soluble et le carbone organique total) et d'autres paramètres de qualité et de productivité des sols, tels que la résistance du sol, la teneur en carbonates, la densité et les rendements agricoles. On a étudié, à différents établissements agricoles de l'Ontario, la relation entre les propriétés des sols et les composantes carbonées ainsi que les implications de cette relation sur la productivité des sols.

La redistribution des sols attribuable à la topographie et aux pratiques agricoles influe sur la distribution des propriétés des sols dans les paysages. On a donc examiné les propriétés des sols en fonction de la position du paysage dans une pratique agricole. De plus, on a étudié les effets des pratiques agricoles dans une zone composée de champs adjacents soumis à différents modes de gestion à long terme des cultures et du travail du sol.

La gestion des sols et la topographie exercent une influence sur les composantes carbonées. Les sols soumis à une culture sans labour contenaient environ 1,5 fois plus de carbone organique et environ 2,5 fois plus de carbone de la biomasse microbienne que les sols labourés. L'effet de la position du paysage sur le carbone dans chaque système de gestion était moindre que celui des pratiques agricoles.

Tous les sites étudiés, la teneur en carbone organique était inversement proportionnelle au degré d'inclinaison des sols. Toutefois, il n'en allait pas toujours de même pour le carbone de la biomasse microbienne, même si la teneur en matières organiques labiles tendait à être plus élevée quand l'inclinaison était faible.

Les paramètres chimiques, physiques et de productivité des sols étaient souvent moins sensibles aux méthodes de gestion et au paysage que la teneur en carbone total et en carbone labile. En d'autres termes, les changements dans la teneur en carbone organique des sols peuvent se répercuter plus facilement sur la teneur en carbone labile que, par exemple, sur la densité apparente.

Les variations de la teneur en carbone de la biomasse microbienne n'étaient pas évidentes à tous les sites et, lorsqu'on en décelait, les teneurs maximales ne coïncidaient pas avec la date d'échantillonnage correspondant à peu près au stade de reproduction initial de la croissance des cultures. Toutefois, il faudrait mener, dans une même saison, un programme d'échantillonnage plus intensif que celui qu'on a exécuté au cours de cette étude pour déterminer à quel moment les populations microbiennes sont à leur maximum.

La grande variation de la teneur en carbone de la biomasse microbienne montre que les mesures de la biomasse ne fournissent pas à elles seules beaucoup d'information sur la qualité des sols. Pour pouvoir caractériser cette qualité, il importe de comparer des mesures du carbone de la biomasse avec d'autres mesures du carbone labile.

TABLE OF CONTENTS

TABLES

FIGURES

APPENDICES

1. INTRODUCTION

Microbial biomass and organic carbon are constituents of soil organic matter. The amount and composition of soil organic matter present in soils influences the size and diversity of microbial populations which control the mineralization of nutrients available to plants. Enhanced soil structure which is dependent on the amount of organic matter in the soil enhances the soil's capacity for water infiltration. Adequate water infiltration within agricultural soils limits the soil's susceptibility to compaction, smearing and erosion (Voroney, 1989).

Studies examining the negative effect of soil erosion on crop productivity indicate that reduced rooting depth, degradation of soil structure, decrease in available water content and nutrient imbalance contribute to declines in crop yields (Lal, 1987). Soil disturbances such as through tillage contribute to a decline in organic carbon storage in soil (Richter *et al.*, 1990). In addition, soil erosion processes will redistribute organic matter and topsoil from upper to lower slope positions in a landscape (de Jong and Kachanoski, 1989). Soil organic carbon levels and related soil properties which reflect soil quality will therefore relate to soil disturbance by tillage and to position in the landscape.

Changes in soil organic matter, such as a result of tillage, are considered to be detectable over a longer time frame since the existing pool of organic C in the soil is large, relative to changes which could be detected in the short term. It would be desirable to find an indicator of such longer term change so that soil management effects on soil quality could be assessed before major long term changes, such as a decline in organic matter, take place.

Measurements of soil microbial biomass were shown to provide an early indication of the relatively slow changes in soil organic matter which occurred as a result of incorporation of barley straw and stubble annually over an 18 year period (Powlson, *et al.*, 1987). Perfect *et al.* (1990) determined that soil moisture and soil microbial biomass were significant predictors of the temporal variation in structural stability, in particular, dispersible clay and wet aggregate stability, for a variety of cropping treatments.

In long term tillage plots in the United States, Doran (1987) found that microbial biomass C of no-tillage soils was 54% higher than that in plowed soils. While biomass C levels in no-till were greatest in the 0-7.5 cm depth, those in the plowed soils were greatest at 7.5-15 cm. Microbial biomass C levels were correlated with total C and N, soil moisture, and soluble carbon. Absolute levels of microbial biomass and the relative differences between tillage systems were dependent on climatic, cropping, and soil conditions across locations.

Variations in microbial biomass C levels within a growing season have been demonstrated to relate to crop growth, with maximum biomass C levels coinciding with the initial reproduction stage although factors other than crop-related ones may account for patterns other than this, including soil disturbance, fertilizer application, and increases in soil temperature, and moisture (Ritz and Robinson, 1988).

The present study was established to examine soil carbon components and to attempt to relate these to soil quality and productivity parameters. Its objectives were:

- to relate soil biomass and soil carbon components to the physical, chemical and biological properties of soil, and to directly relate these properties to soil fitness, crop performance, and yield, as a practical means of indicating agro-ecological status;
- to assist in the development and refinement of existing methodologies by applying current methodologies of measuring resident biomass and organic carbon in soil over a range of soil conditions; and
- to characterize the forms and the spatial and temporal variation of soil biomass and carbon on the basis of landscape position, geographic location, and seasonal variability.

In related research Agriculture Canada has established a soil quality monitoring program to examine natural soil degradation processes and the impacts of farm practices on the rate of these processes (Wang *et al.*, 1994). Under this program, 23 soil quality benchmark sites have been established across Canada for assessing trends in soil quality change within existing farm management systems.

The present study provided for sampling of a benchmark site near Rockwood, Ontario. The soil quality monitoring program of Agriculture Canada was thereby supplemented with data concerning soluble organic and microbial biomass carbon, to provide a comparison between adjacent fields of differing farm management.

Three additional sites were used to address the objectives of the study. These farm sites varied in soil type and management history. At these sites comparisons of soil carbon were assessed within a single tillage management system.

2. STUDY APPROACH

2.1 Site Selection

In addition to the established soil quality benchmark site (14-ON) located near the village of Rockwood in Wellington County, three sites under conservation farming practices were also examined. These sites were located in Haldimand-Norfolk, Huron and Glengarry counties (Figure 1). The additional sites were chosen to fulfil the following selection criteria:

- use of conservation tillage practices for at least 5 years;
- no application of manure for 5 years;
- the existence of a simple slope greater than 50 m in length with well defined slope positions;
- variety of soil texture from site to site; and
- corn or soybean crop, preferably in rotation.

A site was defined by delineating both a simple and uniform portion of slope within a field. Site dimensions, including slope positions and slope lengths, are shown in Appendix A.

Site Description Summary
The established soil quality benchmark site near Rockwood contained agricultural fields in differing tillage management and separated by a wooded area. Corn and soybean crops were grown in each of the two agricultural systems (Table 1).

The Clinton site was in no-till management and soybeans were the test crop. The Teeterville site was a sandy soil with corn grown under a reduced tillage management. The Bainsville site, in eastern Ontario was a ridge tillage strip crop management with corn and soybeans in alternate strips. Additional details of each site are provided in Section 3.

Several site and sampling parameters are summarized in Table 1.

At each site, three to five landscape positions were delineated as separate sampling treatments. Sites at Rockwood and Bainsville were further delineated into two crop types as treatments for some or all of the sampling parameters. At the Rockwood site only comparisons between tillage management were made. This was made possible by the use of adjacent fields and a wooded area in-between.

Sampling of baseline soil physical and chemical properties were completed once, between 1991 and 1994 at each site. Sampling of the labile carbon components - microbial biomass and soluble organic carbon - was conducted twice during a single year. All sites were sampled for the labile components in August of the year of sampling which was chosen to correspond with the initial reproduction stage of corn.

Table 1. Site treatments, description, and sampling summary

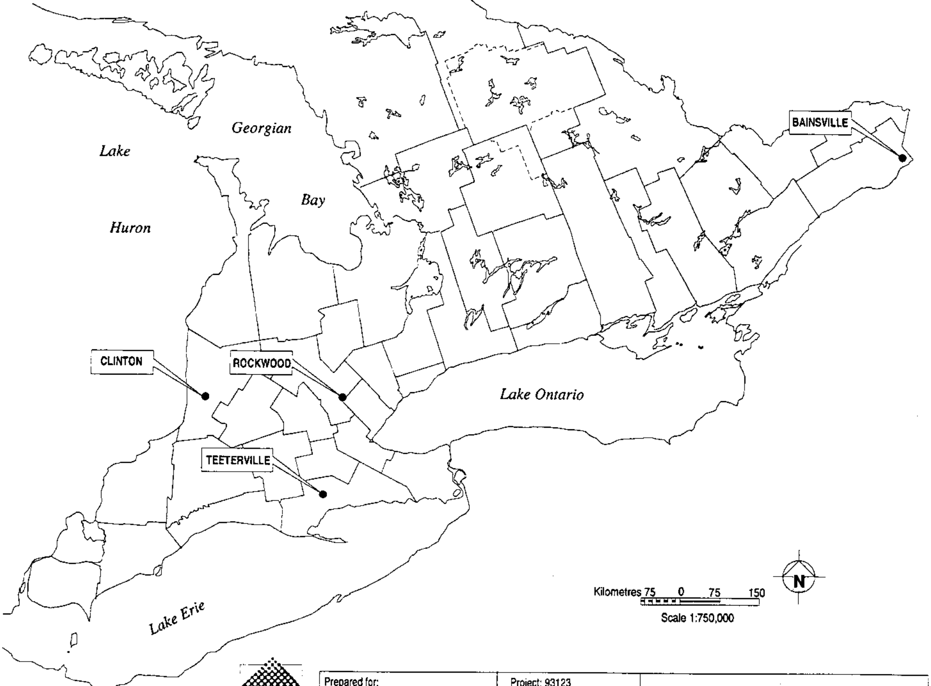
	Rockwood	Clinton	Teeterville	Bainsville
Tillage	1. no-till 2. fall plowing	1. no-till	1. fall chisel, spring disc	1. ridge tillage strip cropping
Crop	corn and soybeans in each agricultural tillage system; a forest system	soybeans	corn	corn and soybeans in alternate strips
Slope positions	(3): upper, middle, lower	(5): crest, upper, middle, lower, toe	(5): crest, upper, middle, lower, toe	(3): upper, middle, lower
Location	Eramosa Twp., Wellington Co.	Goderich Twp., Huron Co.	Delhi Twp., R.M. of Haldimand-Norfolk	Lancaster Twp., Glengarry Co.
Soil series	well drained Guelph loam to poorly drained Parkhill silt loam	well to moderately well drained Harriston silt loam to loam	well drained Scotland sandy loam	well drained Oka gravelly sand to poorly drained Bainsville loam
Sampling date, microbial biomass and soluble organic carbon	August, November, 1993	May, August, 1994	May, August, 1994	August, November, 1994
Sampling date, baseline soil physical and chemical properties	October, 1991 (no till) May, 1992 (conventional)	July 1994	July 1994	November 1994

2.2 Data Collection

A description of the methods used to carry out the sampling and field measurements is given below. A number of the procedures used were adopted from the methodologies used at the Rockwood ON-14 benchmark site and described in "Benchmark Sites For Monitoring Agricultural Soil Quality" (Wang, *et al.*, 1994). The replication of samples within a landscape position varies depending on the measurement made and the site. Details are provided for each parameter.

2.2.1 Microbial Biomass and Soluble Organic Carbon

Loose soil samples about 1 kg in size were taken at two soil depths, 0-15 cm and 15-30 cm. The soils were packaged into insulated containers and shipped to the Agriculture Canada Centre for Land and Biological Resources Research (CLBRR) facility in Ottawa within 24 hours of sampling. Samples were obtained at two times of the year as outlined in Table 1 (above).



ECOLOGICAL SERVICES GROUP

Prepared for: AGRICULTURE CANADA	Project: 93123	LOCATION OF STUDY SITES
	Date: APRIL, 1995	
Project Name: DEVELOPMENT OF METHODOLOGIES for BIOMASS AND ORGANIC CARBON	Drawn by: A.M.	
	Checked by: V.A.	FILE: 93123_02.DWG — FIGURE 1

In Rockwood, Teeterville, and Clinton five replicate samples were obtained per landscape position and treatment (where applicable). At Bainsville, three subsamples were obtained in each of two (replicate) crop strips, for each crop in August. One sample in each of three (replicate) crop strips were obtained in November.

The concentration of microbial biomass and soluble carbon is expressed as mgCkg $soil^{-1}$. In addition, the mass of these labile components was calculated for the upper 0-15 cm soil layer using soil bulk density values from the surface (0-15 cm) soil layer and is expressed in mgC cm^{-2} (in 15 cm). Soil organic carbon values are similarly expressed in concentration (g kg^{-1}) and mass (mg cm^{-2}).

2.2.2 Baseline Data - Soil Properties

Soil samples were collected from each slope position from the surface 0-15 cm layer with a Dutch auger. These samples were submitted to the Soil Characterization Lab at the University of Guelph (Agriculture Canada) for analysis for baseline soil chemical properties: pH, calcium carbonate equivalent (%), total carbon (Bainsville, Teeterville, and Clinton), and organic carbon. Five replicate samples per treatment were obtained at Teeterville and Clinton, three at Bainsville, and four (pH, $CaCO_3$) and five (organic carbon) at Rockwood.

Undisturbed core samples from the surface soil layer were obtained at each slope position for determination of soil bulk density and soil moisture. Five replicate samples per treatment were obtained at Teeterville and Clinton, three at Bainsville, and four at Rockwood.

Soil moisture was measured using Time Domain Reflectometry (TDR) (Topp *et al.*, 1980) at the Rockwood site. Three replicate samples per treatment were obtained.

2.2.3 Soil Pedon Descriptions

Two soil pits for detailed pedon description and sampling were dug at the crest and lower slope position at each site. Soil samples were collected and analyzed for particle size distribution. Detailed descriptions of these pedons can be found in Appendix B.

2.2.4 Penetrometer Resistance

Soil penetration resistance was digitally measured in 1.5 cm increments from the surface to 30 cm in the soil profile using the Rimik Cone Penetrometer (Bainsville and Rockwood) or the Star Centre Cone Penetrometer (Clinton and Teeterville). The maximum resistance was recorded. Three determinations in each of five replicate treatments were obtained at Teeterville and Clinton, three replicate measurements per treatment were obtained at Bainsville, and three replicate measurements per treatment were obtained at Rockwood. All measurements were taken at each landscape position within 5 m of carbon sampling.

2.2.5 Crop yields

Both corn and soybean yields were taken at Rockwood and Bainsville. Corn yields were taken at Teeterville and soybean yields were taken at Clinton.

Crop yields were determined by hand harvesting at Rockwood, Teeterville and Clinton.

Ears were removed from two 5 m rows of corn and the number of plants was recorded. The number of ears was counted and total ear weight was recorded. A 10-ear subsample was weighed, dried, shelled and weighed. Corn yields are expressed as grain weight at 15.5% moisture.

Whole soybean plants from 1 m^2 plots were cut near ground level and removed from the field. The plants were dried, weighed and threshed, and the grain weight determined. Soybean yields are expressed as grain weight at 14% moisture.

Soybean and corn yields were measured at the Bainsville site using a yield monitor mounted on a combine harvester which recorded harvest yields every 3 m.

Five replicates per treatment were obtained at Teeterville and Clinton, and three replicates at Bainsville and Rockwood.

2.3 Lab Analysis

Particle size distribution was determined using the pipette method for the fine fraction, and sieving for the sand fraction (Sheldrick and Wang, 1993). Percent organic carbon was determined by dichromate oxidation (Tiessen and Moir, 1993) and percent total carbon obtained with the LECO induction furnace method (Sheldrick, 1984). Calcium carbonate equivalent was determined using the inorganic carbon calcimeter method (Sheldrick, 1984), and the soil pH was measured with a pH meter using a 1:2 soil to 0.001 M $CaCl_2$ solution (Sheldrick, 1984). Bulk density values in g cm^{-3} were obtained from oven-dry core samples in the method outlined by Culley (1993).

The soluble organic and microbial biomass carbon analyses were conducted at the Agriculture Canada Centre for Land and Biological Resources Research (CLBRR) laboratories in Ottawa and Guelph. Microbial biomass carbon was determined using the fumigation-extraction method (Voroney, *et al.*, 1993) and soluble organic carbon in the soil samples was determined by measuring soluble carbon in the unfumigated extracts. Extracted soluble organic carbon in the fumigated and unfumigated extracts was determined on a Soluble Carbon Analyzer (Shimadzu, TOC 5050).

2.4 Statistical Analysis

The data were analyzed separately for each site. Analysis of variance was used to test main effects of slope position, and tillage and crop systems and their 2-way interactions at sites where these occurred. For microbial biomass and soluble organic carbon, analysis of variance was conducted with sample depth and sampling date as factors. Significance was tested at p # 0.05. Means were separated using Tukeys PSD. Summary statistics are provided in Appendix C for each site. The data have been organized to provide a summary for each parameter for each slope position within the smallest treatment unit.

3. STUDY FINDINGS

3.1 Rockwood

Site Description

This western Ontario site is located approximately 10 km northeast of the City of Guelph, near the village of Rockwood in Eramosa Township, Wellington County. The area is characterized by rolling to undulating surface topography and the site is typical of the overall physiographic region (Chapman and Putnam, 1984). The soil parent material is derived from loamy, stony, calcareous till. The soils are from the Guelph Catena.

The overall site is made up of agricultural fields and a small wooded area. The fields represent differing history of soil and crop management. One field is currently under conservation tillage and the other under a conventionally fall plowed system. The site contains a simple slope, 200 m long, ranging from 3 to 8.5% at the upper and middle slope positions, and 2 to 5% at the lower landscape positions.

Fields in the conservation tillage site have been in no-till since 1991 with a corn-soybean-wheat rotation. Prior to this the site was in a corn-forage rotation. The soil has not been tilled since 1987. The conventionally tilled site was under a monoculture corn, fall moldboard system from 1979 to 1992, at which time crop management changed to include a three crop rotation.

Soil Properties

Soil profile descriptions for the crest and lower slope positions appear in Appendix B. Pedon descriptions were made at the no-till site. At the crest position of the slope the soil is a well-drained Guelph loam; the Ap horizon is 29 cm deep and the B/C interface is at 62-75 cm from the soil surface. At the lower slope position the soil is a poorly drained silt loam with an Ap horizon extending to 34 cm and the B/C interface at 66 cm.

Detailed measurements of A horizon depth were taken at the Rockwood sites. Depths were found to range from 19 to 36 cm but not to be affected by tillage system or slope position. The depth of the Ap averaged 27 cm for the site, hence, soil characterization in 0-15 and 15-30 cm layers should largely reflect the same soil horizon (Ap) in soil under both management systems and all slope positions.

Characteristics of soil sampled appeared to be influenced by soil management and/or slope position. Differences in characteristics with slope position would be expected to reflect the differences due to soil texture and drainage described at the site.

Maximum penetrometer resistance did not change significantly with slope position within the no-till system. Under conventional tillage, however, the upper and mid slope positions had much higher maximum values than the lower slope suggesting the presence of soil compaction within the 30 cm profile at some slope positions under the conventional management. Values on the lower slope of the conventional system were similar to those in no-till. The maximum values were greater than 4000 kPa where compaction occurred but were 2000-3000 kPa at most for other slope positions.

Soil bulk density was lower at the lower slope than other slope positions within the no-till system, but did not change significantly with slope position under conventional tillage.

In both systems soil moisture values were lower on the upper slope than on the lower slope position at the time of sampling.

Soil pH was higher overall in conventional tillage (7.4) than in no-till (6.9), and was overall higher at the mid slope (7.4 over both systems), than either upper or lower slope positions (avg. 7.0 over both systems).

Soil Carbon

The soil characteristic which showed perhaps the greatest effect of soil management was the organic C and N content measured at 0-15 and 15-30 cm soil depths.

Organic C and N concentrations in the no-till system were greater than 1.5 times those in the conventional system (Table 2). Values of organic C and N were highest on the lower slope, and lowest on the mid slope position, and values decreased with depth for both systems (Tables 3 & 4).

Table 2. Effects of Tillage system on organic C (g C/kg soil) and N (g N/kg soil) concentrations, Rockwood

System (averaged over slope position and depth)	Organic C (±sem)	Organic N (±sem)
Conventional	14.7 (1.2)	1.45 (0.103)
No-till	25.9 (1.2)	2.39 (0.100)

Table 3. Effects of Slope position on organic C and N concentrations (g/kg soil), Rockwood

Slope position (averaged over system and depth)	Organic C (±sem)	Organic N (±sem)
Upper	20.2 (2.0) ab	1.97 (.141) a
Middle	14.6 (1.5) b	1.39 (.145) b
Lower	25.5 (1.5) a	2.37 (.128) a

means within a column followed by the same letter are n.s. different, p # 0.05

Table 4. Effects of Soil Depth on organic C and N values (g/kg soil), Rockwood

Depth (cm) (averaged over system and slope position)	Organic C (±sem)	Organic N (±sem)
0-15	22.2 (1.4)	2.15 (0.111)
15-30	18.3 (1.7)	1.69 (0.142)

The effect of varying concentrations of organic carbon in the soils resulted in significant differences in the total storage of organic C (and N) in the upper 15 cm of the profile. In the upper 15 cm of soil in the conventional system, the lowest quantity of organic C was mid-slope (221 mgC cm^{-2}) followed by the upper slope (330 mgC cm^{-2}) and the lower slope (424 mgC cm^{-2}). In the no-till system the storage of organic C did not vary across slope positions and averaged 536 mg cm^{-2} (± 17) and was significantly higher than quantities in the conventional system (Figure 2).

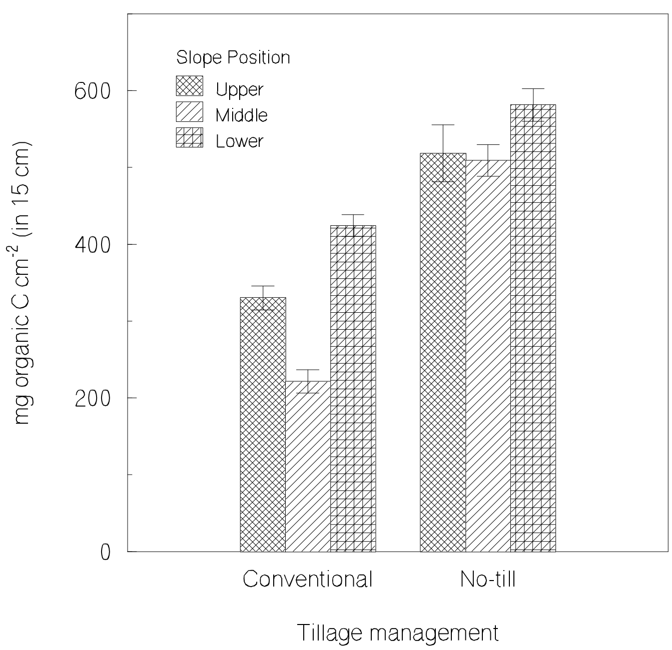


Figure 2. Mass of organic carbon at Rockwood (standard error bars shown)

The sampling for microbial and soluble C concentrations within the agricultural fields at the Rockwood site provided for several factors to be examined including: conventional and no-till systems, soybean and corn crops within each system, and slope position, sampling depth, and sampling date.

To break down effects and their interactions to aid in interpretation, soil variables were analyzed separately for each sampling depth. Crop main effects and interactions were tested and where the crop grown could be omitted as a factor, analysis proceeded to examine effects of tillage systems, slope position and sampling date on the soil carbon variables. In the case of the microbial biomass carbon (15-30 cm depth), a significant slope x crop interaction occurs. In this case, data analysis was completed separately for each of the soybean and corn crops.

Soluble organic carbon (SOC) concentrations in the surface (0-15 cm) soil was 50% higher in the no-till management at the August sampling date than in conventional tillage management. In November SOC levels showed no differences between tillage systems, and levels were approximately one-fifth the levels measured in August.

In August, SOC levels, regardless of tillage system varied with slope position - highest levels occurred in the lower slope, and lowest levels mid slope. By November, when SOC values were relatively low, levels of SOC were uniform with slope.

SOC in the subsurface (15-30 cm) followed the same pattern as that in the surface. That is, the no-till system had more SOC than the conventional system when sampled in August, but not November; SOC was similar in all slope positions in November, while in August, the lower slope position had higher SOC. These data suggest that the soluble C contribution derived from decomposing soil organic matter or root exudates, is greater in August than in November.

Microbial biomass carbon (MBC) concentrations in the surface (0-15 cm) soils were not found to differ between samplings in August and November suggesting that temperatures in November were not cold enough to limit microbial population. Tillage management or past site management, reflected differences in the MBC levels. At each slope position, no-till soil contained more MBC than the conventional system. The no-till site had been previously managed with rotations which included grasses while the conventionally tilled site was under continuously cropped corn. While in the conventional system, MBC levels did not vary with slope position, in the no-till system, the lower slope had 40% more MBC than the upper and mid slope positions. This meant that MBC levels in the no-till system were 1.8 times those in the conventional system at the upper and mid slope positions, but 3.4 times in the lower slope position.

The amount of microbial biomass C stored in the upper 15 cm of the soil, measured in August, was much higher in the no-till system, averaging 9.43 mg cm^{-2} (±.89), than in the conventional tillage system, which averaged 3.54 mg cm^{-2} (±.38) (Figure 3). Similarly, in November, the mass of microbial C was greater in the no-till (9.46 ±1.42 mg cm^{-2}), than in the conventionally tilled soil (4.90 ±.86 mg cm^{-2}), although the slope position effect differed in the two systems.

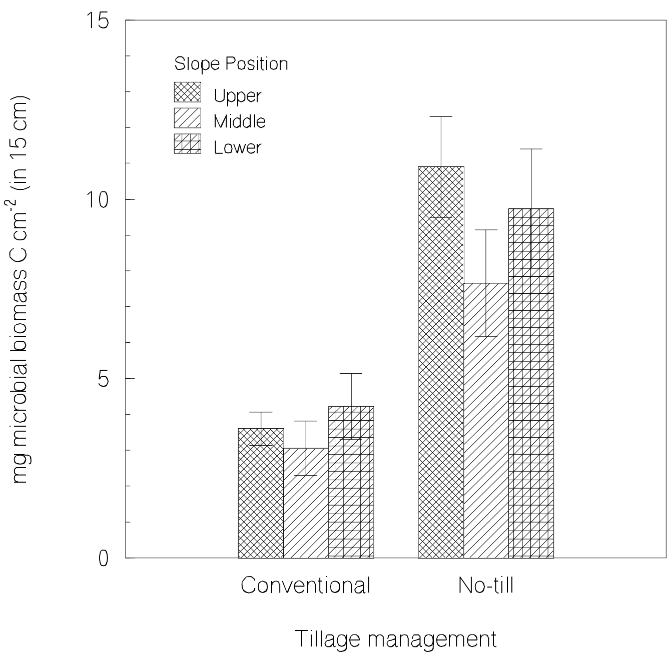


Figure 3. Mass of microbial biomass carbon at Rockwood from August sampling, 0-15 cm depth (standard error bars shown)

A somewhat similar pattern as the surface soil emerged for MBC levels in the subsurface soil for each of the corn and soybean crops. That is, the conventional system had uniform levels on average, with slope. The no-till system had higher MBC levels at the lower slope relative to the upper and mid slope positions. Differences between tillage systems, were not evident at upper slope positions (both crops) or mid slope position (corn).

Measurements of soluble and microbial biomass carbon were also made in the forested section of the site. Concentrations of soluble organic carbon (SOC) did not vary significantly with slope position in the forest site. At the August sampling date, SOC levels were much higher than at the November sampling date, and the surface soil contained more than twice the soluble organic carbon as the subsurface (277 and 122 mg C/kg soil, respectively). By November, SOC levels were similar at the two sampling depths, and the average level was 42.8 mg C/kg soil (±3.7).

Soil microbial biomass carbon (MBC) levels did not consistently vary according to slope position in the forest system. At the August sampling date, MBC levels did not differ with slope position, and averaged 448 mg C/kg soil. In November, the microbial biomass carbon levels had more than doubled from the earlier sampling date in the upper slope position only.

Overall, MBC in the subsurface (15-30 cm) at the forest site was less than half that in the surface soil (0-15 cm). The total carbon storage in microbial carbon cannot be calculated because soil bulk density is not known.

A comparison of the carbon components in the topsoil of the agricultural and forested system indicated overall there was a trend to lower values for soluble and microbial carbon levels in the conventional tillage system than in the other systems. This was apparent at both dates and soil depths (Table 5, Figures 4 and 5).

Table 5. Effects of Soil Management Systems and Slope Position on Microbial Biomass Carbon Concentrations (mg C kg^{-1}) in 0-15 cm measured in August at Rockwood on corn and forested sites

System	Slope Position		
	Upper	Middle	Lower
Conventional	163 b	143 b	221 b
No-till	539 a	390 b	549 a
Forest	609 a	855 a	558 a

means within a column followed by the same letter are n.s. different p # 0.05

The microbial biomass C concentrations in the soil at both depths measured in August were similar in the no-till and forest systems, which were higher than the levels obtained in the conventional system. In addition, higher values of soluble C were measured at depth (15-30 cm) in the forest soil in November, compared with the agricultural systems.

Crop Yields

Corn yields were much higher in the no-till system (6.26 $Mgha^{-1}$) than in the conventional system (3.66 $Mgha^{-1}$) at Rockwood. These large differences are not believed to be solely due to the tillage system; the conventional system was planted later, and worked under high soil moisture conditions.

Soybean yields were uniform with slope position in the no-till system but the midslope position of the conventional tillage produced higher yields than the upper slope (Table 6). There were no differences between systems at each slope position.

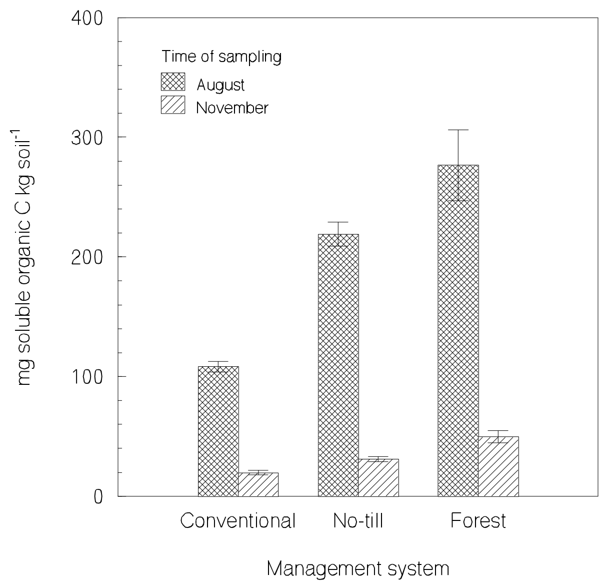


Figure 4. Concentration of soluble organic carbon measured at two sampling dates at Rockwood, 0-15 cm depth (standard error bars shown)

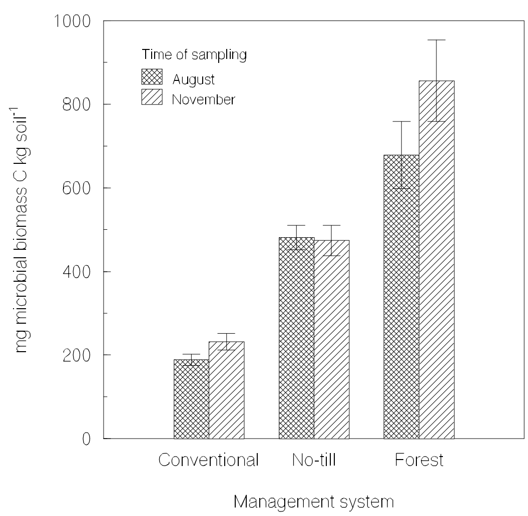


Figure 5. Concentration of microbial biomass carbon at two sampling dates at Rockwood, 0-15 cm depth (standard error bars shown)

Table 6. Soybean Yields (Mg ha^{-1}), Rockwood

System	Slope Position		
	Upper	Middle	Lower
Conventional	2.07 b	3.39 a	2.88 ab
No-Till	3.04 ab	3.01 ab	2.69 ab

means followed by the same letter are n.s. different p # 0.05

3.2 Clinton

Site Description
The western Ontario site is located approximately 10 km northwest of the town of Clinton in Goderich Township, Huron County.

The site is situated in an area of rolling topography. The soil parent material consists of calcareous loamy till with variable amounts of weathered stone. The soil is well to moderately well drained and classified as a Harriston loam (Hoffman *et al.*, 1952).

The site consists of a simple southeast facing slope approximately 130 m in length. Slope percentages range from 11-12% on the upper to mid portion of the slope and 4-6% on the mid to lower slope.

The farm on which this site is located has been under no till management for at least 10 years with a corn-soybean rotation. In the 1994 season the site was planted in soybeans.

Soil Properties
Soil profile descriptions for the crest and lower slope positions appear in Appendix B. At the crest position of the slope, the soil is a well-drained silt loam containing carbonates; the C horizon is at 19 cm from the soil surface. At the lower slope position the soil is a moderately well-drained loam; the A/C interface occurs at 36 cm.

The presence of carbonates and shallower A horizon at the crest position relative to the lower slope suggests the crest is eroded and the lower slope is recently depositional. The lack of B horizon in the profile suggests historically, there has been erosion at both slope positions. Higher levels of carbonates in the C horizon and the calcareous surface horizon at the crest slope position indicate the crest is more eroded than the lower slope. There is also an indication that the A and C horizons have been mixed probably by cultivation.

Characteristics of the soil, measured in the upper 0-15 cm of the profile, differ with the position on the slope (Table 7).

Calcium carbonate levels, indicative of soil movement downslope or of topsoil/subsoil mixing, are high at the upper/crest positions and tend to be higher and more variable, than at the mid and lower/toe positions.

The lower slope positions tend to have lower soil bulk densities and contained more moisture at the time of sampling than the upper and crest positions. Soil compaction, as measured by resistance to penetration was evaluated for a 30 cm profile. Maximum resistance tended to be higher at the upper and crest slope positions than that at the mid slope. At this site, the 30 cm profile would include a significant portion of the subsoil (C) at the crest and would include entirely the A horizon, at the lower slope.

Table 7. Soil Properties Measured in the Upper 0-15 cm Soil Profile (0-30 cm for resistance), Clinton

Slope Position	% $CaC0_3$	% Soil Moisture (w/w)	pH	Bulk Density (g cm^{-3})	Maximum Penetrometer Resistance (0-30 cm), kPa
Crest	15.5 a	15.9 b	7.42	1.54 ab	2683 a
Upper	13.7 a	15.4 b	7.44	1.63 a	2700 a
Middle	6.4 ab	16.4 b	7.30	1.60 ab	2050 b
Lower	4.8 b	19.3 a	7.36	1.48 b	2233 ab
Toe	5.9 b	20.1 a	7.26	1.49 b	2283 ab

Means followed by the same letter within a column are not significantly different (p # 0.05)

Soil Carbon

Organic carbon concentrations in the topsoil (0-15 cm) also varied significantly with slope position, with higher concentrations at the lower and toe slope. As a result, as much as twice the organic carbon is stored in the 0-15 cm profile of the toe slope position than at the upper slope position (Table 8). Total carbon concentrations were similar with slope position and total carbon storage was not significantly influenced by slope position.

Table 8. Organic Carbon in the 0-15 cm Soil Depth (mg C cm^{-2}), Clinton

Slope Position				
Crest	Upper	Middle	Lower	Toe
335 cd	259 d	363 c	467 b	583 a

means followed by the same letter are not significantly different, p # 0.05

Soluble carbon concentrations were overall higher at the May sampling date (49 mg

C/kg soil) than at the August sampling date (28 mg C/kg soil).

Microbial biomass carbon levels were overall higher in surface than in subsurface soil layers. Microbial biomass was not significantly influenced by slope position or sampling date alone. An interaction between slope position and soil depth was evident. Microbial biomass C levels were higher in the surface at each slope position except the toe, where values were similar with depth. In the subsurface soil, the crest, upper, and mid slope had the lowest levels of microbial C and highest levels were at the toe. Effects of soil depth reflect the observation that the A horizon extends to >30 cm at the lower slope while the C horizon occurs at 19 cm at the crest.

In the microbial biomass C component the concentrations of biomass C in the upper 15 cm were not influenced by slope position, in contrast to most other soil parameters measured. At both sampling dates, May and August, MBC concentrations (0-15 cm) were similar with slope position, and despite differences in soil density with slope position, the mass of microbial C in the upper 15 cm profile did not reflect differences in slope position at the August sampling date (Table 9).

Table 9. Microbial Biomass Carbon in the 0-15 cm Soil Depth (mg C cm^{-2}), Clinton

Date	Slope Position				
	Crest	Upper	Middle	Lower	Toe
May	6.92 ab	4.92 b	6.87 ab	8.32 ab	9.97 a
August	9.13	6.83	7.59	10.66	8.65

means followed by the same letter within a row are not significantly different, p # 0.05

Crop Yield
At this site, soybean yields were unrelated to slope position and averaged 3.688 (±0.134) Mg ha^{-1}.

3.3 Teeterville

Site Description
The southern Ontario site is located approximately 4 km east of the village of Teeterville in Delhi Township, Regional Municipality of Haldimand-Norfolk.

The site is situated on undulating topography dominated by sandy soils with calcareous coarse till parent material. Surface soil textures identified on site range from fine sandy loam to loamy sand. The soil is well to moderately well drained and is classified as a Scotland sand (Presant and Acton, 1984).

The site is located on a single simple south facing slope approximately 90 m in length.

Slopes range from 8-9% on the upper and middle locations to 2% on the lower slope position.

The farm on which this site is located has been in corn for at least 5 years and is under conservation tillage management, with chisel ploughing in the fall and discing in the spring.

Soil Properties
Soil profile descriptions for the crest and lower slope positions appear in Appendix B. At both slope positions the soil is identified as well drained sandy loam. At the crest, the A horizon is at 18 cm soil depth and the B/C interface is at 41 cm. At the lower slope position the A horizon is at 33 cm soil depth and the B/C interface is at 120 cm.

Surface soil pH is strongly acidic to very strongly acidic and organic matter levels are relatively low.

The deeper Ap, lower depth to C, and presence of slightly illuviated B horizons at the lower slope position relative to the upper slope suggests that historically the soil profile at the crest position has been eroded while the soil profile at the lower slope position is located at an area of either balanced soil erosion/deposition or net soil accumulation.

Some characteristics of the topsoil, measured in the upper 0-15 cm of the profile were found to differ with slope position while others remained relatively constant (Table 10).

Levels of carbonates and soil moisture content were found to be uniform with slope position. Bulk density in the topsoil also did not differ with slope position and averaged 1.55 g cm^{-3} (± 0.020).

On the other hand, topsoil pH was higher at the upper and crest slope positions than those further downslope. The maximum resistance to penetration in the 0-30 cm profile was higher at the crest than at the upper to lower slope positions. At the crest position a sampling to 30 cm takes in both A and B soil horizons.

Table 10. Soil Properties Measured in the Upper 0-15 cm Soil Profile (0-30 cm for resistance), Teeterville

Slope Position	% $CaC0_3$	% Soil Moisture (w/w)	pH	Bulk Density (g cm^{-3})	Maximum Penetrometer resistance (0-30 cm), kPa
Crest	1.4	11.9	6.78 a	1.60	4033 a
Upper	1.3	11.0	6.74 a	1.51	3233 bc
Middle	0.82	11.3	4.98 b	1.53	2800 c
Lower	1.1	12.6	4.98 b	1.58	2750 c
Toe	1.3	11.0	5.24 b	1.51	3800 ab

means followed by the same letter within a column are n.s. different, p # 0.05

Soil Carbon

Organic carbon concentrations increased downslope with lowest concentrations in topsoil at the crest and highest concentrations at the lower and toe slopes (Table 11). With largely similar topsoil densities, the amount of organic carbon stored in the 0-15 cm depth ranged from 159 mg C cm^{-2} at the crest, to 280 mg C cm^{-2} at the toe slope.

Table 11. Organic Carbon in the 0-15 cm soil depth (mg C cm^{-2}), Teeterville

Slope Position				
Crest	**Upper**	**Middle**	**Lower**	**Toe**
159 c	218 b	191 bc	246 ab	280 a

means followed by the same letter within a row are n.s. different, p # 0.05

Soluble carbon and microbial biomass carbon levels were overall higher in surface (0-15 cm) than in subsurface (15-30 cm) soil layers. Microbial biomass was not significantly influenced by slope position or sampling date at this site. Soluble carbon levels were overall higher at the May sampling date (43 mg C/kg soil) than at the August sampling date (31 mg C/kg soil).

The mass of microbial carbon in the upper 15 cm of soil was relatively uniform with slope position at each sampling date, averaging 5.90 mg cm^{-2} (±.56) in May, and 4.24 mg cm^{-2} (±.37) in August.

Crop Yield

Grain corn yields were lower on the crest position of the slope (average 10 Mg ha^{-1}) than on other slope positions (range 12.7 - 13.5 Mg ha^{-1}) (Table 12). The lower plant biomass production at the crest position of the slope indicates lower quantities of organic carbon will be returned to the soil in crop residue and differences in soil carbon levels between crest and other slope positions will continue.

Table 12. Grain corn yields (Mg ha^{-1}), Teeterville

Slope Position				
Crest	Upper	Middle	Lower	Toe
10.14 b	13.00 a	13.53 a	12.65 a	12.87 a

Means followed by the same letter are n.s. different, p # 0.05

3.4 Bainsville

Site Description

The eastern Ontario site is located approximately 1 km east of the hamlet of Bainsville in Lancaster Township, Glengarry County.

The site is situated on a ridge consisting of gravelly, coarse to moderately coarse stratified beach parent material characteristic of the Oka association mapped in the Ottawa Urban fringe (Marshall *et al.*, 1979). This well drained coarse textured soil grades into a modified Castor association soil on the lower slopes.

The site contains a single simple slope approximately 52 m in length on the south facing side of the ridge. Slope percentages range from a maximum of 6% on the upper and middle parts of the slope to 2% at the lower sampling position.

The farm on which this site is located was last ploughed in the fall of 1987 and has been under ridge tillage cropped in strips since 1990 in a corn, soybean rotation.

Soil Properties

Soil profile descriptions for the crest and lower slope positions appear in Appendix B. At the crest position of the slope, the soil is a well drained gravelly sandy loam; the A horizon extends to 17 cm depth and the B/C interface is found at 75 cm depth below the soil surface. At the lower slope, the soil is a poorly drained loam over a gravelly sandy loam; the A horizon extends to 26 cm and the B/C interface is found at 110 cm below the soil surface.

The shallower A horizon at the crest position relative to the lower slope position suggests the crest is eroded and the lower slope is recently depositional. However, the soil profiles at both slope positions are well-developed, suggesting that historically, soil erosion has not been severe.

Differences in topsoil characteristics between slope positions would be expected to reflect differences in soil texture and drainage described at the site.

Lower slope positions had higher moisture, lower density and least maximum resistance to cone penetrometer, relative to upper and mid slope positions, which were similar (Table 13).

The influence of crop type or interactions with slope position were not significant for soil moisture and bulk density. Penetrometer resistance was marginally influenced by crop ($p<0.10$). The resistance to cone penetration was higher in soybeans (2452 kPa ±285) than in corn (2220 kPa ±256) although this difference is small relative to those measured between slope positions.

Topsoil pH values were higher on the lower slope position while calcium carbonate levels were not affected by slope position. However, carbonate levels were lower where corn was grown compared with soybeans.

Table 13. Soil Properties Measured in the Upper 0-15 cm Soil Profile (0-30 cm for resistance), Bainsville (over both crops)

Slope position	% $CaC0_3$	% Soil moisture (w/w)	pH	Bulk density (g cm^{-3})	Maximum Penetrometer resistance, kPa
Upper	1.267	19.77 b	4.9 b	1.48 a	2762 a
Middle	0.750	19.07 b	4.7 b	1.41 a	2938 a
Lower	0.783	32.37 a	5.9 a	1.23 b	1307 b

values followed by the same letter within a column are n.s. different, p # 0.05

Soil Carbon

Organic carbon content of the topsoil was higher in soils at the lower slope position and were higher in strips in which corn rather than soybean were grown. Similarly, the quantity of organic carbon was higher in the 1994 corn crop strips, (607 mg cm^{-2}) than in soybean strips (562 mg cm^{-2}).

Table 14. Organic Carbon in the 0-15 cm Soil Depth (mg C cm^{-2}), Bainsville

Slope Position		
Upper	**Middle**	**Lower**
598	566	589

The amount of carbon stored in the 0-15 cm profile did not change significantly with slope position reflecting higher organic C concentration and lower density of soils at the lower slope relative to other positions (Table 14).

Concentrations of soluble organic and microbial biomass carbon in the soil were influenced by slope position, soil depth, and date of sampling. No two way interactions of these factors were significant.

The lowest values of soluble organic carbon were found on the upper slope (48.2 mg C/kg soil) and the highest values, mid slope (58.1 mg/kg) (Table 15). On the other hand, microbial biomass C values on the lower slope position were approximately twice those on either the mid, or upper slope positions.

Table 15. Effects of Slope position on soluble organic and microbial biomass C (mg C/kg soil), Bainsville

Slope position (averaged over depth and date)	Soluble Organic C	Microbial biomass C
Upper	48.2 b	364.6 b
Middle	58.1 a	342.1 b
Lower	52.7 ab	676.1 a

means within a column followed by the same letter are n.s. different p # 0.05

Surface soil layers (0-15 cm) produced higher values of both soluble organic carbon and microbial biomass carbon, with the relative difference higher for microbial biomass measurements (38% higher) than for the soluble organic carbon (18% higher) (Table 16).

Table 16. Effects of Soil Depth on soluble organic and microbial biomass C (mg C/kg soil), Bainsville

Depth (cm) (averaged over slope position and date)	Soluble Organic C	Microbial biomass C
0-15	58.1	569.9
15-30	47.9	352.0

The effect of date differed for the soluble organic and microbial carbon, with more soluble carbon in August than November (9% more), but more microbial carbon in November (511.4 mg C/kg) than in August (385.1 mg C/kg) (Table 17).

Table 17. Effects of Sampling date on soluble organic and microbial biomass C (mg C/kg soil), Bainsville

Date (averaged over slope position and depth)	Soluble Organic C	Microbial biomass C
August	56.1	385.1
November	50.9	511.4

The data also suggested that overall microbial biomass levels were higher in corn than soybeans although the difference was small (14%).

The amount of microbial C in the surface soil (0-15 cm) did not change significantly with slope position in the corn, when measured in August, and averaged 10.78 mg cm^{-2} (±.57). For the soybean crop measured in August, and both crops measured in November, the mass of microbial C was highest at the lower slope position (Table 18).

Table 18. Effect of Slope Position on the Amount of Microbial Carbon in the upper 15 cm of soil at Bainsville.

Slope position	Microbial Biomass Carbon, mg C cm^{-2}	
	August, (in soybeans)	November, (both crops)
Upper	7.49 b	11.87 ab
Middle	6.43 b	10.07 b
Lower	12.47 a	15.89 a

means within a column followed by the same letter are n.s. different, p # 0.05

Crop Yields

Corn yields were unaffected by slope position, with an average yield of 9.06 Mg ha^{-1} (±.365). On the other hand, soybean yields were lower on the lower slope position, with an average drop in yield of 0.78 Mg ha^{-1} or 27% lower than on the remainder of the slope.

4. DISCUSSION

Soil microbial biomass is the living component of soil organic matter that responds rapidly to changes in soil management. Soil microorganisms are important as a source and sink of plant nutrients and are the driving force behind decomposition and soil nutrient transformations. Since actively cycling organic matter fractions are usually correlated with total soil organic matter, estimation of the percentage of soil organic C or N in the active fraction may be useful in assessing changes caused by management.

Measurements of soil movement, using Cs-137 at Rockwood indicated that a significant amount of soil redistribution had occurred at all slope positions at the conventionally managed site (D. King, pers. comm.). Soil losses were greatest at the upper and mid-slope positions at this site with smaller losses occurring at the lower slope positions. On the no-till site, soil losses were measured at upper and mid-slope positions whereas substantial amounts of deposition had occurred at the lowest slope position at this site.

Measurements of organic carbon and microbial biomass carbon at Rockwood reflected the impacts of management and soil redistribution. The organic carbon levels at all of the slope positions on the no-till site were higher than those at the conventionally tilled site. No-till soils had about 1.5 times more organic carbon than conventionally tilled soils. The amounts of organic carbon at upper and mid-slope positions at both sites were smaller than those at the lower slope positions; with more than 25% more carbon at the lower slope.

The microbial biomass carbon levels showed similar trends as those of total organic carbon. No-till soil contained more microbial biomass carbon than the conventionally tilled soil. In the surface 15 cm of no-till soils the microbial biomass was about 2.5 times larger than that in conventionally tilled soils. These data indicate that there is a larger active fraction of organic matter in no-till soils.

Additional evidence of soil degradation at Rockwood was found in the measure of maximum penetrometer resistance. Soil strength measurements followed the trend of soil losses. The upper and mid slope positions of the conventionally tilled soil had relatively higher soil strength than no-till or the lower slope position of the conventionally managed site. At the Rockwood site, soil physical and chemical properties that would affect organic matter levels in the soil appeared to be less sensitive to management and slope position than the total and labile organic C components.

Further evidence of the movement of soil organic matter downslope was found at Clinton with loam/silt loam soils and Teeterville with sandy loam soils. Concentrations and total quantity of organic carbon were highest at the lower and toe slope. However, the labile components, soluble carbon and microbial biomass carbon concentrations and mass, were not as clearly influenced by slope position at either site.

At Clinton many soil chemical and physical properties differed with slope position and pointed to soil degradation at the crest and upper slope positions. Soils at these slope positions contained relatively large amounts of carbonates. The C horizon was located at 19 cm from the soil surface at the crest, compared with 36 cm at the base of the slope.

Microbial C levels were similar with depth only at the toe slope position. Hence, the amount of total labile carbon is expected to be highest at the toe slope where topsoil depth is greater and MBC concentrations are consistent to 30 cm.

At Teeterville, crop yield showed effects of slope position, with the crest position having lower productivity than other slope positions.

At Bainsville, concentrations but not quantity of organic carbon were higher at the lower slope than the upper and middle slopes. Concentrations of microbial biomass carbon were highest for the lower slope positions and the mass of MBC tended to be highest there as well. Several soil properties were substantially different between lower and mid/upper slope positions. Soils at the lower slope positions differed in texture and drainage from that soil at the upper slope positions.

Overall, it appears that soils in the lower slope positions contained more total and labile organic matter because of the redistribution of biologically active materials by erosion by tillage or water.

In this study, sampling frequency was not sufficient to conclude the nature of temporal variations in the labile carbon components. While the literature has suggested maximum biomass C levels coincide with the initial reproduction stage of crop growth, this pattern was not detected in this study. In fact, at Rockwood and Teeterville, seasonal differences in MBC were not evident, while at Bainsville and Clinton, values of MBC were lower in August than May or November. This may relate to soil moisture or temperature effects controlling the MBC content at time of sampling. Also, while August sampling was estimated to be near the initial reproduction stage of the crop, the timing may not have been sufficiently precise to capture the maximum biomass levels in this study. In future studies, it would be important to determine when microbial populations are at a maximum. For such studies, one landscape position could be chosen and measurements taken more intensively throughout the growing season.

High coefficients of variation for microbial biomass C underscores the fact that biomass measurements by themselves do not indicate much about the soil quality. Many samples over time and at one location are needed to characterize the microbial biomass. In addition, the biomass needs to be compared with other measurements of labile carbon in order to characterize soil quality.

The microbial biomass has been suggested as a sensitive indicator of changes in soil processes because it has a much faster rate of turnover than total soil organic matter. It has been suggested by researchers that trends in microbial biomass content of soils will predict longer term trends in total organic matter contents. This is consistent with the results of this study which indicate that the absolute microbial C content of a soil is of limited value as an indicator of soil quality. This suggests that rates of change in soil parameters, rather than absolute values, can provide an assessment of long term soil quality.

In addition to microbial biomass contents, other organic matter fractions should be measured. Many researchers suggest that the microbial quotient (microbial biomass

C/total soil organic C) indicates changes in soil quality and is a more useful measure than either measurement alone. Because microbial C is normalized by the total soil C, calculation and use of the microbial quotient avoids the problems of working with absolute values and comparing different soils with different amounts of soil organic matter.

The light fraction of organic matter consists of mainly plant residues minimally affected by decomposition. As such it serves as a readily decomposable substrate in various stages of decomposition. As with the other measurements of labile C it should be expressed as a proportion of the total soil C in order to make valid cross-site comparisons.

The measurements described above should be evaluated as a suite of measurements and must be evaluated with respect to the processes and mechanisms operating at a given site. For example, the reliability of any one of these indicators depends on the mechanism of soil organic matter accumulation. If a change in light fraction C occurs because of greater C inputs, then it can be assumed that the changes will eventually be reflected in higher total soil C. On the other hand, if a change in light fraction C occurs in response to the suppression of decomposition rate, then it simply represents a gain in labile C. In the latter case, the change in light fraction C is the soil C change.

For any of the measurements to be used as an indicator of soil quality it is necessary to have some soil-specific baseline for comparison. The baseline should be obtained from the same soil type under alternative management, such as a native or uncultivated site.

Future sampling at the study sites should include soil quality and productivity parameters in addition to carbon sampling in order to describe the interactions among organisms and the agricultural environment. The monitoring of soil quality at Rockwood is to continue under the National Soil Quality Benchmark Study, wherein land management practices and landscape variability will be the focus. These should similarly be the focus of the sampling at the other sites.

Land management practices should be documented annually. Over the intermediate to long term (5-10 years), the soil horizon depths, organic carbon (consistent soil volume and mass known), $CaC0_3$, and soil pH should be determined.

Dynamic parameters, such as crop yield, and a measure of the active organic matter fraction should be sampled annually. In addition, in-field measurements of infiltration of water into the soil is suggested. The quality of soils is reflected in their ability to prevent water pollution by resisting erosion, by absorbing and partitioning rainfall (Hallberg, 1995). In fact, it has been suggested that the best way to make environmental and economic progress in agriculture is to focus on active soil organic matter and infiltration (Porterfield, 1995). Documented increases in active organic matter and improved infiltration rates should certainly indicate where enhancements to soil quality have been made.

5. REFERENCES

Chapman, L.F. and D.F. Putnam. 1984. The physiography of southern Ontario: Ontario Geological Survey. Special Volume 2, 270 pp. with map.

Cochran, W.G., and G.M. Cox. 1957. Experimental designs. John Wiley and Sons Inc. Toronto.

Culley, J.L.B. 1993. Density and compressibility. In: M.R. Carter (ed.) Soil sampling and methods of analysis. CRC Press Inc.

deJong, E., and R.G. Kachanoski. 1988. The importance of erosion in the carbon balance of prairie soils. Can. J. Soil Sci. 68: 111-119.

Doran, J.W. 1987. Microbial biomass and mineralizable nitrogen distributions in no-tillage and plowed soils. Bio. Fertil. Soils 5: 68-75.

Hallberg, G.R. 1995. Soil and water quality: Issues for the farm bill. In: The Farm Bill - A Keystone of Environmental Policy. Water Resources Update. 101:39-45.

Hoffman, D.W., N.R. Richards and F.F. Morwick. 1952. Soil survey of Huron county. Report No. 13 of the Ontario Soil Survey.

King, D.J. and C. Wang. 1994. Benchmark site documentation -14-ON, soil quality evaluation program interim report. Agriculture and Agri-Food Canada, CLBRR, Ottawa, ON.

Lal, R. 1987. Effects of soil erosion on crop productivity. CRC Critical Reviews in Plant Sciences 5: 303-367.

Marshall, I.B., J. Dumanski, E.C. Huffman, and P.G. Lajoie. 1979. Soils, capability and land use in the Ottawa urban fringe. Report No. 47 of the Ontario Soil Survey.

Matthews, B.C., N.R. Richards and R.E. Wicklund. 1957. Soil survey of Glengarry county. Report No. 24 of the Ontario Soil Survey.

Perfect, E., B.D. Kay, W.K.P. van Loon, R.W. Sheard, and T. Pojasok. 1990. Factors influencing soil structural stability within a growing season. Soil Sci. Soc. Am. J. 54: 173-179.

Porterfield, J. 1995. Environmental aspects of the 1995 Farm Bill. In: The Farm Bill -A Keystone of Environmental Policy. Water Resources Update. 101:29-38.

Powlson, D.S., P.C. Brookes, and B.T. Christensen. 1987. Measurement of soil microbial biomass provides an early indication of changes in total soil organic matter due to straw incorporation. Soil Biol. Biochem. 19: 165-170.

Presant, E.W. and C.J. Wang. 1984. The soils of the Regional Municipality of

Haldimand-Norfolk. Report No. 57. Ontario Institute of Pedology.

Richter, D.D., L.I. Babbar, M.A. Huston, and M. Jaeger. 1990. Effects of annual tillage on organic carbon in a fine textured Udalf: the importance of root dynamics in soil carbon storage. Soil Science 149: 78-83.

Ritz, K., and D. Robinson. 1988. Temporal variations in soil microbial biomass C and N under a spring barley crop. Soil Bio. Biochem. 20: 631-636.

Sheldrick, B.H. and C. Wang. 1993. Particle-size distribution. In: M.R. Carter (ed.) Soil sampling and methods of analysis. CRC Press Inc.

Sheldrick, B.H. 1984. Analytical methods manual. LRRI Contrib. No. 84-30, Research Branch Agriculture Canada, Ottawa.

Tiessen, H. and J.O. Moir. 1993. Total and organic carbon. In: M.R. Carter (ed.) Soil sampling and methods of analysis. CRC Press Inc.

Topp, G.C., J.L. Davis and A.P. Anan. 1980. Electromagnetic determination of soil water content: measurements in coaxial transmission lines. Water Resource Res. 16: 574-582.

Voroney, R.P. 1988. Loss of Organic Matter in Ontario Soils. Highlights of Agricultural Research in Ontario 3: 25-28.

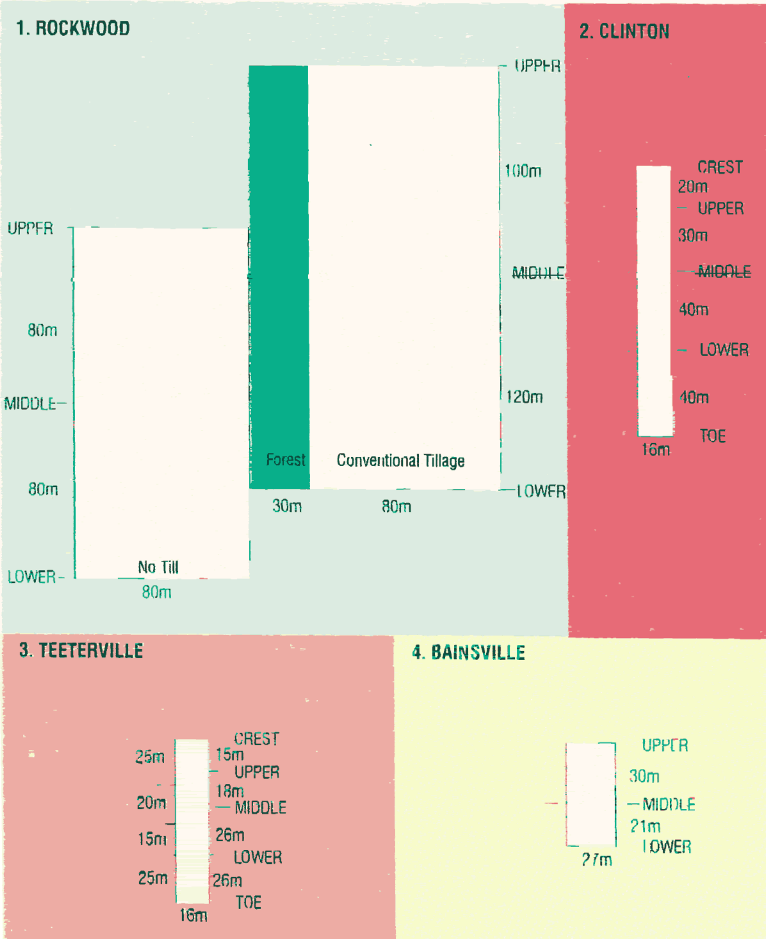
Voroney, R.P., J.P. Winter, and R.P. Bayaert. 1993. Soil microbial biomass C and N. In: M.R. Carter (ed.) Soil sampling and methods of analysis. CRC Press Inc.

Wang, C., BD. Walker, H.W. Rees, L.M. Kozak, M.C. Nolan, W. Michalyna, K.T. Webb, D.A. Holmstrom, D. King, E.A. Kenney, and E.F. Woodrow. 1994. Benchmark sites for monitoring agricultural soil quality in Canada. Soil Quality Evaluation Program Technical Report 1. CLBRR, Research Branch, Agriculture and Agri-Food Canada.

APPENDIX A

Site Dimensions

APPENDIX A: SITE DIMENSIONS



APPENDIX B

Soil Pedon Descriptions

1. PEDON DESCRIPTION - ROCKWOOD

LOCATION: Rockwood, Eramosa Township, Wellington County

SLOPE POSITION: Crest

LANDFORM & PARENT MATERIALS: Very gently sloping till plain, dominantly loamy textures

SLOPE: 1% Simple

DRAINAGE: Well drained

SOIL TYPE: Guelph loam

CLASSIFICATION: Orthic Grey Brown Luvisol, mildly alkaline, moderately calcareous

Horizon	Depth cm	Colour	Texture	Primary Structure	Consistence	Mottles
Ap	0-29	10 YR 3/1-5	L	structureless	friable	--
Btj	29-51	10 YR 4/4	L	weak, fine - medium, subangular blocky	firm	--
Btk	51-62	10 YR 4/4	L	weak, medium - coarse, subangular blocky	firm	--
IIBCk	62-75	10 YR 5/4	SL	massive	firm-v.firm	--
IICca	75	10 YR 5/3	SL	massive	firm	--

Horizon	Depth cm	Grav (>2mm) %	Sand %	Silt %	Clay %	pH $CaCl_2$	OM %	$CaCO_3$ Equiv. %
Ap	0-29	--	35	48	17	6.8	2.59	2.10
Btj	29-51	--	39	45	16	6.8	1.02	1.93
Btk	51-62	--	41	44	15	7.0	0.65	2.28
IIBck	62-75	--	55	36	9	7.6	--	9.52
IICca	75	--	42	39	9	7.7	--	13.30

LOCATION: Rockwood, Eramosa Township, Wellington County

SLOPE POSITION: Depressional

LANDFORM AND PARENT MATERIALS: Nearly level till plain, dominantly loamy textures

SLOPE: 1% Simple

DRAINAGE: Poorly drained

SOIL TYPE: Parkhill silt loam

CLASSIFICATION: Orthic Humic Gleysol, loamy, mildly alkaline, moderately calcareous

Horizon	Depth cm	Colour	Texture	Primary Structure	Consistence	Mottles
Ap	0-34	10 YR 3/1	SIL	weak, fine, subangular blocky	v. friable	--
Bg1	34-46	10 YR 5/4	L	structureless	friable	25Y7/2, 10YR5/6
Bg2	46-66	10YR5/4	L	massive	friable	15YR7/2
Ck	66 +	10 YR 5/4	SL	weak, fine, subangular blocky	firm	25YR/72

Horizon	Depth cm	Grav (>2mm) %	Sand %	Silt %	Clay %	pH $CaCl_2$	OM %	$CaCO_3$ Equiv. %
Ap	0-34	--	26	54	20	7.0	2.23	2.30
Bg1	34-46	--	36	49	15	7.1	0.93	5.52
Bg2	46-66	--	51	35	14	7.3	0.44	3.20
Ck	66+	--	57	34	9	7.5	--	9.76

2. PEDON DESCRIPTION - CLINTON

LOCATION: Clinton, Goderich Township, Huron County

SLOPE POSITION: Crest

LANDFORM & PARENT MATERIALS: Moderately undulating till plain, dominantly silt loam textures.

SLOPE: 11% Simple

DRAINAGE: Well drained

SOIL TYPE: Harriston silt loam

CLASSIFICATION: Orthic Humic Regosol, loamy, mildly alkaline, extremely calcareous

Horizon	Depth cm	Colour	Texture	Primary Structure	Consistence	Mottles
Apk	0-19	--	SIL	strong, very fine, subangular blocky	friable	--
Ck1	19-40	--	SIL	strong, medium, subangular blocky	friable	--
Ck2	40-73	--	SIL	strong, medium, subangular blocky	friable	--
Ck3	73-100	--	L	strong, medium, subangular blocky	friable	--

Horizon	Depth cm	Grav (>2mm) %	Sand %	Silt %	Clay %	pH $CaCl_2$	OM %	$CaCO_3$ Equiv. %
Apk	0-19	3.5	25.67	54.5	19.8	7.5	2.2	16.9
Ck1	19-40	1.3	18.50	67.3	14.2	7.7	0.7	45.9
Ck2	40-73	11.1	25.87	59.9	14.3	7.7	0.4	48.5
Ck3	73-100	--	--	--	--	--	--	--

LOCATION: Clinton, Goderich Township, Huron County

SLOPE POSITION: Lower

LANDFORM & PARENT MATERIALS: Gently undulating till plain, dominantly silt loam texture

SLOPE: 5% Simple

DRAINAGE: Moderately well

SOIL TYPE: Harriston loam

CLASSIFICATION: Orthic Humic Regosol, loamy, mildly alkaline, very strongly calcareous

Horizon	Depth cm	Colour	Texture	Primary Structure	Consistence	Mottles
Ap	0-36	--	L	strong, medium, subangular blocky	friable	--
Ck1	36-58	--	FSL	moderate, medium, subangular blocky	friable	--
Ck2	58-86	--	SIL	very weak, medium, subangular blocky	v. friable	--
Ckgj	86-110	--	L	moderate, coarse, subangular blocky	friable	--

Horizon	Depth cm	Grav (>2mm) %	Sand %	Silt %	Clay %	pH $CaCl_2$	OM %	$CaCO_3$ Equiv. %
Ap	0-36	1.7	36.21	46.0	17.8	7.2	4.5	5.4
Ck1	36-58	11.5	61.35	31.3	7.3	7.6	0.7	36.9
Ck2	58-86	0.0	6.07	68.8	25.1	7.7	0.5	27.8
Ckgj	86-110	--	--	--	--	--	--	--

3. PEDON DESCRIPTION - TEETERVILLE

LOCATION: Teeterville, Delhi Township, Regional Municipality of Haldimand-Norfolk

SLOPE POSITION: Crest

LANDFORM & PARENT MATERIALS: Gently undulating till moraine, 40-100 cm of sandy eolian or glaciolacustrine sediments over gravelly sandy loam till

SLOPE: 8% Simple

DRAINAGE: Well drained

SOIL TYPE: Scotland sandy loam

CLASSIFICATION: Orthic Gray Brown Luvisol, loamy, neutral, moderately calcareous

Horizon	Depth cm	Colour	Texture	Primary Structure	Consistence	Mottles
Ap	0-18	--	FSL	moderate, fine, subangular blocky	friable	--
Bt	18-41	--	SCL	moderate, coarse, subangular blocky	friable-firm	--
IICk	41-61	--	FSL	weak, coarse, subangular blocky	v. friable	--
IIICk	61-100	--	FS	moderate, medium, subangular blocky	v. friable	--

Horizon	Depth cm	Grav (>2mm) %	Sand %	Silt %	Clay %	pH $CaCl_2$	OM %	$CaCO_3$ Equiv. %
Ap	0-18	3.7	61.84	28.6	9.5	5.5	1.4	1.4
Bt	18-41	1.0	57.89	17.5	24.6	6.1	0.7	0.8
IICk	41-61	6.3	77.98	13.9	8.2	7.3	0.3	13.3
IIICk	61-100	--	--	--	--	--	--	--

LOCATION: Teeterville, Delhi Township, Regional Municipality of Haldimand-Norfolk

SLOPE POSITION: Lower

LANDFORM & PARENT MATERIALS: Very gently undulating till moraine, with 40-100 cm of sandy eolian or glaciolacustrine sediment over gravelly sandy loam till

SLOPE: 3% Simple

DRAINAGE: Well drained

SOIL TYPE: Scotland sandy loam

CLASSIFICATION: Gleyed Brunisolic Grey Brown Luvisol, loamy

Horizon	Depth cm	Colour	Texture	Primary Structure	Consistence	Mottles
Ap	0-33	--	FSL	weak, fine, subangular blocky	v. friable	--
Bfj	33-44	--	--	weak, medium, subangular blocky	v. friable	--
Bm	44-63	--	FSL	weak, medium, subangular blocky	v. friable	--
IIBtgj	63-120	--	L	strong, coarse, subangular blocky	firm-friable	--
IICk	120-	--	SL	--		--

Horizon	Depth cm	Grav (>2mm) %	Sand %	Silt %	Clay %	pH $CaCl_2$	OM %	$CaCO_3$ Equiv. %
Ap	0-33	3.0	71.03	23.2	5.8	4.6	1.9	2.0
Bfj	33-44							
Bm	44-63	3.3	57.09	38.3	4.6	5.8	0.3	0.5
IIBtgj	63-120	3.7	46.36	36.3	17.3	5.9	0.5	0.5
IICk	120							

4. PEDON DESCRIPTION - BAINSVILLE

LOCATION: Bainsville, Lancaster Township, Glengarry County

SLOPE POSITION: Crest - upper slope

LANDFORM & PARENT MATERIALS: Very gently sloping marine beach ridge, dominantly gravelly sand and gravel sediments.

SLOPE: 3-5% complex

DRAINAGE: well drained

SOIL TYPE: Oka gravelly sand

CLASSIFICATION: Gleyed Melanic Brunisol, sandy, neutral, weakly calcareous

Horizon	Depth cm	Colour	Texture	Primary Structure	Consistence	Mottles
Ap	0-17	10YR 3/2	GSL	moderate, fine, subangular blocky		
Bmgj	17-38	10YR 4/4	GSL	moderate, fine, subangular blocky		10YR 4/6
Bm	38-75	10YR 4/2	GCSL	weak, medium, subangular blocky		
Ck	75-90	10YR 4/2	GLS	weak, medium, subangular blocky		

Horizon	Depth cm	Grav (>2mm) %	Sand %	Silt %	Clay %	pH $CaCl_2$	OM %	$CaCO_3$ Equiv. %
Ap	0-17	27.4	60.25	27.50	12.30	5.4	4.7	0.8
Bmgj	17-38	34.5	69.50	24.70	5.80	6.0	1.1	0.7
Bm	38-75	37.6	69.65	24.50	5.80	5.9	0.7	0.9
Ck	75-90	--	--	--	--	--	--	--

LOCATION: Bainsville, Lancaster Township, Glengarry County
SCOPE POSITION: Lower

LANDFORM & PARENT MATERIALS: Gently sloping glacio-marine plain, 40-100 cm loam textures over fine textured material

SLOPE: 6% Simple
DRAINAGE: Poorly drained
SOIL TYPE: Bainsville loam
CLASSIFICATION: Orthic Humic Gleysol, loamy, mildly alkaline, moderately calcareous

Horizon	Depth cm	Colour	Texture	Primary Structure	Consistence	Mottles
Ap	0-26	10YR 3/2	L	Moderate, medium, subangular blocky	Friable	
Bg 1	26-46	2.5YR 5/3	L	Weak, medium, angular blocky	Friable	
Bg 2	46-57	2.5YR 5/2	L	Moderate, medium, platy	Friable	10YR 5/4
Bcg	57-110	2.5YR 5/2	L	Moderate, fine, platy	Friable	10YR 4/6
CKg1	110-120	2.5YR 5/2	--	Moderate,fine, platy	Friable	10YR 4/4
II Ckg2	120	2.5YR 5/2	GFSL	--	Friable	10YR 4/4

Horizon	Depth cm	Grav (>2mm) %	Sand %	Silt %	Clay %	pH $CaCl_2$	OM %	$CaCO_3$ Equiv. %
Ap	0-26	4.1	41.58	39.4	19.0	6.4	5.5	1.0
Bg1	26-46	0.2	48.06	35.9	16.0	6.8	0.7	0.7
Bg2	46-57	0.2	46.56	36.5	17.0	6.8	0.4	0.7
BCg	57-110	0.4	47.29	36.0	16.7	6.8	0.3	0.7
CKg1	110-120							
II CKg2	120	29.1	61.91	28.2	9.9	7.5	0.4	6.2

APPENDIX C

Summary Statistics

Table C.1. Summary Statistics, Rockwood

System	Parameter		Slope Position: Upper	Middle	Lower	ANOVA: Source	P
Concentrations of Carbon, Nitrogen Components							
Conventional	Organic C g C kg^{-1}	mean	15.919	13.078	21.976	Rep	.441
	0-15 cm	sd	8.704	0.601	1.186	Pos'n	.061
	Organic C g C kg^{-1}	mean	11.180	6.773	18.602	Rep	.320
	15-30 cm	sd	3.076	1.372	4.466	Pos'n	.001
	Organic N g C kg^{-1}	mean	1.877	1.218	2.111	Rep	.201
	0-15 cm	sd	0.094	0.061	0.136	Pos'n	.000
	Organic N g C kg^{-1}	mean	1.224	0.638	1.730	Rep	.378
	15-30 cm	sd	0.435	0.144	0.372	Pos'n	.003
No-Till	Organic C g C kg^{-1}	mean	27.992	22.578	32.447	Rep	.478
	0-15 cm	sd	1.087	1.387	2.122	Pos'n	.000
	Organic C g C kg^{-1}	mean	25.581	16.426	29.129	Rep	.048
	15-30 cm	sd	3.032	5.396	5.653	Pos'n	.003
	Organic N g C kg^{-1}	mean	2.546	2.187	2.972	Rep	.642
	0-15 cm	sd	0.188	0.167	0.275	Pos'n	.003
	Organic N g C kg^{-1}	mean	2.314	1.551	2.652	Rep	.033
	15-30 cm	sd	0.325	0.475	0.423	Pos'n	.002
Soluble C mgC/kg							
Conventional, corn	August 0-15 cm	mean	102.200	88.250	126.500	Rep	.816
		sd	24.682	15.392	25.684	Pos'n	.254
	August 15-30	mean	104.000	59.000	82.600	Rep	.735
		sd	12.845	6.164	21.548	Pos'n	.008
	November 0-15 cm	mean	23.000	8.800	20.200	Rep	.419
		sd	8.746	5.119	11.054	Pos'n	.066
	November 15-30 cm	mean	18.600	16.400	18.000	Rep	.671
		sd	15.694	6.841	8.860	Pos'n	.956
Conventional, soybeans	August 0-15 cm	mean	122.400	104.400	105.000	Rep	.078
		sd	17.053	23.933	22.417	Pos'n	.201

Table C.1. Summary Statistics, Rockwood

System	Parameter		Slope Position			ANOVA	
			Upper	Middle	Lower	Source	P
	August 15-30	mean	69.600	60.500	92.200	Rep	.178
		sd	17.430	11.619	11.300	Pos'n	.018
	November 0-15 cm	mean	20.000	28.000	17.600	Rep	.850
		sd	5.874	14.353	11.371	Pos'n	.432
	November 15-30 cm	mean	22.250	22.000	17.000	Rep	.379
		sd	19.906	9.407	6.042	Pos'n	.803
No-Till, corn	August 0-15 cm	mean	240.400	199.400	240.000	Rep	.127
		sd	48.076	32.408	41.863	Pos'n	.149
	August 15-30	mean	121.000	128.800	221.400	Rep	.075
		sd	32.550	64.500	35.851	Pos'n	.003
	November 0-15 cm	mean	25.800	28.200	41.600	Rep	.851
		sd	7.727	9.471	9.839	Pos'n	.084
	November 15-30 cm	mean	30.200	17.800	23.400	Rep	.580
		sd	31.729	5.675	7.861	Pos'n	.634
No-Till, soybeans	August 0-15 cm	mean	171.400	172.400	290.000	Rep	.295
		sd	26.969	36.053	48.270	Pos'n	.001
	August 15-30	mean	108.400	96.200	224.600	Rep	.308
		sd	25.996	23.690	67.715	Pos'n	.002
	November 0-15 cm	mean	37.600	26.000	26.800	Rep	.270
		sd	20.477	4.062	9.149	Pos'n	.291
	November 15-30 cm	mean	20.200	17.600	20.000	Rep	.170
		sd	7.662	6.656	3.082	Pos'n	.693

Table C.1. Summary Statistics, Rockwood

System	Parameter		Slope Position			ANOVA	
			Upper	Middle	Lower	Source	P
Forest	August 0-15 cm	mean	232.600	352.400	244.800	Rep	.767
		sd	124.925	124.743	63.982	Pos'n	.277
	August 15-30	mean	123.400	131.200	109.800	Rep	.820
		sd	19.957	60.156	27.271	Pos'n	.754
	November 0-15 cm	mean	56.400	41.600	51.000	Rep	.809
		sd	10.991	20.020	26.805	Pos'n	.602
	November 15-30 cm	mean	35.200	29.800	43.000	Rep	.707
		sd	3.768	12.911	30.741	Pos'n	.625
Microbial Biomass C (mgC/kg)							
Conventional, corn	August 0-15 cm	mean	162.800	143.250	221.000	Rep	.604
		sd	53.063	53.556	79.771	Pos'n	.421
	August 15-30 cm	mean	165.200	74.400	117.000	Rep	.783
		sd	27.087	31.722	68.909	Pos'n	.067
	November 0-15 cm	mean	323.400	267.800	148.800	Rep	.097
		sd	151.064	52.380	67.976	Pos'n	.022
	November 15-30 cm	mean	154.400	137.800	26.000	Rep	.175
		sd	91.808	70.219	13.657	Pos'n	.015
Conventional, soybeans	August 0-15 cm	mean	245.400	191.400	163.200	Rep	.063
		sd	52.075	80.878	87.776	Pos'n	.119
	August 15-30 cm	mean	100.200	66.250	158.000	Rep	.207
		sd	47.124	37.473	42.497	Pos'n	.034
	November 0-15 cm	mean	235.800	183.400	229.800	Rep	.732
		sd	104.517	149.587	54.965	Pos'n	.760
	November 15-30 cm	mean	87.250	74.600	62.800	Rep	.823
		sd	46.133	52.262	44.969	Pos'n	.709
No-Till, corn	August 0-15 cm	mean	539.200	390.400	548.800	Rep	.275
		sd	116.276	105.035	91.212	Pos'n	.055

Table C.1. Summary Statistics, Rockwood

System	Parameter		Slope Position: Upper	Slope Position: Middle	Slope Position: Lower	ANOVA: Source	ANOVA: P
	August 15-30 cm	mean	223.800	252.000	488.400	Rep	.082
		sd	90.594	174.452	89.996	Pos'n	.004
	November 0-15 cm	mean	404.600	315.000	690.000	Rep	.615
		sd	129.150	139.961	198.951	Pos'n	.019
	November 15-30 cm	mean	248.600	198.000	300.800	Rep	.175
		sd	101.219	79.508	70.297	Pos'n	.143
No-Till, soybeans	August 0-15 cm	mean	374.200	340.200	693.200	Rep	.347
		sd	67.221	113.931	132.061	Pos'n	.001
	August 15-30 cm	mean	209.400	160.800	532.000	Rep	.394
		sd	76.585	54.412	186.439	Pos'n	.002
	November 0-15 cm	mean	461.800	349.000	621.200	Rep	.771
		sd	97.346	110.472	201.774	Pos'n	.074
	November 15-30 cm	mean	189.400	243.800	546.600	Rep	.950
		sd	55.545	171.708	151.160	Pos'n	.016
Forest	August 0-15 cm	mean	609.000	855.400	557.600	Rep	.734
		sd	323.063	334.415	199.187	Pos'n	.364
	August 15-30 cm	mean	247.600	255.600	194.400	Rep	.823
		sd	69.205	174.265	79.198	Pos'n	.737
	November 0-15 cm	mean	1128.800	652.600	788.200	Rep	.998
		sd	321.641	246.028	431.580	Pos'n	.235
	November 15-30 cm	mean	730.600	163.000	423.000	Rep	.949
		sd	362.398	110.345	301.611	Pos'n	.096

Table C.1. Summary Statistics, Rockwood

System	Parameter		Slope Position: Upper	Slope Position: Middle	Slope Position: Lower	ANOVA: Source	ANOVA: P
Mass of carbon components in 15 cm depth - based on concentration x density in 0-15 cm							
Conventional	Organic C	mean	330.300	221.288	424.013	Rep	.546
	mg cm^{-2}	sd	31.536	30.632	28.247	Pos'n	.000
No-Till	OrganicC	mean	518.400	509.048	581.329	Rep	.893
	mg cm^{-2}	sd	74.196	40.564	41.803	Pos'n	.291
Soluble C mg cm^{-2}							
Conventional	August	mean	2.115	1.793	2.400	Rep	.251
		sd	.414	.387	.247	Pos'n	.390
	November	mean	.497	.203	.427	Rep	.638
		sd	.078	.110	.269	Pos'n	.256
No-Till	August	mean	4.786	4.072	4.297	Rep	.169
		sd	.918	.738	1.310	Pos'n	.580
	November	mean	.536	.695	.696	Rep	.909
		sd	.167	.167	.256	Pos'n	.671
Microbial Biomass C mg cm^{-2}							
Conventional	August	mean	3.585	3.046	4.217	Rep	.247
		sd	.814	1.310	1.305	Pos'n	.733
	November	mean	6.826	4.892	2.971	Rep	.066
		sd	3.386	.875	1.791	Pos'n	.069
No-Till	August	mean	10.914	7.657	9.729	Rep	.329
		sd	2.415	2.559	2.853	Pos'n	.349
	November	mean	8.815	6.389	13.163	Rep	.832
		sd	3.546	3.520	3.495	Pos'n	.240

Table C.1. Summary Statistics, Rockwood

System	Parameter		Slope Position			ANOVA	
			Upper	Middle	Lower	Source	P
Other soil properties							
Conventional	Topsoil depth	mean	27.000	27.250	28.250	Rep	.961
	cm	sd	2.582	.500	2.363	Pos'n	.756
	pH	mean	7.025	7.325	7.150	Rep	.640
		sd	0.126	0.050	0.173	Pos'n	.055
	Bulk density	mean	1.258	1.373	1.300	Rep	.345
	g cm^{-3}	sd	.062	.013	.056	Pos'n	.034
	Moisture	mean	23.4	19.567	29.467	Rep	.503
	% (v/v)	sd	--	.907	5.024	Pos'n	.150
	Corn Yield	mean	4.167	3.629	3.195	Rep	.148
	Mg ha^{-1}	sd	.818	1.873	.866	Pos'n	.528
	Soybean Yield	mean	2.070	3.388	2.876	Rep	.900
	Mg ha^{-1}	sd	.157	.075	.397	Pos'n	.014
	Maximum Penetrometer	mean	4042	4169	2810	Rep	.941
	Resistance (kPa)	sd	223	673	341	Pos'n	.068
No-Till	Topsoil depth	mean	27.250	22.000	27.500	Rep	.219
	cm	sd	6.702	2.944	5.196	Pos'n	.229
	pH	mean	6.800	7.100	6.850	Rep	.094
		sd	.082	.082	.129	Pos'n	.003
	Bulk density	mean	1.375	1.403	1.193	Rep	.581
	g cm^{-3}	sd	.082	.056	.057	Pos'n	.010
	Moisture	mean	19.333	29.833	28.267	Rep	.460
	% (v/v)	sd	2.203	3.786	3.002	Pos'n	.027
	Corn Yield	mean	6.210	6.145	6.421	Rep	.752
	Mg ha^{-1}	sd	1.301	.417	.532	Pos'n	.936
	Soybean Yield	mean	3.042	3.013	2.685	Rep	.500
	Mg ha^{-1}	sd	.481	.848	.475	Pos'n	.768

Table C.1. Summary Statistics, Rockwood

System	Parameter		Slope Position			ANOVA	
			Upper	Middle	Lower	Source	P
	Maximum Penetrometer	mean	2953	2019	2137	Rep	.730
	Resistance (kPa)	sd	179	192	549	Pos'n	.084

Table C.2. Summary Statistics, Clinton

Parameter		Slope Position					ANOVA	
		Crest	Upper	Middle	Lower	Toe	Source	P
Concentrations of Carbon Components								
Organic C g kg^{-1}	mean	14.52	10.62	15.14	20.94	26.10	Rep	.170
0-15 cm	sd	3.37	1.28	0.991	2.21	1.22	Pos'n	.000
Total C %	mean	3.456	3.256	2.546	2.750	3.174	Rep	.683
0-15 cm	sd	.552	.823	.357	.365	.384	Pos'n	.115
Total C %	mean	4.282	3.548	2.968	2.265	3.026	Rep	.364
15-30 cm	sd	1.664	1.627	1.496	.907	.143	Pos'n	.207
Soluble C mgC/kg								
May 0-15 cm	mean	55.036	46.451	52.834	49.387	42.857	Rep	.645
	sd	7.121	3.052	11.999	4.789	9.974	Pos'n	.202
May 15-30	mean	54.881	49.602	44.279	43.173	49.452	Rep	.748
	sd	6.648	15.341	12.894	7.219	9.536	Pos'n	.517
August 0-15 cm	mean	35.172	31.430	25.030	29.597	34.384	Rep	.076
	sd	2.643	4.052	6.184	3.220	4.294	Pos'n	.004
August 15-30 cm	mean	33.247	25.368	24.560	21.512	19.562	Rep	.725
	sd	6.989	6.366	4.259	5.856	3.088	Pos'n	.023
Microbial Biomass C (mgC/kg)								
May 0-15 cm	mean	300.814	201.553	286.251	307.799	447.042	Rep	.291
	sd	54.526	38.286	72.302	95.159	95.140	Pos'n	.000
May 15-30 cm	mean	69.304	63.596	166.460	218.146	265.360	Rep	.682
	sd	31.867	47.469	44.337	64.212	55.818	Pos'n	.000
August 0-15 cm	mean	397.495	278.848	317.701	474.882	389.767	Rep	.679
	sd	103.107	138.820	85.175	108.962	83.862	Pos'n	.096
August 15-30 cm	mean	142.910	138.112	174.183	215.450	380.320	Rep	.537
	sd	27.423	72.862	58.779	63.070	83.594	Pos'n	.000

Table C.2. Summary Statistics, Clinton

Parameter		Slope Position					ANOVA	
		Crest	Upper	Middle	Lower	Toe	Source	P
Mass of carbon components in 15 cm depth - based on concentration x density in 0-15 cm								
Organic C	mean	335.032	259.170	363.214	466.990	582.534	Rep	.130
mg cm^{-2}	sd	80.888	27.172	30.276	66.512	42.788	Pos'n	.000
Total C	mean	796.674	798.570	610.856	608.975	710.660	Rep	.652
mg cm^{-2}	sd	131.970	208.455	93.301	36.793	110.994	Pos'n	.113
Soluble C mg cm^{-2}								
May	mean	1.272	1.134	1.266	1.104	.948	Rep	.427
	sd	.187	.053	.294	.172	.172	Pos'n	.089
August	mean	.810	.770	.596	.656	.768	Rep	.159
	sd	.047	.121	.132	.048	.094	Pos'n	.007
Microbial Biomass C mg cm^{-2}								
May	mean	6.920	4.916	6.870	8.324	9.970	Rep	.394
	sd	1.195	.867	1.804	2.482	2.182	Pos'n	.006
August	mean	9.130	6.832	7.592	10.656	8.652	Rep	.611
	sd	2.234	3.451	1.948	3.046	1.684	Pos'n	.237
Other soil properties								
$CaC0_3$ %	mean	15.480	13.740	6.440	4.840	5.860	Rep	.298
	sd	7.227	7.643	1.563	1.442	1.150	Pos'n	.005
pH	mean	7.420	7.440	7.300	7.360	7.260	Rep	.292
	sd	.084	.055	.122	.055	.114	Pos'n	.023
Bulk density	mean	1.536	1.630	1.598	1.484	1.488	Rep	.779
g cm^{-3}	sd	.044	.063	.044	.101	.086	Pos'n	.025
Moisture	mean	15.886	15.448	16.376	19.260	20.066	Rep	.242
% (w/w)	sd	.943	1.093	.610	.956	1.380	Pos'n	.000
Yield Mg ha^{-1}	mean	3.595	3.195	3.892	4.071	--	Rep	.718
	sd	.481	.634	.531	.489	--	Pos'n	.136

Table C.2. Summary Statistics, Clinton

Parameter		Slope Position					ANOVA	
		Crest	Upper	Middle	Lower	Toe	Source	P
Penetrometer	mean	26.333	27.000	20.500	22.333	22.833	Rep	.587
Resistance (bars)	sd	4.952	4.351	5.362	5.041	4.616	Pos'n	.001

Table C.3. Summary Statistics, Teeterville

Parameter		Slope Position					ANOVA	
		Crest	Upper	Middle	Lower	Toe	Source	P
Concentrations of Carbon Components								
Organic Carbon g kg^{-1}	mean	6.66	9.66	8.300	10.38	12.38	Rep	.338
0-15 cm	sd	1.30	1.22	0.938	0.867	1.21	Pos'n	.000
Soluble C mgC/kg								
May 0-15 cm	mean	42.039	46.505	46.954	56.860	71.285	Rep	.328
	sd	5.205	11.105	13.493	10.990	24.810	Pos'n	.035
May 15-30	mean	52.526	37.065	38.160	49.596	42.625	Rep	.830
	sd	17.828	6.162	4.069	9.161	10.783	Pos'n	.187
August 0-15 cm	mean	29.378	31.003	32.827	41.491	28.480	Rep	.249
	sd	10.216	4.569	11.614	6.157	5.090	Pos'n	.116
August 15-30 cm	mean	34.018	26.441	25.613	27.312	30.718	Rep	.402
	sd	2.665	7.132	3.182	3.852	4.217	Pos'n	.073
Microbial Biomass C (mgC/kg)								
May 0-15 cm	mean	192.888	230.125	256.326	254.206	315.790	Rep	.936
	sd	28.820	121.423	122.651	96.188	174.505	Pos'n	.720
May 15-30 cm	mean	99.388	115.679	72.879	91.456	66.770	Rep	.639
	sd	22.980	28.934	33.024	32.455	43.861	Pos'n	.216
August 0-15 cm	mean	211.022	197.523	188.736	163.854	155.998	Rep	.318
	sd	121.787	57.853	71.226	59.424	66.669	Pos'n	.706
August 15-30 cm	mean	71.802	126.857	74.765	96.725	66.713	Rep	.756
	sd	22.979	25.546	38.327	47.989	31.628	Pos'n	.462
Mass of carbon components in 15 cm depth - based on concentration x density in 0-15 cm								
Organic C	mean	159.018	217.854	190.842	245.925	279.639	Rep	.308
mg cm^{-2}	sd	31.083	22.273	25.091	23.932	19.559	Pos'n	.000

Table C.3. Summary Statistics, Teeterville

Parameter		Slope Position					ANOVA	
		Crest	Upper	Middle	Lower	Toe	Source	P
Soluble C mg cm^{-2}								
May	mean	1.008	1.044	1.085	1.345	1.602	Rep	.306
	sd	.159	.211	.342	.264	.534	Pos'n	.043
August	mean	.715	.707	.745	.982	.644	Rep	.231
	sd	.294	.090	.227	.147	.105	Pos'n	.086
Microbial Biomass C mg cm^{-2}								
May	mean	4.876	5.244	5.798	6.035	7.227	Rep	.915
	sd	.831	2.677	2.571	2.322	4.168	Pos'n	.791
August	mean	5.057	4.496	4.280	3.874	3.528	Rep	.247
	sd	3.071	1.226	1.405	1.399	1.546	Pos'n	.644
Other soil properties								
$CaC0_3$ %	mean	1.380	1.320	.820	1.120	1.280	Rep	.145
	sd	.798	1.431	.740	.963	.622	Pos'n	.851
pH	mean	6.780	6.740	4.980	4.980	5.240	Rep	.971
	sd	.517	.404	.249	.444	.586	Pos'n	.000
Bulk density	mean	1.602	1.508	1.532	1.578	1.510	Rep	.940
g cm^{-3}	sd	.189	.064	.075	.035	.065	Pos'n	.585
Moisture	mean	11.920	11.018	11.316	12.630	11.030	Rep	.989
% (w/w)	sd	1.465	.482	.985	.801	2.047	Pos'n	.354
Yield (corn)	mean	10.138	13.003	13.526	12.653	12.867	Rep	.721
Mg ha^{-1}	sd	1.604	.402	.891	1.374	1.886	Pos'n	.013
Penetrometer	mean	40.333	32.333	28.000	27.500	38.000	Rep	.093
Resistance (bars)	sd	7.784	6.779	6.211	8.183	4.351	Pos'n	.000

Table C.4. Summary Statistics, Bainsville

Crop	Parameter		Slope Position			ANOVA	
			Upper	Middle	Lower	Source	P
Concentrations of Carbon Components							
Corn	Organic carbon g kg^{-1}	mean	28.00	28.37	32.83	Rep	.470
	0-15 cm	sd	3.58	1.29	1.39	Pos'n	.117
Soybeans	Organic carbon g kg^{-1}	mean	25.90	25.50	31.07	Rep	.268
	0-15 cm	sd	1.35	1.85	0.924	Pos'n	.011
Soluble C mgC/kg							
Corn	August 0-15 cm	mean	53.647	59.050	59.447	Rep	.732
		sd	6.700	8.738	2.559	Pos'n	.603
	August 15-30	mean	43.190	55.383	41.487	Rep	.475
		sd	6.074	14.547	8.163	Pos'n	.311
	November 0-15 cm	mean	52.462	67.298	62.638	Rep	.026
		sd	4.460	18.510	3.485	Pos'n	.050
	November 15-30	mean	43.187	64.120	45.085	Rep	.005
		sd	5.572	11.203	5.471	Pos'n	.000
Soybeans	August 0-15cm	mean	50.120	51.123	62.570	Rep	.021
		sd	7.423	12.643	8.538	Pos'n	.050
	August 15-30cm	mean	38.883	49.293	47.137	Rep	.770
		sd	10.881	10.680	13.521	Pos'n	.641
	November 0-15cm	mean	58.478	67.922	59.070	Rep	.163
		sd	7.826	14.044	2.630	Pos'n	.166
	November 15-30 cm	mean	49.102	59.205	44.415	Rep	.952
		sd	7.631	5.536	6.088	Pos'n	.006

Table C.4. Summary Statistics, Bainsville

Crop	Parameter		Slope Position			ANOVA	
			Upper	Middle	Lower	Source	P
Microbial Biomass C (mgC/kg)							
Corn	August 0-15 cm	mean	569.100	520.170	918.503	Rep	.800
		sd	115.471	52.062	290.956	Pos'n	.151
	August 15-30 cm	mean	272.903	298.867	709.073	Rep	.557
		sd	65.627	13.352	176.317	Pos'n	.017
	November 0-15 cm	mean	504.082	456.845	640.983	Rep	.165
		sd	49.356	67.379	91.901	Pos'n	.001
	November 15-30 cm	mean	256.053	235.697	419.953	Rep	.017
		sd	22.201	37.167	75.127	Pos'n	.000
Soybeans	August 0-15 cm	mean	500.720	438.130	811.750	Rep	.842
		sd	133.436	28.861	298.802	Pos'n	.204
	August 15-30 cm	mean	254.067	246.790	596.920	Rep	.151
		sd	80.853	30.380	189.015	Pos'n	.015
	November 0-15 cm	mean	345.273	304.327	658.677	Rep	.112
		sd	55.794	48.364	78.003	Pos'n	.000
	November 15-30 cm	mean	145.193	168.047	486.608	Rep	.775
		sd	51.203	39.583	64.138	Pos'n	.000
Mass of carbon components in 15 cm depth - based on concentration x density in 0-15 cm							
Corn	Organic C	mean	641.410	578.200	599.970	Rep	.734
	mg cm^{-2}	sd	90.275	20.885	15.090	Pos'n	.503
Soybeans	Organic C	mean	555.150	552.945	578.000	Rep	.518
	mg cm^{-2}	sd	17.346	42.675	34.532	Pos'n	.648

Table C.4. Summary Statistics, Bainsville

Crop	Parameter		Slope Position Upper	Middle	Lower	ANOVA Source	P
Soluble C mg cm^{-2}							
Corn	August	mean	1.221	1.355	1.109	Rep	.258
		sd	.121	.358	.007	Pos'n	.512
	November	mean	1.225	1.203	1.090	Rep	.619
		sd	.117	.168	.108	Pos'n	.530
Soybeans	August	mean	1.267	1.454	1.117	Rep	.514
		sd	.002	.457	.069	Pos'n	.589
	November	mean	1.073	1.129	1.161	Rep	.092
		sd	.140	.366	.132	Pos'n	.805
Microbial Biomass C mg cm^{-2}							
Corn	August	mean	11.736	9.274	11.339	Rep	.244
		sd	1.291	.143	.986	Pos'n	.140
	November	mean	12.959	10.622	16.815	Rep	.816
		sd	2.139	1.269	5.305	Pos'n	.264
Soybeans	August	mean	7.492	6.435	12.468	Rep	.454
		sd	1.272	.749	1.399	Pos'n	.065
	November	mean	10.771	9.510	14.956	Rep	.843
		sd	3.073	.851	5.111	Pos'n	.333
Other soil properties							
Corn	$CaC0_3$ %	mean	.567	.533	.600	Rep	.432
		sd	.058	.153	.300	Pos'n	.918
	pH	mean	5.100	4.900	5.800	Rep	.399
		sd	.436	0.500	.361	Pos'n	.122

Table C.4. Summary Statistics, Bainsville

Crop	Parameter		Slope Position			ANOVA	
			Upper	Middle	Lower	Source	P
	Bulk density	mean	1.527	1.360	1.220	Rep	.933
	g cm^{-3}	sd	.090	.056	.070	Pos'n	.032
	Moisture	mean	20.433	18.800	32.500	Rep	.371
	% (w/w)	sd	1.464	.755	1.212	Pos'n	.000
	Yield	mean	8.313	9.513	9.366	Rep	.575
	Mg ha^{-1}	sd	.994	1.202	1.039	Pos'n	.455
	Maximum Penetrometer	mean	2685	2710	1263	Rep	.422
	Resistance (kPa)	sd	303	433	162	Pos'n	.008
Soybeans	$CaC0_3$ %	mean	1.967	.967	.967	Rep	.100
		sd	.850	.115	.896	Pos'n	.107
	pH	mean	5.033	4.800	6.233	Rep	.150
		sd	.493	.436	.058	Pos'n	.008
	Bulk density	mean	1.430	1.450	1.240	Rep	.879
	g cm^{-3}	sd	.030	.139	.053	Pos'n	.121
	Moisture	mean	19.100	19.333	32.233	Rep	.169
	% (w/w)	sd	1.308	1.474	2.458	Pos'n	.001
	Yield	mean	2.858	2.847	2.074	Rep	1.000
	Mg ha^{-1}	sd	.079	.095	.174	Pos'n	.053
	Maximum Penetrometer	mean	2839	3165	1351	Rep	.723
	Resistance (kPa)	sd	183	265	144	Pos'n	.001