

RESEARCH SUB-PROGRAM

Development of Standard Methodologies: Resident Biomass and Organic Carbon

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**Prepared by: Dr. R. Gary Kachanoski
Environmental Soil Services
883861 Ontario Ltd.
605 Arkell Rd.
Arkell, Ontario. N0B 1C0**

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

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FORWARD

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 Agri-Food 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 Site: <http://res.agr.ca/lond/gp/gphompag.html>

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INTERPRETATIVE SUMMARY

Organic matter is an essential component of soil. It increases the ability of the soil to provide the proper conditions to grow agricultural crops and to resist processes such as soil erosion. Soil organic matter is composed of many different components, the most important being various forms of carbon and nitrogen. The decomposition of the organic carbon and nitrogen in soil releases nutrients to growing crops. Knowledge of how this decomposition occurs will help farmers predict how much fertilizer is needed and not over apply fertilizer which may cause environmental problems. Thus, understanding the nature of soil carbon and nitrogen is very important and an area of active research. Part of that research is directed at obtaining estimates of how much soil organic carbon is presently in many of our soils and to set up permanent sampling locations so that the amounts of soil carbon can be monitored with time. This gives us an indication of the “State” of the soil resource and whether our current farming management is ensuring that the resource is sustainable.

This study used different methods to characterize the different forms of soil organic C and N, at a large number of southern Ontario sites where significant amounts of other information had already been collected. The similarities of the different methods and the influence of other soil properties such as the amount of sand content were determined. A chemical extraction method for predicting the amount of nitrogen which might be released by the biological breakdown of soil organic matter was developed. It gave very similar estimates to a long term(22 weeks) incubation method which measures the release of nitrogen during biological decomposition. The quick extractant method may be a good soil test for farmers to use in making decisions on the amount of fertilizer nitrogen to apply. In addition, the study characterized in detail the seasonal changes in soil organic C and the amount of variability within the monitoring area at any time, for 3 different fields. This allows the accuracy of the estimate of soil organic C to be determined and thus, the accuracy of any future estimates of how much change has occurred. At these sites, the amount of soil that has been lost or gained from soil erosion was the main factor in determining the amount of soil carbon present and also the amount of crop yield that was obtained. An easily measured soil erosion tracer, 137-cesium, was used to determine the amount of soil loss or gain at a site and was recommended as a useful indicator for determining the “State” of the soil resource. Finally, all measurement were included in an electronic database with geographic locations so that the information can be used for future studies examining how the soil resource is changing.

SOMMAIRE

Les matières organiques sont une composante essentielle des sols. Grâce à elles, les sols sont mieux en mesure de fournir les conditions propices aux cultures agricoles et de résister aux phénomènes comme l'érosion. Les matières organiques des sols renferment de nombreuses composantes, les plus importantes étant le carbone et l'azote, présents sous diverses formes. La décomposition du carbone et de l'azote organiques dans le sol assure le dégagement de matières nutritives propices à la croissance des cultures. En sachant comment s'opère cette décomposition, on aidera les agriculteurs à prévoir quelles quantités d'engrais ils devront épandre et à éviter d'utiliser des engrais qui pourraient nuire à l'environnement. Il est donc très important de connaître la nature du carbone et de l'azote des sols, qui fait l'objet de recherches intensives. Une partie de ces recherches vise à estimer les concentrations de carbone organique dans de nombreux sols et à établir des postes d'échantillonnage permanents pour la surveillance de l'évolution de ces concentrations dans le temps. On pourra ainsi savoir quel est l'«état» des sols et si les pratiques agricoles courantes assurent la pérennité de cette ressource.

L'étude dont il est ici question s'est appuyée sur différentes méthodes de caractérisation des diverses formes de carbone et d'azote organiques dans les sols à de nombreux endroits, dans le sud de l'Ontario, où d'importantes quantités d'autres données avaient déjà été recueillies. On a déterminé les points communs aux différentes méthodes et l'influence d'autres propriétés des sols, comme la teneur en sable. De plus, on a mis au point une méthode d'extraction chimique visant à prévoir la quantité d'azote que pourrait dégager la biodégradation des matières organiques des sols. Cette méthode a fourni des estimations très comparables à une méthode d'incubation sur une longue période (22 semaines) ayant pour objet de mesurer le dégagement d'azote pendant la décomposition chimique. La méthode d'extraction rapide pourrait se révéler une bonne analyse des sols que les agriculteurs pourraient employer pour décider de la quantité d'engrais à base d'azote à utiliser. L'étude a également permis la caractérisation détaillée des variations saisonnières de la teneur en carbone organique des sols et du degré de variabilité à n'importe quel moment dans trois champs situés dans la zone de surveillance. Cela permet de mesurer l'exactitude des estimations de la teneur en carbone organique et, partant, des estimations futures des variations. À ces endroits, la quantité de sol perdue ou gagnée sous l'effet de l'érosion était le principal facteur utilisé pour déterminer la quantité de carbone présente et le rendement des cultures. Un indicateur assurant la mesure facile de l'érosion du sol, le césium 137, a été utilisé pour la mesure des pertes ou des gains en sols à un endroit donné et jugé utile pour la détermination de l'«état» des sols. Enfin, toutes les mesures ont été entrées dans une base de données avec indication des lieux, de sorte qu'elles pourront servir à l'étude de l'évolution des sols.

TECHNICAL ABSTRACT

The objectives of this project were, (1) to develop and test methodologies to measure resident biomass and organic soil C, (2) to characterize forms and spatial and temporal variations of soil C sufficient to distinguish a 20% change over and above seasonal and random variations, and (3) to relate the soil C measurements to other soil properties.

The study has two parts; (1) method development and (2) field characterization including spatial and temporal variations. Both parts of the study make use of extensive information already collected as part of the Provincial Tillage-2000 project. In part 1, a total of 150 A_p horizon soil samples were selected from the Tillage-2000 benchmark monitoring locations (ie. 75 soil landscapes x 2 tillage systems = 150 samples). The samples cover a wide range in soil texture/type (Brookston Clay-loam to Fox sand) and have detailed back-up information already available. Analysis carried out on these samples as part of this project include; Light Fraction C and N (150 samples), Macro-organic C and N (150 samples), total C and N (150 samples), potentially mineralizable C (100 samples), and total mineral N (150 samples). In addition, a subset of 20 A_p horizon soil samples were selected which cover a range in soil textures (sand to clay-loam), landscape position (severely eroded, depositional), and total organic C. These samples were used for detailed chemical analysis using ¹³C-NMR and a new hot CaCl₂ chemical extraction procedure. These detailed analyses are being completed by Dr. E. Gregorich, CLBRR, Agric. Canada (Ottawa), and Dr. M. Goss (Univ. of Guelph).

In part 2, two T2000 sites covering three textural groups were chosen for field sampling. The sites are the Lobb farm (Huron Co.), which has a sand to sandy loam textured catena sequence and a silty clay-loam to clay-loam catena sequence, and the Pottruff farm (Brant Co.), which has a loam catena sequence. Each catena sequence has three benchmark monitoring locations; upper (eroded), middle (transitional), lower (depositional). Sampling was by soil horizons with the objective of obtaining a measure of the solum specific mass (ie the amount of C and N per unit land area from the surface to the depth of the pedogenic B/C interface). A monitoring area (15 m by 15 m) was established at each benchmark with 15 subsampling points of reference. At each sampling time, an undisturbed soil core (3.175 cm diam.) was taken in the immediate area surrounding each of the 15 subsample grid points. The cores were sliced according to A and B horizon. Sampling times were set to characterize major crop growth stages (planting/spring, sidedress/emergence, full canopy, harvest/fall). A separate measurement of soil bulk density and thickness was obtained for each of the subsamples. Each of the subsamples were combined to get a single bulk sample representing the benchmark. Chemical analysis were completed on the composite samples. For one sampling each year, the individual grid samples were separately dried, weighed and analysed for chemical properties to get an idea of the spatial covariance between chemical composition and solum thickness, and the inherent spatial variability. The above ground crop biomass at time of harvest was also sampled as well as surface crop residue amounts. All plant and surface residues samples were analysed for Total C and N. Soil samples were analysed for total C, inorganic C, organic C, total N, macro-organic matter C and N, and microbial biomass C and N.

In part 1., statistical analysis indicated many of the C and N measurements were correlated to each other. Soil sand content was significantly correlated to many variables. The Light Fraction and

Macro-organic fractions are measuring different components of the soil organic C and have different C/N ratios. The Macro-organic fraction had the highest correlation to potentially mineralizable C and N. A new hot CaCl_2 chemical extraction procedure was very highly correlated ($r=0.98$) to potentially mineralizable N, suggesting it might be an excellent new soil N test. It may also be a good extractant for raw manure to estimate mineralizable N. The measurements of all of the C and N fractions have been entered into a digital database which contains all of the other T2000 measurements. The database has been submitted along with this report.

In Part 2., the spatial and temporal variations of soil C and N were characterised and included in a digital database. Total solum C was measured with an accuracy of at least 16% at all benchmarks. The sampling procedure was accurate enough to measure seasonal changes and active deposition was measured at 2 out of the 3 lower slope positions. Variability of the Macro-organic fraction was higher than for total C, and microbial biomass measurements had the highest variability. All measurements of C had to have a correction for inorganic C because of high carbonates particularly in eroded benchmarks. Measurements of C by Loss on Ignition (LOI) at 500 C did not correlate well to organic C calculated from total C corrected for inorganic C. Thus, LOI should not be used for monitoring purposes to track the state of the soil resource. The major influence on soil C amounts was the amount of soil mass at a benchmark from the surface to the depth of the solum. Sampling by solum depth also allows a mass balance of soil C to be calculated. Measurement of a soil erosion tracer (137 -cesium) at the benchmarks indicated that soil loss could explain the landscape differences in soil C, which was also reflected in current crop yields and above ground plant biomass C production. Thus, 137 -cesium may be a good agri-environmental indicator for the state of the soil resource.

OBJECTIVES

The objectives of this project were,

1. Develop and test methodologies to measure resident biomass and organic soil C
2. Characterize the forms and spatial and temporal variations of soil C sufficient to distinguish a 20% change over and above seasonal and random variations.
3. Relate the soil C measurements to other soil properties directly related to soil fitness.

METHODOLOGY

The study has two parts; (1) method development and (2) field characterization including spatial and temporal variations. Both parts of the study make use of extensive information already collected as part of the Provincial Tillage-2000 project. A summary of the information already collected on the sites is summarized in the Soil Water Environmental Enhancement Program (SWEEP) report by Kachanoski et al.(1992), and the National Soil Conservation Program (NSCP) report by Kachanoski and von Bertoldi (1993).

Part 1. METHOD DEVELOPMENT

A total of 150 Ap horizon soil samples were selected from the Tillage-2000 benchmark monitoring locations. The samples represent 75 soil landscape positions each split into a conservation and conventional tillage system (ie. 75 soil landscapes x 2 tillage systems = 150 samples). The samples cover a wide range in soil texture/type (Brookston Clay-loam to Fox sand)and have detailed back-up information already available including(Kachanoski et al. 1992);

- S detailed topographic characterization using a laser theodolite(digital elevation map) showing location of the soil landscape,
- baseline ¹³⁷Cs measurements so an erosion class can be assigned and future soil loss from the benchmark measured,
- 5 yrs of yield measurements(by tillage system),
- soil cores to depth with horizonation, classification, bulk density, texture,% CaCo₃, soil tests, and other standard soil survey characterization ,
- some have hydraulic characterization(saturated hydraulic conductivity, infiltration, macro porosity, water holding capacity)
- cropping history

The Potentially Mineralizable N in the soil samples has been measured as part of the Agric. Canada NSCP program(Kachanoski and von Bertoldi, 1993)using the procedure outlined by Stanford and Smith(1972). Analysis carried out on these samples as part of this project included;

- Light Fraction C and N (150 samples)
- Macro-organic matter, C and N (150 samples)
- total C and N (150 samples)
- 6 week incubation for mineralizable C (100 selected)
- total mineral N (150 samples)

The light fraction C and N were analysed by Dr. E. Gregorich (CLBRR, Agric. Canada, Ottawa) using the procedure outlined in detail by Gregorich and Ellert (1993, pg 397-408). The macro-organic matter C and N were also determined using the methods outlined in Gregorich and Ellert (1993, pg 397-408). The physical fractionation of the samples for the macro-organic matter were carried out by Environmental Soil Services (ESS), the C and N analysis on the fractions were

analysed by the Land Resource Science Analytical Service (Univ. of Guelph). The total C and N were determined by combustion @1000 °C on a Leco Analyser with correction for inorganic C.

The mineralizable C was determined from a 6 week incubation of the soil samples at 25 °C at the ESS lab. Inert quartz sand (40 g) was mixed with 10 g of each of the soil samples. The mixture was placed in a vial along with 10 g of water, and the vial placed in a 1.0 L incubation chamber with needle access ports. Cumulative CO₂ production was measured in the incubation chambers after 2, 4, 8, 16, and 32 days, by sampling the head space of each incubation chamber with a syringe. The gas samples were analysed for CO₂ concentration the same day using gas chromatography (Land Resource Science Analytical Service, Univ. of Guelph). The incubation chambers were vented at each sampling to maintain aeration and a small amount of water was added to the bottom of the chambers to control humidity and prevent drying of the samples in the vials. Cumulative C released as CO₂ with time was fitted using non-linear least squares methods to

$$C(t) = C_T (1 - e^{-K_c t})$$

where C_T = potentially mineralizable C (mg C/Kg soil), and K_c = carbon mineralization constant (d⁻¹). Similar values for potentially mineralizable N (N_o) were already available for the samples.

The remaining analyses on the samples were carried out by the Land Resource Science Analytical Service (Univ. of Guelph). In addition, a subset of 20 A_p horizon soil samples were selected which cover a range in soil textures(sand to clay-loam), landscape position (severely eroded, depositional), and total organic C. Chemical analysis using ¹³C-NMR and GC-MS were completed by Dr. E. Gregorich, CLBRR, Agric. Canada (Ottawa), and Dr. M. Goss (Univ. of Guelph) to characterise the nature of the soil C in detail. All of the analyses were entered into an electronic database with the other benchmark information. A copy of the database has been submitted with this report.

Modified Hot Calcium Chloride Extraction Procedure

A number of papers from Germany have indicated that using 0.01 M CaCl₂ as an extractant, it is possible to obtain fractions of soil mineral and organic nitrogen that correlate with the N taken up by crops during the growing season (eg Appel and Mengel, 1990, 1992). The method has been investigated and developed in several laboratories in Germany and Holland (eg Houba and co-workers). Based on a critical analysis of the literature a modified procedure has been developed. To ensure comparability between the approach taken here and the standard KCl extraction (2 M KCl solution), a comparison between the efficiency of two separate methods for extracting different forms of nitrogen from soil at 20EC was also included.

The KCl extraction involved weighing 10 g air-dried, benchmark soil samples into 250 ml polyethylene bottles, adding 100 ml 2 M KCl solution into each bottle and shaking for 2 hr at 20 °C. The extracts were then filtered with NH₄-N free Whatman #42 filter paper and the filtrate was analyzed for NH₄-N and NO₃-N using a TRAACS automated colorimetric analyzer.

The CaCl₂ extraction initially involved weighing air-dried 10 g soil samples from each benchmark field site. To each sample; 100 ml of 0.01 M CaCl₂ solution was added then shaken for two hours at room temperature in 250 ml polyethylene bottles. The extracts were then filtered with 'NH₄ - free' Whatman # 42 filter paper. The filtrate was retained as the N-min fraction at 20 °C. The filter papers and remaining soil material were then returned to the original extraction bottles and an additional 100 ml of 0.01 M CaCl₂ solution was added and shaken in a heated water bath at 80 °C for 20 min. This more strongly bound organic N fraction was then filtered, and the filtrate was retained until analysis.

Sub-samples from both the 20 °C and 80 °C extractions were analyzed for NH₄-N and NO₃-N on a TRAACS 800 automated colorimetric analyzer.

An acid digest was performed on 20 ml aliquot from the 20 °C treatment to measure the amount of 'reduced nitrogen' (= soluble organic nitrogen plus NH₄-N). 2.5 ml. of conc. H₂SO₄ containing 3.5 g Se per liter, was added to each aliquot. 5 ml of H₂O₂ (30% v/v) solution was then added to each sample. The mixture was heated at 100 °C, in a block digester, until 2.5 ml remained. Hydrogen peroxide was added in three 1 ml portions and the samples were heated to 330 °C, to volatilize nitrate as HNO₃.

The samples were brought to a final volume of 20 ml, with distilled water, and then analyzed for NH₄-N using a Technicon Auto-Analyzer, utilizing the indophenol blue method.

The soil samples were also analyzed for total N using a Leco automated C and N analyzer.

Part 2. TEMPORAL AND SPATIAL VARIATIONS

Site selection

Two sites covering three textural groups were chosen for detailed field sampling in the second and third years, to quantify the status of soil C and N. The sites are in Southern and Western Ontario and are the Lobb farm (Huron Co.), which has a sand to sandy loam textured catena sequence and a silty clay-loam to clay-loam catena sequence, and the Pottruff farm (Brant Co.), which has a loam catena sequence. The benchmark locations were chosen to represent three catena sequences with three benchmark monitoring locations; upper (eroded), middle (transitional), lower (depositional). A map showing the location of each of the sample sites, a detailed topographic map, and the location of the soil landscape benchmarks are given in Appendix 1. All of the site location data were collected as part of the Tillage-2000 project (Aspinall and Kachanoski, 1992) and the Agric. Canada SWEEP/TED project "Management of Farm Field Variability; Kachanoski et al., 1992). The locations of the farms and the sites have been geo-referenced with a high resolution Global Positioning System.

Sampling for soil C and N

Sampling for determination of the amount of C and N was based on sampling by soil horizons with the objective of obtaining a measure of the solum specific mass (ie the amount of C and N per unit land area from the surface to the depth of the pedogenic B/C interface). A permanent monitoring area of 225 m² (15 m by 15 m) was established at each benchmark. The size of the monitoring area is large enough to accommodate the intensive soil sampling from the study, yet small enough to represent a distinct landscape unit. A sampling grid was established with 15 subsampling points as shown in Figure 1.

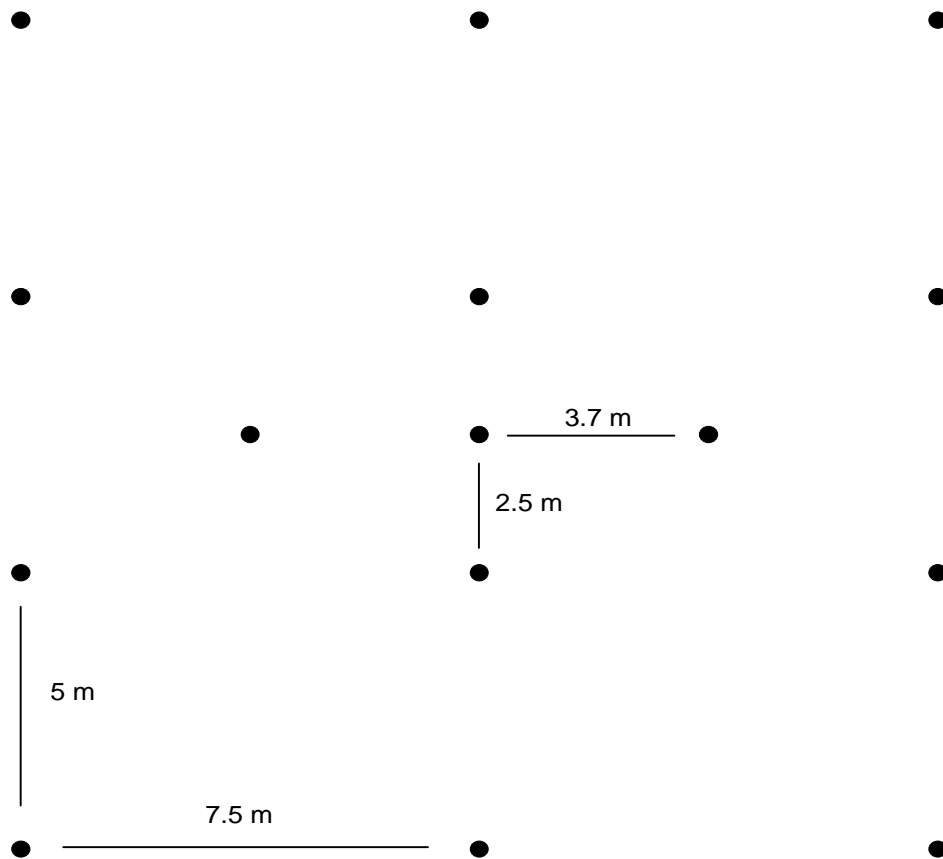


Figure 1. Grid sampling pattern for each benchmark

The subsampling grid points served as permanent points of reference for all sampling times. An electronic marking sond (3M Ltd.) is buried at one of the subsampling grid points. The location of the sond is the marker location of the original Tillage-2000 sampling benchmark. The subsampling grid was orientated around this point in a manner which best defined the landscape unit. Benchmarks chosen were; Pottruff #1(lower/depositional), #9 (middle/transitional), #12 (upper/eroded) ; Lobb #9 (lower/transitional), #11 (middle/transitional), #14 (upper/eroded); and Lobb #21 (lower/depositional), #32 (middle/transitional), and #27 (upper/eroded)

At each sampling time, an undisturbed soil core (3.175 cm diam.) was taken in the immediate area surrounding each of the 15 subsample grid points, of each of the 9 soil landscape benchmarks. The cores were hand pushed into the soil and sliced according to A and B horizon. The end of the B horizon-start of the C horizon was determined by the presence of a significant increase in carbonates using effervescence from application of dilute acid solution, and from color change. Individual samples from each horizon of each subsample location were separately tagged and bagged and the corresponding horizon thickness recorded. For each sampling time there was a possibility of 15 subsample grid locations x 2 horizons/benchmark x 3 benchmarks/ catena x 3 catenas = 270 soil subsamples. Sampling times were set to characterize major crop growth stages (planting/spring, sidedress/emergence, full canopy, harvest/fall). The actual number of subsamples at each benchmark varied because some of the benchmarks are significantly eroded and have an A/C horizon profile. Thus no B horizon sample was available. The location of the subsample relative to the subsample grid location was noted and the location of the subsampling at subsequent sampling times were shifted slightly to ensure an undisturbed area was sampled.

Each of the 270 subsamples were weighed to get an individual wet weight and a small amount of soil removed. The small soil sample was immediately weighed (wet) and placed in drying oven at 105°C for determination of oven dried soil water content. The measurement of soil water content on each subsample along with the sampling depth allowed a separate measurement of soil bulk density for each of the subsamples. The sampling will allow an extremely accurate measurement of the averages and standard errors of the A horizon, B horizon and solum specific mass (g soil m^{-2}). This can be combined with the chemical analysis of the soil samples to obtain average C and N values and their confidence intervals. Each of the subsamples for a sampling time and soil horizon were combined to get a single bulk sample representing the benchmark. All chemical analyses were completed on the composite samples.

At the harvest/fall sampling in year 2 and the sidedress/emergence sampling in year 3, only 9 grid locations within each benchmark were sampled. However, at each grid location, 3 cores were taken, depths recorded, and the 3 samples composited. Each of the 9 composited samples were separately dried, weighed and analysed for chemical properties to get an idea of the spatial covariance between chemical composition and solum thickness, and the inherent spatial variability.

Crop biomass C and N

At the time of the first sampling it became obvious that a significant component of the total C and N was omitted from the contract proposal; ie the surface crop residue. In many cases this would not be significant, but both of the selected sites are in No-tillage management and have a significant amount of surface crop residue which must be included in a mass balance. Thus, at selected sampling times 2 measurements of surface residue were obtained by placing a 0.75 m x 0.75 m frame at 2 different locations within the benchmark monitoring area, and then manually removing all observable residue into a sampling bag. The 0.75 m size was selected since this is the size of the corn row spacing. No surface residue sample was taken at time of full canopy sampling because it was impossible to sample across row, particularly in soybeans, without significantly destroying the growing plants. The crop residue samples were brought back to the lab, oven dried, weighed and ground as preparation for subsequent chemical analysis.

In addition to the surface crop residue sampling, the above ground crop biomass at time of harvest was also sampled. Hand yield measurements of corn and soybeans were taken by sampling 2 rows x 5 m length of row . In the case of soybeans, the entire plant was removed from the sampling area and the total weight of both stover and grain determined by oven drying and weighing. The samples were hand threshed to obtain the weight of only the grain, and subsamples from both the stover and grain were ground for subsequent analysis. For corn, the cobs from the entire area were sampled, weighed wet, then subsampled for determination of moisture content and shelling fraction. In addition, 2 replicates of 2 whole corn plants were taken for determination of total above ground biomass. The whole plants were dried, weighed, chopped and then ground for subsequent chemical analysis. Yield sampling of oats was similar to soybeans with the entire plant removed from the sampling area. The sampling area for oats was 4 rows x 3 m. The sampling described above allowed a determination of standing crop biomass, and grain yield.

Chemical analysis of samples

All chemical analyses were carried out by the Dept. of Land Resource Science Analytical Service, University of Guelph. Some of the sample preparation was carried out by Env. Soil Services. All plant and surface residues samples were analysed for Total C and N using a Leco Analyser. Soil samples were analysed for,

- Organic C using loss on Ignition @500 °C, and a second method using Total C from combustion on a Leco analyser @1000 °C and a correction for inorganic C.
- Total N using a Leco Analyser and combustion @ 1000 °C
- Microbial Biomass C and N
- Macro-organic matter C and N

The measurement of macro-organic matter also gives a measurement of %sand and the biomass measurement uses a K₂SO₄ extract which was selectively analysed for total mineral N.

RESULTS AND DISCUSSION

Method Development

A summary of the measurements made on the T2000 samples is given in Appendix 2. A copy of the database accompanies this report. A summary correlation matrix of the major variables is given in Table 1. A quality control test for locating the benchmarks was inherently built into the study. When Macro-organic C is measured, the amount of sand in the soil sample is automatically determined. The samples used in the study were from the Ap horizon sampled at the end of the T2000 program (1990). The texture of the Ap horizon of all of the benchmarks was also determined from a separate field sampling of the benchmarks by D. Aspinal (OMAFRA) during pedogenic characterization of the each of the soil landscape benchmarks. A high correlation ($r=0.98$) between the sand% measured from the two separate sampling indicates that the benchmarks are easily found and that future sampling will be able to monitor changes accurately.

The purpose of this section of the study was to examine different methods of characterizing the quality of the soil with respect to soil organic C. The correlation matrix given in Table 1. indicates the general relationships between the different measurements. The minimum number of samples analysed for the different measurements was 100, with many exceeding 150. Thus, any correlation coefficient(r) greater than $r = 0.165$ is statistically significant ($@ p < 0.05$). However, this level of significance indicates that approximately 3% of the variability of one measurement is explained by the other measurement. For the purposes of this report a significant correlation is defined as a value of r greater than 0.45 , which means that at least 20% of the variations of one measurement are explained by the variations of the other variable.

Potentially mineralizable C (C_o) and N (N_o) were significantly correlated ($r = 0.65$) to each other. A graph of C_o versus N_o is shown in figure 2. The average ratio of C_o/N_o is approximately 5. This is quite low since the C/N ratio of organic matter is approximately 10, and microbial biomass approximately 4-5. The values of C_o are most likely low because the incubation for C_o was carried out over only 6 weeks compared with 22 weeks for estimating N_o . Thus, the values of C_o should be viewed as an index of mineralizable C. The values of C_o and N_o were correlated to the sand fraction, total soil N%, Macro-organic N% and the Macro-organic C/N ratio. Total soil C% or any of the light fraction C measurements were not correlated to N_o or C_o . Sand fraction was highly correlated to a number of measurements including the Macro-organic C/N ratio ($r = 0.88$). Graphs of C_o and N_o versus sand fraction are given in figures 3 and 4, and C_o and N_o versus total soil N% in figures 5 and 6. The correlation of both C_o and N_o to total soil %N and to Macro-organic %N suggests that soil N, not C is controlling the dynamic behaviour (ie biological activity).

The correlation of the sand fraction with a number of the C and N indices is similar to other field studies that have shown significant correlations of sand content to concentrations of labile organic fractions. This suggests the need to have good control of soil texture variability on long term monitoring plots. Soil texture should be run on all samples taken in a long term monitoring study to ensure that sample variability in texture is not influencing the observed

temporal changes. The influence of soil texture (sand fraction) is very obvious from the graphs of Macro-organic C% and N% versus sand fraction in Figures 7 and 8. The figures indicate a very well defined relationship, which is highly non-linear. For Sand fraction values greater than 0.4 to 0.5 the Macro-organic C% and N% are essentially constant, declining only slightly as sand content increases. However, for sand fraction values less than 0.40 both the Macro-organic N% and C% increase very sharply in a curvilinear manner. A similar, but less defined increase in C_o is also seen with for sand fraction less than 0.40 (Figure 3). A graph of the Macro-organic C/N ratio indicates that the Macro-organic fraction is increasing in C relative to N as the sand content decreases (Figure 9). This suggests that organic material that could be decomposed is being protected from decomposition as sand content decreases. The average Macro-organic C/N ratio was 31 compared to the whole soil average of 10. This indicates that this fraction is a less decomposed fraction compared to the whole soil C pool.

The Light Fraction C and N were not highly correlated to C_o or N_o , which was unexpected. This measurement is thought to be an index of the easily decomposable C in the soil. The average Light Fraction C/N ratio was 21, which is higher than the whole soil C/N ratio (10), but considerably less than the average of the Macro-organic C/N ratio (31). This is probably why the Macro-organic fraction was more highly correlated to C_o and N_o than the Light Fraction. The Light Fraction C/N ratio increased as the sand fraction decreased (Figure 10). This is similar to the Macro-organic C/N ratio. However, a graph of the Light Fraction C/N ratio versus the Macro-organic C/N ratio indicated that the two fractions are not the same material (Figure 11). A graph of Light Fraction C% or N% versus sand fraction (Figure 12, Figure 13) did not give the same relationship as Macro-organic C% or N% (Figures 7 and 8). In particular, the sharp increase in C% and N% as the sand fraction decreased below 0.40 was not present with the Light Fraction. This increase was also seen with C_o and N_o . The Light Fraction carbon was evenly distributed across the range of sand contents (Figure 12). The Light Fraction N increased in a curvilinear manner as sand content increased (Figure 13). This is opposite to the relationship of Macro-organic N and sand fraction. The total amount of light fraction (g/g) was not influenced by sand content (Figure 14). The difference in the composition of the Light Fraction and The Macro-organic fraction reflect a combination of the influence of texture on organic C and n dynamics and the methodologies of the fractionation procedures.

The influence of texture on the relationship between N_o and Macro-organic N is shown in the data from the Don Lobb T2000 site (Figure 15). There are two distinct relationships, one for the sandy part of the field and the other from the silty clay loam benchmarks. This illustrates the need to account for texture variations. It also indicates that the Macro-organic fraction may be fine for monitoring changes with time at the same site, but comparisons between sites need to be done with caution.

Table 1. Correlation Matrix of selected variables

	Light Fraction %	C in LF %	N in LF %	C in Soil mg/g	N in Soil mg/g	C/N In LF	Co	Kc	No	Kn	N Fert	TOTAL C	TOTAL N %	C/N Total %	NH4-N mg/Kg	NO3-N mg/Kg	S Sand Fraction	C %/Wt	N %/Wt	C in Sand	N in Sand	C/N in Sand	Sand %	Silt %	Clay %
Light Fraction%	1.000																								
N in LF %	-0.067	1.000																							
C in LF %	-0.232	0.524	1.000																						
C in Soil mg/g	0.923	0.271	-0.051	1.000																					
N in Soil mg/g	0.918	0.131	0.112	0.936	1.000																				
C/N in LF	0.160	0.425	-0.517	0.291	-0.026	1.000																			
Co	0.436	-0.087	-0.214	0.366	0.347	0.122	1.000																		
Kc	-0.038	0.230	0.130	0.101	0.047	0.058	-0.161	1.000																	
No	0.263	-0.061	-0.109	0.221	0.234	0.011	0.645	0.040	1.000																
Kn	0.077	-0.016	0.039	0.071	0.114	-0.072	0.138	-0.018	-0.161	1.000															
N Fert	0.067	0.010	-0.131	0.069	0.031	0.124	0.440	-0.052	0.567	-0.193	1.000														
TOTAL C %	0.218	0.020	-0.082	0.236	0.199	0.086	0.157	-0.056	0.258	-0.045	0.005	1.000													
TOTAL N %	0.254	0.284	-0.013	0.369	0.258	0.315	0.612	0.216	0.588	-0.004	0.261	0.278	1.000												
C/N TOTAL	0.052	-0.115	-0.106	0.008	0.012	-0.019	-0.151	-0.095	-0.023	-0.055	0.027	0.780	-0.278	1.000											
NH4-N mg/Kg	0.011	0.094	0.209	0.044	0.070	-0.106	0.165	-0.245	-0.016	0.314	-0.170	0.210	0.042	0.130	1.000										
NO3-N mg/Kg	0.191	0.033	-0.018	0.241	0.203	0.046	0.048	0.179	0.021	0.228	-0.207	0.274	0.221	0.103	0.521	1.000									
S Sand Fraction	-0.291	0.215	0.696	-0.184	-0.031	-0.510	-0.434	0.039	-0.459	0.032	-0.364	-0.127	-0.302	-0.019	0.208	0.039	1.000								
C %/Wt	0.248	0.205	-0.221	0.351	0.196	0.485	0.267	0.211	0.287	-0.033	0.147	0.117	0.424	-0.075	-0.082	0.125	-0.414	1.000							
N %/Wt	0.426	0.197	-0.202	0.530	0.379	0.434	0.591	0.063	0.543	-0.048	0.305	0.225	0.667	-0.075	-0.067	0.089	-0.591	0.627	1.000						
C in Sand	0.086	0.232	-0.005	0.202	0.119	0.282	0.013	0.277	0.038	-0.017	-0.046	0.054	0.199	-0.054	-0.017	0.156	0.020	0.837	0.183	1.000					
N in Sand	0.433	0.237	-0.113	0.599	0.444	0.369	0.387	0.131	0.405	-0.092	0.207	0.235	0.579	-0.055	-0.051	0.190	-0.398	0.725	0.889	0.390	1.000				
C/N in Sand	-0.384	0.064	0.547	-0.327	-0.195	-0.508	-0.516	0.008	-0.543	0.007	-0.360	-0.201	-0.469	0.008	0.128	0.000	0.888	-0.436	-0.544	-0.080	-0.414	1.000			
Sand %	-0.347	0.172	0.599	-0.263	-0.163	-0.405	-0.653	0.102	-0.482	-0.014	-0.341	-0.295	-0.428	-0.079	0.109	-0.175	0.980	-0.457	-0.639	-0.043	-0.446	0.900	1.000		
Silt %	0.283	-0.230	-0.640	0.185	0.096	0.379	0.638	-0.102	0.422	-0.055	0.367	0.288	0.313	0.126	-0.115	0.152	-0.969	0.402	0.561	0.032	0.384	-0.869	-0.962	1.000	
Clay %	0.383	-0.026	-0.367	0.325	0.252	0.342	0.699	-0.083	0.484	0.138	0.238	0.234	0.563	-0.033	-0.072	0.175	-0.775	0.456	0.661	0.062	0.456	-0.747	-0.831	0.623	1.000

The previous discussion indicates that the Light fraction and the Macro-organic fraction are not measuring the same carbon pool across the range of soils used in this study. The Macro-organic fraction appears to be a better indicator measurement of easily decomposable C than the Light Fraction. This is significant because the Macro-organic fraction is much easier to measure in the laboratory, requiring little specialized equipment. In addition, most labs are already set up for texture analysis and the measurement could easily be incorporated into their routine activities.

Tillage and Soil Loss

As reported previously by Kachanoski and von Bertoldi(1993), there was no significant effect of tillage system on total soil C (%).The effect of tillage system and soil erosion class on the amount of Macro-organic C and Light Fraction is summarized in Table 2. Conservation tillage resulted in a 13.0% drop in the measured Light Fraction(% wt). This was significant at the 0.01 probability level. The lower light fraction amounts in conservation tillage are likely related to the decrease or absence of tillage incorporation of crop residues into the soil. Thus, surface residue values may be higher in conservation tillage, but this may result in lower amounts of certain C fractions within the soil matrix. No significant differences were observed for Light Fraction C% or N%, or C/N ratio. Thus, tillage did not influence the composition of the Light Fraction.

Table 2. Summary of the influence of tillage system and erosion class on the Light fraction and Macro-organic Fractions of soil.

Paired Tillage Group	Erosion Class	LIGHT FRACTION (% wt)			MACRO-ORGANIC C (%)		
		Tillage system		Difference %	Tillage system		Difference %
		Conv.	Conserv		Conv.	Conserv	
MB vs MIN	E	0.431	0.353	0.078	na	na	
	M	0.331	0.317	0.014	na	na	
	D	0.323	0.345	-0.022	na	na	
MB vs NT	E	0.334	0.338	-0.004	2.638	2.02	0.618
	M	0.353	0.331	0.022	4.731	4	0.731
	D	0.347	0.251	0.096	2.843	2.328	0.515
MIN vs NT	E	0.321	0.214	0.107	1.21	0.847	0.363
	M	0.358	0.33	0.028	1.167	1.132	0.035
	D	0.343	0.25	0.093	1.3	1.627	-0.327
Average=		0.349	0.3032	0.0458 **	2.31	1.992	0.318 *

* significant @ 0.05 probability ** significant @ 0.01 probability

MB= moldboard, MIN = minimum, NT = no-till system

E = eroded, M= moderate, D = depositional

The Macro-organic C% was lower by 13.0 % in the paired conservation tillage systems compared to the conventional systems (significant at the 0.05 probability level). However, the total Macro-organic C (g/g soil) was not significantly different. The effect of erosion class was not statistically significant.

Previously, Kachanoski and von Bertoldi (1993) indicated that conservation tillage systems significantly increased the value of N_o and total N supplying power NF, in eroded landscapes compared to conventional systems. It would appear that the N_o measurement is more sensitive to management changes than either Light Fraction or Macro-organic C and N. The fact that tillage system resulted in the opposite change in light fraction (ie decrease in conservation tillage) compared to N_o (ie increase in conservation tillage), again suggests that the Light Fraction is not a good index of N mineralization potential.

As a final comment, all of the changes in the quality/composition of the various indices are small compared to the major influence of soil loss on the specific mass of soil (g/cm^2) in the Ap horizon. Thus, the main problem/effect of soil erosion is related to soil quantity and not the quality of the carbon in the soil.

Fig.2. Comparison of potentially mineralizable C and N

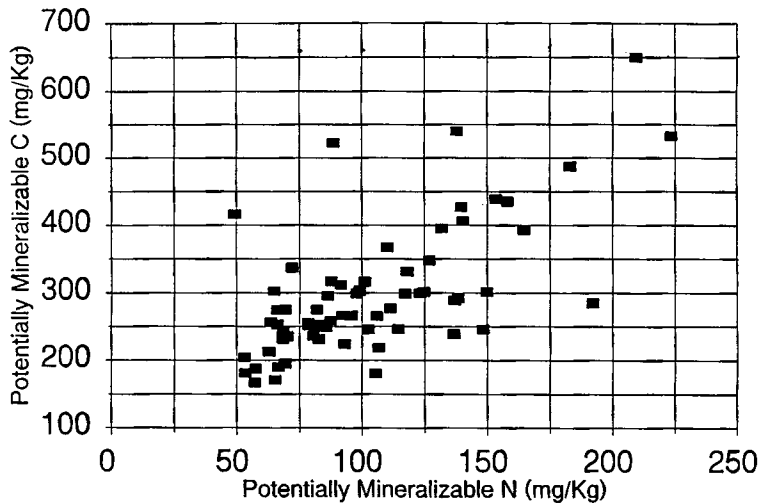


Fig. 3. Amount of potentially mineralizable C versus soil sand fraction

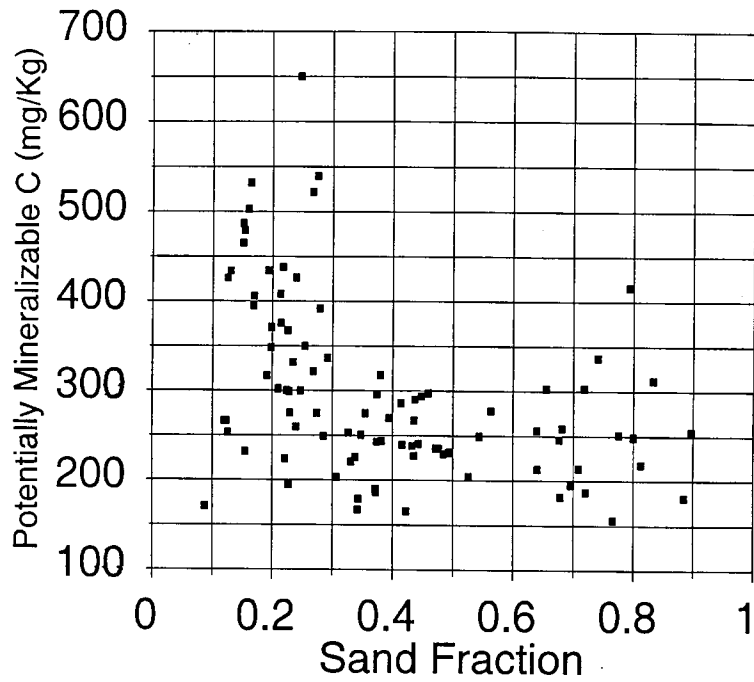


Fig. 4. Amount of potentially mineralizable N versus soil sand fraction

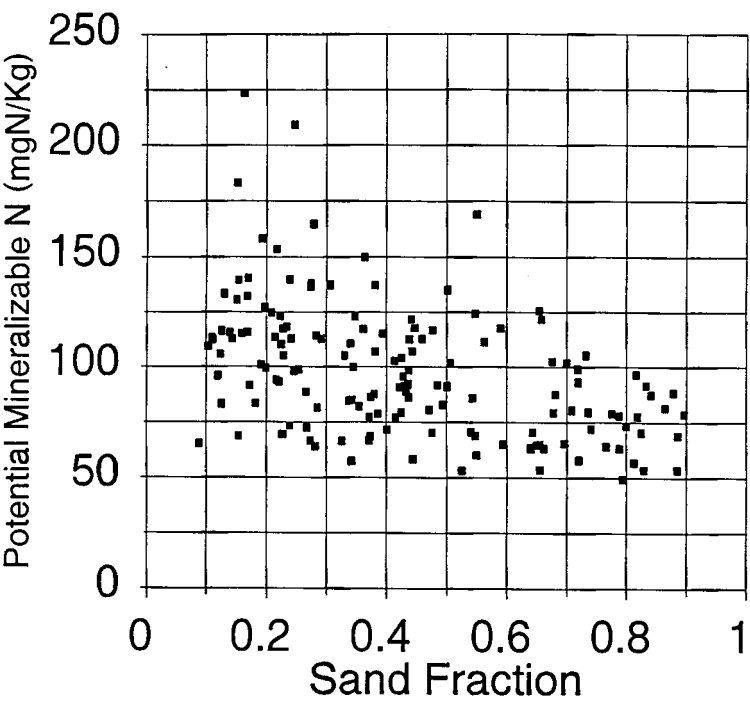


Fig. 5. Amount of potentially mineralizable C in soil versus amount of soil N

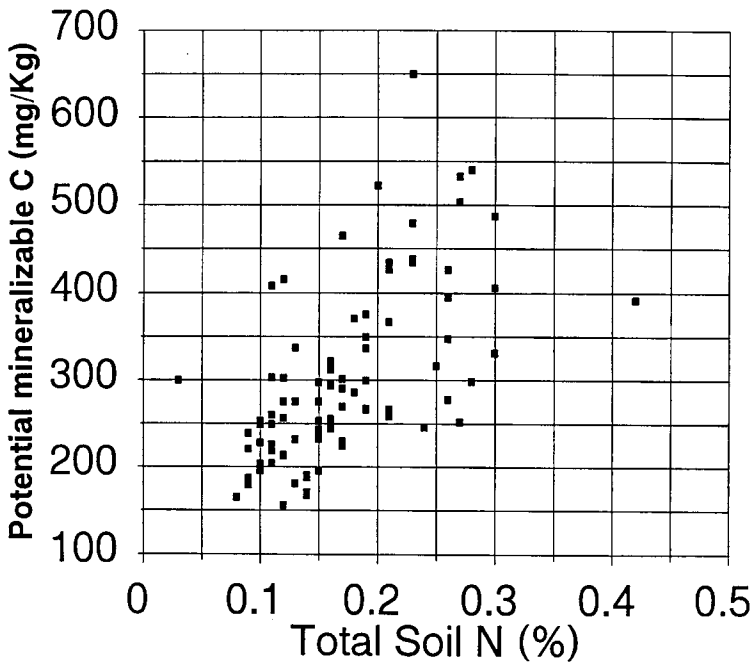


Fig. 6. Amount of potentially mineralizable N versus soil N (%)

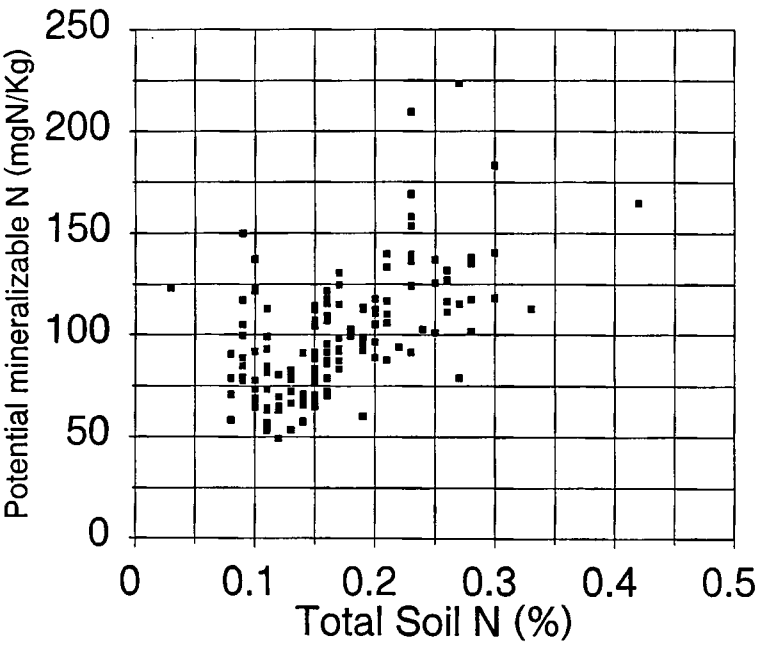


Fig. 7. Amount of C in the sand fraction(macro C) versus soil sand fraction

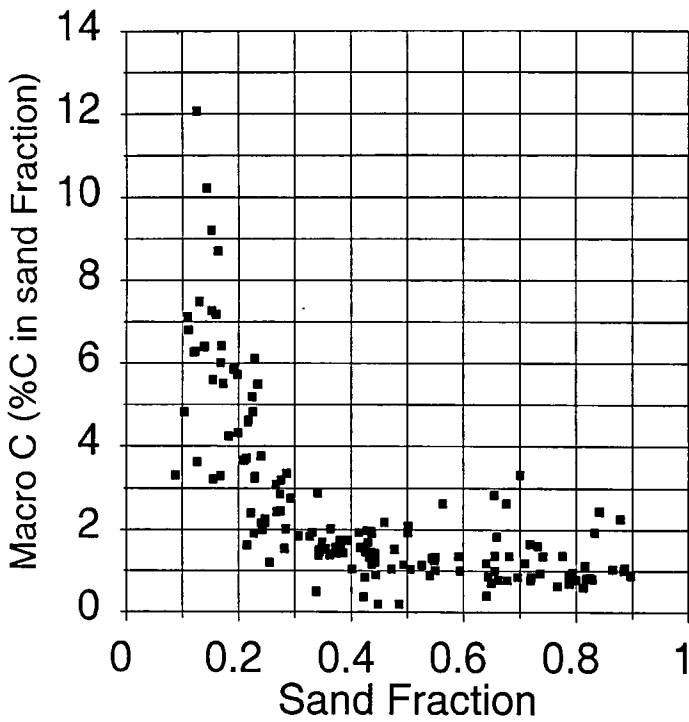


Fig. 8. Amount of macroorganic N in the sand fraction versus sand fraction

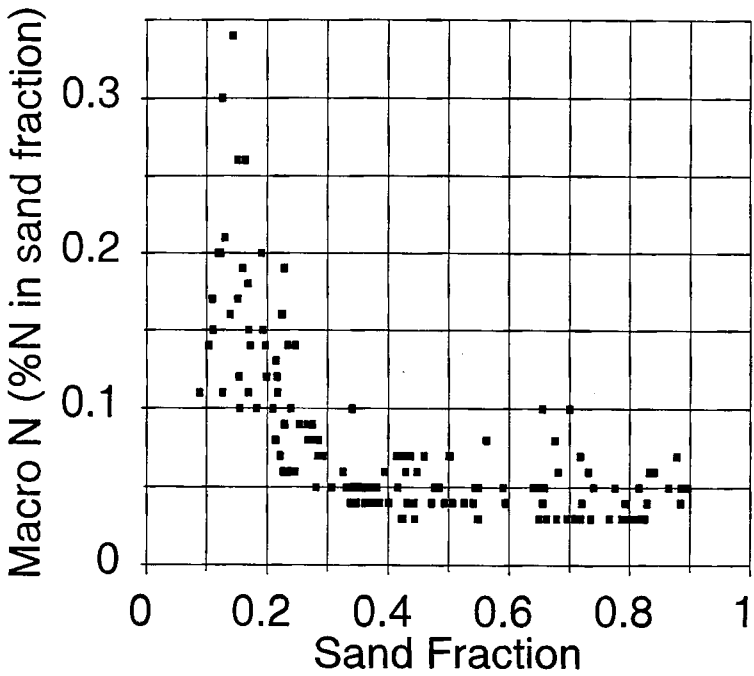


Fig. 9. Influence of soil sand content on macroorganic C/N ratio

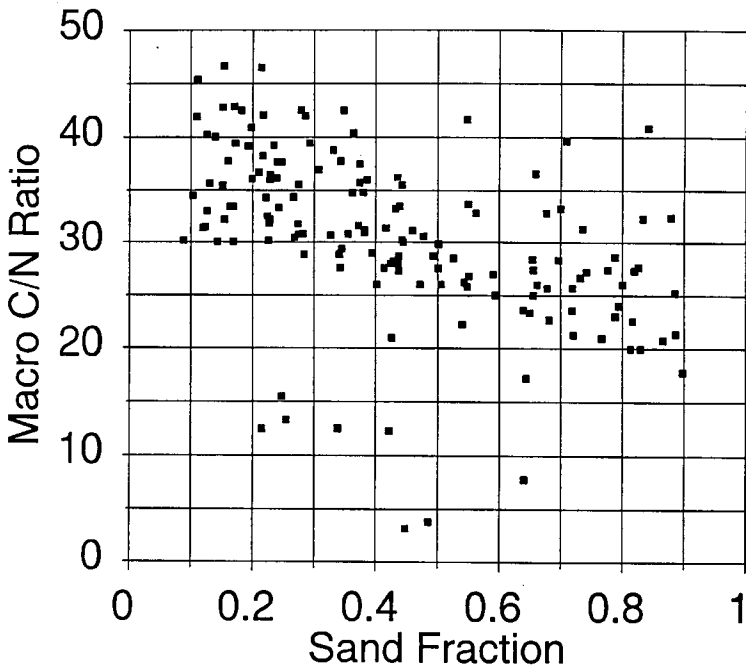


Fig. 10. Influence of sand content on light fraction C/N ratio

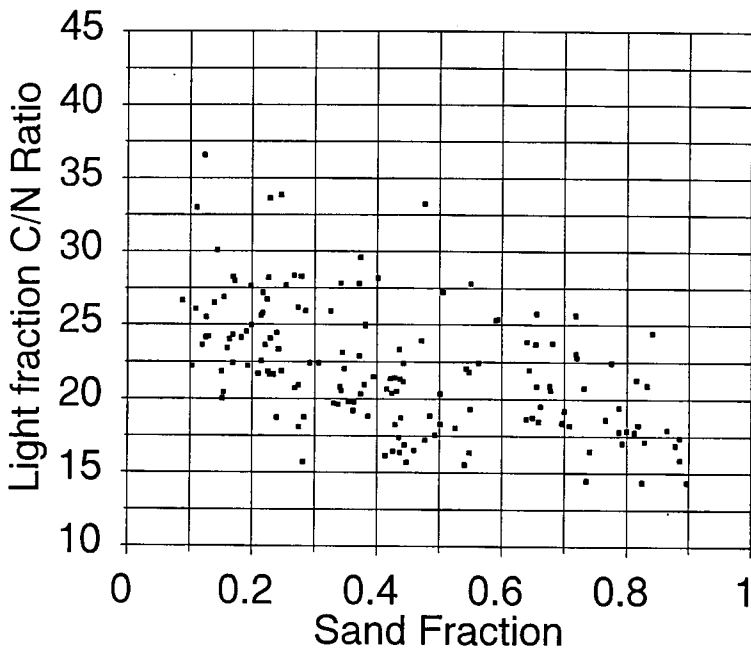


Fig. 11. Comparison of C/N ratios in the light and macroorganic fractions

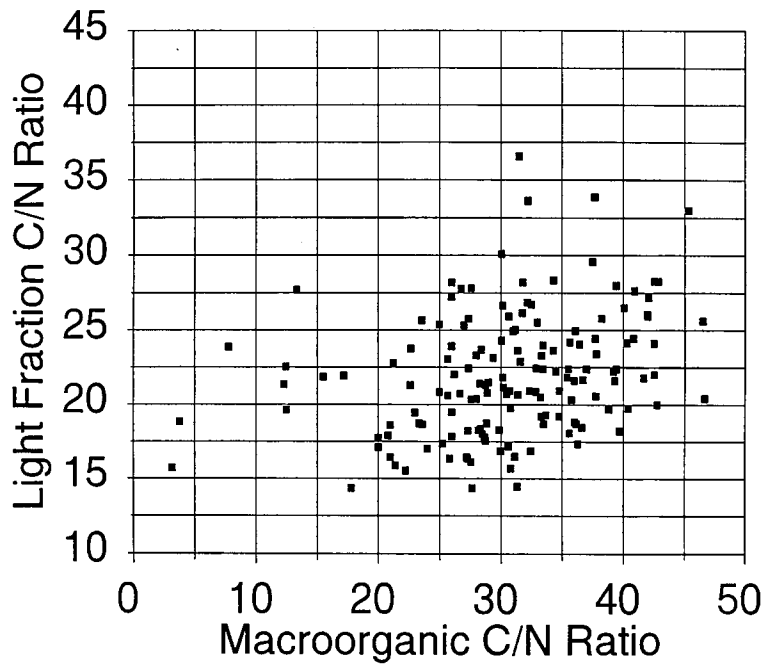


Fig.12. Amount of C in the light fraction versus sand content

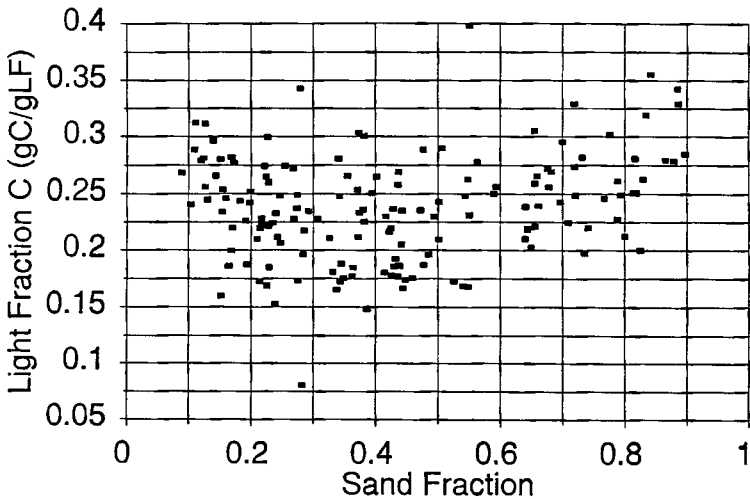


Fig. 13. Amount of N in the light fraction versus sand content

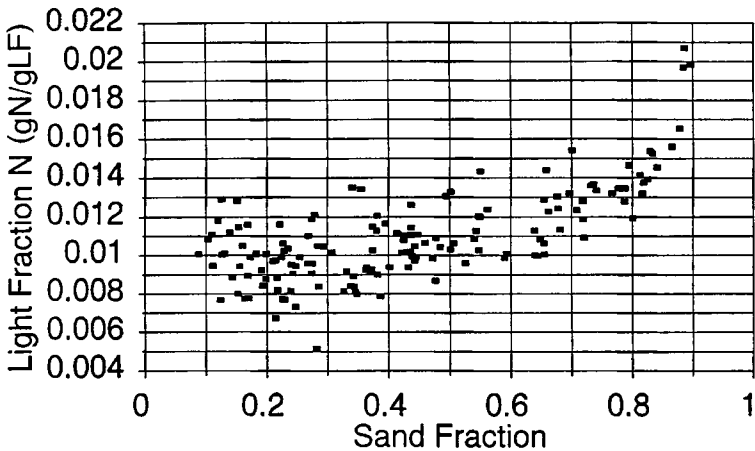


Fig. 14. Amount of light fraction in soil versus sand content

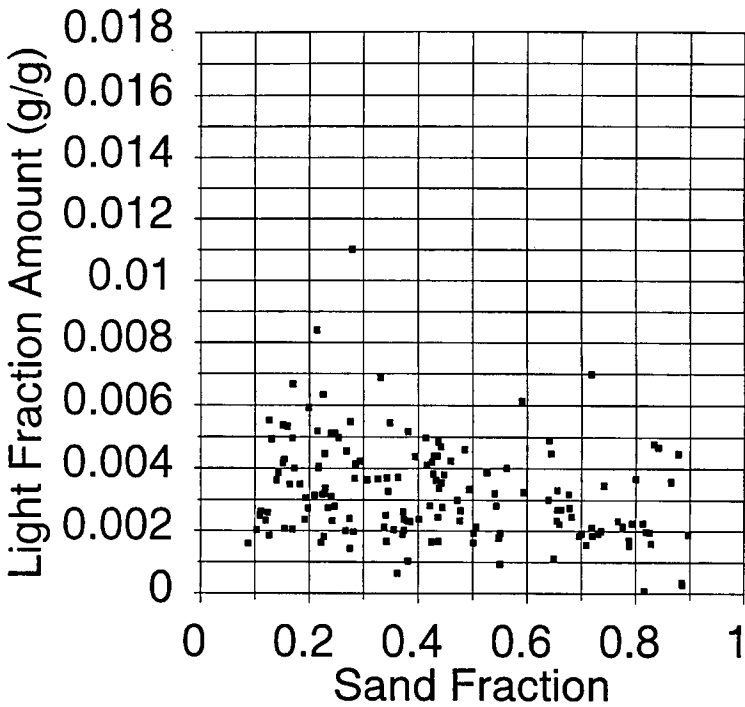
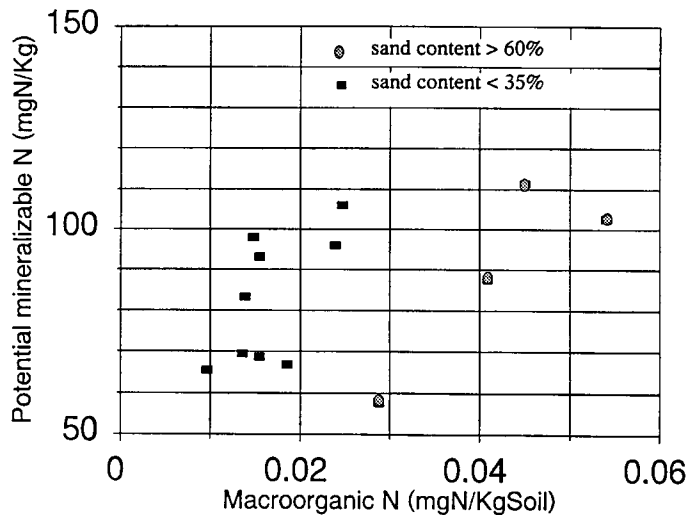


Fig. 15. Influence of sand content on the relationship between potentially mineralizable N and the macroorganic N amount.



Assessment of the Modified Hot Calcium Chloride Extraction Procedure

There was a good correlation between the extraction with CaCl_2 and with KCl at room temperature (20EC) for NO_3^- -N and NH_4^+ -N (Fig. 16). The KCl extraction is the same procedure used for the OMAFRA soil N test in Ontario. The use of CaCl_2 at 80EC as an indicator for the mineralizable nitrogen N_0 predicted by the laboratory incubation (Stanford and Smith, 1972) was tested (Fig. 17). Using data obtained previously for the mineralization potential (N_0) of the soils as the independent variable in a regression, the extraction with CaCl_2 was reasonably well correlated with N_0 ($r^2 = 0.63$) once a single outlier soil from benchmark 110 on the Murray Lobb farm was removed from the data set. This soil sample contained $87 \text{ mg kg}^{-1} \text{ NH}_4^+$ -N, and consistently was more than two standard deviations from the mean of other soils.

The reduced-N fraction was also investigated as a potential indicator for N_0 by regression on the measured values of N_0 . The regression equation ($y = 30.6 + 0.1 x$) gave only a weak fit with an $r^2 = 0.22$ ($0.05 < p > 0.01$).

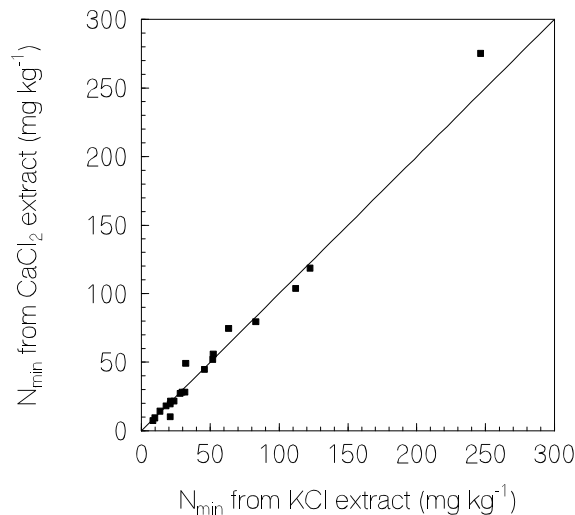


Figure 16. Relationship between N_{\min} , the total mineral nitrogen (NO_3^- -N + NH_4^+ -N) extracted with KCl or with CaCl_2 at 20EC. Regression equation: $y = 1.06 x$; $r^2 = 0.99$; $p < 0.0001$.

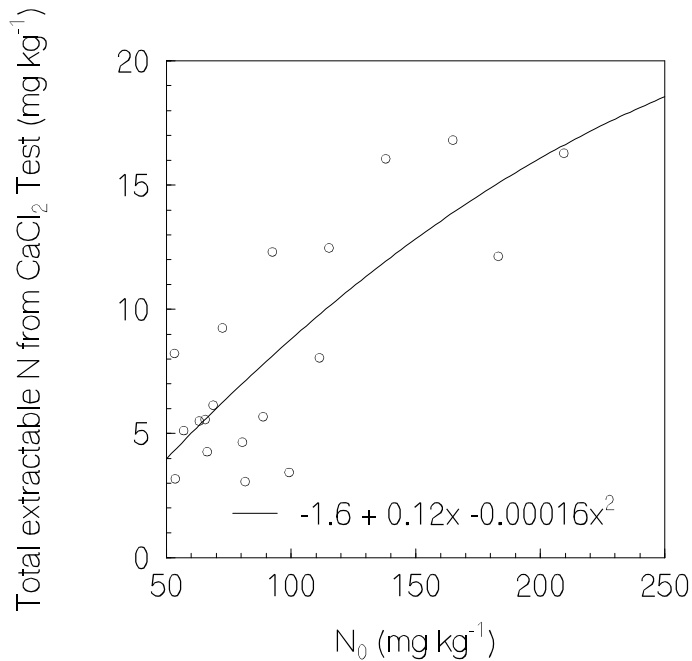


Figure 17. Relationship between mineralizable potential (N_0) and the N_{\min} extracted at 80EC by CaCl_2 . Regression equation: $y = 0.12x - 0.0016x^2 - 1.6$; $r^2 = 0.63$; $p = 0.0003$.

The final analysis was an investigation of the applicability of the total available-N obtained from the three CaCl_2 fractions as an indicator of available-N in the soil. Values of total available soil-N were calculated as the sum of $N_0 + N_{\min}(\text{KCl})$, where $N_{\min}(\text{KCl})$ denotes the N_{\min} value obtained from the KCl extraction (Fig. 18).

The total available N determined by the CaCl_2 extraction procedure was highly correlated ($r^2 = 0.97$) with the available N obtained from the addition of the mineralization potential value (N_0) and the KCl extractable mineral N. Based on this analysis it would be possible to use the combined CaCl_2 analytical procedure as a soil test of available N. The available N would be given by the equation:

$$y = 1.56x$$

This result is based on 19 benchmark sites only. One site gave a much higher prediction than was measured by the incubation and extraction procedure. It is clear that more assessment is necessary before this can be recommended as a standard test in the province. However, the value of a soil test that accurately predicts mineralizable N, plus mineral N cannot be overstated.

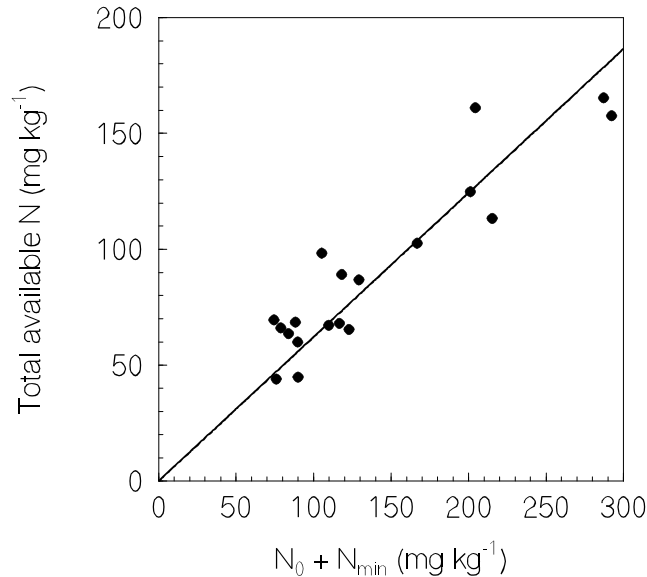


Figure 18. Relationship between available N (estimated from measured from $N_{min} + N_0$) and total available N estimated from $CaCl_2$. Regression equation $y = 0.62x$; $r^2 = 0.97$; $p < 0.001$

The main problem with the current soil N test is that it has high error for soils with additions of organic materials such as manure, legumes, cover crops, food wastes, etc. If the test developed here can predict the amount of N which will be mineralized from the organic N fraction of soil, then the ability to predict fertilizer N requirements will be substantially better. The highest research priority should be to test this procedure more thoroughly and to field test its relationship to fertilizer response on soils with organic N additions.

Spatial and Temporal Variations

A summary of the measurements from the spatial/temporal characterization of the 3 catena sequences is given in Appendix 3. The primary objective of this part of the study was to quantify the total organic C ($Kg\ C/m^2$) at each of the benchmark sites within 20% at the 5% probability level. A summary of total solum organic C measured at each of the benchmarks at each sampling time is given in Table 3, along with the overall average and coefficient of variation(CV). The accuracy of the estimates can be given by

$$\text{accuracy (\%)} = t \frac{CV}{\sqrt{N}} (100)$$

where t = students t statistic, and N = number of samplings. The highest CV is 0.20 which for $N=8$ (ie 8 samplings) gives a maximum estimation error of 16.7%. Thus, all benchmarks can be used to measure changes in total organic C of less than 20%. The changes in total solum organic C as a function of sampling date(month) during the study is given in Figures 19, 20, and 21 for the three catena sequences. As indicated in the graphs, active deposition is occurring in the lower slope positions of the two Lobb catenae . Total solum organic C increased from approximately 18 Kg C/m² to 24 Kg C/m² over the duration of the study at Lobb benchmark L#21. At the Pottruff catena no active deposition was measured in the lower slope benchmark (P#1). However, there was a definite trend of decreasing solum organic C for the upper eroded benchmark(P#12). Small seasonal variations are present, which are believed to be real and not sampling artifacts. All samples within a year were run simultaneously, so no systematic error in analysis is present. The data indicate that accurate estimates of organic C can be obtained with careful sampling similar to the procedures used in this study.

The total organic C in the A horizon and B horizon are given in Tables 4 and 5. As expected, most of the C is present in the A horizon. The temporal variability of solum organic C is less than or equal to the variability of the C in the individual horizons. This suggests that sampling errors associated with estimating organic C in the A horizon are compensated for by the matching estimate in the B horizon. This is probably the result of slicing an entire intact soil core for each sampling point. Any errors in estimating the location of the A/B horizon interface are compensated for in the remainder of the soil core. The data also suggest that sampling to solum depth will not result in less accurate C estimates and in fact may result in gains in accuracy relative to A horizon sampling. Since sampling by solum also allows a carbon mass balance to be monitored with time, it should be the standard method used for setting up benchmarks.

The estimates of total organic C (Kg C/m²) are calculated from the measurements of the horizon thickness and bulk density values. Average values of bulk density, thickness, specific mass and the carbon concentration(%wt) in the A horizon are given in Tables 6 through 9. Similar values are available for the B horizon and the solum in Appendix 3. Each of the thickness, density, and mass values in the tables are the averages of 15 values. The individual values are given in the digital database accompanying the report. Horizon thickness measurements have more variability than bulk density values.

The advantage of the grid sampling with local randomization around the sampling grid points can be demonstrated by examining the estimate of solum thickness from Pottruff benchmark#12. Average solum thickness for all 120 measurements was 44.6 cm and the CV=0.713. According to the Central Limit Theorem(Dixon and Massey, 1969), repeated random sampling of the population with 15 measurements should give a population of average values with a CV=0.184. The measured CV was 0.13. The reason for the increased accuracy can be seen in the estimated spatial pattern of solum

thickness for the 15 m x 15 m benchmark sampling area shown in Figure 22. There is a very distinct non-random spatial pattern that is accurately characterized by the grid sampling pattern. Random sampling would result in a poorer characterization of the pattern for any one sampling, compared to a systematic sampling that was set to measure the pattern. Thus, the accuracy of repeated samplings is more accurate than that predicted from the Central Limit Theorem, which assumes random sampling.

The Macro-organic C(% of sand fraction) of the A horizon was more variable than the solum organic C (Table 10). However, on all but one benchmark (Lobb L#9) the accuracy should be at least 20%. Accuracy of total Macro-organic matter also depends on the variability of the %sand in the samples. The %sand variability was small with CV's all less than 0.09 and most less than 0.05(Table 11). However, the variations of %sand and Macro-organic C% were generally additive and estimates of Macro-organic C (mg C/Kg) are accurate at 20-25%(Table 12).The Macro-organic C values in the B horizon were more variable than values in the A horizon (Tables 14 to 17). Significant temporal trends were present in the B horizon Macro-organic C values, which accounts for some of the increased variability.

As mentioned in the first section of this report, the Macro-organic fraction was not influence by soil erosion class. The data presented in Tables 10 through 13 indicate that for the Pottruff catena, the Macro-organic C concentration (%wt of sand fraction) is significantly lower in the eroded benchmark(P#12) compared to the depositional benchmark(P#1). However, the amount of sand in the eroded P#12 benchmark is significantly higher than P#1. Thus, the Macro-organic C on a whole soil basis (mg C/Kg soil) is actually larger at P#12 than P#1. To complicate things further, the total soil mass in the A horizon at P#1 is larger than P#12. This results in the Total Macro-organic C in the A horizon (Kg C/m²) being equal in both the eroded and depositional benchmarks. This suggests that the Macro-organic fraction may be a useful indicator for temporal changes in soil C at the same benchmark, but not for comparing different benchmarks where texture differences are present. These interactions are likely the reason erosion class had no effect on Macro-organic C in the first part of the study.

The measurements for the crop biomass C and N for 1994 and 1995 are given in Tables 18 and 19. Surface residue C and N amounts are given in Tables 20 to 22. Significant temporal trends in surface C and N amounts were present which were related to crop harvesting. The amount of C and N in the surface residue is significant and needs to be accounted for in determining any changes in the soil C.

A summary of the influence of landscape (ie benchmark) position on the relative values of measured variables at the Pottruff Catena is given in Table 23. Included in the measurements is the amount of 137-cesium, which is a soil tracer for estimating the amount soil loss that has occurred at the site (Kachanoski, 1992). The values are given as a percentage of the value in the lower depositional benchmark. The influence of landform position is evident from the measurements. The eroded upper slope positions is much lower in crop yield, organic soil C, and 137-cesium. The cesium differences are the result of soil redistribution over the past 30 years. Soil loss is obviously a major cause of the soil organic C distribution in the landscapes monitored. This is a result of soil loss and subsequent lower crop yields which decrease carbon inputs to the soil landscape position. This is evident in the relative stover C values at the benchmarks. Similar relationships were observed for the other two catena sequences. The measurements are included in the digital database submitted with this report. The data

suggest that ¹³⁷-cesium may be a good environmental indicator of the state of the soil resource. It is easy to analyse and since no cesium is found in the B horizon, sampling can be limited to the A horizon. The major limitation for using cesium as an indicator is its 30 yr half life.

Figure 19. Temporal changes in total solum organic C at the Lobb #2 Catena.

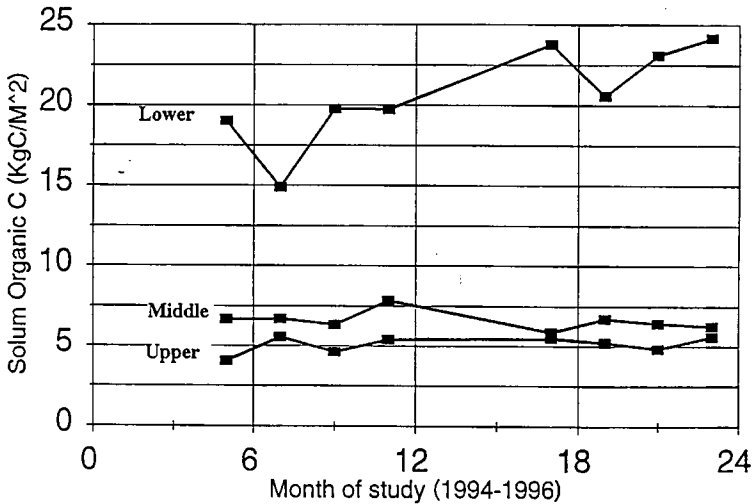


Fig. 20. Temporal changes in total solum organic C at the Lobb#1 Catena

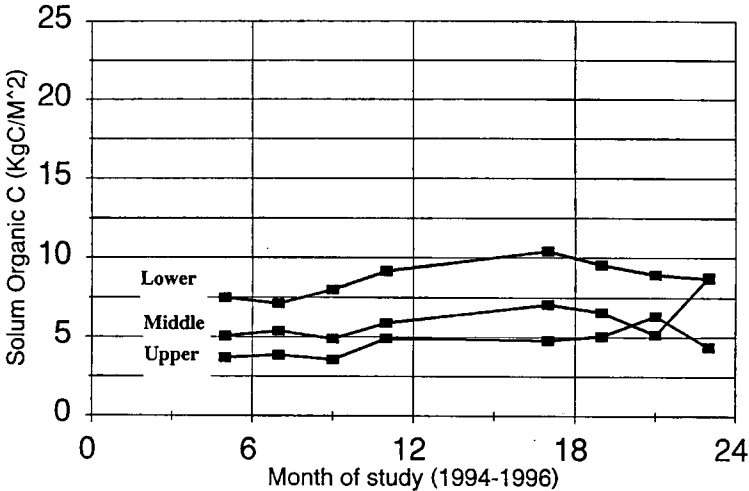
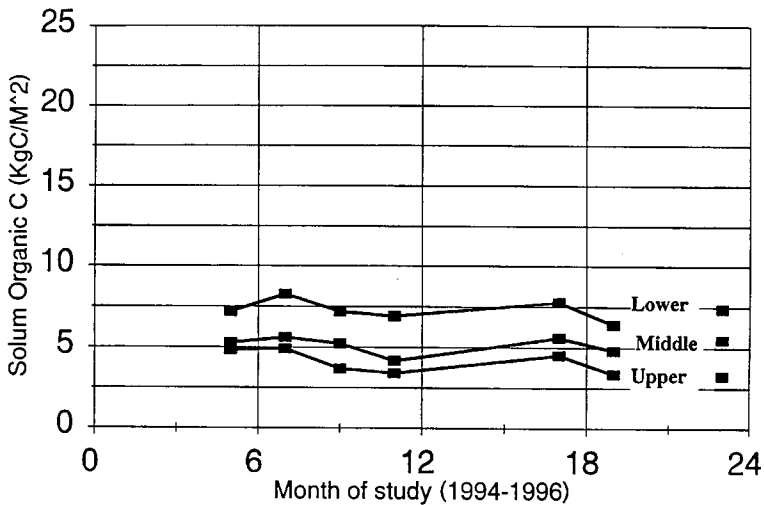


Fig. 21. Temporal changes in total solum organic C at the Pottruff Catena



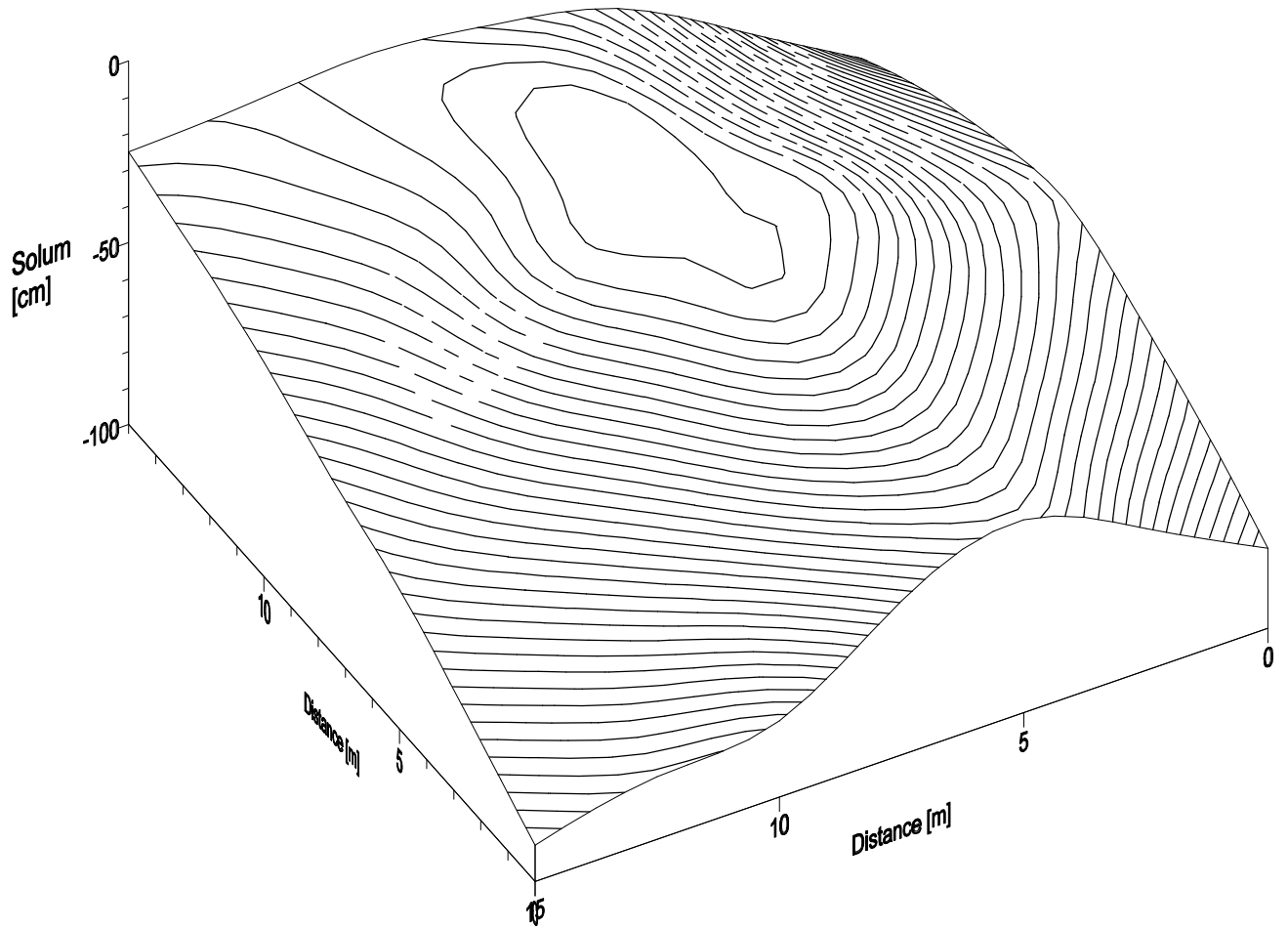


Figure 22. Pattern of solum thickness at Pottruff Benchmark # 12.

Table 3. Total Solum Carbon for all benchmarks and sampling dates.

Catena	Bench mark	Total Solum Organic Carbon (Kg C/m ²)									
		May/94	June/94	Aug/94	Nov/94	May/95	June/95	Aug/95	Nov/95	Ave	CV
Pottruff	P1	7.18	8.27	7.21	6.93	7.78	6.4		7.39	7.31	0.08
	P9	5.3	5.6	5.24	4.2	5.61	4.83		5.49	5.18	0.09
	P12	4.85	4.9	3.71	3.43	4.51	3.37		3.27	4.01	0.17
Lobb#1	L9	7.49	7.13	7.99	9.16	10.41	9.56	8.94	8.71	8.67	0.12
	L11	5.05	5.37	4.88	5.89	7.07	6.57	5.16	8.77	6.1	0.2
	L14	3.7	3.86	3.56	4.93	4.78	5.06	6.37	4.39	4.58	0.19
Lobb#2	L21	19.02	14.89	19.78	19.75	23.79	20.58	23.08	24.15	20.63	0.14
	L27	4.04	5.55	4.62	5.4	5.49	5.23	4.85	5.61	5.1	0.1
	L32	6.66	6.7	6.31	7.87	5.88	6.74	6.44	6.26	6.61	0.08

Table 4. Total A horizon Carbon for all benchmarks and sampling dates.

Catena	Bench mark	Total A Horizon Organic Carbon (Kg C/m ²)									
		May/94	June/94	Aug/94	Nov/94	May/95	June/95	Aug/95	Nov/95	Ave	CV
Pottruff	P1	3.18	4.18	3.55	3.54	4.46	3.83		4.21	3.85	0.11
	P9	2.53	2.89	2.76	2.55	3.28	3.11		3.3	2.92	0.1
	P12	3.02	3.53	2.32	2.07	3.01	2.52		2.41	2.7	0.17
Lobb#1	L9	7.02	6.56	6.53	7.14	9.51	7.82	8.38	7.13	7.51	0.13
	L11	3.24	3.21	2.79	3.85	5.43	4.67	3.78	5.67	4.08	0.24
	L14	3.06	2.45	2.76	3.1	3.45	4.07	4.28	3.54	3.34	0.17
Lobb#2	L21	16.38	11.18	13.55	12.69	19.35	16.22	19.13	18.97	15.93	0.19
	L27	2.65	3.7	4.13	4.06	4.7	4.07	3.85	4.11	3.91	0.14
	L32	5.13	5.28	5.3	6.56	5.28	5.55	4.79	5	5.36	0.1

Table 5. Total B horizon Carbon for all benchmarks and sampling dates.

Catena	Bench mark	Total B Horizon Organic Carbon (Kg C/m ²)									
		May/94	June/94	Aug/94	Nov/94	May/95	June/95	Aug/95	Nov/95	Ave	CV
Pottruff	P1	4	4.09	3.66	3.38	3.32	2.57		3.18	3.46	0.14
	P9	2.77	2.71	2.49	1.64	2.33	1.72		2.19	2.26	0.18
	P12	1.83	1.37	1.38	1.36	1.51	0.86		0.86	1.31	0.25
Lobb#1	L9	0.47	0.57	1.46	2.02	0.9	1.75	0.57	1.57	1.16	0.49
	L11	1.81	2.16	2.09	2.04	1.64	1.91	1.38	3.1	2.02	0.24
	L14	0.64	1.41	0.8	1.83	1.33	0.99	2.09	0.85	1.24	0.39
Lobb#2	L21	2.65	3.72	6.22	7.06	4.44	4.36	3.95	5.18	4.7	0.28
	L27	1.39	1.85	0.49	1.35	0.79	1.16	1.01	1.49	1.19	0.34
	L32	1.54	1.42	1.02	1.31	0.6	1.19	1.64	1.25	1.25	0.25

Table 6. A horizon bulk density for all benchmarks and sampling dates.

Catena	Bench mark	A Horizon Bulk Density (g/cm ³)									
		May/94	June/94	Aug/94	Nov/94	May/95	June/95	Aug/95	Nov/95	Ave	CV
Pottruff	P1	1.39	1.54	1.37	1.52	1.48	1.4	1.41	1.4	1.44	0
	P9	1.32	1.58	1.45	1.4	1.5	1.51	1.49	1.49	1.47	0.1
	P12	1.46	1.63	1.59	1.42	1.57	1.55	1.45	1.57	1.53	0.1
Lobb#1	L9	1.37	1.2	1.22	1.35	1.3	1.33	1.33	1.31	1.3	0
	L11	1.52	1.37	1.45	1.34	1.42	1.44	1.48	1.43	1.43	0
	L14	1.53	1.46	1.4	1.66	1.46	1.45	1.57	1.53	1.51	0.1
Lobb#2	L21	1.4	1.5	1.37	1.37	1.36	1.37	1.37	1.32	1.38	0
	L27	1.47	1.42	1.42	1.61	1.43	1.36	1.46	1.47	1.46	0.1
	L32	1.45	1.43	1.49	1.49	1.4	1.44	1.43	1.38	1.44	0

Table 7. A horizon thickness for all benchmarks and sampling dates.

Catena	Bench mark	A Horizon Thickness (cm)									
		May/94	June/94	Aug/94	Nov/94	May/95	June/95	Aug/95	Nov/95	Ave	CV
Pottruff	P1	23.33	25.27	23.13	23.48	26	24.92	25.4	26.4	24.74	0.1
	P9	18.33	16.8	18.27	21.22	20.79	20.89	19.33	19.6	19.4	0.1
	P12	23.07	22.47	17.27	21.52	22.07	19.19	13.2	18.8	19.7	0.16
Lobb#1	L9	21.33	22.67	21.27	20.33	24.67	21.3	22.2	22.27	22	0.1
	L11	20.2	20.87	17.27	22.74	22.87	20.67	23.73	21.53	21.23	0.1
	L14	20.27	17	17.93	18.48	20.2	18.81	18.4	17.13	18.53	0.1
Lobb#2	L21	49	40.53	43.4	46.63	55.87	52.37	53.46	58.93	50.02	0.12
	L27	11.67	16.27	19.07	16.07	19.07	18.56	16.93	18.73	17.05	0.14
	L32	20.2	20	19.93	22.44	21.67	19.93	18.4	19.2	20.22	0.1

Table 8. A horizon specific mass for all benchmarks and sampling dates.

Catena	Bench mark	A Horizon Specific Mass (Kg/m ²)									
		May/94	June/94	Aug/94	Nov/94	May/95	June/95	Aug/95	Nov/95	Ave	CV
Pottruff	P1	32.15	39.08	31.66	35.58	38.53	34.82	35.58	36.87	35.53	0.14
	P9	24.7	26.65	26.57	28.76	31.23	31.72	28.64	29.04	28.41	0.18
	P12	33.09	36.27	27.57	29.25	34.73	29.78	19.33	29.38	29.92	0.25
Lobb#1	L9	29.2	27.12	25.75	27.36	31.82	28.51	29.37	29.27	28.55	0.49
	L11	30.6	28.15	23.45	28.42	32.29	29.8	34.65	30.83	29.77	0.24
	L14	31.22	25.01	25.08	30.71	29.48	27.36	29.09	26.2	28.02	0.39
Lobb#2	L21	66.52	60.35	59.55	60.31	75	70.55	72.83	76.3	67.68	0.28
	L27	17.33	23.1	27.01	25.88	27.37	25.15	24.74	27.63	24.78	0.34
	L32	29.38	28.59	29.68	33.01	30.37	28.84	26.16	26.61	29.08	0.25

Table 9. A horizon organic carbon (%) for all benchmarks and sampling dates.

Catena	Bench mark	A Horizon Organic Carbon (% wt)									
		May/94	June/94	Aug/94	Nov/94	May/95	June/95	Aug/95	Nov/95	Ave	CV
Pottruff	P1	0.99	1.07	1.12	0.98	1.16	1.1		1.14	1.08	0.1
	P9	1.02	1.09	1.04	0.89	1.05	0.98		1.14	1.03	0.1
	P12	0.91	0.97	0.84	0.7	0.87	0.84		0.82	0.85	0.1
Lobb#1	L9	2.4	2.42	2.54	2.59	2.99	2.74	2.85	2.44	2.62	0.1
	L11	1.06	1.14	1.19	1.3	1.68	1.57	1.09	1.84	1.36	0.2
	L14	0.98	0.98	1.1	1.01	1.17	1.49	1.47	1.35	1.19	0.17
Lobb#2	L21	2.46	1.85	2.28	2.03	2.58	2.3	2.63	2.49	2.33	0.11
	L27	1.53	1.6	1.53	1.56	1.72	1.62	1.56	1.49	1.58	0
	L32	1.75	1.85	1.78	1.94	1.74	1.92	1.83	1.88	1.84	0

Table 10. A horizon Macro-organic C amount in the sand fraction for all benchmarks and sampling dates.

Catena	Bench mark	A Horizon Macro-organic C in the Sand Fraction (%)									
		May/94	June/94	Aug/94	Nov/94	May/95	June/95	Aug/95	Nov/95	Ave	CV
Pottruff	P1	0.65	0.68	0.7	0.67	0.75	0.58		0.87	0.7	0.12
	P9	0.52	0.53	0.54	0.55	0.38	0.32		0.75	0.51	0.25
	P12	0.36	0.61	0.4	0.4	0.43	0.31		0.69	0.46	0.28
Lobb#1	L9	1.1	1.04	1.87	0.82	1.1	0.6	0.63	0.66	0.98	0.4
	L11	0.58	0.52	0.57	0.36	0.53	0.53	0.54	0.3	0.49	0.2
	L14	0.47	0.32	0.71	0.45	0.41	0.42	0.46	0.46	0.46	0.22
Lobb#2	L21	1.36	0.69	0.76	0.95	0.8	1.13	0.74	1.29	0.97	0.25
	L27	1.86	1.63	1.81	1.69	1.29	1.02	1.33	1	1.45	0.22
	L32	1.3	1.78	1.27	1.35	1.33	1.28	0.95	1.44	1.34	0.16

Table 11. A horizon sand content (%) for all benchmarks and sampling dates.

Catena	Bench mark	A Horizon Sand Content (%)									
		May/94	June/94	Aug/94	Nov/94	May/95	June/95	Aug/95	Nov/95	Ave	CV
Pottruff	P1	27.4	27.92	30.75	31.78	29.23	30.69	30.3	29.4	29.68	0.1
	P9	41.85	40.9	42.7	43.18	43.21	47.56	44.41	45.79	43.7	0.1
	P12	49.48	51.16	48.58	47.64	53.39	50.42	50.02	54.25	50.62	0
Lobb#1	L9	63.01	60.41	73.04	65.34	63.04	64.23	64.42	63.23	64.59	0.1
	L11	82.34	82.92	83.66	83.64	83.82	83.05	83.65	84.16	83.4	0
	L14	68.44	66.79	70.37	72.6	66.35	69.99	72.67	72.1	69.91	0
Lobb#2	L21	35.85	45.37	34.58	41.27	38.47	37.61	36.17	35.67	38.12	0.1
	L27	15.46	15.88	15.9	17.18	15.27	15.27	13.95	13.05	15.24	0.1
	L32	18.36	24.37	25.68	22.17	20.91	19.57	20.09	18.29	21.18	0.12

Table 12. A horizon Macro-organic C amount in the whole soil for all benchmarks and sampling dates.

Catena	Bench mark	A Horizon Macro-organic C amount in Whole Soil (mg C/Kg Soil)									
		May/94	June/94	Aug/94	Nov/94	May/95	June/95	Aug/95	Nov/95	Ave	CV
Pottruff	P1	1770	1896	2143	2140	2190	1783		2565	2070	0.13
	P9	2193	2151	2286	2375	1659	1512		3448	2232	0.26
	P12	1781	3121	1938	1914	2286	1579		3733	2336	0.31
Lobb#1	L9	6925	6283	13680	5354	6954	3848	4079	4193	6414	0.47
	L11	4776	4328	4768	3023	4451	4410	4526	2533	4102	0.19
	L14	3217	2137	4997	3269	2736	2942	3359	3333	3249	0.24
Lobb#2	L21	4861	3117	2628	3930	3096	4245	2693	4617	3648	0.22
	L27	2874	2595	2872	2903	1965	1556	1851	1301	2240	0.27
	L32	2388	4329	3248	2986	2786	2507	1913	2638	2849	0.24

Table 13. A horizon Macro-organic C specific mass for all benchmarks and sampling dates.

Catena	Bench mark	A Horizon Macro-organic Carbon Specific Mass (Kg C/m ²)									
		May/94	June/94	Aug/94	Nov/94	May/95	June/95	Aug/95	Nov/95	Ave	CV
Pottruff	P1	0.57	0.74	0.68	0.76	0.84	0.62		0.95	0.74	0.16
	P9	0.54	0.57	0.61	0.68	0.52	0.48		1	0.63	0.26
	P12	0.59	1.13	0.53	0.56	0.79	0.47		1.1	0.74	0.34
Lobb#1	L9	2.02	1.7	3.52	1.46	2.21	1.1	1.2	1.23	1.81	0.41
	L11	1.46	1.22	1.12	0.86	1.44	1.31	1.57	0.78	1.22	0.22
	L14	1	0.53	1.25	1	0.81	0.8	0.98	0.87	0.91	0.21
Lobb#2	L21	3.23	1.88	1.56	2.37	2.32	2.99	1.96	3.52	2.48	0.26
	L27	0.5	0.6	0.78	0.75	0.54	0.39	0.46	0.36	0.55	0.26
	L32	0.7	1.24	0.96	0.99	0.85	0.72	0.5	0.7	0.83	0.26

Table 14. B horizon Macro-organic C amount in the sand fraction for all benchmarks and sampling dates.

Catena	Bench mark	A Horizon Macro-organic C in the Sand Fraction (%)									
		May/94	June/94	Aug/94	Nov/94	May/95	June/95	Aug/95	Nov/95	Ave	CV
Pottruff	P1	0.16	0.18	0.21	0.17	0.05	0.1		0.2	0.15	0.34
	P9	0.27	0.2	0.13	0.12	0.04	0.23		0.34	0.19	0.49
	P12	0.25	0.19	0.16	0.08	0	0.03		0.02	0.1	0.86
Lobb#1	L9	0.5	0.23	0.35	0.12	0.47	0.81	1.78	1.52	0.72	0.79
	L11	0.25	0.35	0.51	0.25	0.47	0.59	0.86	0.9	0.52	0.45
	L14	0.38	0.58	0.17	0.08	0.06	1.28	1.46	0.85	0.61	0.84
Lobb#2	L21	0.36	0.42	0.49	0.49	0.02	0.86	0.46	0.3	0.42	0.52
	L27	2.15	1.72	0.43	0.75	1.16	0.98	0.78	0.37	1.04	0.56
	L32	1.52	0.47	0.85	0.9	0.84	0.85	0	0.19	0.7	0.63

Table 15. B horizon sand content (%) for all benchmarks and sampling dates.

Catena	Bench mark	A Horizon Sand Content (%)									
		May/94	June/94	Aug/94	Nov/94	May/95	June/95	Aug/95	Nov/95	Ave	CV
Pottruff	P1	43.98	46	47.57	49.15	51.31	46.45	45.4	50.38	47.53	0.1
	P9	57.38	54.69	59.94	54.82	56.58	49	45.17	53.08	53.83	0.1
	P12	47.44	50.12	44.19	42.65	48.61	48.16	45.07	48.57	46.85	0.1
Lobb#1	L9	76.77	71.93	75.56	73	79.71	74.02	76.32	72.2	74.94	0
	L11	86.35	87.91	86.96	87.95	83.01	86.15	87.16	89.34	86.85	0
	L14	62.37	70.18	74.16	71.02	65.86	64.01	70.75	74.87	69.15	0.1
Lobb#2	L21	52.31	58.88	60.62	59.24	60.54	57.62	61.89	57.45	58.57	0.1
	L27	13.18	6.46	15.56	11.6	1.67	5.25	2.54	4.11	7.55	0.65
	L32	12.78	25.6	10.41	12.32	7.07	10.85	12.89	10.14	12.76	0.4

Table 16. B horizon Macro-organic C amount in the whole soil for all benchmarks and sampling dates.

Catena	Bench mark	A Horizon Macro-organic C amount in Whole Soil (mg C/Kg Soil)									
		May/94	June/94	Aug/94	Nov/94	May/95	June/95	Aug/95	Nov/95	Ave	CV
Pottruff	P1	708	831	985	822	275	455		1005	726	0.35
	P9	1561	1100	795	662	240	1134		1807	1043	0.47
	P12	1195	952	703	361	0	135		82	490	0.88
Lobb#1	L9	3839	1633	2645	860	3715	5960	13555	10947	5394	0.79
	L11	2133	3033	4400	2210	3863	5043	7490	8035	4526	0.46
	L14	2383	4042	1246	571	391	8189	10339	6374	4192	0.84
Lobb#2	L21	1857	2479	2983	2919	127	4961	2816	1701	2480	0.52
	L27	2832	1113	671	874	193	515	197	153	818	1.01
	L32	1937	1214	888	1108	596	924	0	192	857	0.67

Table 17. B horizon Macro-organic C specific mass for all benchmarks and sampling dates

Catena	Bench mark	A Horizon Macro-organic Carbon Specific Mass (Kg C/m ²)									
		May/94	June/94	Aug/94	Nov/94	May/95	June/95	Aug/95	Nov95	Ave	CV
Pottruff	P1	0.589	0.838	0.887	0.602	0.234	0.332		0.933	0.631	0.402
	P9	1.248	0.843	0.489	0.398	0.15	0.594		0.906	0.661	0.512
	P12	0.583	0.339	0.285	0.118	0	0.039		0.028	0.199	0.997
Lobb#1	L9	0.484	0.084	0.482	0.138	0.372	1.089	3.192	2.869	1.089	1.065
	L11	0.535	1.145	1.186	0.497	1.245	0.953	1.805	3.717	1.385	0.696
	L14	0.336	0.982	0.152	0.142	0.073	1.325	1.817	1.26	0.761	0.823
Lobb#2	L21	0.601	1.163	1.664	1.784	0.059	2.363	1.615	0.877	1.266	0.545
	L27	0.32	0.303	0.057	0.12	0.025	0.079	0.033	0.041	0.122	0.922
	L32	0.166	0.202	0.11	0.192	0.05	0.119	0	0.027	0.108	0.66

Table 18. Summary of Crop Biomass C and N Measurements For 1994.

Catena	Bench mark	Yield (dry) t/ha	grain %N	grain %C	grain C Kg/m ²	grain N Kg/ha	Crop Stover t/ha	Stover %N	Stover %C	Stover C Kg/m ²	Stover N Kg/ha
Pottruff corn	1	9.76	1.355	44.1	0.43	132.244	12.552	0.982	43.93	0.551	123.257
	9	8.183	1.315	43.1	0.353	107.61	7.821	1.07	44.57	0.349	83.681
	12	6.413	1.628	43.6	0.28	104.409	5.972	0.977	44.1	0.263	58.351
Lobb soybean	9	3.131	6.805	50.1	0.157	213.08	2.572	0.765	44.7	0.115	19.677
	11	2.142	6.034	45.7	0.098	129.232	1.882	0.532	50.7	0.095	10.012
	14	2.633	6.262	45.3	0.119	164.85	1.948	0.625	50.5	0.098	12.172
	21	3.115	6.579	45.2	0.141	204.968	2.394	0.618	50.8	0.122	14.793
	32	2.318	6.704	44.5	0.103	155.371	1.501	0.529	50.3	0.076	7.942
	27	2.402	6.752	45.7	0.11	162.154	1.522	0.573	50.8	0.077	8.723

Table 19. Summary of Crop Biomass C and N Measurements For 1995.

Catena	Bench mark	Yield (dry) t/ha	grain %N	grain %C	grain C Kg/m ²	grain N Kg/ha	Crop Stover t/ha	Stover %N	Stover %C	Stover C Kg/m ²	Stover N Kg/ha
Pottruff soybeans	1	3.25	6.68	50.35	0.16	216.94	2.81	0.85	46.20	0.13	23.87
	9	3.25	6.65	49.10	0.16	215.96	2.91	0.85	47.70	0.14	24.62
	12	1.81	7.01	52.50	0.10	126.86	2.02	0.83	48.15	0.10	16.68
Lobb oats	9	4.20	1.35	47.65	0.20	56.45	4.65	0.33	48.25	0.22	15.47
	11	2.02	1.98	47.50	0.10	39.90	1.82	0.48	47.80	0.09	8.70
	14	2.35	1.99	46.00	0.11	46.81	2.57	0.44	46.25	0.12	11.23
	21	4.08	1.87	44.25	0.18	76.09	4.50	0.58	47.95	0.22	26.12
	27	3.19	1.87	45.30	0.15	59.72	3.09	0.34	46.20	0.14	10.55
	32	3.19	1.83	43.80	0.14	58.22	2.92	0.35	46.15	0.14	10.14

Table 20. Surface Crop Residue Dry Weight (Kg/m²).

Caten a	Benchmark	Surface Crop Residue Dry Weight (Kg/m ²)				
		May/94	June/94	Nov/94	May/95	Fall/95
Pottruff	1	0.54	0.46	0.86	0.73	0.54
	9	0.54	0.5	0.62	0.95	0.78
	12	0.36	0.4	0.56	0.66	0.48
Lobb	9	0.57	0.5	0.81	0.54	0.4
	11	0.68	0.78	0.54	0.54	0.35
	14	0.45		0.53	0.63	0.27
	21	0.47	0.61	0.61	0.54	0.39
	27	0.43	0.45	0.44	0.57	0.31
	32	0.28	0.47	0.44	0.48	0.36

* Oat straw was baled on the Lobb site before fall sampling

Table 21. Surface Crop Residue C (Kg C/m²).

Catena	Benchmark	Surface residue C (Kg C/m ²)				
		May/94	June/94	Nov/94	May/95	Harvest/95
Pottruff	1	0.36	0.22	0.57	0.32	0.23
	9	0.28	0.23	0.41	0.43	0.27
	12	0.23	0.26	0.36	0.3	0.18
Lobb	9	0.4	0.33	0.51	0.2	0.15
	11	0.41	0.46	0.3	0.23	0.14
	14	0.26		0.33	0.23	0.11
	21	0.31	0.34	0.34	0.16	0.13
	27	0.28	0.24	0.21	0.13	0.1
	32	0.19	0.21	0.22	0.15	0.14

Table 22. Surface Crop Residue N (Kg N/ha).

Catena	Benchmark	Surface Crop Residue N (Kg N/ha)				
		May/94	June/94	Nov/94	May/95	Harvest/95
Pottruff	1	69.33	46.23	108.64	42.79	26.36
	9	64.85	60.8	83.33	54.28	38.9
	12	48.72	48.04	76.09	40.46	27.26
Lobb	9	72.32	64.71	97.74	36.53	22.63
	11	98.8	51	77.23	46.4	29.35
	14	75.53	43.47	81.11	41.21	17.82
	21	64.47	61.01	66.31	28.74	26.29
	27	48.96	43.62	44.06	27.21	16.24
	32	35.09	53.24	43.92	23.24	18.05

Table 23. Summary of relative differences in measured variables at the Pottruff catena sequence.

Property	Upper (Eroded)	Middle (transitional)	Lower (Depositional)
137-Cesium	69%	84%	100%*
Yield (1994)	65%	84%	100%
Yield (1995)	56%	100%	100%
Yield (1985-1990)	60%	75%	100%
Stover (1994)	48%	63%	100%
Stover (1995)	74.6	107%	100%
Solum C (avg)	52%	63%	100%

* Depositional value set to 100%

Microbial biomass estimates are reported in the database. A summary of the 1994 microbial biomass C and N values for the different benchmarks is given in Tables 24 and 25. The results from the biomass measurements were quite variable. A major problem appears to be the influence of high inorganic C in the soil extracts and its interference with the estimate of total organic C in the autoanalyser. There is a carbonate C purging system on the instrument used by the LRS Analytical Service, but it may be inefficient when high inorganic C levels are present. The biomass extractions have been frozen and will be used for testing new procedures for C determination.

¹³C NMR analysis of benchmark soils

A more detailed chemical characterization of the soil C was carried out on the 20 T2000 benchmarks used to test the hot CaCl₂ extract. This analysis is for reference purposes and was completed in a separate contract to Dr. E. Gregorich, AAFC Ottawa. The results are given here for reporting purposes only. Solid state ¹³C NMR spectra were obtained at a frequency of 45.28 MHz on a Bruker CXP-180 NMR spectrometer equipped with a Doty Scientific probe. Single-shot cross-polarization contacts of 2 ms were used with matching radio frequency field amplitudes of 75 kHz. Up to 120,000 500-W decays were co-added with a delay time of 1 s. These were zero-filled to 4 K before Fourier transformation. Magic angle spinning rates were 4 kHz. Each sample was run for at least 10 hours. The large number of samples and the low carbon content of some of the samples precluded the use of NMR experiments to determine the optimum conditions. Therefore the distribution of total acquired signal intensity within the chemical shift units should be taken as semi-quantitative.

The ¹³C NMR spectra were integrated to give relative values on the proportion contributed by each of four spectral regions (Table 26). The subdivision of the spectra was: alkyl C (10-50 ppm), O-alkyl C (50-110 ppm), aromatic C (110-160 ppm), and carbonyl C (160-200 ppm) (Baldock *et al.*, 1992; Wilson, 1987). The chemical shift limits of each region are approximate because there would undoubtedly be some overlap of signals between adjacent regions. As shown in Table 26, the label given to each region is general and is indicative of the major type of carbon present.

Table 24. A horizon microbial biomass C and N for all benchmarks and 1994 sampling dates.

Catena	Bench mark	Microbial Biomass C (mg C/Kg soil)					Microbial Biomass N (mg N/Kg soil)				
		May/94	June/94	Aug/94	Nov/94	Ave	May/94	June/94	Aug/94	Nov/94	Ave
Pottruff	P1	138.89	8.81	137.47	35.50	80.17	9.43	2.80	6.46	8.50	6.80
	P9	124.04	49.35	160.88	34.40	92.17	13.38	10.50	9.04	6.30	9.81
	P12	101.36	109.56	103.85	34.00	87.19	11.20	23.65	9.53	5.20	12.40
Lobb#1	L9	109.51	69.31	210.90	18.50	102.06	14.22	17.48	21.66	11.20	16.14
	L11	99.77	19.31	115.02	10.90	61.25	11.97	11.29	4.36	7.60	8.81
	L14	49.32	37.36	136.36	21.20	61.06	12.32	10.92	7.36	6.10	9.18
Lobb#2	L21	156.75	30.34	227.21	29.90	111.05	17.88	12.84	18.83	14.90	16.11
	L27	96.17	93.51	132.31	36.80	89.70	6.68	21.68	15.64	13.80	14.45
	L32	150.38	91.72	199.07	35.80	119.24	14.99	19.56	21.44	8.50	16.12

Table 25. B horizon microbial biomass C and N for all benchmarks and 1994 sampling dates

Catena	Bench mark	Microbial Biomass C (mg C/Kg soil)					Microbial Biomass N (mg N/Kg soil)				
		May/94	June/94	Aug/94	Nov/94	Ave	May/94	June/94	Aug/94	Nov/94	Ave
Pottruff	P1	94.14	17.56	110.79	21.50	61.00	6.64	0.00	5.55	1.75	3.49
	P9	65.77	0.00	152.70	15.60	58.52	6.56	0.00	5.63	0.82	3.25
	P12	73.50	15.61	95.76	17.40	50.57	4.99	4.60	6.15	1.10	4.21
Lobb#1	L9	0.00	0.00	132.45	9.00	35.36	2.51	1.13	7.61	1.30	3.14
	L11	21.77	0.00	110.97	5.40	34.54	3.32	2.26	4.95	1.33	2.97
	L14	21.64	3.50	136.30	9.10	42.64	4.72	2.58	4.04	2.50	3.46
Lobb#2	L21	111.80	1.39	150.15	19.10	70.61	6.98	4.72	9.73	6.23	6.92
	L27	100.38	11.88	75.04	15.70	50.75	8.56	5.68	2.86	4.49	5.40
	L32	113.44	45.06	108.86	19.30	71.67	4.35	7.00	6.87	0.99	4.80

Table 26. Chemical shifts limits and assignments and of the four spectral regions into which the ^{13}C NMR spectra were divided.

Label	Chemical Shift range (ppm)	Dominant Formas of Carbon
alkyl	10 - 50	methyl, methylene, methine and quaternary carbon
O-alkyl	50 - 110	oxygenated alkyl, alkyl-amino, methoxyl, acetal and ketal carbon
aromatic	110 - 160	protonated and carbon substituted aromatics and unsaturated carbon and oxygenated aromatics
carboxyl	160 - 200	carboxylic carbon, esters and amides

Table 27. Distribution of C in soils from the different benchmark soils.

Site	Benchmark No.	----- % Signal intensity -----				Aliphatic C (10-100 ppm)	Aromaticity †
		Alkyl C	O-Alkyl C	Aromatic C	Carboxyl C		
Bee (B2)	201	27	40	22	11	68	24
Bee (B2)	204	21	42	22	14	63	26
Anthony (A1)	206	24	43	21	12	67	23
Anthony (A1)	207	19	50	18	13	68	21
Chips (C6)	302	31	41	18	10	72	21
Chips (C6)	303	23	42	24	12	65	27
Dykstra (D9)	101	17	43	24	16	60	29
Dykstra (D9)	104	18	44	23	15	62	27
Dykstra (D9)	105	20	42	26	13	61	30
Johnson (J14)	102	19	42	27	12	61	31
Johnson (J14)	105	23	40	22	15	62	26
Johnson (J14)	113	34	38	18	10	72	20
Murray Lobb (LM)	105	18	46	26	10	64	29
Murray Lobb (LM)	110	23	39	26	12	62	29
Don Lobb (L0)	104	23	43	22	12	66	25
Don Lobb (L0)	123	27	42	20	11	69	22
Strathroy (S27)	202	20	43	24	13	63	27
Strathroy (S27)	208	28	39	23	10	67	26
Templeman (T31)	103	11	43	31	15	54	37
Templeman (T31)	104	18	44	26	12	62	29

† aromaticity = (aromatic C / (aliphatic C +aromatic C X 100

Organic C Determination

The values for organic C presented in the report were determined from a measurement of total C with a correction for inorganic C. A second method, Loss on Ignition at 500 °C was also used to determine organic C. The correlation between the 2 methods was $r=0.848$ for the A horizon, and $r=0.365$ for the B horizon. The slope for the relationship changed for each horizon and was significantly higher than the value of $1/1.72 = 0.58$, which is normally used for the LOI method. The data suggest that LOI estimates of organic C are probably not very accurate and should not be used for monitoring soil C.

SUMMARY

Major aspects of the study are presented in point form.

Soil C and N were characterised from Ap horizons from approximately 150 soil landscape positions in Ontario. These sampling locations are permanently marked and geo-positioned so that future sampling can be carried out at the same locations. An independent test indicated the sites can be located and accurately sampled again. The data have been included into an electronic database which accompanies this report.

The Macro-organic Fraction and Light Fraction of soil are measuring significantly different components of the soil C. The Macro-organic fraction has a higher C/N ratio than the Light Fraction, and is more highly correlated to the potentially mineralizable C and N in the soil. Both fractions are affected by soil sand content, but in different ways.

Mineralizable C and N were highly correlated to each other and were more correlated to soil N components than soil C.

A new hot CaCl_2 extractant procedure was very highly correlated to the potentially mineralizable N from a 22 week incubation. This suggests this procedure may be a good soil N test or even a good extractant for manure. It may overcome the limitation of the current N test, which has high error in soils with high potentially mineralizable N.

Conservation tillage resulted in a decrease in the amount of Light Fraction and Macro-organic Fraction, which may be related to the decreased incorporation of crop residues into the soil.

The spatial and temporal (2 yr) variability of soil C and N components were quantified for 3 soil landscape positions from each of 3 catena sequences in Ontario. Total standing crop biomass C and N were also measured. The estimates of total solum C are accurate enough to measure a 20% change over and above seasonal variations. The sampling locations are permanently marked and geo-positioned so future sampling can be carried out at the same locations. The measurements have been included into an electronic database which accompanies this report.

Seasonal changes in total solum C and Macro-organic C were observed. Active deposition of soil C was measured at 2 out of 3 lower slope benchmarks. A trend of decreasing solum C was measured at one of the upper slope benchmarks.

Spatial variability of total solum carbon was less than or equal to the spatial variability of total A horizon carbon, or total B horizon carbon. Thus, to reach a desired level of accuracy, sampling to solum depth does not require more samples than sampling only the A horizon. Since sampling by solum depth allows a mass balance of soil C to be calculated with time, this should be the method used to monitor benchmarks.

Establishing a sampling procedure which characterizes the pattern of solum depth at the benchmark results in an increase in accuracy of estimated soil C amounts over and above that predicted from statistical theory that assumes random sampling.

Macro-organic C was more variable than solum C, and microbial biomass C was the most variable. Macro-organic C can be used to monitor temporal changes at a site, but care must be used in interpreting differences between sites because of the dependence of the measurement on soil sand content.

Soil loss or deposition are the major factors controlling the spatial distribution of soil C in the landscape. Changes in carbon concentration are also occurring, but soil mass in the solum the dominate factor controlling Total solum C. Current crop yield and above ground plant biomass C production are also highly influenced by landscape position and soil loss.

Seasonal changes in the amount of surface crop residue C and N were quantified. Significant changes were measured indicating this component must be measured in any study monitoring the temporal changes in soil C and N.

Loss On Ignition at 500 C should not be used to estimate soil organic C. It was moderately correlated to organic C measured using Total C corrected for inorganic C, and the slope of the relationship changed depending on soil horizon. The correction factor(1/1.72) usually used with Loss On Ignition was not correct.

The amount of 137-cesium, a soil erosion tracer, at a site appears to be a good environmental indicator of current soil C status and crop yield potential. It should be measured at all monitoring sites

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APPENDICES

**APPENDIX 1. LOCATION, ELEVATION MAPS, AND MANAGEMENT OF THE
TILLAGE-2000 SAMPLING SITES.**

Crop Management Information for Pottruff and Lobb Tillage-2000 sites(1994-1995)

LOBB FARM

1995

Crop- Oats (Stewart)

Plant date: March 28,1995

Harvest date : August 2,1995

Herbicide: 24D@0.4L/ac

Fertilizer ; 50lbsN,50lbs P2O5, 25 lbs K/ac

Field yields : 118 b/ac

1994

Crop: Soybean (t5505)

Plant Date: May 21,1994

Harvest Date: Oct. 15,1994

Fertilizer: 6-24-6@ 3 US gal/ac

Yield (notill): 52 b/ac

POTTRUFF FARM

1995

Crop: Soybeans(Marathon)

Plant Date: May 23,1995

Harvest Date: Sept. 26,1995

Fertilizer: 100lbs Kcl/acre

Yield: 35 b/ac

1994

Crop: Corn (Funk 4120)

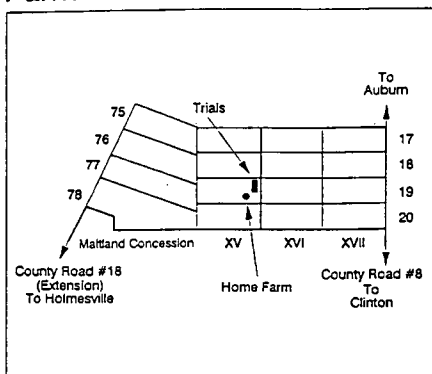
Plant Date: May 3,1994

Harvest Date Oct 28,1994

Fertilizer: 110 lbsN/ac as 28%N, 46lb/ac 18-46-0

Yield : 133 b/ac

Farm Location



Don Lobb
 Huron County
 Goderich Township
 Lot 19, Concession XV

Detailed Plot Description

All distances in metres

Conventional Moldboard

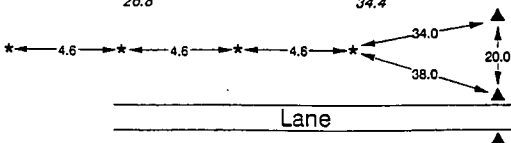
8 *
 37.6
 7 *
 118.6
 6 *
 79.0
 5 *
 31.0
 4-Sond *
 37.0
 3-Sond *
 130.0
 2-Sond *
 41.0
 1-Sond *
 26.8

Conservation No-Till

8 *
 39.4
 7 *
 136.6
 6 *
 69.4
 5 *
 31.0
 4 *
 42.8
 3 *
 117.2
 2 *
 44.6
 1 *
 34.4

LEGEND

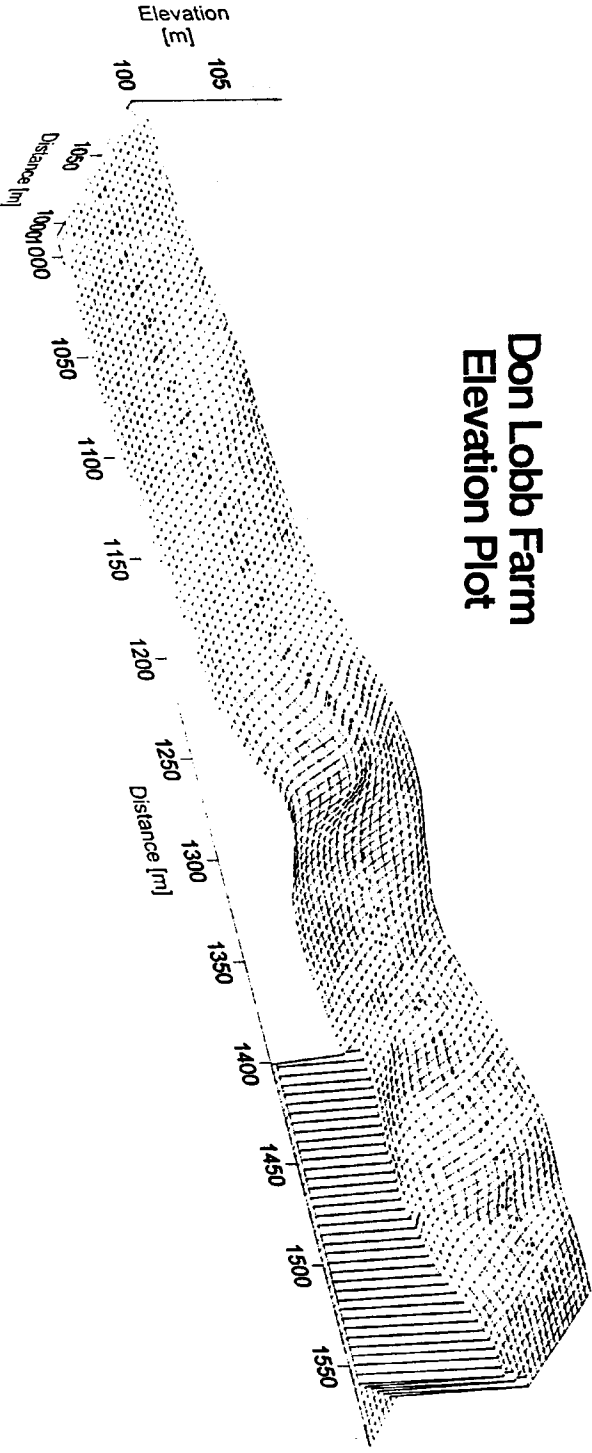
- * Steel Plate and/or Sond
- ▲ Bell Marker



Don LOBB Farm, Cs Benchmark

T1 No		4.4 m Dist	Bmk. Post	T2 Conv			Side Reps.
Sond	Sum			4.4 m Dist	Sum	Sond	
		6.30		6.30			
	6.30		0		6.30		
		30.00		42.00			
x	36.30		1		48.30	x	
		40.00		28.10			
	76.30		2		76.40		
		30.00		30.80			
x	106.30		3		107.20	x	
		11.50		9.60			
	117.80		4		116.80		
		20.10		21.60			
x	137.90		5		138.40	x	
		26.10		24.60			
	164.00		6		163.00		
		20.90		21.40			
x	184.90		7		184.40	x	
		20.40		20.00			
	205.30		8		204.40		
		14.00		14.50			
	219.30		9		218.90		
		12.00		11.50			
x	231.30		10		230.40	x	*
		11.10		7.00			
x	242.40		11		237.40	x	*
		10.00		10.00			
x	252.40		12		247.40	x	*
		10.10		11.00			
x	262.50		13		258.40	x	*
		8.00		8.00			
x	270.50		14		266.40	x	*
		12.10		14.40			
x	282.60		15		280.80	x	*
		10.70		12.00			
x	293.30		16		292.80	x	*
		11.30		11.30			
x	304.60		17		304.10	x	*
		10.60		9.50			
x	315.20		18		313.60	x	*
		12.70		12.00			
x	327.90		19		325.60	x	*
		15.90		20.50			
x	343.80		20		346.10	x	
		50.20		48.00			
	394.00		21		394.10		
		23.50		21.50			
x	417.50		22		415.60	x	
		9.40		9.00			
	426.90		23		424.60		
		18.50		19.00			
x	445.40		24		443.60	x	
		18.00		20.00			
	463.40		25		463.60		
		15.90		13.60			
x	479.30		26		477.20	x	
		9.70		11.40			
	489.00		27		488.60		
		6.30		10.40			
x	495.30		28		499.00	x	
		9.00		10.80			
	504.30		29		509.80		
		7.30		7.50			
x	511.60		30		517.30	x	
		10.70		3.10			
x	522.30		31		520.40	x	
		26.10		26.30			
	548.40		32		546.70		

Don Lobb Farm Elevation Plot



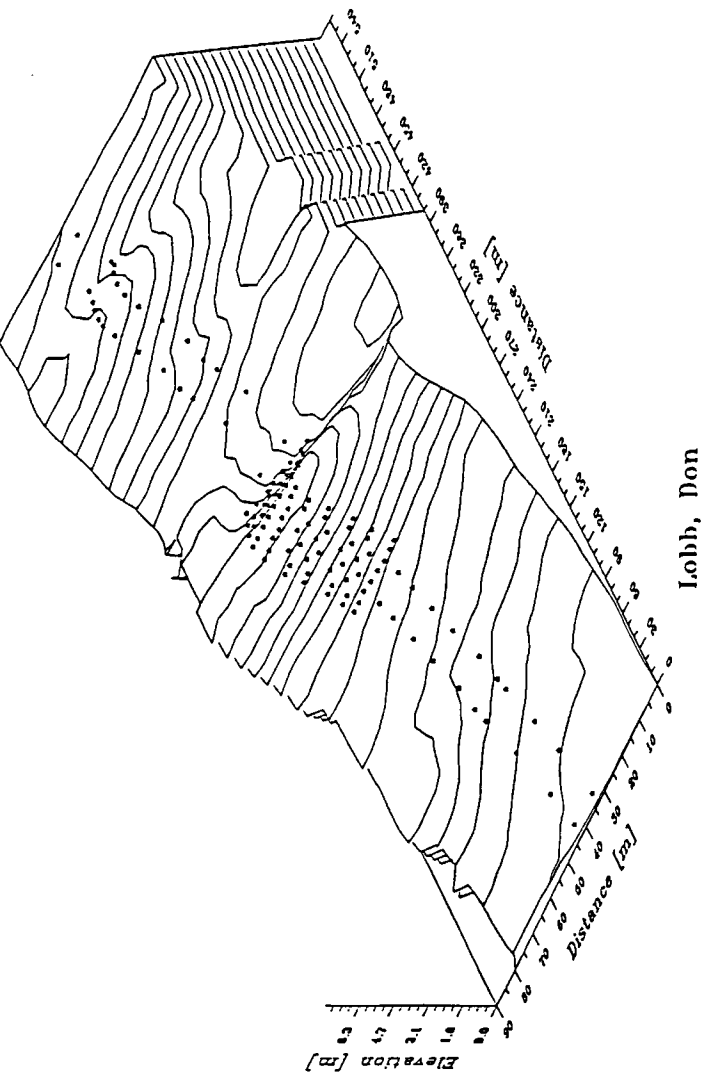
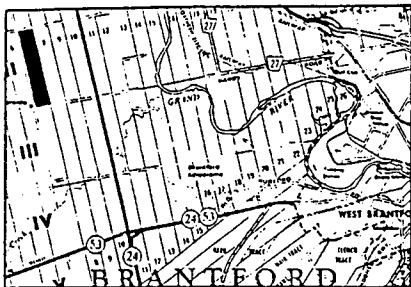
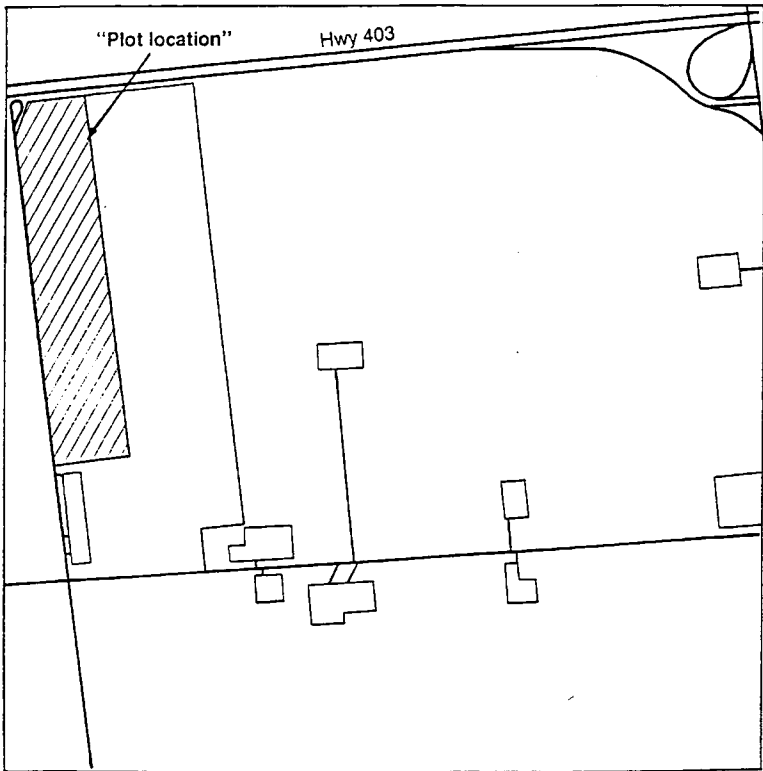


Figure IV.14: Don Lobb Tillage-2000 field site 3D relief map.

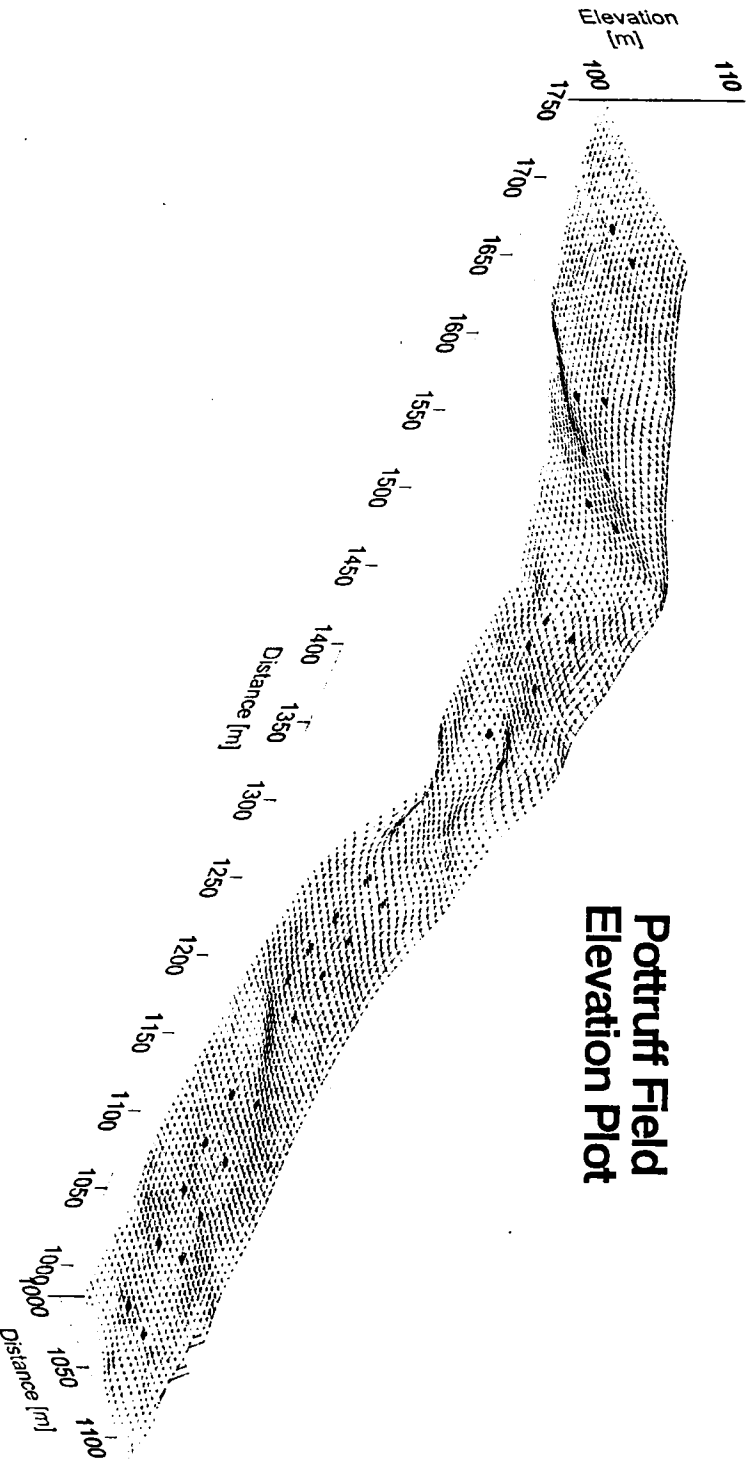
"FARM LOCATION"

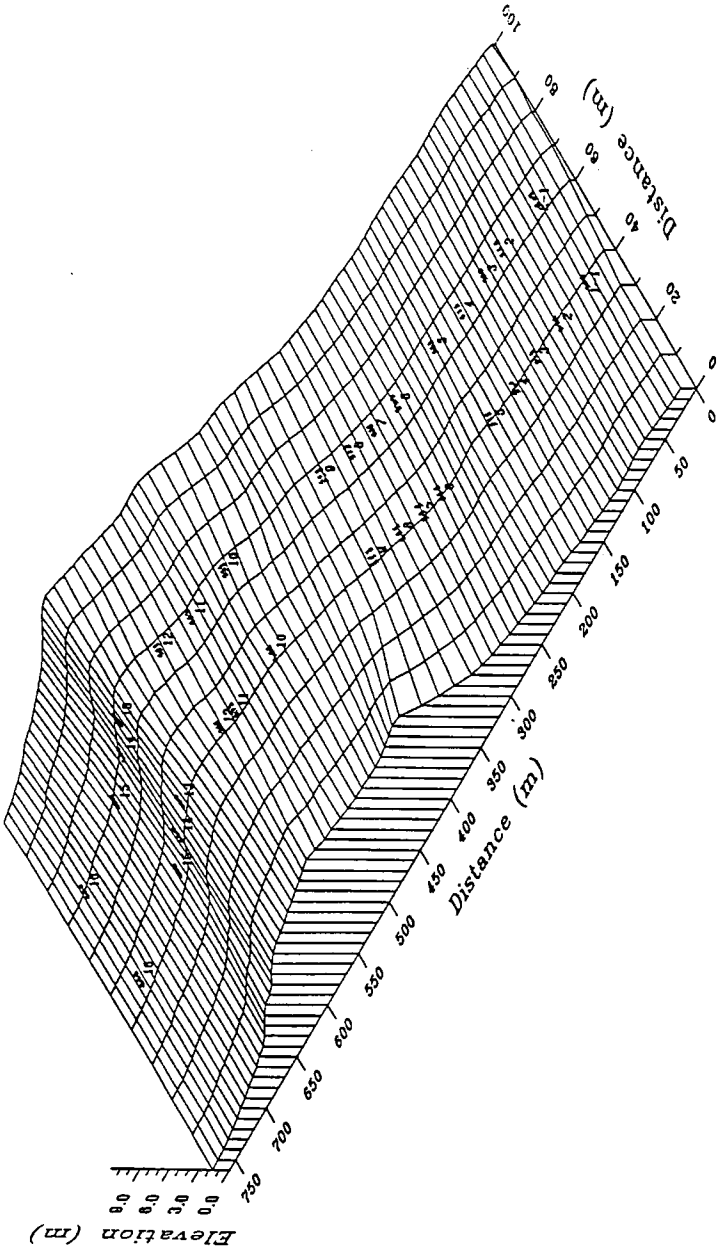


Clinton Pottruff
Brant County
Brantford Township
Lot 7, Concession II
(519) 442-6252



Potruff Field Elevation Plot





Potruff

**APPENDIX 2. EXAMPLE OF DATABASE FOR MEASUREMENTS ON THE T2000
BENCHMARKS FOR PART 1. METHOD DEVELOPMENT.**

NOTE: The full database has been submitted in electronic format with this report

T2000 Database

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
CODE NAME		BM	Farm	TILLAGE Type	Group	P	Erosion Class	Carbon Co ml/g	Mineraliz Kc 1/d	Co mg/Kg	Nitrogen No mg/Kg	Miner Kn 1/d	N Fert Kg/M^2	Ap Mass g/cm-2	Soil g/g	Light Fraction C g/gLF	N g/gLF
A01 102	AI	102	Anthony SSS	SSS	MIN	12	C				95.7	0.159	239	25	0.004	0.223	0.008
A01 104	AI	104	Anthony SSS	SSS	MIN	12	B				80.6	0.134	314	39	0.005	0.281	0.006

19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
Light Fraction C in Soil g/Kg	N in Soil g/Kg	LF C/N	Light Fraction C Mass Kg/M^2	N Mass Kg/M^2	Soil C %	Soil N %	Soil C/N	Macro Sand fraction	Macro C %	Macro N %	Macro C/N	Macro C g/g	Macro N g/g	A Horiz C mass Kg/M^2	A Horiz N mass Kg/M^2	A Horiz Macro C Kg/MA 2	A Horiz Macro N Kg/M^2
0.853	0.031	27.681	0.213	0.008													
1.353	0.031	43.643	0.528	0.012													

37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56
SLOPE	PCV	CCV	alltop	Position	Lower Solum	Gravel		Sand	Silt	Clay	TXT	pH	CaC03	OM	BID	SOIL TEST P	K	Mg	pH
1.13	0.05	0.07	dsh	L	26.0	56.0	7.2	48.2	38.3	13.2	L	6.5	0.0	3.3	1.3	29	90	191	6.9
2.00	0.10	-0.75	csh	M	16.5	63.5	5.8	53.0	37.0	10.0	FSL	6.4	0.0	2.7	1.3	19	83	160	6.1

57	58	59	60	61	62	63	64	65	66	67	68
Water Availability DRAIN	AFP1	AW	1987	137Cesium 1990	87-90	1986	1987	Relative Yield 1988	1989	1990	Average
W	15.73	22.77	1353	1351	-2		0.20	-0.10	-0.44	-0.01	-0.09
W	15.79	21.22	1513	1178	-335		-0.15	0.02	0.44	0.06	0.09

APPENDIX 3. EXAMPLE OF THE DATA COLLECTED AT THE 3 CATENA SEQUENCES IN PART 2. OF THE STUDY.

NOTE: The full database has been submitted in electronic format with this report

Date	Site	Bench mark	1	2	3	4	5	6	7	8	9	10	11	12	
			Thick A horiz cm	A horiz density g/cm^3	A horiz. Mass g/cm^2	A horiz. Total C%	A horiz. Organic C%	A horiz Total N%	A horiz. Organic C Mass KgC/M^2	A horiz LOI %	A Horiz sand %	A horiz. macro LOI %	A horiz macro C Mass KgC/M^2		
May/94	POTTRUF	1	23.33	1.39	32.15	0.99	0.989	0.054	3.179	4.073	7.61	27.40	2.018	1.03	
		9	18.33	1.32	24.70	1.06	1.024	0.055	2.529	3.785	5.44	41.85	1.322	0.79	
		12	23.07	1.46	33.09	1.61	0.914	0.034	3.024	3.200	6.16	49.48	1.062	1.01	
	LOBB	9	21.33	1.37	29.20	3.23	2.404	0.202	7.020	8.418	14.29	63.01	2.440	2.61	
		11	20.20	1.52	30.60	2.22	1.060	0.073	3.243	3.762	6.69	82.34	1.313	1.92	
		14	20.27	1.53	31.22	2.34	0.980	0.064	3.059	4.022	7.30	68.44	1.020	1.27	
Date	Site	Bench mark	13	14	15	16	17	18	19	20	21	22	23	24	25
			A horiz Organic macro C%	A horiz Organic macro C mg/Kg	Organic A horiz. macro C Mass KgC/M^2	A horiz biomass C mg/Kg	A horiz biomass N mg/Kg	Thick B horiz cm	B horiz density g/cm^3	B horiz Mass g/cm^2	B horiz. Total C%	B horiz. Organic C%	B horiz. Total N%	B horiz. Organic C Mass KgC/M^2	B horiz. LOI %
May/94	POTTRUF	1	0.646	1769.88	0.569	138.89	9.43	57.73	1.49	83.13	0.63	0.481	0.015	4.00	4.418
		9	0.524	2193.04	0.542	124.04	13.38	45.40	1.50	79.94	0.65	0.346	0	2.77	2.539
		12	0.360	1781.15	0.589	101.36	11.2	30.60	1.59	48.74	0.54	0.375	0.004	1.83	2.840
	LOBB	9	1.099	6925.30	2.022	109.51	14.22	7.53	1.69	12.61	1.55	0.37	0.016	0.47	2.675
		11	0.580	4775.65	1.461	99.77	11.97	17.47	1.49	25.08	0.99	0.721	0.016	1.81	3.241
		14	0.470	3216.79	1.004	49.32	12.32	9.00	1.63	14.12	1.13	0.454	0.011	0.64	3.276
Date	Site	Bench mark	26	27	28	29	30	31	32	33	34	35	36	37	38
			LOI B horiz C Mass KgC/M^2	B horiz sand %	B horiz macro LOI %	B horiz macro C Mass	B horizo Organic macro C%	Organic macro C mg/Kg	B horiz biomass mg/Kg	B horiz biomass N mg/Kg	Solum Thick cm	Solum Mass g/cm^2	Solum C Mass KgC/M^2	Solum Macro C Mass	Solum organic C mass Kg/M^2
May/94	POTTRUF	1	21.35	43.98	0.876	1.86	0.161	708.05	94.14	6.64	81.07	115.28	28.97	2.90	
		9	11.80	57.38	0.675	1.80	0.272	1560.85	65.77	6.56	63.73	104.64	17.24	2.60	5.30
		12	8.05	47.44	0.919	1.24	0.252	1195.46	73.5	4.99	53.67	81.83	14.20	2.25	4.85
	LOBB	9	1.96	76.77	0.535	0.30	0.5	3838.68	0	2.51	28.87	41.82	16.25	2.91	7.49
		11	4.73	86.35	1.281	1.61	0.247	2132.94	21.77	3.32	37.67	55.68	11.42	3.54	5.05
		14	2.69	62.37	0.675	0.35	0.382	2382.52	21.64	4.72	29.27	45.34	9.99	1.61	3.70