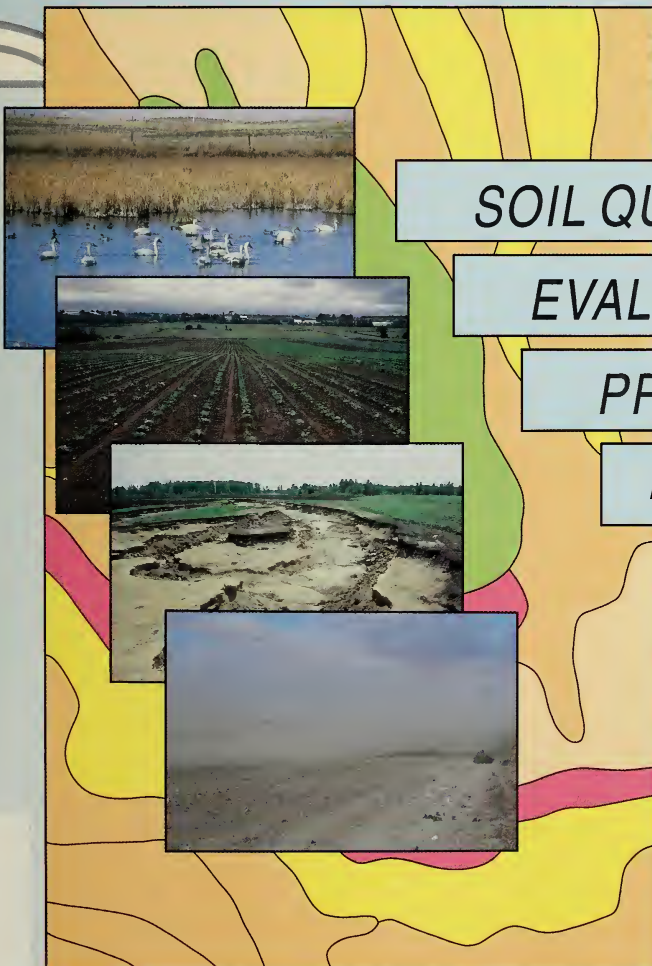
BENCHMARK SITES FOR MONITORING AGRICULTURAL SOIL QUALITY



SOIL QUALITY EVALUATION PROGRAM

Report 1

Agriculture Canada

Research Branch
Direction générale de la recherche

Canada

Benchmark sites for monitoring agricultural soil quality in Canada

Soil quality evaluation program
technical report 1

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SUMMARY

A network of 23 soil quality benchmark sites have been established across Canada. These sites will be monitored for at least ten years. Sites were selected to represent various agroecosystems. It is anticipated that monitoring selected soil variables of the landscape under typical farm production systems for ten years may be adequate to demonstrate changes in soil quality. The objectives were: i) to provide a baseline data set for assessing change in soil quality and biological productivity (yields, etc.) of representative farming systems, ii) to provide a means of testing and validating predictive models of soil degradation and productivity, iii) to evaluate agricultural sustainability of current major farming systems in Canada, and iv) to provide a network of benchmark sites at which integrated multidisciplinary research programs could be developed.

Baseline data sets of detailed characterization for each benchmark site are being achieved by the measurement of various chemical, physical, mineralogical, morphological, and topographical properties. Also included are detailed in situ climatological data gathering at eight sites. The types of information being collected are outlined below:

- Site history - as far back as we can obtain on cropping and tillage systems, on fertilizer & pesticide use.
- Soil map - approximately 1:2000 scale.
- Contour map - same scale as soil map with 0.1 to 1 m contour interval, depending on relief.
- Farm operation - kind and type of farm machinery, current cropping and tillage system.
- Pedon descriptions - two most representative pedons per site.
- Laboratory analyses - soil reaction, total C, total N, $CaCO^3$ equivalent, CEC and exchangeable cations, total elements, extractable Fe and A1 (Podzolic soils), available P and K, soil surface area, particle size distribution, clay mineralogy, and dry aggregate size distribution (Prairie sites).
- Field data - saturated and unsaturated hydraulic conductivities, penetrometer reading and soil moisture, EM38 conductivity, biopore, earthworm (except Prairies), crop yields, climatic data (eight sites have automated weather stations) and farmer's management diary.

The sites are to be resampled about every five years to monitor soil properties sensitive to change. Field data are to be collected yearly or measured in situ at regular intervals.

Baseline data sets have been completed or nearly completed for fourteen sites (sites 3, 5, 9, 10, 11, 12, 15, 16, 17, 18, 19, 20, 21 and 22). Six sites were resampled (site 20 in 1992, sites 5, 9, 16, 18 and 22 in 1993). As an example, the organic carbon at site 20 was reduced from an average of 2.02% in 1989 to 1.91% in 1992. This reduction is statistically significant.

A total of 19 research and technology-transfer papers are either published or in press. Twelve presentations were made in three countries.

INTRODUCTION

Soil degradation processes such as water and wind erosion, compaction (or destruction of structure), salinization, and acidification are natural processes which deteriorate soil quality. These processes are in many cases enhanced by routine agricultural practices such as intensive tillage, application of chemicals, summerfallowing, and harvesting operations. Water and wind erosion and salinization are the most significant degradation processes in the Prairie region; water erosion, compaction and acidification are the most important processes for the other agricultural regions of Canada (Coote et al. 1981). A report by the Standing Senate Committee on Agriculture, Fisheries and Forestry (Sparrow 1984) examined the issue of "soil degradation". According to the Senate report this issue cost Canadian farmers more then one billion dollars in income in 1984 alone. On the other hand, crop rotations (Campbell et al. 1992) and conservation tillage (Campbell et al. 1989) may reduce or even reverse soil quality decline.

Questions about trends in soil quality change under current cultivation systems arose in the late 80's, in response to the 1984 Senate report and the subsequent sustainable agriculture issue (Bentley and Leskiw 1984, Poincelot 1986, Brundtland 1987). Baseline data sets, with which to evaluate soil quality change, however, were either generally not available or incomplete, or the quality of the data sets were questionable.

In January 1988 a two-day workshop on soil quality monitoring (Wang 1988) was conducted in Ottawa. It was attended by 17 agrologists from all regions of Canada. All participants agreed that a soil quality monitoring system was needed if we were to address the issue of sustainable agriculture. Most of the participants believed that establishing benchmark sites would be an effective way for monitoring soil quality and to collect baseline data sets. Many other monitoring related issues were also discussed in the workshop. The discussion on other issues such as: which soil properties to monitor, how many monitoring sites, site selection criteria, etc., are presented in other sections of this report. There was no established benchmark system for monitoring soil quality change available anywhere in the world in 1988, prior to the soil quality monitoring workshop. In 1989, a document on a proposed soil quality monitoring network for France (Lavallee 1988) suggested 100 sites of one ha each. Since most of our agricultural land is undulating to gently rolling or hummocky and landscape position is important to soil quality evaluation, it was felt that a benchmark site had to be larger than one ha. The United States is monitoring some 250,000 sites but no chemical or physical properties are being measured. Only soil type, slope, and land use were noted; the USLE was applied to estimate current rate of soil erosion.

To maximize the limited available resources in 1989, five pilot benchmark sites plus two satellite sites were sampled in eastern Canada. Starting in 1990, three years of funding from the National Soil Conservation Program (Acton 1989) became available for the Benchmark study. By 1993, an additional 16 benchmark sites were selected and sampled. The collection of baseline data sets for all benchmark sites are to be completed in 1995. Soil quality monitoring activities are to be continued for at least ten years after establishing a baseline data set for the sites, or until trends in soil quality change are demonstrated.

The purposes of this report are to document the concepts and processes used in establishing a benchmark network for soil quality monitoring and to report on the progress of this study.

HYPOTHESIS, OBJECTIVES AND SITE SELECTION CRITERIA

Hypothesis

Monitoring selected soil variables of a soil landscape under a typical production system for ten years can demonstrate changes in soil conditions.

To test this hypothesis one needs to : establish a baseline data set; monitor all positions of a soil landscape; select a typical production system, i.e. representative soil, landscape, climate and crop management; and monitor for at least ten years after establishing the baseline data set. This hypothesis sets the stage for Objectives and Site Selection Criteria.

Objectives

1. **Provide a baseline data set for assessing change in soil quality and productivity (yields, etc.) of representative farm production systems.**

   A baseline data set is needed to test the hypothesis. For agricultural land, soil quality is closely tied to crop yields and crop quality. A representative production system provides broader applications to research findings.

2. **Provide a means of testing and validating predictive models of soil degradation and productivity.**

   Production of a reliable predictive model is expensive. A soil erosion model such as WEPP (Water Erosion Prediction Project) took hundreds of professional person years to develop. Even the best model may not be suitable for use in some regions without testing. A few years of data collection from benchmark sites may provide a means of evaluating many models for their suitability as predictive tools.

3. **Provide a means of evaluating agricultural sustainability of current production systems in major agricultural regions of Canada.**

   The sustainable agriculture issue is part of the larger picture "towards sustainable development" proposed by the World Commission on Environment and Development (Brundtland 1987). Sustainable development will remain as an important issue in agriculture and the environment for many years to come.

4. **Provide a network of benchmark sites at which integrated multi-disciplinary research programs can be developed.**

   By mid-1995 every benchmark site will have "site documentation" (example for site 05-AB in Appendix I) in which, the site is described and available data sets are listed. Typically site documents contain farming history, soil map and soil descriptions, topographic map, soil sampling methods, analytical methods, available soil chemical, physical and mineralogical data, yields, climatic data, and a list of monitoring properties. These should provide a good background to attract integrated multi-disciplinary research into developing a better understanding of the processes of soil degradation, as one example.

Site Selection Criteria

Seven criteria were developed by consultation with soil scientists and agrologists from across Canada to guide the selection of benchmark sites. The main goal was to represent the dominant landscape within major agro-ecological regions. Each benchmark site should:

1. **represent a major soil zone and/or agro-ecological region;**

2. **represent a typical physiographic region (landscape) and/or broad textural grouping of soils;**

3. **represent a major (or potentially major) farm production system within a region;**

4. **complement provincial priorities and opportunities;**

5. **provide some potential to be impacted by a degradation process(es);**

6. **cover about 5 to 10 ha in size, or a small watershed in some cases; and**

7. **be limited to cultivated agricultural land.**

Top priority was given to the first three criteria. Of the many different agro-ecological areas and farm production systems that occur in Canada, it would be feasible to monitor only a few. Careful selection of a site within a major agro-ecological area, on a dominant soil landscape, and managed under a typical production system would fulfil two aspects of the vision: 1) to represent the largest possible area, and 2) to permit extrapolation of monitoring results and assessments to similar landscapes and production systems over a broader area.

It was anticipated that monitoring activities at benchmark sites should in some way augment, compliment or contribute to provincial research and demonstration needs. Selection of sites that would provide mutual benefit, or lead to collaboration in research and monitoring activities, was considered highly desirable (criterion 4). On the other hand, several agricultural research facilities, e.g. Agriculture Canada research stations, have long-term soil, climate and yield data that adequately represent their agro-ecological areas. Accordingly, in these regions benchmark sites were selected to form a monitoring network that would expand existing efforts, not duplicate them.

The site should provide some potential to be impacted by a degradation process or processes (criterion 5); that is, to have the possibility of change in one or more soil characteristics due to management. While most change is thought of as negative, e.g. loss of organic matter and nutrients due to erosion, there may be situations in which change is positive, e.g. an increase in soil organic matter content. Areas with problem soils might have been selected for their obvious response to degradation but were generally avoided, usually because they were not representative of a region. Information about problem soils tends to be plentiful; much less is known about soil quality change on "medium to good quality" farmlands that dominate many agricultural regions. Accordingly, representative agricultural land with reasonably good quality was usually selected.

Five to 10 ha, or a small watershed in some cases (criterion 6), was considered an appropriate size for benchmark monitoring for 3 reasons:

- all segments of the targeted landscape could be sufficiently represented, especially for replication of sampling positions;
- sufficiently large so as not to interfere with most farm management systems; and
- sufficiently small to be suitably characterized in detail by the benchmark site manager.

Each benchmark site should be restricted to cultivated agricultural land (criterion 7). Since there were only enough resources to establish a few sites, cultivated landscapes were emphasized. While rangelands were recognized as important in Alberta, Saskatchewan and B.C., insufficient resources and expertise excluded such landscapes from the benchmark site study. If the benchmark site study proves highly successful, its methodology may be extended to rangelands.

Final site selection occurred in the field. Factors that affected the final decision included representativeness of the soils and topography, type of farming system in use, cooperativeness of the farm operator, and, in some cases, proximity to a climate station.

According to the site selection criteria, 25 sites were recommended and a total of 23 sites were selected and sampled by 1992; 15-QU and 17-QU are satellite sites of 16-QU and 18-QU, respectively. The geographic distribution of the 23 benchmark sites is illustrated in Figure 1. General information for these sites is summarized in Table 1.

Fig. 1. General location of benchmark site across Canada.

Table 1. Site information

Site No.	Site Name	Location*	Size (Ha)	Year Established	Ecological Setting
01-BC	Chilliwack	SE28-26-N.W.D.	5.0	1991	South Coastal Pacific
03-AB	Falher	SW1-78-22-W5	7.5	1991	Parkland - Boreal Transition
04-AB	Mundare	NE9-53-16-W4	16.3	1992	Northern Parkland
05-AB	Provost	SE7-40-1-W4	8.8	1990	Prairie - Parkland Transition
06-AB	Bow Island	SE4-9-11-W4	7.5	1991	Southern Prairie
07-SK	Swift Current	NE16-15-13-W3	4.8	1992	Southern Prairie
08-SK	Regina	SW3-16-19-W2	7.5	1991	Mixed grass Prairie
09-SK	Termuende Farm	SE35-33-21-W2	7.3	1990	Prairie - Parkland Transition
10-SK	Loon Lake	SW32-58-21-W3	7.5	1991	Southern Boreal
11-MB	Brunkild	SE19-6-1-W1	5.1	1991	Eastern Parkland
12-MB	Carman	NC10-6-5-W1	5.1	1990	Eastern Parkland
13-ON	Ingersoll	43° 00′ N 80° 48′ W	4.0	1990	Southern Temperate
14-ON	Rockwood	43° 38′ N 80° 11′ W	1.5	1991	Mid Temperate
15-QU	St-Elzear	46° 25′ N 71° 07′ W	5.2	1989	Northern Temperate
16-QU	St-Elzear	46° 25′ N 71° 07′ W	5.2	1989	Northern Temperate
17-QU	St-Marc	45° 38′ N 73° 13′ W	5.1	1989	Mid Temperate
18-QU	St-Antoine	43° 39′ N 73° 10′ W	4.3	1989	Mid Temperate
19-NS	Stewiacke East	45° 10′ N 63° 18′ W	4.8	1989	Atlantic Temperate
20-NB	Drummond	47° 00′ N 67° 41′ W	4.3	1989	Mid Temperate
21-PE	Albany	46° 17′ N 63° 37′ W	7.5	1989	Atlantic Temperate
22-NB	Salmonhurst Corner	46° 59′ N 67° 40′ W	8.3	1990	Mid Temperate
24-ON	C.E.F.	45° 22′ N 75° 44′ W	2.5	1991	Mid Temperate
25-NF	St. John's Res. St.	47° 31′ N 52° 47′ W	5.0	1992	Atlantic Boreal

* Legal location or latitude and longitude

Table 1. Site information (continued)

Site No.	Physiography	Parent Material and Surface Form	Great Group	Series	Problem	Cropping System	Tillage System
01	Fraser Valley Lowland, eastern	Medium-textured fluvial. Level	Humic Gleysol	Pelly	Water quality, compaction	Silage corn	Tiled drainage, conventional tillage
03	Peace River Lowland, Falher Plain	Fine-textured glaciolacustrine. Level	Dark Gray	Falher	Structure, O.M.*, degradation, acidity	Cereals - canola - forage	Conventional tillage
04	Eastern Alberta Plains, Whitford Plain	Medium-textured fluvial over till. Undulating to ridged.	Black	Hobbema	Water and winter erosion, O.M.* loss, salinity	Cereals - forage	Conventional vs no-till
05	Eastern Alberta Plains, Provost Upland	Medium-textured fluvial over till. Hummocky to undulating	Dark Brown	Hughenden & Provost	Wind and mechanical erosion, O.M.* degradation	Canola - wheat - fallow	Conventional tillage
06	Eastern Alberta Plains, Etzikom Plain	Medium-textured lacustrine over till. Undulating	Brown	Cranford & Helmsdale	Salinity, wind erosion, O.M.* loss, structure	What (seed) - beans - sugar beets	Irrigated, conventional tillage
07	Alberta Plains, Cypress Hills Upland	Medium-textured loess over till. Undulating, dissected	Brown	Swinton+	Wind erosion, water erosion	Wheat - fallow	Conventional tillage
08	Saskatchewan Plains Assiniboine River Plain	Fine-textured lacustrine Undulating	Dark Brown	Regina+	Wind erosion	Extended rotation, mainly wheat	Conventional tillage
09	Saskatchewan Plains, Quill Lake Plain	Medium-textured till. Hummocky	Black	Oxbow+	Water and wind erosion	Extended rotation (continuous cereal)	Conventional tillage
10	Saskatchewan Plains Beaver River Plain	Medium-textured till. Undulating	Gray Luvisol	Loon River+	Water and wind erosion, structure	Barley - oilseed	Conventional tillage
11	Red River Valley	Fine-textured lacustrine. Level	Humic Gleysol	Osborne & Glenmoor	Wind erosion, O.M.* degradation, salinity	Continuous cereals	No-till
12	Red River Valley	Medium over fine-textured lacustrine. Level	Black	Rignold & Kronstal	Wind erosion, O.M.* degradation	Wheat - canola	Minimum tillage
13	Great Lakes - St. Lawrence (Huron & Erie)	Fine-textured glaciolacustrine. Level and hummocky	Gray Brown Luvisol	Huron & Perth - Brookston	Structure, water erosion	Corn - soybean - wheat	Minimum tillage
14	Great Lakes - St. Lawrence (Huron & Erie)	Medium-textured till. Rolling	Gray Brown Luvisol	Guelph & London - Parkhill	Water erosion, compaction	Corn - soybean - wheat	No-till

\+ Soil Association
* Organic Matter

Table 1. Site information (continued)

Site No.	Physiography	Parent Material and Surface Form	Great Group	Series	Problem	Cropping System	Tillage System
15	Appalachian Hills	Medium-textured till. Rolling	Dystric Brunisol	Woodbridge	Water erosion, O.M.* degradation	Silage corn - forage	Conventional tillage
16	Appalachian Hills	Medium-textured till. Rolling	Dystric Brunisol	Woodbridge	Water erosion, O.M.* degradation	Silage corn - forage	Conventional tillage
17	Montreal Lowland	Marine clay. Level	Humic Gleysol	Providence	Compaction, O.M.* degradation	Corn - forage	Conventional tillage
18	Montreal Lowland	Marine clay. Level	Humic Gleysol	Providence	Compaction, O.M.* degradation	Corn - wheat - soybean - barley	Minimum tillage
19	Appalachian Lowland	Medium-textured till. Undulating	Gray Luvisol	Queens	Compaction, water erosion	Corn - forage	Moldboard plow, Spring disked
20	Appalachian Region, Chaleur Uplands	Coarse-textured till. Rolling	Humo-Ferric Podzol	Holmesville	Water erosion, compaction	Potato - grain	Chisel plow
21	Appalachian Lowland	Coarse-textured till. Undulating to rolling	Humo-Ferric Podzol	Charlottetown	Unstable structure, compaction, water erosion	Potato - grain - forage - forage	Conventional (plowdown forage)
22	Appalachian Region, Chaleur Uplands	Coarse-textured till. Rolling. Diversions and grassed waterway	Humo-Ferric Podzol	Holmesville, Undine	Water erosion, compaction	Potato - potato - grain	Chisel plow
24	Eastern Ontario Marine Lowland	Medium-textured fluvial. Level	Humic Gleysol	North Gower	Organic matter degradation, compaction	Corn - soybean - alfalfa	Conventional and no-till
25	Avalon Peninsula	Coarse-textured till. Hummocky	Humo-Ferric Podzol	Cochrane & Pouchcove	Water erosion, compaction	5 years hay - 1 year grain	Single furrow plow

* Organic Matter

Table 1. Site information (continued)

Site	Cooperator	Address	City	Postal Code	Site Manager
01	Adrian Prinse	R.R. 1, 8325 Banford Road	Chilliwack, BC	V2P 6H3	L. Kenney
03	Paul Houde	Box 240	Girouxville, AB	T0H 1S0	B. Walker
04	Agriculture & Agri-Food Canada Experimental Station	P.O. Box 1408	Vegreville, AB	T9C 1S6	B. Walker
05	Dennis Carter	Box 115	Provost, AB	T0B 3S0	B. Walker
06	Tony Crooymans	Box 572	Bow Island, AB	T0K 0G0	B. Walker
07	Agriculture & Agri-Food Canada Experimental Station	P.O. Box 1030	Swift Current, SK	S9H 3X2	L. Kozak
08	J.R. McAllister	1-10 RR3	Regina, SK	S4P 2Z3	L. Kozak
09	University of Saskatchewan	Department of Animal and Poultry Science	Saskatoon, SK	S7N 0W0	L. Kozak
10	Walter Kisling	Box 245	Loon Lake, SK	S0M 1L0	L. Kozak
11	Leonard Rance	Box 129	Saerling, MB	R0G 2M0	W. Michalyna
12	Tim Koster	Box 37	Carman, MB	R0G 0J0	W. Michalyna
13	Charles Shelton	R.R. 5	Ingersoll, ON	N5C 3J8	D. King
14	Arthur J. Davis	R.R. 4	Rockwood, ON	N0B 2K0	D. King
15	Ferme B. Lehoux et Fils I	160, Bas-St-Olivier	St-Elzear, QC	G0S 2J0	M. Nolin
16	Ferme B. Lehoux et Fils I	160, Bas-St-Olivier	St-Elzear, QC	G0S 2J0	M. Nolin
17	Ferme Belvallee Enr.	103, Rang des Trente	St-Marc, QC	J0L 2E0	M. Nolin
18	C. & P.-A. Girouard	1652, Durivage	St-Antoine, QC	J0L 1R0	M. Nolin
19	Eli Habers (J. Visser)	Winding River Farms, R.R.2	Stewiake, NS	B0N 2J0	K. Webb
20	Hermel Ouellette	R.R. 2, Desjardin Road, Drummond	Frand Falls, NB	E0J 1M0	H. Rees
21	Ingleside Farms Inc.		Albany, PE	C0B 1A0	D. Holmstrom
22	Leopold Desjardin	R.R. 2, Desjardin Road, Drummond	Grand Falls, NB	E0J 1M0	H. Rees
24	Agriculture and Agri-Food Canada, Central Experimental Farm	CLBRR, K.W. Neatby Building	Ottawa, ON	K1A 0C6	C. Wang
25	Agriculture and Agri-Food Canada, Research Station	P.O. Box 7098	St. John's, NF	A1E 3Y3	E. Woodrow

ESTABLISHING BASELINE DATA SETS

Farm History

The Farm History Database, (Appendix II) was designed to obtain information from an interview with the farmer. The Farm History Database has 3 parts: 1) Site identification: includes site ID number; site name; legal location; Agro-ecoregion; site manager's name; farmer's name, address and phone number. 2) Site history: includes land acquisition; first cultivation; early year's land management; major changes in agronomic practices; crop rotation; tillage system; crop yields and quality; commercial fertilizers; organic fertilizers and soil conditioners; chemical pesticides/herbicides; and degradation problems. 3) Current cropping and tillage practices: includes crop rotation system; tillage, crop management and harvesting procedures; farm machinery inventory; and special notes. Appendix II gives an example of the Farm History Database of the Benchmark site in Newfoundland.

Soil and Contour Maps

A. Soil map

Soil maps at a scale of 1:2000 or larger usually using single series map units with surface texture phases were compiled from at least 40 ground inspection points.

B. Topographic contour map

Topographic data is a key element in the characterization of benchmark sites. The data can be used to display landscape features, and provides the basis for overlaying other soil and terrain characteristics. Locations of sampling points and other features can be pinpointed for future repositioning. A detailed contour map with 0.2 to 0.5 m intervals, depending on local relief, was created for each site.

Collection of X (easting), Y (northing) and Z (elevation) coordinate data in meters is the most desirable. Where the terrain is relatively level, elevation data alone will suffice if the grid points have been accurately chained. Relative (within site) accuracy should be high (eg. sub-meter); absolute ("real-world") accuracy can vary. Regardless of which system is used, 2 permanent topographic benchmarks should be installed at each site for future reference.

Soil Sampling and Preparation

A. Sampling representative pedons of a benchmark site.

The procedures for taking undisturbed cores and loose soil samples from representative pedons were as follows:

1. Two pedons were selected that represented the typical soils of the benchmark site.

2. Pits were opened at the selected locations, by hand or more commonly by backhoe, (about 1 m wide by 2 m long by 1.5 m deep).
3. All main soil horizons were identified on one exposed face of the freshly dug pedon and the profile described, according to Day (1982).
4. Cores (7.5 cm diameter by 7.5 cm length) were collected from each horizon by a hand-operated Uhland sampler as per procedure 2.211 (McKeague 1978). In general, 5 cores were taken from Ap horizons, other horizons were sampled in triplicate.
5. About 1 kg of representative loose soil was collected from each horizon.

B. Taking loose samples for establishing baseline data of a benchmark site.

Since most changes in soil properties will occur in the surface layer, it was decided that sampling be concentrated on the Ap horizon with occasional samples taken from B and C horizons. About 60 to 100 sampling points were selected to cover a benchmark site, using one of the following two sampling methods:

1. Grid sampling - generally a 25 x 25 m grid was used to cover an entire benchmark site, typically about 100 grid sampling points; the grid sampling method was used on benchmark sites that have no significant surface relief or on sites of gently rolling or undulating topography.

2. Transect sampling - i.e. a stratified random sampling method as described by Wang (1982); landforms were typically used for stratification. The transect method of sampling was used on benchmark sites that had significant surface relief such as hummocky landscape; due to stratification, fewer sampling points were needed for the transect method than the grid method, typically 5 to 6 transects or about 60 sampling points were selected at each benchmark site.

    - A representative loose sample of Ap horizon was taken at every sampling point. Additional loose samples were collected at 50-60 cm (usually B or C horizon) on every 4th sampling point; at a few sites, a C horizon sample at about 1 m was also collected. At each sampling point depth of sampling, soil color, structure, field texture, consistence and landscape position were recorded.
    - The sampling design for each benchmark site is detailed in Appendix III.

C. Taking loose samples for ^{137}Cs analysis

For selected benchmark sites where surface soil redistribution or water erosion are part of monitoring, loose samples were collected for ^{137}Cs analysis.

The sampling method was the same as for collecting loose samples for baseline data (B. above) except that only the Ap (or Ah) was sampled at every sampling point. Bulk density samples, collected in 7.5 x 5.0 cm Kubiena boxes or 5 cm x 5 cm cores, were taken from the middle of the A horizon at every sampling point. The depth of the A horizon was recorded.

D. Sample handling, preparation, and archiving

1) Core samples were stored at 4°C in a cold room until processing.

2) Loose samples were air-dried and ground to separate the fine earth fraction (<2 mm) from coarse fragments as per procedure 1.2 (McKeague 1978).

3) The fine earth fraction of the loose sample was split into two equal parts, one part was used for detailed laboratory characterization, the other part was stored in a paper container lined with plastic and was archived for future use.

Laboratory Characterization

Soil chemical, physical and mineralogical properties deemed to be important in the 1988 soil quality workshop are being analyzed in laboratories to establish the baseline data sets for all benchmark sites. Soil properties (mostly of Ap horizons) were classified into one of the following three categories: 1) sensitive properties, with significant changes likely to occur in less than 10 years, including soil reaction (pH), available P and K, organic C, total N, ^{137}Cs distribution, extractable Fe and Al and bulk density; 2) moderately sensitive properties, with changes likely to occur in decades, including exchangeable cations, CEC, carbonates, and soil moisture retention; and 3) non-sensitive properties, with no significant changes expected in 100 years, including particle size distribution, clay mineralogy, total surface area and total elements (Al, Ca, Co, Cr, Cu, Fe, K, Li, Mg, Na, Ni, Pb and Zn). The non-sensitive properties, although not expected to change significantly in the life of this monitoring study, are important properties in assessing the overall soil quality of each benchmark site.

Soil moisture retention and bulk density were completed for all core samples taken from the representative pedons of each benchmark site. Additional bulk density determinations were also made for samples in Kubiena boxes. ^{137}Cs is being measured for all samples taken for ^{137}Cs studies. Extractable Fe and Al were determined for all loose samples from Quebec and Atlantic provinces. The rest of the sensitive and moderately sensitive properties, have either been completed or are being determined in laboratories for all loose samples from all benchmark sites. The non-sensitive properties are being determined for approximately 15% of all loose samples selected from each of the benchmark sites.

Laboratory methods used are listed in Appendix IV.

In Situ Field Data

Data sets for a few selected soil physical and biological properties were collected in situ for most of the benchmark sites. These properties include saturated hydraulic conductivity, near-saturated hydraulic conductivity, penetrometer readings with soil moisture data, and electromagnetic ground conductivity. The two kinds of hydraulic conductivity will provide information on soil water movement within the rooting zone under both saturated and un-saturated conditions. For long-term monitoring, hydraulic conductivities will also provide information on the kind and direction of change to soil structure. Penetrometer readings can provide information on soil strength which is a major factor influencing plant root growth, which in turn will determine, to a large degree, soil moisture availability to plants. Biological data sets include biopore counts, earthworm counts and crop yields. Biopores include root channels and earthworm holes. Biopores are important to saturated hydraulic conductivity and aeration of soil. Earthworms in general, are closely related to soil structure. A high earthworm population provides more desirable soil structure, as well as readily available organic nutrients. Crop yield is the bottom line of soil quality. The yield data includes both quantity and quality of the crop.

In 8 of the 23 benchmark sites (03-AB, 05-AB, 08-SK, 09-SK, 14-ON, 20-NB, 21-PE and 22-NB) automated weather stations were installed.

The field methods used are described in Appendix V.

MONITORING FREQUENCY AND RESAMPLING

Monitoring frequency is determined by anticipated rates of change of the concerned soil properties. For the properties to be characterized in the laboratory, resampling will be required.

In principle, the same number of sampling points and sampling coordinates that were used for the collection of the baseline data are recommended for resampling. This resampling design will fix the level of all variables at one point in space and time so that change over time may be accurately measured. The same principle also applies to monitoring in situ properties.

The properties to be analyzed in the laboratory were classified into three categories according to sensitivity to change, as discussed earlier. They are: sensitive, moderately sensitive and non-sensitive. Soil properties in the sensitive category are pH, total organic C, total N, available P and K, extractable Fe and Al (Podzolic soils only), bulk density and dry aggregate size distribution (Prairies only). It is recommended that the monitoring frequency for the properties in the sensitive category be about every five years. The exact frequency for resampling will be dictated by the crop rotation system at each site. Resampling should be under the same crop and time of the year as was present during the year of baseline sampling. Soil properties in the moderately sensitive category (i.e. carbonate equivalent, exchangeable cations and CEC) are to be monitored about every ten years. For the non-sensitive category (i.e. particle size distribution, soil surface area, total elements and clay mineralogy) no monitoring is recommended. In some special cases, heavy application of N and K fertilizer may alter some silicates such as expandable clay minerals in just a few years. Special studies may be needed in such cases.

For data collected in situ such as hydraulic conductivities, penetrometer readings and soil moisture, biopore, earthworm and EM38 conductivity measurements should be taken yearly for at least 5 years or should complete at least one crop rotation cycle, whichever is longer. After completing the initial 5 years of yearly data collection, these in situ measurements may be monitored every 5 years. Other information such as crop yields and farmer's management diaries are to be collected annually. Climatic data is on going, with hourly and daily measurements recorded automatically.

Monitoring frequency of selected properties is summarized in Table 2.

Table 2. Recommended Monitoring Frequency for selected properties

Selected Property	Recommended Monitoring Frequency
Soil reaction (pH)	5 years
Total organic carbon and total nitrogen	5 years
Bulk density	5 years
$CaCO_3$ equivalent	10 years
Cation exchange capacity and exchangeable cations	10 years
Total elements (i.e. Al, Ca, Cd, Co, Cr, Cu, Fe, K, Li, Mg, Mn, Ni, Pb and Zn)	None
Extractable Fe and Al (by oxalate, dithionite-citrate and by pyrophosphate) for Podzolic soils only	5 years
Available P and K	5 years
Soil surface area	None
Particle-size distribution	None
Clay mineralogy	None*
Dry aggregate size distribution (Western sites)	5 years
Saturated hydraulic conductivity (in situ)	Yearly
Near-saturated hydraulic conductivity (in situ)	Yearly
Penetrometer reading and soil moisture (in situ)	Yearly
EM38 conductivity measurements (in situ) (only for area with potential salinity problem)	Yearly
Biopore and root counts (in situ)	Yearly
Earthworm counts (in situ) (except Prairies)	Yearly
Crop yields	Yearly
Climatic data (in situ)	Daily
Farmer's management diary	Yearly

* Some silicates such as expendable clay minerals may be affected by intensive agriculture (heavy applications of NH_4 & K fertilizer) within a few years.

PROGRESS

Baseline Data Sets

Baseline data sets are either completed or very nearly completed for 14 sites. They are 03-AB, 05-AB, 09-SK, 10-SK, 11-MN, 12-MN, 15-QU, 16-QU, 17-QU, 18-QU, 19-NS, 20-NB and 22-NB. The other 9 sites are in various stages of completion. It is expected that by mid-1995 the baseline data sets will be completed for the entire network of 23 sites. A relational database was designed for the Benchmark site study and details of this database are provided as an appendix in the site documentation (Appendix I).

Site documentations excluding the detailed site history file (see Appendix 2), field and laboratory data sets are available for 14 sites. An example of site documentation for site 05-AB is provided in Appendix I. By mid-1995, site documentation will be available for all sites.

Resampling for Monitoring Dynamic Soil Properties

By the end of 1993, six sites had been resampled. Site 20-NB was resampled in 1992, sites 05-AB, 09-SK, 16-QU, 18-QU and 22-NB in 1993. Dynamic soil properties such as pH and total carbon were analyzed for the 1992 samples of site 20-NB.

The mean pH ($CaCl_2$) and % org. C values of the 1989 baseline data were 5.01 and 2.02, respectively, for site 20-NB, while the mean pH ($CaCl_2$) and % org. C values of the 1992 samples were 4.84 and 1.91%, respectively. The differences in means for both pH and org. C were significant at the 5% level by the Student-Newman-Keuls Test. The decrease in pH and org. C, therefore, were significant between 1989 and 1992 for site 20-NB.

The influence of landscape position on org. C content is evident for site 20-NB. Most of the losses occurred on steep slopes and shoulder positions (Fig. 2) while most of the gains occurred on level areas and depressions (Fig. 3). This preliminary finding is similar to the findings of Cao et al. (1994). ^{137}Cs was measured to study soil redistribution by erosion and tillage at site 20-NB. The estimated redistribution rates varied from a loss of 190 t ha^{-1} yr^{-1} to a gain of 43 t ha^{-1} yr^{-1} depending on landscape position for a net loss of 53 t ha^{-1} yr^{-1}. The loss of surface soil was negatively correlated to org. C and potato yield.

Publications and Presentations

A total of 19 research and technology-transfer papers are either published or in press. Twelve presentations were made in three countries. The list of publications and presentations appear in Appendix VI.

Future Deliverables

1. By mid-1995 the baseline data sets will be completed for the entire network of 23 benchmark sites.

2. Starting in 1997 the database (baseline plus monitoring) will be used to validate some predictive models for various soil degradation processes; and recommend suitable environmental degradation indicators for some major agricultural regions.

3. By the year 2000, analyses and reports of soil quality changes in major agricultural regions of Canada will be produced as part of the State of the Environment Report.

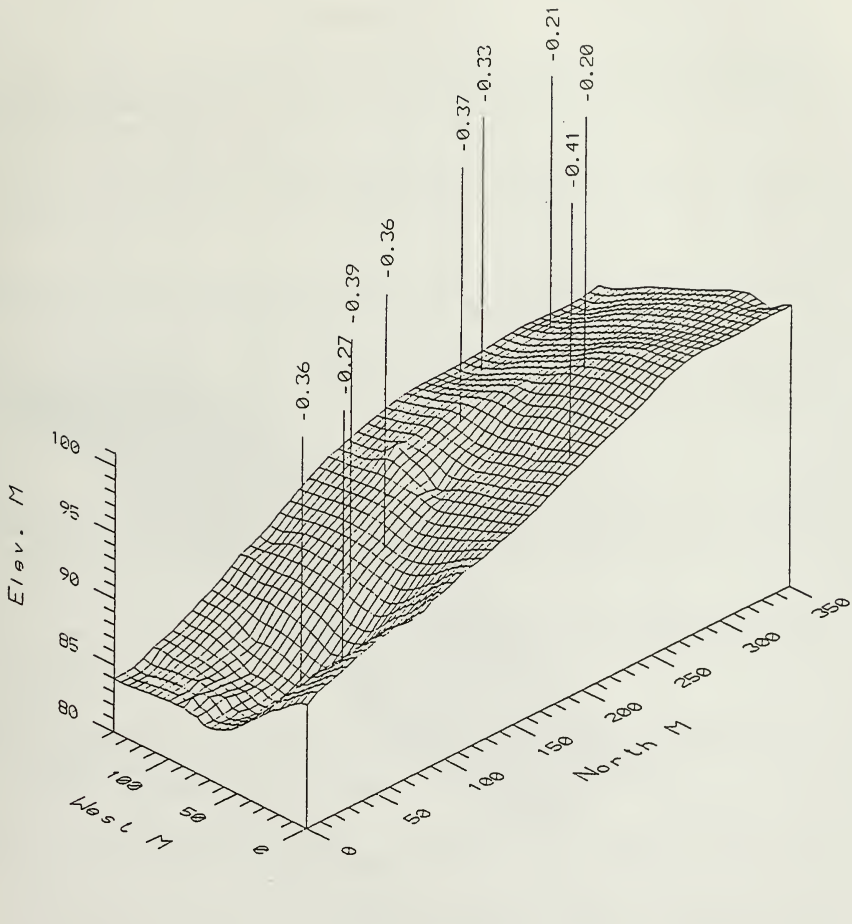

Fig. 2. Point locations showing organic C loss of 0.20% or more between 1989 and 1992 at site 20-NB.

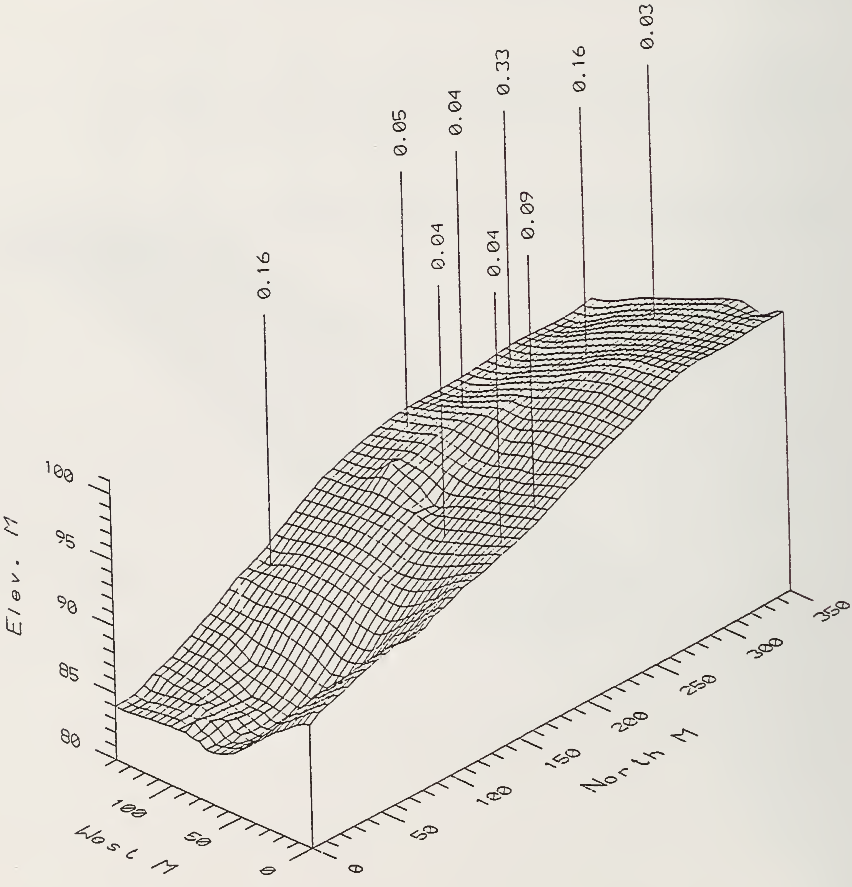

Fig. 3. Point locations showing organic C gain of 0.03% or more between 1989 and 1992 at site 20-NB.

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APPENDIX I

AN EXAMPLE OF SITE DOCUMENTATION

BENCHMARK SITE DOCUMENTATION

05-AB

SOIL QUALITY EVALUATION PROGRAM

Interim Report

B.D. Walker and C. Wang

Agriculture and Agri-Food Canada, Research Branch
Centre for Land and Biological Resources Research

Edmonton, AB and Ottawa, ON

March 1994

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SOIL QUALITY BENCHMARK SITES - THE STUDY

INTRODUCTION

Questions about trends in soil quality and means of measuring those trends, if detectable, arose in the late 80's in response to the sustainable agriculture issue (Mathur and Wang 1991). The popular opinion was that the value of agricultural soil resources has deteriorated, and may continue to be declining under conventional farming practices. The rate of decline is only speculative. Baseline data sets with which to make such evaluations aren't available for many regions. Information about problem soils tends to be plentiful; much less is known about the "medium to good quality" farmlands that dominate many agricultural regions.

In 1988, Agriculture Canada's Land Resource Research Centre (now Centre for Land and Biological Resources Research, CLBRR) started a pilot project in eastern Canada to establish benchmark sites for collecting baseline data to monitor trends in soil quality. This study was adopted nationally, in 1990, by the National Soil Conservation Program (NSCP) as part of the Soil Quality Evaluation Project (SQEP) managed by CLBRR. The study was labelled Soil Quality Benchmark Sites (SQUBS).

A network of 23 benchmark monitoring sites were established across Canada by late 1992. Various land, soil and air characteristics are to be monitored for at least 10 years. The Provost site, coded 05-AB, was established in September 1990. It represents the northern belt of Dark Brown soils that occur in the Prairie-Parkland Transition, also called Aspen Groveland. The landscape is representative of the relative rough, hummocky to undulating, morainal terrain that is commonly through east-central Alberta and west-central Saskatchewan.

OBJECTIVES

The benchmark site study was envisaged as a "case study" approach for monitoring the trends in soil quality change. Two basic assumptions underlie this approach. 1) Landscapes representative of major agro-ecosystems and managed under typical farm production systems could be characterized in detail to create baseline data sets with which to make soil quality assessments. 2) Monitoring selected soil variables within these landscapes (benchmark sites) for 10 or more years would facilitate the evaluation of trends in soil quality change. To complete the picture, it was anticipated that benchmark site information could be used to support expert systems for making general statements on soil quality trends regionally and nationally.

To implement this vision, three national objectives for establishing benchmark sites were developed. In order of priority, these were:

1. to provide a baseline data set for assessment of change in soil quality and biological productivity of representative agro-ecosystems,

2. to provide a means of testing and validating predictive models of soil degradation and productivity, and

3. to provide a network of benchmark sites at which integrated research projects can be developed.

In keeping with the national objectives, several major agro-ecosystems and agricultural landscapes were identified by a group of federal-provincial agrologists from across Canada. One such grouping - Dark Brown soils of the Prairie - Parkland Transition occurring on medium-textured till or shallow fluviolacustrine materials with undulating to hummocky terrain - was designated for east-central Alberta. Characterization of complex segmented terrain, and the prospect of monitoring organic matter loss, wind and water erosion, and perhaps salinity, were viewed as objectives for this benchmark site. Comparison with other Great Plains sites of similar terrain in the thin and thick Black soil belts was also anticipated.

SITE SELECTION CRITERIA

Criteria were developed to guide the selection of benchmark sites, the main goal being to represent the dominant landscape within major agro-ecological regions. Based on the specific objectives above, the east-central Alberta site was to:

1. represent the northern Dark Brown soil zone under the Prairie-Parkland Transition Ecoregion;

2. represent undulating to hummocky glacial terrain comprised of medium-textured till, preferably with a shallow fluviolacustrine or glaciolacustrine veneer;

3. represent a wheat - oilseed (or barley) - fallow cropping rotation managed under a conventional tillage system;

4. be about 5-10 ha in size, sufficient to adequately represent all segments of the complex landscape;

5. show potential for change in soil organic matter, and for impact by wind and/or water erosion and salinity; and

6. complement or provide information for Alberta Agriculture's on-farm conservation planning activities and rainfall simulation studies.

The research for a site, based on the guidelines above, began in September 1990, mainly in the Neutral and Provost uplands within the Municipal District of Provost (M.D. No. 52). Alberta Agriculture's local District Agriculturalist, Agnes Whiting, provided valuable guidance on the landscapes and farm operators throughout the area. The final selection was made in early October from among several potential candidates. The M.D. of Provost's Agricultural Fieldman, Bert Forbes, assisted with the final decision, and especially farm cooperator negotiations. A site about 16 km (10 mi.) NE of Provost, on land owned and managed by Dennis Carter, was selected. Several factors affected the final decision:

1. The soils, terrain and farm management system were representative of an extensive area in the targeted region.

2. All landscape segments, from hilltops to depressions, could be adequate sampled with several short transects (50-100 m) within an area of 5-10 ha.

3. The farm operator, Dennis Carter, was fully cooperative and supportive, belonged to a family with a long history and good standing in the community, and offered a stable farm operation.

4. Potential for comparing the cultivated site to similar natural terrain, located within 1 km and owned by the Carter family, was a bonus attraction.

BENCHMARK SITE 05-AB (PROVOST)

SITE LOCATION

The Provost Benchmark Site is situated in east-central Alberta, about 300 km (185 mi.) south-east of Edmonton and only 8 km (5 mi.) from the Saskatchewan border. It is located within Legal Survey Division (LSD) 8 and the SE quarter of Section 7, Township 40, Range 1, west of the 4th Meridian. The NE corner of the site occurs at approximately 52°25'35" N latitude and 110°07'35" W longitude; UTM coordinates Zone 12, Easting 559464.69 m and Northing 5808583.24 m. From Provost townsite, the site can be reached by travelling 10 km (6 mi.) east along Highway No. 13, to the village of Hayter, and about 8 km (5 mi.) north along a gravel road (Fig. 1).

SAMPLING DESIGN AND METHODOLOGY

Field Sampling Design

Terrain at the Provost site is hummocky to undulating with distinct internal relief. An area 250 m east-west by 350 m north-south, totalling 8.8 ha (21.7 ac.) in size, was selected to represent this landscape. Nine transects, labelled T1 to T9, were laid out within this area. Orientation of each transect was perpendicular to the contour, or nearly so, stretching from the top of a "hill" to the bottom of an adjacent depression. Transect length ranged from 40 m (T1) to 120 m (T8). Sampling points were chained out at 10 m intervals along each transect, starting at Tx.0 on the hilltop. The nine transects encompassed a total of 67 sampling points. Points T9.06-T9.08 were located on uncultivated land, a wetland depression and its margin. Figures 2 and 3 show transect and sampling point locations relative to topographic and soil features of the area.

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

Two pedons were selected to characterize and sample, in detail, 2 of the major soils of the area. Pedon 1 (P1, Fig. 2) represented Rego Dark Brown soils of the hilltop positions; Pedon 2 (P2, Fig. 2) represented Orthic Dark Browns of mid-slopes.

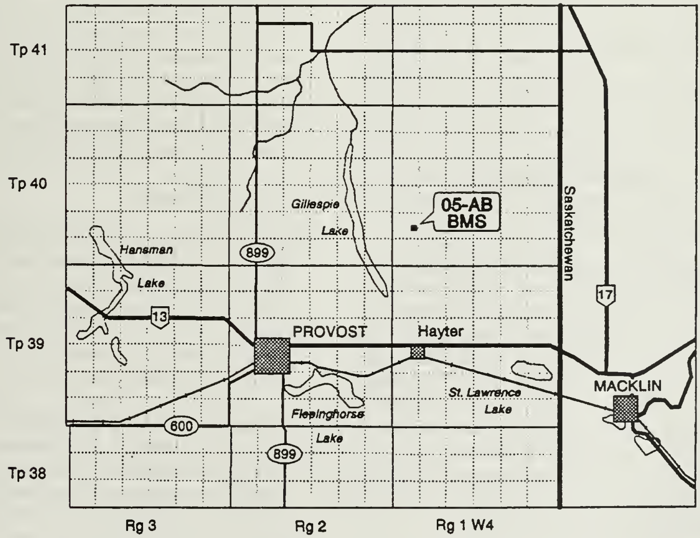

Figure 1. Location of the 05-AB (Provost) Benchmark Site in east-central Alberta.

Soil and Topographic Characterization

Topographic Data and Contour Map: A detailed contour map, with a 0.5 m interval, was created for the site (Fig. 2). Two independent data sources were related to create the X-Y-Z digital database for the contour mapping. The initial dataset was derived photogrammetrically, by contract with Stewart Weir Land Data Inc. of Edmonton. X (easting), Y (northing) and Z (elevation) co-ordinates, all in meters, were based on Universal Transverse Mercator (UTM) co-ordinates and elevation, estimated from 1:50,000 series NTS maps. The "real-world" accuracy of this estimation method was gauged at 15-30 m horizontally (X-Y) and 4-8 m vertically (Z). Follow-up field data was collected, using a total station instrument and Alberta Agriculture expertise, to correct some problem areas. In addition, the coordinates for all transect points, both pedon sampling sites, two topographic benchmarks, and the NE site corner were measured. The field survey coordiantes were initially set to arbitrary values, but later merged to the photogrammetric UTM dataset.

Detailed Soil Map: The soils of the site were mapped at a scale of about 1:2000 (Fig. 3). The complex landscape was subdivided into repeating unit areas with similar patterns of terrain and soils. These repeating landscape units are identified by mapping units based on the series (or variant) and phase levels of classification (E.C.S.S. 1987a, 1987b). Delineation and mapping unit decisions were based on sampling point inspections, additional random soil and terrain inspections, traverses of the site, aerial photo interpretation, and topographic characteristics.

Sampling Activities

Four types of sampling activities were conducted to establish the baseline field and pedological characteristics of the Provost Benchmark Site. The first three activities were conducted in the late fall of 1990, the fourth, for aggregates, in the spring of 1991. Sampling followed the final fall cultivation in the fallow year of a wheat-fallow rotation.

Transect Point Sampling for Baseline Data: A loose sample of the contemporary Ap, Apk or Ah horizon was taken at every sampling point. For comparison purposes, loose sample of an "older" Ap2 or Ap3 horizon was collected at 15 transect points. In addition, loose sample at approximately 50-60 cm depth (usually B or C horizon) was collected at every 4th sampling point. Horizon type and depth, color, structure, field texture, consistence, landscape position, classification, and other morphological and site information were recorded for each sampling point and sample.

Pedon Sampling: Pits about 1 m by 2 m by 1.5 m deep were opened by backhoe at the P1 and P2 locations (Fig. 2). The soil horizons of the exposed pedons were identified and described according to Day (1982). About 1 kg of loose soil was collected from each horizon. Cores (7.5 x 7.5 cm) were taken from 3 or 4 main horizons by hand operated Uhland sampler as per procedure 2.211 in McKeague (1978). Five cores were taken from each of the upper two horizons, four cores from other horizons.

Transect Point Sampling for ^{137}Cs Analysis: Surface soil redistribution, including water erosion, is part of monitoring activities at the Provost Benchmark Site. A volume loose sample (1-2 kg) of the contemporary Ap, Apk or Ah horizon was taken at every transect sampling point. For comparison purposes, a volume sample of an "older" Ap2 or Ap3 horizon was also collected at 15 transect points. A bulk density sample, collected in a 7.5 x 5.0 cm Kubiena box, was taken from the middle of each A horizon. The thickness of each A horizon was recorded.

Sampling for Dry Aggregate Size Distribution: The size distribution of dry aggregates was considered a means of quantifying surface soil structure at the Provost Benchmark Site. Representative transect points, a minimum of 2 per slope position, were selected for sampling. A volume loose sample (about 2 kg) of the soil surface to 5 cm depth was collected at each of the selected points. Timing was judged critical to provide some standardization for temporal comparisons. Thus sampling was done after spring thaw, before the first cultivation, when the soil was reasonably dry.

Field Measurements

The baseline set of *in situ* field measurements were begun prior to spring tillage in 1991. Yield and root and pore counts were first measured in late summer, 1991; yield information will be collected annually. Climatological data collection was initiated in May, 1991; climate parameters will be measured continuously for the duration of the project.

Hydraulic Conductivity (KSAT): Saturated hydraulic conductivity was measured by Guelph Permeameter at three depth ranges (5-10, 15-25 and 30-40 cm) using 5 and 10 cm heads per procedure 56.2.1 by Reynolds (1993a). Measurements were made at 23 transect points, selected in a stratified random manner with a minimum of 3 per landscape position. Results were calculated and recorded in cm/hr and placed in classes as defined by McKeague *et al.* (1986). Results from the 5-10 cm depth range (Ap) were highly variable and changed with tillage; hence measurements at this depth were discontinued at most sites.

Penetration Resistance and Soil Moisture: Resistance to penetration was measured for 3 depths (0-10, 10-20 and 20-30 cm) using the Centre-Cone Penetrometer, operated manually per the user's manual (Star Quality Samplers 1990). Reported results, in bars, are the averages of 5 readings per depth per sampling point. Measurements were made at 34 transect points, selected in a stratified random manner, with a minimum of 3 per landscape position. Small samples, one from each depth at each sampling point, were collected in moisture tins for gravimetric determination of soil moisture. Results from the 0-10 cm depth (Ap) were highly variable and changed with tillage; thus measurements at this depth were discontinued at most sites.

Electromagnetic Ground Conductivity (EM38) Measurements: Electromagnetic inductance readings can be converted to electrical conductivity values that provide an estimate of soil salinity. Measurements were made at over 50% of the transect sampling points using a Geonics EM38 Ground Conductivity Unit. Readings were made in the horizontal (0-60 cm) and vertical (0-120 cm) modes at the selected points. Results were converted to saturated paste EC equivalents (dS m^{-1}), based on estimated soil temperature and moisture conditions, and on soil texture (McKenzie *et al.* 1989).

Root and Biopore Counts: A root and pore counting procedure was tested at 5 transect sampling points. Counts were made at the bottom of the Ap/Apk (10- 15 cm), at about 25 cm, and at about 50 cm. The procedure was found to be time consuming and destructive. Large countable roots and pores were almost non-existent; tiny, nearly microscopic roots and pores were too numerous to count. There was virtually no difference between results at this cultivated site and those from a nearby natural site where the procedure was also tested. Based on these experiences, root and biopore measurements were not recommended for the prairie benchmark sites.

Crop Yield Sampling, Grains Group: The first two crops grown since site establishment - canola in 1991 and wheat in 1992 - were sampled at the time of maximum growth, just prior to harvesting by the producer. Sampling points were selected (at least 3 per slope position as circumstances permitted) by stratified random means. At the selected points, all above-ground crop material within a 1 m^2 area was clipped, using large shears, at about 1-3 cm above the soil surface. The samples were collected in large porous bags and transported to Alberta Agriculture's threshing facility near Edmonton. After air drying, the crop samples were threshed to separate grain and residue (straw). Weights of both, in kg ha^{-1}, harvest index (grain weight as % of total dry matter weight) and residue - grain ratio are reported.

Climate: A climate monitoring station, based on the Campbell Scientific CR10 measurement and control module, was installed along the fenceline about 70 m north of the site, on an east-facing, mid-slope position. Sensors for measuring air temperature, relative humidity, global solar radiation, and wind speed were attached to a galvanized-steel radio tower at about 2 m above the ground. Other measuring devices were installed to collect soil temperature at 20, 50 and 100 cm; total rainfall and 15-minute rainfall intensity; and snow depth. Measurements were initiated in mid May, 1991. A major programming change, which added some new measurements and daily summaries, was instituted in mid November, 1991. Corrections and other minor changes followed until late May, 1992, when the current program functioned smoothly. Hourly, daily and monthly output are available for selected parameters.

Analytical (Laboratory) Methods

Sample Handling and Preparation: Loose samples for chemical, physical and ^{137}Cs analyses were air-dried and roller-ground to separate the fine earth fraction (<2mm) from coarse fragments as per procedure 1.2 (McKeague, 1978). The prepared $cesium^{137}$ samples were shipped to the Univ. of Guelph's Dept. of Land Resource Sci. for analysis. Pedon and field samples prepared for detailed laboratory characterization were split into two equal parts, one part for analysis and the other for future use. Core samples from the pedons were stored at low temperatures (about 4°C) until processing. Samples for aggregate analysis were very carefully collected and transported in pizza-style cardboard boxes to minimize aggregate breakage. After air drying, the samples were shipped to the SK Land Resource Unit, Saskatoon, for rotary sieve analysis.

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

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

Organic Carbon: Calculated as the difference between total carbon and inorganic carbon determined in the $CaCO_3$ procedure.

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

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

Cation Exchange Capacity and Exchangeable Cations: Cation exchange capacity (CEC) and exchangeable cations (Ca, Mg, Na, K, and in a few cases Al) were measured by one of three methods, depending on $CaCl_2$ pH of the sample. Except as noted, extracted cations were determined by inductively-coupled, plasma spectrophotometry (ICPS); displaced ammonium by nitrogen analyzer.

- pH less than 5.5 - 2M NaCl method, as per procedure 84-004 in Sheldrick (1984). Cation replacement is by Na, hence Na cation and CEC are not determined. Exchangeable Al and permanent charge CEC (the sum of Ca, Mg, K and Al) were determined on a few samples, as per procedure 84-004 in Sheldrick (1984), including detection by atomic absorption spectrophotometry.
- pH 5.5 to 6.4 - 1M, buffered (pH 7), NH_4OAc steam distillation method (USDA Soil Conservation Service 1984).
- pH 6.5 and greater (calcareous soils) - 1M, buffered (pH 7), NH_4Cl steam distillation method (USDA Soil Conservation Service 1984).

Available P: "Plant-available" or extractable phosphorus was measured by one of two methods, depending on the predominance of calcareous versus acidic, non-calcareous soils at a site.

- Mainly neutral to alkaline and calcareous samples - sodium bicarbonate ($NaHCO_3$) extraction with P determined by using ammonium molybdate solution, as per procedure 84-017 in Sheldrick (1984).
- Mainly acid to neutral samples - Bray method (0.03M NH_4F 0.025 M HCl), extractable P determined by using ammonium molybdate solution, as per procedure 84-018 by Sheldrick (1984).

Available K: "Plant-available" or extractable potassium was measured by one of two methods, depending on calcareousness of the samples. Extracted K was determined by ICPS.

- Calcareous samples (pH 6.5 or greater) - 1M, buffered (pH 7), NH_4OAc extraction, as per procedure 84-005 in Sheldrick (1984).
- Non-calcareous samples - cold, 0.05M, H_2SO_4 extraction (Knudsen *et al.* 1982).

Total Elemental Analysis: Total amounts of selected elements (Al, Ca, Cd, Co, Cr, Cu, Fe, K, Li, Mg, Mn, Na, Ni, Pb and Zn) were determined using the perchloric acid digestion method (84-023 in Sheldrick 1984) on all pedon and 10% of field samples.

Electrical Conductivity and Soluble Salts: Subsets of the pedon and selected field samples were submitted to Alberta Agriculture's Soil and Animal Nutrition Testing Laboratory for EC and soluble salt analyses. Electrical conductivity (EC) and soluble salts (cations) were determined on saturation extracts (method 3.21 in McKeague 1978); EC by a conductivity bridge, cations by ICPS. Sodium adsorption ratios (SAR, ratio of soluble Na to Ca + Mg) were also calculated.

$Cesium^{137}$ Analysis: Samples collected for ^{137}Cs determinations were analyzed using high resolution Gamma-spectroscopy methods described by deJong *et al.* (1982).

Particle Size Distribution Analysis: The fine earth fraction of all pedon and 10% of field samples was separated into particle size groups using a pipette or filter candle system, per procedure 84-026 in Sheldrick (1984). Samples were pretreated to remove soluble salts, carbonates, and organic matter as required. Clays were collected for mineralogical analysis; sands were fractionated by sieve analysis, per procedure 47.2.3.2 in Sheldrick and Wang (1993).

Mineralogical (XRD) Analysis: Minerals present in clay fractions, collected during the particle size analysis procedure, were identified by X-ray diffraction (XRD) analysis. Mineral identification was based on a composite of diffraction data from air-dry, glycerol. and thermally treated specimens of each clay sample. Mineral content was estimated from diffraction intensities using procedures like those described by Kodama *et al.* (1977). Semi-quantitative results are presented.

Soil Moisture Retention: Undisturbed 7.5 cm diameter x 7.5 cm length cores were used for determining moisture retention at tensions equivalent to 0, 10, 30, 60 and 100 cm of water on a glass bead tension table; at $^1/_3$ and 1 bar tensions (333 and 1000 cm of water) on an aluminum oxide tension table. Moisture retention at 4 and 15 bars were determined on ground samples with pressure plate extraction as per procedure ... by Topp (1993).

Surface Area: Total surface area of all pedon samples and about 10% of field point samples were determined by the ethylene glycol monoethyl ether (EGME) method of Cihacek and Bremner (1979).

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

AGRONOMICS

Information on the agronomic history and current farming practices was obtained through an interview process using a standard questionnaire. The owner/operator, Dennis Carter, and his father, Bill Carter, who is still actively involved in the farming operation, were interviewed about the Provost site. The following is a summary of the interview data.

Farm History

The quarter section that contains the Provost Benchmark Site was purchased from a neighbor in 1984. Fortuneately, the early farming history has been passed on.

The Early Years: The land was first broken and cropped in 1912. The cropping rotation was usually cereal (wheat) - fallow (clover grown in 1935). The plow was the principal tillage tool, drawn by horses until 1940. Fertilization methods, including manuring, and weed and pest control measures were not used until 1950. Harvesting, until 1947, was mainly by stationary threshing machine, which required removal of the crop material, bound in sheaves, to a threshing site.

Major Changes: Tractor power was introduced in 1940. Deep-tillage cultivators replaced the plow as the main tillage implement in about 1950. Use of chemical fertilizers (11-48-0) and herbicides (2-4-D ester) also began *circa* 1950. Use of fertilizers high in nitrogen (eg. 34-0-0) began in 1977. Fertilizer use has decreased slightly in recent years due to soil testing. Pre-emergent herbicide usage (eg. Treflan and Avadex) began in 1980. In recent years there has been some chemical tillage. Harvesting changed in 1947 with the introduction of a combine. Most of the time since then, crop residue has been left on the field and tilled into the soil. In 1991 the crop rotation was extended to include canola.

Co-operator Assessment: The interviewees noted that yields and crop quality have increased over the 80^+ years of cultivation. They felt that yields in the immediate vicinity were usually higher than most in the area. Comments were that they farm "in a good area", that crop "quality has always been good" but has increased because of "better wheat varieties now". No degradation problems were observed.

Current Management Practices

Crop Rotation System: A canola - cereal - fallow rotation, common throughout the area, has been used since the introduction of canola in 1991. The system has some flexibility in that cereals may be grown for a second consecutive year if moisture reserves are favorable. This was also a common practice in the past. The cereal grain is usually wheat, occasionally barley. When sampled and characterized in 1990-91, the site was in fallow. The 1991 crop was canola, the 1992 crop wheat.

Equipment: Current farm equipment for tillage and seeding include one large 4-wheel drive tractor (Versatile 875), two 2-wheel drive tractors (John Deere 4440 and 4020), a deep-tillage cultivator, a hoe-type press drill, and a harrow-packer. A pull-type field sprayer is used for spraying some herbicides. Harvesting equipment includes a 25-foot pull-type swather, a self-propelled combine (John Deere 7720), and two grain trucks (3-ton and 2-ton).

Management Procedures: Table 1 presents a yearly account of "typical" farm management activities used throughout the rotation, including an optional second year of cereals. For the presentation, canola was arbitrarily chosen as the first year of the rotation. An annual diary of actual operational activities will be kept by the farm operator for the duration of the monitoring study.

Table 1. Typical tillage, crop management and harvesting procedures.

Crop Year	Main Activity	Time Frame	Operational Procedures
1. Canola:	Spring cultivation	Mid April start	Deep tillage cultivator, usually 2 passes
	Planting	Early May	Drill followed by harrow-packer
	Fertilizer application	Early May	12-51-0 (30 lbs/ac) starter with seed
	Cutting/harvesting	Mid-late August	Swathed; combined about 2 weeks later
	Fall cultivation	Late September	Deep tillage cultivator with spikes (anhydrous)
	Fall fertilization	Late September	Anhydrous-N spiked in if moisture adequate (one pass with fall cultivation)
2. Cereal: (wheat)	Spring cultivation	Mid April start	Deep tillage cultivator, usually 2 passes
	Planting	Early May	Drill followed by harrow-packer
	Fertilizer application (optional)	(Mid April)	Broadcast 34-0-0 if too dry for anhydrous-N the previous fall
		Early May	12-51-0 starter with seed
	Spraying	Early-mid June	2-4-D amine herbicide
	Cutting/harvesting	Late August	Swathed; combined about 2 weeks later
	Fall cultivation	N/A	Usually no cultivation with normal to low moisture reserves
		(Late September)	Spiked (with anhydrous-N) if moisture reserves considered good
	Fall fertilizer	N/A	Usually none with normal to low moisture
		(Late September)	Anhydrous-N spiked in if moisture is good
3. Optional Cereal:	If moisture conditions are favorable, a cereal crop (wheat or barley) is planted and harvested (see 2. above) for the second consecutive year.		
	Fall cultivation	N/A	None; stubble left standing
	Fall fertilization	N/A	None
4. Fallow:	Spring cultivation	Late May start	Deep tillage cultivator, depending on types of weeds - might be sprayed instead
	Spraying (optional)	(Late May)	Broadleaf herbicide may replace cultivation depending on types of weeds present
	Summer cultivation	Mid June & on	Cultivator; total summer & fall passes = 3 to 5
	Fall cultivation	Late September	Cultivator; last pass to incorporate pre-emergent herbicide for canola crop next year

SOIL AND LANDSCAPE DESCRIPTION

Ecology and Climate

The Provost Benchmark Site occurs in the Grassland Ecoclimatic Province (Ecoregions Working Group 1989) or Ecoprovince (Strong 1992). This broad region has a continental macroclimate with cold winters, short summers, and low precipitation. Large yearly and daily temperature ranges plus maximum precipitation in summer (June or July) attest to the continental conditions (Table 2).

Ecoclimatic provinces are further subdivided into ecoclimatic regions (Ecoregions Working Group 1989) or ecoregions (Strong 1992). Sources disagree on which ecoclimatic region fits the Provost area although descriptions of the area are comparable. It is situated in the north-central part of the Arid Grassland Ecoclimatic Region (Ecoregions Working Group 1989) in one perspective, the southern part of the Aspen Parkland Ecoregion (Strong 1992) in another. This disparity clearly demonstrates that the area, once aptly termed aspen groveland (Strong and Leggat 1981), is transitional between the drier treeless grassland to the south and aspen-dominated parkland to the north. The Dark Brown soil group is characteristic of the area (Alberta Soil Survey 1993); Black and Gleysolic soils are also common.

The vast majority of the area has been cultivated for several decades; native vegetation has been replaced with cereal and oilseed crops. Remnant natural landscape is rare; a small parcel of about 35 ha exists less than 1 km north of the benchmark site. It is typical of the groveland area as described by Strong (1992). Grassland plant communities are dominant and associated with the driest segments of the landscape. Groves of aspen (*Populus tremuloides*) occur in moister sites such as shallow depressions, north-facing slopes, creek banks, and seepage sites, and account for about 15% of the land cover. Upland shrub communities, developed in localities where snow commonly accumulates, account for another 10-15% cover. Slough-like depressions, usually ringed with willows and dominated by wetland vegetation such as sedges, account for about 15% of the hummocky to undulating terrain in this vicinity. Even though they rarely contain permanent water, many of the largest and wettest depressions remain uncultivated in surrounding fields.

The Site is located in Agroecological Resource Area (ARA) I1, Provost (Pettapiece 1989). Its agroclimate is classed as 2AH which signifies slight moisture and heat limitations for arable crop production (ASAC. 1987). Selected climate indices, computed from climate normals (AES N.d.) and generalized for the ARA (No. 34 in the prairie region, Kirkwood *et al.* 1993), are:

- Seasonal growing degree days >5 °C: 1419.
- Growing season start (date that mean daily air temp. is ≥5 °C in spring): Apr. 21.
- Growing season end (date that mean daily air temperature is ≤5 °C in fall): Oct. 14.

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

Terrain

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

The undulating to hummocky moraine of the Provost Benchmark Site has distinct internal relief. The contour map (Fig. 2) shows this complex terrain in plain view. The hillier parts have complex slope patterns, mostly of class 3 and 4 topography with minor class 5 to 6 on the steepest slopes and some class 2 slopes across broad hilltops. Lower lying localities have level to very gentle slopes, mostly of class 2 topography. Uncultivated patches are mainly bowl-shaped wetland depressions with surprisingly sharp steep margins.

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

Table 2. Selected temperature and precipitation data (climate normals) for Macklin, SK (52°20'N 109°57'W, 667m ASL) (AES N.d.) .

Month/ Year	Mean Temp. (°C)	Mean Max. Temp. (°C)	Mean Min. Temp. (°C)	Total Precip. (mm)	Rain-fall (mm)	Snow-fall (cm)	Max. 24-hour Rainfall[1] (mm)	PE[2] (mm)
Jan.	-17.9	-12.7	-22.9	20.5	0.6	19.9	7.6	0
Feb.	-13.0	-7.4	-18.4	16.0	0.4	15.7	6.4	0
Mar.	-7.7	-2.0	-13.4	19.3	0.9	18.4	10.2	0
Apr.	3.1	9.4	-3.2	21.8	13.9	7.9	52.1	41
May	10.7	18.0	3.3	34.6	33.6	0.5	41.7	112
Jun.	15.0	21.9	7.9	70.7	70.7	0.0	78.7	132
Jul.	17.6	24.7	10.4	72.5	72.5	0.0	71.1	145
Aug.	16.5	23.8	9.1	58.6	58.6	0.0	83.8	122
Sep.	10.6	17.4	3.7	30.4	29.4	0.9	52.1	63
Oct.	4.6	11.3	-2.2	14.7	8.2	6.5	25.4	15
Nov.	-5.7	-0.5	-10.7	14.3	3.0	11.4	12.7	0
Dec.	-13.2	-8.3	-18.0	20.9	0.7	20.2	6.4	0
Year	1.7	8.0	-4.5	394.3	292.5	101.4	83.8	630

[1]Greatest rainfall in 24 hours (Aug., 59 years of record), based on 33 (Dec.) to 61 (Jul.) years of record.
[2]Potential Evapotranspiration, derived for the ARA from daily temperature normals interpolated from monthly values (Kirkwood *et al.* 1993).

Soil Patterns

Figure 3 shows the complex soil patterns of the Provost Benchmark Site, indicated by mapping units that are described in an adjoining legend. A generalized, terrain-oriented description of the soil patterns follows. The sampling points are listed, with landscape and soil features, in Appendix A.

The hillier, well drained, "upland" parts of the landscape have the most exposed till soils, and exhibit the most visible signs of erosion. Slopes are dominated by Orthic Dark Brown soils on till (Hughenden series, HND), some with thin Ap horizons. Soils developed on veneer overlying till (Provost series, PRO) are also common. Most prominent hilltops are clearly dominated by Rego Dark Browns on till (Neutral-zr variant, NUTzr). Small, very gently sloping basins within the "upland" contain a variety of mainly imperfectly and some poorly drained soils. These range from Gleyed Solonetzic Dark Brown (Hansman series, HAS) to Humic Gleysols. Appendix B contains pedon descriptions and selected data for the HND and NUTzr soils.

A large lower-lying area with very gentle to nearly level slopes cuts the site from southwest to northeast. Moderately well drained Orthic Dark Brown soils developed on veneer over till (Provost series, PRO) dominate. A variety of imperfectly to poorly drained soils, including gleyed Blacks and Dark Browns (e.g. HAS) and Humic Gleysols, are significant.

Depressional localities contain some form of wetland and are poorly to imperfectly drained. The dominant soils are Gleysols, mainly Humic Luvic Gleysols. A variety of related gleyed soils also occur. The parent materials, whether slopewash, lacustrine or till deposits, tend to be slightly finer textured than on surrounding parts of the terrain.

Most of the smaller depressions are wet early in the season but dry out sufficiently in most years to raise good crops. The largest and wettest remains uncultivated even though it does not contain permanent or semi-permanent water. The lower end of Transect 9, which includes sampling points T9.06, T9.07 and T9.08, extends into this aspen-ringed depression located in the southeastern part of the Benchmark Site.

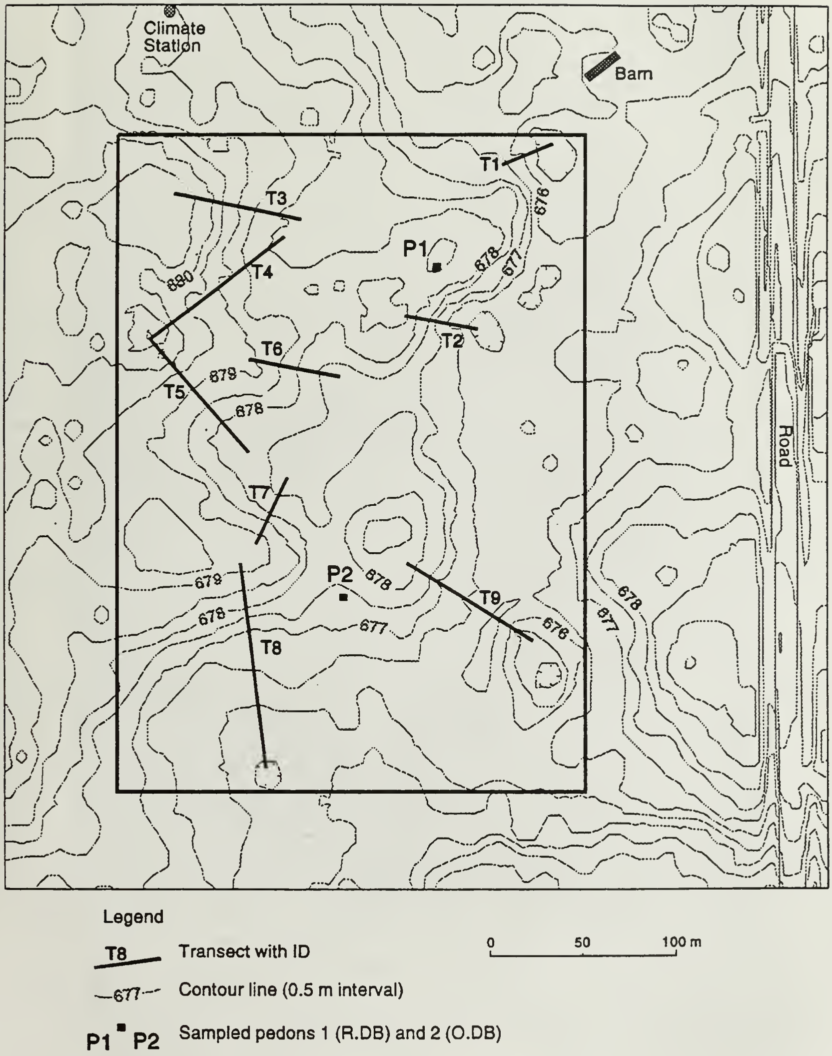

Figure 2. Contour map of the northeast part of SE7-40-1-W4 with 05-AB Benchmark Site.

05-AB (PROVOST) SOIL MAP LEGEND

MAP UNIT[1]	DESCRIPTION
HAS1/2-3	**Landscape**: Small basins within the "upland" that consist of nearly level to very gentle lower slopes. **Soils**: Mainly imperfectly drained GLSZ.DB (Hansman. HAS) and GLE.DB (HASze) on SiL-L slopewash or lacustrine veneer overlying CL-L till. Veneer extends to over 1m thick in places. Other soils include several gleyed Blacks (eg. GLSZ.BL) and some Gleysols, mostly HU.LG.
HND4/3	**Landscape**: Very gentle broad hilltop on the "upland". **Soils**: Mainly well drained O.DB on CL-L till (Hughenden, HND), commonly with a thin (10 cm or less) Ap horizon. CA.DB and R.DB (Neutral, NUT & NUTzr) "eroded" soils are significant.
HNPR4/3-4	**Landscape**: Majority of the undulating to hummocky "upland" areas; consists of very gentle to gentle mid slopes and small hilltops. **Soils**: Well drained. Mainly O.DB on CL-L till (Hughenden, HND) with significant O.DB on SiL-L slopewash or lacustrine veneer overlying till (Provost, PRO). Also, most small hilltops and other exposed sites have CA.DB and R.DB (Neutral, NUT & NUTzr) soils. In places hummock foreslopes are moderate to strong (>9% slope).
NUT4/3-4	**Landscape**: Prominent, very gently to gently sloping, "eroded" hilltops within the "upland" areas. **Soils**: Mainly well to rapidly drained R.DB (Neutral-zr, NUTzr) developed on CL-L till; some CA.DB (Neutral, NUT). Calcareous to the surface. In places hummock foreslopes are moderate to strong (>9% slope).
PRO2/3-2	**Landscape**: Large lower-lying area with very gentle to nearly level slopes. **Soils**: Mainly moderately well drained O.DB developed on SiL-L slopewash or lacustrine veneer overlying CL-L till (Provost, PRO). Significant imperfectly drained, gleyed Dark Browns and Blacks; eg. GL.DB (PROgl), GLSZ.DB (HAS) and GLE.DB (HASze) on the same parent material sequence. Profiles with carbonated B horizons are common. The slopewash / lacustrine veneer extends to over 1m thick in places. Small shallow depressions with Gleysols, mostly HU.LG, are also common.
ZGL	**Landscape**: Nearly level to gentle depressions (wetlands). **Soils**: Mainly poorly to imperfectly drained HU.LG developed on SiL slopewash or lacustrine veneer overlying CL till (Fleet-zlxt variant, FLTzlxt). Veneer extends to over 1m thick occasionally. Other Gleysols, eg. O.HG and SZ.LG, can be found. Various gleyed Dark Browns, eg. HAS and HASze, and Blacks occupy margins and better drained sites.

[1]Numerator consists of series code(s) plus number signifying typical for series (1), significant wet soils (2), or significant "eroded" profiles (4). Denominator signifies slope classes per E.C.S.S. (1987b) with slope gradients, in percent slope (%), as follows: 2 = 0-2%, 3 = 2-5%, 4 = 6-9%, 5 = 9-15%, 6 = 15-30%, etc.

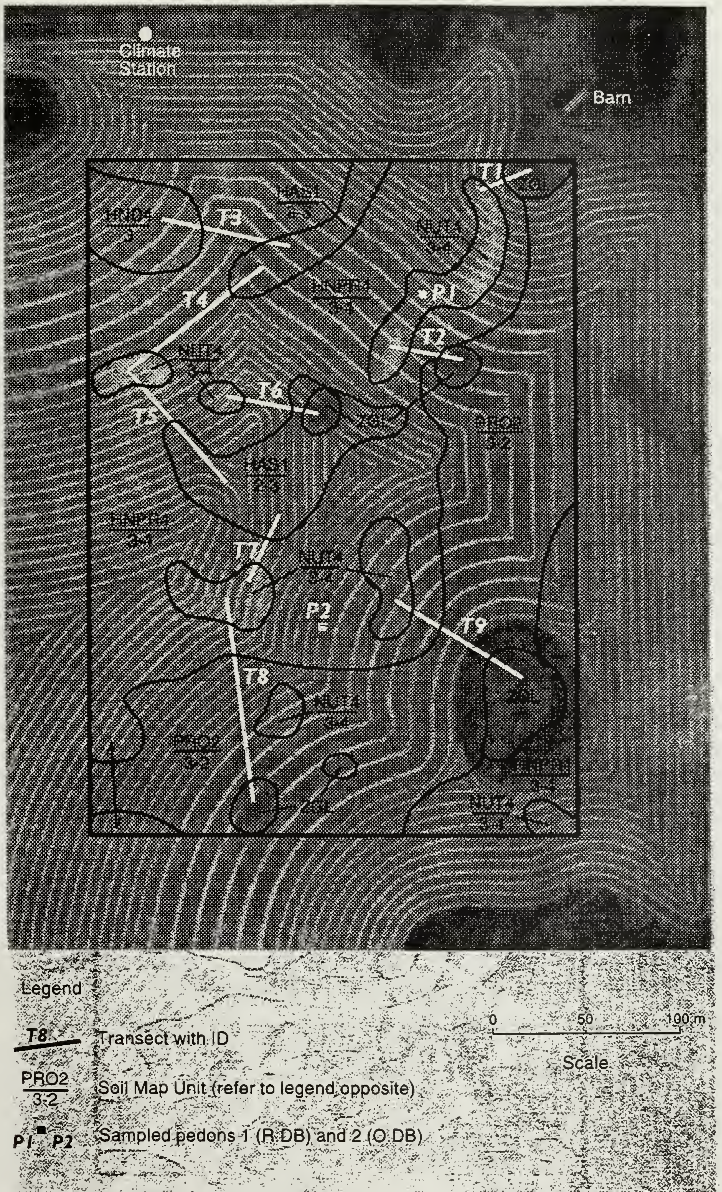

Figure 3. Detailed soil map of the 05-AB Benchmark Site.

EXAMPLES OF BENCHMARK SITE BASELINE DATA ANALYSIS

Copious amounts of baseline data have been collected on the benchmark sites. Most of this data has been refined and arranged into a national benchmark site database. Further, on-going measurements on yield and climate are being attached to the database. Repeat measurements will be added as completed. A listing and brief explanation of files that make up the database is provided in Appendix C. Data on a particular site or several sites can be extracted from the database. Requests should be channeled through the authors or any unit of CLBRR.

Besides the large amount of data, there are a number of ways to analyze the data when looking for meaningful relationships, especially where the terrain is complex. At the Provost Site for example, data can be examined according to different landscape positions, slope shapes, map units, soil series/variants, soil subgroups, horizon types, or other factors and combinations of factors.

When the Provost Site was established, it was anticipated that soil attributes connected with degradation would be examined, mainly on a landscape position basis. By way of example, Table 3 summarizes organic carbon, total nitrogen, C/N ratios, carbonate content and pH data for each of the five slope position classes (see methods). Definite trends are evident The currently cultivated topsoil is uniformly thick regardless of slope position. On hilltops (crests and upper slopes) the topsoil is low in organic carbon and contains appreciable carbonates incorporated from subsoil horizons. On lower slopes and depressions, organic carbon content is much higher, carbonates are absent, and pH's are quite low. Mid slope soils are quite variable, exhibiting features of both hilltop and lower slope - depressional soils.

Table 3. Selected data on "modern" Ap/Apk (topsoil) horizons, organized by slope position.

SLOPE POSITION & STAT.		THICK-NESS (cm)	pH[1] $CaCl_2$	ORG. C (%)	TOTAL N (%)	C/N RATIO	$CaCO_3$ EQUIV. (%)
Crest,	**Average:**	11	7.5	1.95	0.18	10.9	4.24
	Std. Dev.[1]:	2	6.5-7.8	0.36	0.03	0.6	3.48
Upper,	**Average:**	10	7.4	1.88	0.18	10.5	2.05
	Std. Dev.[1]:	1	6.9-7.7	0.25	0.03	0.2	1.47
Mid,	**Average:**	11	6.2	2.90	0.23	12.2	0.70
	Std. Dev.[1]:	1	4.8-7.7	0.77	0.04	1.4	1.74
Lower,	**Average:**	11	5.2	3.98	0.31	13.1	--
	Std. Dev.[1]:	2	4.6-6.2	0.40	0.04	1.5	--
Depression,	**Average:**	11	5.1	4.05	0.33	12.3	--
	Std. Dev.[1]:	2	4.9-5.4	0.23	0.01	0.4	--

[1]Std. Dev. means standard deviation; listed for all parameters except pH where the full range of pH values are reported.

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APPENDIX A: SELECTED SOIL AND LANDSCAPE FEATURES OF SAMPLING POINTS

Selected physical soil features and landscape position information is presented in the following tables. The data is sorted by slope shape (3 classes) within slope position (5 classes; see methods). Soil subgroup codes are standard (E.C.S.S. 1987b). Soil series and variant codes are from the recently developed Generation 2 Alberta Soil Names File (Alberta Soil Series Working Group 1992). The last column lists total depth of humus-rich topsoil. The current Ap or Apk plus any underlying older Ap or uncultivated Ah or AB horizon were summed; strongly eluviated (Ae) horizons were excluded. For comparison, soils in "upland" landscape positions at the nearby natural site commonly have Ah horizons <10 cm thick (Finlayson 1992).

SLOPE POSITON	SAMPLING POINT ID	SLOPE SHAPE	SOIL SUBGROUP	SOIL SERIES	TOTAL Ap/Ah DEPTH (cm)
Crest:	05T4.00	Convex	R.DB	NUTzr	12
	05T1.00	Convex	R.DB	NUTzr	8
	05T6.00	Convex	R.DB	NUTzr	16
	05T7.00	Convex	R.DB	NUTzr	11
	05T2.00	Convex	R.DB	NUTzr	11
	05T9.00	Convex	R.DB	NUTzr	10
	05T8.00	Convex	R.DB	NUTzr	20
	05P1	Convex	R.DB	NUTzr	11
	05T3.00	Straight	O.DB	HND	18
	Average:				13
	Std. Dev.:				4
Upper Slope:	05T9.01	Convex	R.DB	NUTzr	9
	05T5.01	Convex	CA.DB	NUT	12
	05T3.02	Convex	O.DB	HND	10
	05T8.01	Convex	R.DB	NUTzr	17
	05T4.01	Convex	O.DB	NUT	9
	05T3.01	Convex	O.DB	PRO	10
	05T6.01	Convex	CA.DB	NUT	13
	Average:				11
	Std. Dev.:				3
Depression:	05T6.05		HU.LG	FLTzlxt	45
	05T7.04		GLE.DB	CNNfigl	27
	05T8.11		HU.LG	FLTzlxt	19
	05T2.04		HU.LG	FLTzlxt	38
	05T1.03		GL.DB?	HNDgl	8
	05T9.07		HU.LG	FLTzlxt	30
	05T3.07		O.HG	FLTxt	25
	05T9.08		SZ.LG	FLTzlzt	25
	05T4.09		GLSZ.DB	HAS	16
	Average:				26
	Std. Dev.:				11

SLOPE POSITON	SAMPLING POINT ID	SLOPE SHAPE	SOIL SUBGROUP	SOIL SERIES	TOTAL Ap/Ah DEPTH (cm)
Mid Slope:	05T4.04	Concave	O.DB	PRO	16
	05T4.03	Concave	O.DB	HND	15
	05T3.04	Concave	O.DB	PRO	20
	05T4.05	Concave	O.DB	PRO	16
	05T8.02	Convex	CA.DB	PROca	12
	05T5.02	Convex	CA.DB	NUT	11
	05T7.02	Straight	O.DB	HND	13
	05T6.03	Straight	E.DB	LFE	15
	05T3.03	Straight	O.DB	HND	11
	05T4.06	Straight	O.DB	HND	18
	05T1.01	Straight	O.DB	NUT	13
	05T5.03	Straight	O.DB	HND	20
	05T2.01	Straight	O.DB	NUT	30
	05T5.04	Straight	O.DB	PRO	20
	05T8.03	Straight	O.DB	HND	22
	05T6.02	Straight	O.DB	PRO	20
	05T2.02	Straight	O.DB	PRO	35
	05T8.07	Straight	O.DB	HND	14
	05T7.01	Straight	O.DB	HND	11
	05T4.02	Straight	O.DB	PRO	11
	05T8.06	Straight	O.DB	HND	12
	05P2	Straight	O.DB	HND	11
	05T9.02	Straight	O.DB	HND	33
	05T9.04	Straight	O.DB	PRO	20
	05T9.05	Straight	O.BL	BLL?	17
	Average:				17
	Std. Dev.:				7
Lower Slope:	05T2.03	Concave	GLSZ.DB	HAS	45
	05T5.08	Concave	GLSZ.DB	HAS	17
	05T9.03	Concave	GLE.DB	HASze	30
	05T8.08	Concave	GLSZ.BL?	BLLztgl	30
	05T8.04	Concave	O.DB	PRO	19
	05T4.07	Concave	O.DB	HND	23
	05T4.08	Concave	GL.DB	PROgl	23
	05T5.06	Concave	SZ.BL	BLLzt	13
	05T8.09	Convex	GLE.BL?	BLLzegl	23
	05T7.03	Straight	GLE.DB	CNNglze	17
	05T5.07	Straight	GL.DB	PROgl	16
	05T1.02	Straight	GLE.DB	HNDglze	18
	05T9.06	Straight	GLSZ.BL	BLLztgl	20
	05T5.05	Straight	O.DB	PRO	15
	05T8.10	Straight	GLSZ.DB	HAS	30
	05T3.05	Straight	O.DB	PRO	18
	05T3.06	Straight	GLE.DB	HASze	15
	05T8.05	Straight	O.DB	PRO	14
	05T6.04	Straight	HU.LG	FLTzlxt	22
	Average:				21
	Std. Dev.:				8

APPENDIX B: PEDON DESCRIPTIONS

Pedons representing two of the five major soils of the site were described and sampled in detail when the site was established. Locations of these pedons are shown in Fig. 2. The descriptions and selected analytical data follow. Other available data for some or all horizons include cation exchange capacity, exchangeable cations (Na, Ca, Mg, K), available P and K, electrical conductivity and soluble salts, mineralogical analysis, and soil moisture retention and bulk density from core samples.

PEDON 1: NEUTRAL, REGO VARIANT (NUTzr)

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

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

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

Horizon	pH $CaCl_2$	Organic C %	Total N %	$CaCO_3$ Eqiv. %	Sand %	Silt %	Clay %
Apk	7.6	2.04	0.18	3.48	36	38	26
Cca	7.9	0.77	0.07	14.22	24	38	38
Ck1	8.0	0.00	0.04	11.28	33	36	31
Ck2	8.2	0.18	0.02	8.26	41	32	27

PEDON 2: HUGHENDEN SERIES (HND)

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

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

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

Horizon	pH $CaCl_2$	Organic C %	Total N %	$CaCO_3$ Eqiv. %	Sand %	Silt %	Clay %
Ap	5.2	2.77	0.21	--	32	42	26
Bt	6.8	1.08	0.11	0.59	32	34	34
BC	7.9	0.56	0.06	10.59	27	37	36
Ck1	8.1	0.31	0.04	10.82	27	44	29
Ck2	8.1	0.44	0.03	7.28	30	36	34

APPENDIX C: CLBRR BENCHMARK SITE DATABASE

A relational database was designed for the Soil Quality Evaluation Program, Benchmark Site Study. With a host of data types on a variety of measured entities, the main goal was to attain efficient data storage that would support reasonably simple manipulation and retrieval. The Benchmark Site Database achieved this goal by using many small files, developed in dBASE IV (Ver. 1.5). Each file contains similar types of data on similar kinds of soil and landscape entities. Most files can be linked to perform analyses across data types and landscape entities, as demonstrated in Table 3 above.

Currently the files contain baseline, reference or on-going data. Results of repeat measurements will be entered in files like those containing baseline data so that temporal comparisons can be made. As yet only a few sites have a complete set of baseline data. And there are still a few sites with very little refined data for entry to the database.

The dBASE files that comprise the database system are listed and briefly described below. File name extensions, always .DBF but sometimes including .DBT and others, are omitted. File names that begin with BS indicate baseline data. Most files contain data on all benchmark sites, if appropriate and available. Extracting data by site (and other filters) can be done quite easily.

SITEINFO Reference file. General information about each benchmark site including identification, location, agroecological region, major soils and landform, potential degradation problem(s), type of management, site manager, farm co-operator, and so on.

BSPTINFO Baseline and reference data. Landscape and spatial information about the field sampling points, eg. slope position and shape, soil series/variant, map unit, etc.

BSDESCR Baseline and reference data. Descriptions (color, texture, structure, etc.) of the soil horizons that were sampled.

BSSLCHEM Baseline data. "Routine" chemical data (pH, total C, total N, $CaCO_3$ equivalent, CEC and exchangeable cations, available P, and available K) on all samples.

BSPTSIZ Baseline data. Particle size and surface area on selected samples.

BSEALFE Baseline data. Extractable aluminum and iron, analyzed by various methods, on selected samples. (Analysis done mainly on humid region soils, ie. Podzols)

BSECSEL Baseline data. Electrical conductivity, soluble cations and SAR for selected samples.

BSTTLELM Baseline data. Total analysis, for at least 14 elements (Al, Ca, Co, Cr, Cu, Fe, K, Li, Mg, Mn, Na, Ni, Pb, and Zn), on selected samples.

BSNO3_N Baseline data. Nitrate-N data on selected deep samples from selected sites.

BSCS137 Baseline data. $Cesium^{137}$ counts expressed per unit weight and unit area for selected samples and sites. Includes bulk density by the Kubiena box method.

BSSLMINE Baseline or reference data. Mineralogical analysis (semi-quantitative results) of clays from selected samples.

BSEM38 Baseline data. Electrical conductivity values (0-60 & 0-120 cm ranges) derived from electromagnetic inductance readings at selected points and selected sites.

BSMSTRN Baseline or reference data. Moisture retention at 0, 10, 30, 60, 100, 333, and 1500 cm water column equivalent, determined on cores from pedons, and at 4 and 15 bars determined on ground sample. Includes bulk density determined by the core method.

BSAGREG Baseline data. Dry aggregate analysis (rotary sieve) results from selected sites.

BSKSAT Baseline data. Saturated hydraulic conductivity, measured by Guelph Permeameter, for 2 or 3 depths at selected field points

BSPTRMST Baseline data. Penetrometer resistance and moisture content (dated) for 3 or 4 depths at selected field points. Spring and fall results are included at some sites to compare moist and dry seasons.

BSTHWRM Baseline data. Earthworm counts and weights for selected horizons at selected sites (mainly humid region sites).

BSBIOPRT Baseline data. Biopore and root counts for selected depths at selected sites (mainly humid region sites).

YLDINFO On-going reference data. Yearly information on crop type, harvest notes and the file that contains the yield data for each site.

GRYLD91 On-going data. Grain and residue yield (kg ha^{-1}), harvest index (%) and residue - grain ratio for the grains group (cereals, oilseeds and other seed-bearing crops where the seed, ie. grain, is separated from the rest of the above-ground dry matter, ie. residue) for selected field points at the appropriate sites for the 1991 crop year.

GRYLD92 etc. On-going data. As above for the 1992 and subsequent crop years.

Note 1: Yields of other types of crops (eg. sugar beets, sweet corn, potatoes) will be reported in different yield files than the grains group because harvesting methods and yield parameters differ.

Note 2: Climate data from the Campbell Scientific monitoring stations (installed at a few sites) will likely be added to the database in the near future. Hourly, daily and monthly summary files are envisaged.

APPENDIX II

AN EXAMPLE OF FARM HISTORY DATABASE

AGRICULTURE CANADA
CENTRE FOR LAND AND BIOLOGICAL RESOURCE RESEARCH

NATIONAL SOIL CONSERVATION PROGRAM (NSCP)
SOIL QUALITY EVALUATION PROJECT (SQEP)

SOIL QUALITY BENCHMARK SITE STUDY (SQUBS)

FARM HISTORY DATABASE

PREAMBLE

The Soil Quality Benchmark Site Study (SQUBS) was initiated as a means of assessing and monitoring changes in soil quality over time for major agro-ecological landscapes in Canada. About 22 benchmark sites have been established, from 1989 through 1993, all on cultivated lands. Information on the agronomic history and current farming systems is important to characterize the sites, and to assess and interpret much of the soil data collected.

An interview process, following the questions below, will be used to collect an historical record of the farming practices that have affected the benchmark sites, and to characterize the current cropping and tillage systems. The information will become part of the benchmark site databases, and will assist in the evaluation of long-term agricultural sustainability.

Benchmark Site Managers and the Study Leader, listed below, can provide more information on SQUBS and other NSCP Monitoring Studies.

British Columbia	L. Kenny	604-224-4355	Quebec	M. Nolin	418-648-7749
Alberta	B. Walker*	403-495-6122	New Brunswick	H. Rees	506-452-3260
Saskatchewan	L. Kozak	306-975-5637	Nova Scotia	K. Webb	902-893-6724
Manitoba	W. Michalyna	204-474-6122	P.E.I.	D. Holmstrom	902-566-6860
Ontario	D. King	519-766-9180	Newfoundland	E. Woodrow	709-772-5964
			Ontario	C. Wang**	613-995-5011

*Western Co-ordinator ** Study Leader

PART 1. SITE IDENTIFICATION

To be completed by the provincial Benchmark Site Manager.

Site ID No:	*Site Name:*	*Legal Location:*	*Agro-ecoregion:*
25-NF	St. John's	Research Station	Atlantic Boreal

Site Manager	Co-operator	Phone:	Date Completed:
Ed Woodrow	Prov. Agric & Research Stn.	709-772-5964	June 7, 1993

PART 2. SITE HISTORY

To help us understand present conditions, please answer, to the best of your knowledge, the following questions about the agronomic history of the field in which the site is located. If the benchmark site is split and spans more than one field with different histories or farming systems, fill out forms for each of the different parts.

2.1 Land Acquisition. Briefly indicate how the land was acquired (eg. passed down in family, purchased from father or neighbour).

How? Acquired by government Year 1935

2.2 First cultivation. Approximate year(s) in which the field was first cleared, broken, and cropped?

Cleared (if required) ______ Broken (cultivated) 1937
Cropped 1937

2.3 The early years. Briefly outline the cropping methods used in the early years. Include information on rotation(s), tillage method(s), fertilizer use including manuring, weed and pest control measures, and residue management or use, to the best of your knowledge.

Rotation(s) 6 year rotation 5 years in hay, 1 year in grain

Tillage methods Single furrow plough

Fertilizer/manuring 500 lb./ac. 6.12.12.2-3 applications of manure.limed 3 times in 30 years at the rate of 2 tons/ac. Grain undersown to clover legumes.
Weed/pest control None
Residue management Everything except stubble removed. This was used as a cover for clover and alfalfa.

2.4 Major changes in agronomic practices. Briefly describe type and approximate year of a major change(s) in cropping methods(s), if applicable, under the following categories:

2.4.1 Rotation (for example, from wheat-fallow to continuous wheat) and/or crops grown (eg., from cash crop to silage corn).

	Year	Type
Rotation		
6 year rotation for 30 years.		

Crops ______ ______________________________

2.4.2 Tillage system (eg. from draft animals to mechanical power, from moldboard plow to deep-tillage cultivator or discer, etc.).

Year	Type
1947	Horses
1951	Tractor

2.4.3 Installation of a drainage or irrigation system, including general type (eg. tile drainage, sprinkler, sprinkler irrigation).

Year	Type

2.4.4 First use of chemical fertilizers including type(s) if known.

Year	Type
1937	6.12.12
	Annual ever since.

2.4.5 First use(s) of chemical pesticides (herbicides, insecticides, fungicides, etc.), including general type(s) if known.

Year	Herbicide Type:
	None used

Year	Insecticide Type:

Year	Fungicide Type:

2.4.6 Harvesting method(s) including residue management (eg., thresher to combine, burning of straw to baling or plow-down).

Year 1937- Harvesting methods: Grain threshed

Year 1937- Residue management: Hay baled rectangular, later years round bales.

2.5 Crop yields and quality. Briefly describe your observation on crop yields for this field over the time that you know about.

Time Frame (yrs.) 30 yrs.

Yields: Increased ______ Decreased ______ Stayed about same x
Highly variable ______

Yields compared to those in your locality: About the same x
Higher ______ Lower ______

Has crop quality: Increased x Decreased ______ Stayed about the same ______?

Comments: After alfalfa, increase in grain. Production good in response to fertilizer.

2.6 Chemical fertilizers. Briefly describe your observations on chemical fertilizer usage on the field over the time that you know about.

Time Frame (yrs.) 30 yrs.

Has chemical fertilizer usage: Increased ______ Decreased ______
Stayed about the same x ?

Has there been a major change in: Amount 300lb/ac (Year 1975) and/or
Type of fertilizer 5.10.30 (Year ______)?

A second major change in: Amount 400lb/ac. (Year 1985) and/or
Type of Fertilizer 5.10.30 (Year ______)?

A third major change in: Amount ______ (Year ______) and/or
Type of fertilizer ______ (Year ______)?

Comments: ______

2.7 Organic fertilizers and soil conditioners. Briefly describe the use of manuring as a management tool on this field.

Was manuring: Always used ______ Never used _____
Introduced _____ (Year _____) Discontinued _____ (Year _____)?

Has usage been: Regular/consistent ______ Random/sporadic ____?

Type: Livestock wastes _____ Green manures ______ Both ______

Comments: 3 applications in first 30 years. Liquid manure applied 1992.

2.8 Chemical pesticides/herbicides. Briefly describe the use of chemical pesticides on the field over the time that you know about.

Time frame (yrs.) ______

Has pesticide usage: Increased ______ Decreased _____ Stayed about the same ______?

Has there been a major change in: Amount _____ (Year _____) and/or
Type of pesticides ______ (Year _____)?
Other changes: Amount (Year ______) Type (Year _____)?
Amount (Year ______) Type (Year _____)?

Were the changes: Gradual _____ (over a few years) or Sudden _____ in response to an outbreak of some pest (perhaps temporary)?

Comments: None used.

2.9 Degradation problems. Briefly describe any changes in farming practices, including approximate year of adoption, that were strongly motivated by soil degradation problems such as drainage, erosion, salinity, low fertility, acidity, poor trafficability, etc.

Year Cause Agronomic Change

Soils are fertilized annually and limed regularily. Drainage is moderate to imperfect. Trafficability is generally good.

PART 3. CURRENT CROPPING AND TILLAGE PRACTICES

To help us characterize the agricultural system and understand present conditions, please answer the following questions about current cropping and tillage practices used on the field in which the site is located.

3.1 Crop rotation system. Briefly describe your current crop rotation system. Is it:

Fixed Six year rotation, grain - hay.
____

Semi-random ____
____

Completely random (eg. prices or other factors determine what crop is planted each year) ____
____

Approximately when was the "system" above adopted? Year 1937

At what stage of the rotation is the field in this year (eg. fallow year of a wheat-fallow rotation) ____?

3.2 Tillage, crop management and harvesting procedures. Briefly describe your tillage, crop management and harvesting procedures.

Crop year 1: __________

	Approx. start date	Steps (outline, eg., no. of passes, type of equipment)
Spring cultivation	________	________
Planting	________	________
Fertilizer applications	________ ________ ________	________ ________ ________
Irrigation	________	________
Spraying	________	________
Summer cultivation	________	________
Cutting/harvesting	________	________

Fall cultivation ________________ ________________

Fall fertilizer ________________ ________________

Crop year 2: ______

	Approx. start date	Steps (outline, eg., no. of passes, type of equipment)
Spring cultivation	________________	________________
Planting	________________	________________
Fertilizer applications	________________	________________
	________________	________________
	________________	________________
Irrigation	________________	________________
Spraying	________________	________________
Summer cultivation	________________	________________
Cutting/harvesting	________________	________________
Fall cultivation	________________	________________
Fall fertilizer	________________	________________

Crop Year 3: ______

	Approx. start date	Steps (outline, eg., no. of passes, type of equipment)
Spring cultivation	________________	________________
Planting	________________	________________
Fertilizer applications	________________	________________
	________________	________________
	________________	________________

Irrigation	______	______
Spraying	______	______
Summer cultivation	______	______
Cutting/harvesting	______	______
Fall cultivation	______	______
Fall fertilizer	______	______

Crop Year 4: ______

	Approx. start date	Steps (outline, eg., no. of passes, type of equipment)
Spring cultivation	______	______
Planting	______	______
Fertilizer applications	______ ______ ______	______ ______ ______
Irrigation	______	______
Spraying	______	______
Summer cultivation	______	______
Cutting/harvesting	______	______
Fall cultivation	______	______
Fall fertilizer	______	______

Comments: ______

3.3 Farm machinery inventory. Briefly list the types of equipment used in your field operations.

3.3.1 Field tractor(s): Make and model

Team of horses until 1951.
M.F. 265 Tractor
International Tractor 684

3.3.2 Tillage equipment: Types

Plow Kverneland Model E120
Disc Harrow Model 1423
Chain Harrow
Grain Drill model 5300 Case (For Seeding)

3.3.3 Harvesting equipment: Types (eg. for cutting, threshing, etc.)

Cyclomower CM 185H (P.J. Zweegers)
Haybob
Hay Baler M.F. 725

3.3.4 Other types of field equipment (eg. trucks, sprayers, etc.):

Trucks, sprayers and trailers on tractors to remove hay from fields.

3.4 Recent problems. Have you recently noticed any new degradation problems or the recurrence of any old ones? Comments?

It appears that there may be a problem of soil creep on the steeper slopes.

FROM THE FARM FOREMAN'S LOG

1985 Past fence, 10 acres mixed hay.

1986 Mixed Hay
Had plowing match on part of benchmark site prior to establishment of site. Planned to plow, lime and manure this 5 acres, but due to poor weather, this was not done.

1987 No. 5 field (benchmark site location) by Park fence approximately six acres plowed and limed. It was seeded with oats. Oats were cut and baled for straw, some for Avaondale. Plowed again in Fall for reseeding in 1988.

1988 No. 5 field seeded with Timothy and Clover. Cover crop oats sold to the farmers.

1989 Park fence 10 acres Timothy and Clover No. 5 field. Five acres of produce sold to farmers and 615 bales stored in pole barn. Fertilized with 400lb./ac. of 5-10-30.

__1990__ Park fence 10 acres Timothy and Clover. Six acres of produce sold to farmers. and 615 bales stored in pole barn.

__1991__ Ten acres Timothy and Clover. Fertilized with 400lb./ac. of 5-10-30. 453 bales of hay produced.

__1992__ Field No. 5, 10 acres.
Timothy and clover. Fertilized 400lb./ac. of 5-10-30. All the field was done from the Park fence to the Willow trees on roadway.
Got 355 bales of hay off part of this field(near Willows)
July 27, 1992. Took 250 bales of hay from another part of field(near back gate).
August 22, 1992. Had plowing match on part of No. 5 field near Willow trees and roadway. 100ft. wide and put manure on the 100 feet strip before it was plowed. Robert walsh supplied the manure. They applied 4 loads @3000 gallons per load on the plow area. Lime was also applied before plowing.
October 1, 1993. Walsh's finished putting manure (liquid) on No. 5 field today. Ten loads were applied at 3000 gallons per load.

APPENDIX III. SAMPLING DESIGN FOR EACH BENCHMARK SITE

01-BC Grid system with 80 sampling points. An outside row and column along the north and east sides, labelled SO and WO respectively, were not sampled. The second column from the east, labelled W15, was offset to 15 m rather than the normal 25 so that it wouldn't interfere with harvesting operations. Sample Ap horizon at 80 points, B horizon at every third point, and C horizon at every sixth point.

03-AB Grid system with 100 sampling points spaced 25 m apart and surrounded by a 25 m buffer. Total size of the site, including buffer, is 275 x 275 m (7.56 ha). Chained out grid points starting from east-west fence along north side of the site.

04-AB Transect method used. Ten transects were laid out on the ridged (some hummocky) to undulating terrain, each extending from crest to depressional positions, perpendicular to the contour. Total of 68 sampling points in the 10 transects.

The site was split into "pairs", each with different tillage management commencing in 1993. The east block (to retain code 04), estimated at 8.6 ha, is under conventional tillage. The west block, roughly 7.7 ha in size, is under no-till management. It will be designated as a subsite, likely with the Site Code 44 in the future. Each block has 5 transects, with 32 sampling points in the east block and 36 in the west block.

05-AB Transect method. Nine transects were laid out on the hummocky to undulating terrain, each extending from crest to depressional positions in most cases. Total of 67 sampling points in the 9 transects.

06-AB Grid system with 100 sampling points spaced 25 m apart and surrounded by a 25 m buffer. Total size of site, including buffer, is 275 x 275 m (7.56 ha). NW corner of site placed at 50 m from half mile, along the east-west irrigation guide cable (on the 1/4 mile). Chained out the grid points from the guide cable which is along north side of site.

Special sampling: Deep cores (0-210 cm) were collected from 10 grid points, split into 9 increments (0-15, 15-30, 30-45, 45-60, 60-90, 90-120, 120-150, 150-180, & 180-210), and analyzed for soluble salts (below 30 cm) and available nitrate-nitrogen.

07-SK A grid system was used in selecting sampling points. A buffer zone of approximately 5 to 6 m was established along the western, southern and eastern edges of the site. The northern perimeter of the site, however, was more irregular in shape. Seven rows of sampling points were established in a south to north direction across the entire field. The rows were spaced 22 m apart. Individual sampling points were spaced 25 m apart within each row. This resulted in a total of 90 sampling points.

08-SK Sampling layout and design was based on a grid system. The sampling plot measured 225 x 225 m with individual grid points spaced 25 m apart resulting in 100 sampling points. The plot was located in the southeast corner of the quarter. A 25 m buffer zone was established between the eastern edge of the plot and the adjoining field in the next quarter. A 50 m buffer zone was established between the grid road to the south and the southern edge of the plot.

09-SK Transect method. Six transects were laid out on the hummocky terrain, each extending from crest to depressional positions. Sampling interval for all transects was predetermined at 10 m. A total of 69 sampling points were established.

10-SK The benchmark site was set up using a grid system. The site measured 225 x 225 m with 25 m intervals between sampling points resulting in a total of 100 individual sampling points. The site was set up in the southeastern corner of the quarter. A 25 m buffer zone was established between the eastern edge of the site and the fenceline and row of trees that separate the SW1/4 from the SE1/4 of the section. The southern edge of the site was 130 m north of the fenceline along the southern edge of the quarter.

11-MB The site is 225 x 225 m using 25 x 25 m grid resulted in 100 sampling points. Ap horizon was sampled at every grid point. A random selected 20 grid points for B horizon (50-60 cm) and 10 grid points for C horizon (100-120 cm) were also sampled. There were a total of 130 samples collected for baseline data sets.

12-MB The sampling design is the same as site 11-MB. Using 25 x 25 m grid for a total of 100 Ap, 20 B and 2 C horizon samples were collected.

13-ON Two different sampling strategies used. Western 2/3 of the site is hummocky; here the design used five transects with a total of 41 sampling points. Each transect extends from crest to depressional position. Eastern 1/3 of the site is level; here the design consists of 30 sampling points arranged in a 25 x 12.5 m grid. ^{137}Cs and bulk density samples were also taken at each sampling point.

14-ON A total of 40 sampling points in a 20 x 20 m grid. ^{137}Cs and bulk density samples were also taken at every sampling point.

15-QU Five unaligned transects with 10 points each, spaced 40 m apart.

Satellite site; adjacent to and "paired" with 16-QU.

16-QU Five unaligned transects with 10 points each, spaced 40 m apart.

Main benchmark site: adjacent to and "paired" with 15-QU (satellite site).

17-QU Three parallel transects with 17 sampling points spaced 30 m apart. Satellite site; "paired" with 18-QU.

18-QU Three parallel transects with 17 sampling points spaced 30 m apart. Main benchmark site; "paired" with 17-QU (satellite site).

19-NS A total of 88 sampling points in a 20 (East-West) x 25 m (North-South) grid, ^{137}Cs and bulk density samples were also taken at each sampling point.

20-NB A total of 93 sampling points on a 25 x 20 m grid. ^{137}Cs, bulk density, in situ Ksat and yield samples were taken on a 25 x 25 m grid. Worm counts were taken at 10 systematically located points. Biopore and root counts were taken at 5 points. Runoff and sediment quantity and quality are being monitored with a flume/stage height recorder and proportional collector tanks setup.

This site, "paired" with 22-NB, is representative of intensive potato production on a rolling, coarse textured, lodgment till soil, using conventional up and down slope cultivation practices. Slopes are generally 5-9% with a total range of 2-15%.

21-PE Due to irregular shape of the site, a total of 102 sampling points on mostly a 25 x 25 m grid with some on 15 x 25 m grid. In addition to loose samples, ^{137}Cs, and bulk density were also sampled at each grid point.

22-NB A total of 100 sampling points on a 25 x 20 m grid which was modified to accommodate the terracing layout. ^{137}Cs, bulk density, Ksat, and yield data were collected at 2/3 of the sampling points. Worm counts were taken at 12 systematically located points. Biopore and root counts were taken at 5 points. Runoff and sediment quantity and quality are being monitored with a flume/stage height recorder and proportional collector tanks setup.

This site, "paired" with 20-NB, is representative of intensive potato production on rolling, coarse textured, lodgment till soils, using erosion control measures. A diversion terrace/grassed waterway system is used to reduce water erosion.

24-ON This site is divided into 66 9 x 8 m plots. Samples were taken at the centre of each plot. This site is also used by Dr. Ed Gregorich as an organic matter degradation study site. Dr. Lianne Dwyer also uses the site for a rotation study.

25-NF A total of 74 sampling points on a 25 x 25 m grid. Full depth of Ap was sampled. B and C horizons were sampled at standard depth of 50-60 cm and 90-100 cm respectively.

APPENDIX IV. LABORATORY METHODS

A. Chemical methods

1. Soil reaction (pH)

a) In water (H_2O) - using 1:1 soil-to-water ratio as per procedure 84-001 in Sheldrick (1984).

b) In $CaCl_2$ - using 1:2 soil-to-0.01 M $CaCl_2$ solution ratio as per procedure 84-002 in Sheldrick (1984).

2. Total carbon

LECO induction furnace, as per procedure 84-013 in Sheldrick (1984).

3. Total organic carbon

For non-calcareous samples, same as total carbon; for calcareous samples, by modified Walkley-Black method, as per procedure 84-014 in Sheldrick (1984).

4. Total nitrogen

Use LECO CHN600 induction furnace, as per procedure provided by the LECO CHN600 Manual.

5. Carbonates

Gravimetric method - using HCl-$FeCl_2$ solution as per procedure 84-008 by Sheldrick (1984).

6. Extractable Fe and Al

a) Dithionite-citrate extraction - extractable Fe and Al determined by atomic absorption as per procedure 84-010 by Sheldrick (1984).

b) Acid ammonium oxalate extraction - extractable Fe and Al determined by atomic absorption as per procedure 84-011 by Sheldrick (1984).

c) Sodium pyrophosphate extraction - extractable Fe and Al determined by atomic absorption as per procedure 84-012 by Sheldrick (1984).

7. Exchangeable cations

a) 2M NaCl - extractants determined by atomic absorption as per procedure 84-004 by Sheldrick (1984).

b) 2M NH_4Cl - procedure is the same as 2M NaCl except using 2M NH_4Cl instead of 2M NaCl.

c) pH7 1M NH_4OAc - extractants determined by atomic absorption as per procedure 84-005 by Sheldrick (1984).

8. Cation exchange capacity (CEC)

a) pH7 ($Ca(OAc)_2$ + $CaCl_2$) - soils were first saturated with Ca, Ca ions were then replaced by Na ions, Ca ions in solution were determined by atomic absorption as per procedure 84-006 by Sheldrick (1984).

b) pH7 1M NH_4OAc - CEC determined by NH_4 displacement and macro-Kjeldahl distillation as per procedure 3.32 by McKeague (1978).

9. Permanent charge CEC

2M NaCl - the sum of Ca, Mg, K and Al in extractants determined by atomic absorption as per procedure 84-004 by Sheldrick (1984).

10. Available P

a) Sodium bicarbonate extractable - for calcareous or neutral soils, extractable P determined by using ammonium molybdate solution as per procedure 84-017 by Sheldrick (1984).

b) Bray method (0.03M NH_4F + 0.025 M HCl) - for acid or neutral soils extractable P determined by using ammonium molybdate solution as per procedure 84-017 by Sheldrick (1984).

11. Available K

a) pH7 1M NH_4OAc extraction - for calcareous or neutral soils, K was determined in extractants by atomic absorption as per procedure 84-005 by Sheldrick (1984).

b) Cold 0.05 M H_2SO_4 extraction - for acid or neutral soils, K was determined in extractants by atomic absorption (Knudsen et al. 1982).

12. Total elements (other than C and N)

Perchloric acid method - soils were digested in Teflon beakers by adding conc. nitric, perchloric and hydrofluoric acids. All elements in digested solution were determined by atomic absorption as per procedure 84-023 by Sheldrick (1984).

13. ^{137}Cs

Using counting equipment consisting of a high-purity Ge-crystal coupled to a 40% Multichannel Analyzer. The equipment was calibrated using a certified solution of ^{137}Cs in a carrier solution of CsCl in 0.1 M HCl. Detailed procedure as described by DeJong et al. (1982).

B. Physical methods

1. Particle size distribution (fine earth fraction)

a) By the pipette method using filter candle system with pretreatments to remove soluble salts (if present), carbonates (if present) and organic matter as per procedures 47.2.1 by Sheldrick and Wang (1993).

b) Fractionation of sands was done by sieve analysis as per procedures 47.2.3.2 by Sheldrick and Wang (1993).

2. Bulk density

a) Determined on cores either 7.5 cm diameter x 7.5 cm length or 5 cm diameter x 5 cm length collected with Uhland sampler, corrected for coarse fragments (fine earth bulk density) and uncorrected for coarse fragments as per procedures 2.211, 2.212 and 2.213 by McKeague (1978).

b) Determined using a 7.5 x 5 cm Kubiena box; uncorrected for coarse fragments as per procedures 2.212 and 2.213 by McKeague (1978).

3. Soil moisture retention

Undisturbed 7.5 cm diameter x 7.5 cm length cores were used for determining moisture retentions at 0, 10, 30, 60 and 100 cm of water column on glass bead tension table and for moisture retention at 1/3 bar (or 333 cm of water column) and 1 bar on aluminum oxide tension table; moisture retention at 4 and 15 bars were determined from disturbed samples with pressure plate extraction as per procedure 53.4.2 by Topp et al.(1993).

4. Total Surface area

By Ethylene Glycol Monoethyl Ether (EGME) method (Cihacek and Bremner, 1979) as follows: Place about 1.0 g of 40 mesh soil in aluminum can and dry in a vacuum desiccator containing about 200 g P_2O_5; apply vacuum until soil in Al can reaches a constant weight; treat soil with EGME until it becomes a slurry; again apply vacuum until soil reaches a constant weight; the per gram soil weight difference before and after EGME treatment divided by 0.000286 g/cm^2 of EGME gives the total surface area in m^2/g.

C. Mineralogical method

Minerals present in clay fractions were identified by X-ray diffraction (XDR) analysis. Mineral identification was based on a composite of diffraction data from air-dry, glycerolated and thermally treated specimens for each clay sample. For the analysis, preferentially oriented specimens were employed. Thirty mg of Mg-saturated clay (treated with H_2O_2 and DCB prior to fractionation) was suspended in 1 mL of water (for samples to be air-dried and heated at 550°C) or in 1 mL of 2% glycerol aqueous solution (for samples to be solvated with glycerol). Each suspension was pipetted onto a glass slide (30 mm x 25 mm) and allowed to air-dry. The specimens were analyzed using a separate Roman numeral Scintag PAD V diffractometer with Co radiation and a graphite monochromator. Amounts of minerals were estimated from diffraction intensities according to procedures similar to those described by Kodama et al. (1977). Because of single XRD determination and various sample crystallinities, the amounts were presented on a semi-quantitative basis. X-ray amorphous (Σ) was defined as all non-crystalline components that could not be accounted for by XRD. In other words, this equals to 100-Σ crystalline components (%).

D. Special analyses for selected benchmark sites

1. Dry aggregate size distribution (Alberta sites)

Characterization of the aggregates in the Ap horizons at benchmark sites adds a quantitative assessment of surface soil structure, and may prove useful in estimating the potential for wind erosion. Only sites affected or potentially affected by wind erosion need be sampled. The procedure may also provide some interesting data over time if a comparative study is planned, for example, conventional tillage versus a no-till system.

The sampling should be done after spring thaw, before the first cultivation, when the soil is reasonably dry. This timing will provide some standardization for temporal comparisons. Select, by some statistical means, about 15% of grid points; at least 3 (triplicate) transect points in each of the five slope positions.

Collect a volume loose sample (about 2 kg) of the soil surface to 5 cm depth, using a flat square-cornered spade, at each of the selected sampling points. Carefully lift the sample and place it in a suitable tray or bag (Kemper and Chepil 1965). A pizza-style cardboard box, approximately 32 x 30 x 9 cm in size, makes a suitable handling container.

Air dry the samples and submit them for sieve analysis; very careful handling and transportation of samples is required to avoid aggregate breakage. Dry aggregate size distribution is determined using a rotary-sieve machine. The various sizes of aggregates are caught in pans and weighed. Results are expressed as percent passing each sieve size (in mm), with calculations of geometric mean diameter and the log standard deviation (Kemper and Chepil 1965).

Repeat the dry aggregate sampling procedure only in years when the soil surface is susceptible to wind erosion, after fall cultivation for example, or whenever appropriate for a comparative study. Thus at some sites sampling may occur yearly, at others every 3-5 years (maximum interval).

2. Deep samples for monitoring salinity and nitrates (few sites in Prairies)

Samples from deep in the profile can be used to monitor salinity, nitrates or other possible contaminants, especially at sites where water movement through the profile is high, as under irrigation for example.

Select at least 10% of grid or transect points, ensuring appropriate representation from all slope positions or soil landscapes. If using hand tools or a light-truck coring unit, select points that have both topsoil (Ap) and 50-60 cm subsoil samples. Collect an additional subsoil sample from the 100-120 cm depth in such cases. If a large truck and coring unit are available, take deep cores to about 2 m. Sample the cores in increments of 15 cm to 60 cm depth, 30 cm increments below 60 cm. For example, cores taken at the Bow Island (06-AB) site were divided into 9 segments: 0-15, 15-30, 30-45, 45-60, 60-90, 90-120, 120-150, 150-180, and 180-210 cm.

Samples that will be analyzed for nitrate-N must be dried and prepared immediately after collection. Storage of the prepared samples at 4°C or cooler is recommended until analysis begins.

Electrical conductivity and soluble salts (cations) were determined on saturation extracts (Method 3.21 in McKeague 1978); EC by a conductivity bridge, cations by ICP. Nitrate-N is extracted by the NH_4F - H_2SO_4 method for phosphorus and nitrate (Method 4.44 in McKeague 1978) and measured with a Technicon Auto Analyzer.

Sampling and analysis should be repeated every 2-3 years for EC and soluble salts, mainly as a check on the EM38 results. Sampling and analysis for NO_3-N should be repeated every 5 years to monitor changing concentrations at depth, relative to the topsoil, under irrigated conditions.

APPENDIX V. FIELD METHODS

A. Hydraulic conductivity

1. Saturated hydraulic conductivity

Using Guelph Permeameter described as per procedure 56.2.1 by Reynolds (1993a). Most measurements were in Ap horizon, a few in B horizon. On the average, there were about 50 measuring points per site.

2. Classes for saturated hydraulic conductivity

As defined by McKeague et al. (1986): H_2 > 50 cm/h, H_1 15-50 cm/h, M_3 5-15 cm/h, M_2 1.5-5 cm/h, M_1 0.5-1.5 cm/h, L_3 0.15-0.5 cm/h, L_2 0.05-0.15 cm/h and L_1 < 0.05 cm/h.

3. Unsaturated and near-saturated hydraulic conductivity

Using Guelph Tension Infiltrometer method described as per procedure 59.2.1 by Reynolds (1993b). Select about 10 points per site measuring at the same depths as saturated hydraulic conductivity.

B. Penetrometer and soil moisture measurements

1. Center-cone Penetrometer (by Star Quality Samplers, Edmonton)

Manually hand operated penetrometer as per procedure in user's manual by Star Quality Samplers (1990).

2. Soil moisture content

By gravimetric method, weighing about 15 g soil collected in a moisture can, oven drying to a constant weight at 105°C, and reweighing the sample after cooling to room temperature in a desiccator.

C. Biopore counts

Count biopores on a horizontal section of 20 x 20 cm at selected depths by: 1) cleaning and preparing the horizontal section with a forced-air jet as described by Veer and Wang (1992); 2) recording the number of biopores of 0.2-0.5 mm, 0.5-1 mm, 1-2 mm, 2-3 mm, 3-5 mm and > 5 mm in diameter; 3) estimating areal percentage of pores by using Fig. 1 of McKeague et al. (1986); 4) repeating the biopore counting procedure on at least five different areas at various landscape positions each year for each benchmark site.

D. Earthworm counts

Should be done on all benchmark sites except for the sites located on the prairies that have no earthworms. The best time for earthworm counting is when soil is relatively wet and the soil temperature is relatively mild and nearly all earthworms are in the plow layer. The procedure is briefly described as follows: shovel all Ap horizon soil from a selected 75 x 75 cm area onto a heavy plastic sheet; carefully pick out all earthworms from the soil on the plastic sheet and return the soil back to the 75 x 75 cm area dug earlier; record both numbers and total weight of the earthworms picked; return the earthworms to the area dug; count earthworms at least on 5 locations for each benchmark site each year.

E. Electromagnetic ground conductivity (EM38) measurements

Electromagnetic inductance readings can be converted to electrical conductivity values that provide an estimate of soil salinity. A portable, easily operated instrument to make such measurements is the Geonics EM38 Ground Conductivity Unit. Soon after the site has been established, select either by random or stratified random means, at least 50% of all grid/transect points. Ensure that lower slope and depressional points are well replicated. Make readings with the EM38 unit in both the horizontal (0-60 cm) and vertical (0-120 cm) modes at the selected points. Record the results.

While both spring and fall measurements are desirable to explore yearly variability, soil temperatures must be above 0°C to obtain reliable results. Post-harvest, early fall measurements are preferred. To convert EM38 readings to saturated paste EC equivalents (dS m^{-1}), estimates of soil temperature at 30 and 60 cm (20 and 50 cm okay), moisture (dry, moist, wet) and texture (coarse, medium, fine) are needed for both depth ranges. McKenzie et al. (1989) developed the curves and equations necessary to make the conversions.

Soil samples can be collected and analyzed to substantiate the EM38 readings, especially where salinity occurs or may occur. Collect loose soil samples from the Ap and subsoil (50-60 and 100-120 cm) or from deep cores (depth increments) at about 10-20% of the grid/transect points. Submit the samples to a lab to determine saturated paste EC and soluble salt content.

The following guidelines can be used to repeat EM38 measurements to detect potential changes in soil salinity.

- If there is no salinity, readings every 5 years at about the same time of year, with similar moisture conditions, will be sufficient to detect change.

- If salinity is a potential problem, as under irrigation for example, or is very weak and sporadic, readings every one or two years at about the same time of year will be adequate.

- If salinity is present, readings should be taken in the fall and spring of every year.

F. Yield data

1. Mixed forage crop

Randomly select about 20 points in the field to measure yield. At these points place the 1 meter square grid on the ground and cut the forage inside the grid, using hedge clippers, at approximately the same height as the forage harvester would cut the plants. Collect all of the sample inside the grid and weigh it immediately after cutting. A subsample of some of the samples can be taken and brought back to the lab. The subsamples are weighed (for moist weight) and placed in a forage dryer. After 96 hours the samples are removed and again weighed (for dry weight) then sent to the feed lab for quality analyses.

2. Seed potato

Sampling for yield of seed potatoes includes estimates of both quantity (weight of tubers) and quality (grade of tubers). Table and processing stock can be treated in a similar fashion but grade classes must be modified accordingly.

Sampling should be conducted as close to the actual harvest date as possible to ensure accurate estimates of yield. This is at the end of the topkilling period when additional potato sizing will be at a minimum, however, all harvesting should still be completed within as short a period as possible.

Proceed as follows:

- sampling points should be stratified according to landscape positions;

- record the potato variety and crop type, i.e. seed. (There are significant differences in yields between varieties and within varieties for different markets.);

- at each sample point, sample three rows of approximately 3-4 m length. The specific length selected depends upon plant spacing; however, once established it remains constant throughout all sampling. Record this length. Wooden stakes are used to mark row sections sampled. Insert one stake midway between two plants, measure out the established row length and insert the second stake marker;

- count and record the number of individual potato plants per selected row. (Note: Each plant is from a different seed piece, but one seed piece has many stems).

- the potato tubers are dug and graded according to size class (30-50 mm, 50-80mm, > 80mm). Based on Agriculture Canada potato grading guidelines, culls are separated out. The number of potato tubers and total weight in kilograms is recorded for each size class and culls on a per row basis. Tubers less than 30 mm diameter are NOT included in these measurements.

- the potatoes can be reburied for later harvest by the farmer when the entire field is "dug".

Note: where field grading is not possible, one "average" sample row per site is collected and graded at a later date. Since there would be some tuber weight loss during storage, graded weights are adjusted to reflect field weights.

Equipment: Potato hoes, wire baskets, field scale, tape measure, marking stakes, clip board, tuber grading size guides, grading guidelines.

For additional assistance on grading and grading specifications, contact Agriculture Canada, Food Production and Inspection Branch, Agriculture Inspection Directorate.

3. Grains group

The grains group refers to cereal, oilseed and other seed-bearing crops where the seed (grain) is separated from the rest of the above-ground dry matter (straw), and the yields of both are reported. This group includes wheat, oats, barley, canola, flax, rye, dry beans, field peas, seed clover, and others. Sampling of these crops for yield should occur yearly at the time of maximum growth, just prior to harvesting by the producer.

Selection of sampling points at a site may be by either stratified random or random means. Guidelines on the number of samples to collect are as follows:

Grid design at least 20% of grid points.

Transect design optimally 4-5 (minimum of 3) samples per slope position (5 positions); more (6-10) samples on the dominant slope positions (mid & lower slopes).

After relocation of the selected grid/transect points, collection of crop samples at/or near each point can proceed. Sample collection methods differ slightly for field versus row crops:

For field crops a 1 m^2 sampling guide is place in the undisturbed crop and all above-ground crop material within the guide is clipped, using large shears, at about 1-3 cm above the soil surface. Note the average row spacing of the crop for correct determination of yield per unit area.

For row crops a 2 m length of row at the selected location is clipped, using large shears, at about 1-3 cm above the soil surface. The distance between rows is measured, center to center, in several locations and averaged for the field in order to determine yield per unit area.

Crop samples are collected in large porous bags, for ease of drying, and transported to a threshing facility. After air drying, the crop samples are threshed to separate grain and straw. Dry weights of bag, grain and straw are measured and recorded. Grain and straw weights, converted to kg ha^{-1}, and harvest index (grain weight over total dry matter weight), and residue-grain ratio are reported. The latter two parameters provide crude estimates of crop quality, and can be compared year to year for the same crops.

G. Automated weather station

Climate monitoring stations, based on the Campbell Scientific CR10 Measurement and Control Module, were installed at eight sites. Instrumentation and set-up is generally as follows although there is some variation from site to site. Sensors for measuring air temperature and relative humidity (HMP35C Air Temperature and Relative Humidity {Temp-107} Probe inside a 41002-2 12 Plate Gill Radiation Shield), global solar radiation (Lycor LI200S Pyranometer), and wind speed (03101-5 R.M. Young Wind Sentry Anemometer) were attached to a galvanized steel radio tower at about 2 m above the ground. Other measuring devices were installed to collect soil temperature at 20, 50 and 100 cm (thermocouples linked to a 10TCRT Thermocouple Reference); rainfall (TE525 Texas Tipping Bucket Rain Gauge); and snow depth (UDG01 Ultrasonic Depth Gauge). Benchmark sites without automated equipment are usually located near climate stations operated by other federal or provincial agencies.

Campbell Scientific PC208 software was used to program the CR10 modules. Two types of measurements are made. Air temperature, relative humidity, wind speed, global radiation, and rainfall are sampled every 30 seconds. Soil temperatures and snow depth are measured every hour. The only fifteen minute output is rainfall, to monitor intensity. Hourly output consists of average panel, air and soil temperatures; average relative humidity; total rainfall and radiation (total flux); average wind speed; maximum gust speed with time of occurrence; frequency of wind speeds in 0-8, 8-16, 16-24, and >24 m/s categories; and snow depth. Daily output includes mean air and soil temperatures; maximum and minimum air temperatures with times; maximum and minimum 20 cm soil temperatures with times; total rainfall; and average snow depth. Raw data are stored and down-loaded from SM192 Storage Modules. Post processing of hourly data yields daily total global radiation, mean daily wind speed, maximum hourly wind speed, and maximum gust speed (per day). Several parameters can also be summarized on a monthly basis. Extracted and processed climatic data from these stations will be added to the Benchmark Site Database in the future.

APPENDIX VI. PUBLICATIONS

A. Research

Veer, C., and Wang, C. 1992. Cleaning soil profiles with a forced-air jet and describing soil morphological features. Can. J. Soil Sci. 72:295-298.

Nolin, M.C., Cao, Y.Z., Coote, D.R., and Wang, C. 1993. Short-range variability of fallout ^{137}Cs in a Quebec forest soil. Can. J. Soil Sci. 73:381-385.

Cao, Y.Z., Coote, D.R., Nolin, M.C., and Wang, C. 1993. Using ^{137}Cs to investigate net soil erosion at two benchmark sites in Quebec. Can. J. Soil Sci. 73:515-526.

Cao, Y.Z., Coote, D.R., Rees, H.W., Wang, C. and Chow, T.L. 1994. Soil redistribution, landscape position and productivity in N.B. potato field. J. Soil Tillage Res. (in press).

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B. General

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Centre for Land and Biological Resources Research. 1992. Benchmark sites for Agricultural land in Canada. Brochure. Research Branch, Agriculture Canada, Ottawa. ON.

Walker, B.D., and Wang, C. 1992. Benchmark sites for monitoring soil quality. Proc. 29th Annual Alberta Soil Sci. Workshop, Lethbridge, AB.

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