BENCHMARK SITE DOCUMENTATION
06-AB (BOW ISLAND, ALBERTA)

SOIL QUALITY EVALUATION PROGRAM

Site Description Report

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Agriculture and Agri-Food Canada
Lethbridge Research Centre, Land Resource Unit

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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 and Agri-Food Canada's former 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 Program (SQEP) managed by CLBRR. The study was labelled Soil Quality Benchmark Sites (SQUBS).

A network of 23 benchmark monitoring sites was established across Canada by late 1992. Various land, soil and air characteristics were to be monitored for at least 10 years. The Bow Island site, coded 06-AB, was established in October, 1991. It represents irrigated Brown soils of the Mixed Grassland Ecoregion. The landscape is representative of the gently undulating, morainal terrain (with lacustrine veneer) that is common in southeastern Alberta.

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 – Brown soils of the Mixed Grassland Ecoregion occurring on medium-textured lacustrine veneer overlying till with undulating terrain – was designated for southeastern Alberta. Characterization of the irrigated soils, and the prospect of monitoring organic matter loss, wind erosion, and perhaps salinity, were viewed as objectives for this benchmark site.

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 southeastern Alberta site was to:

1. represent irrigated Brown soils in the Mixed Grassland Ecoregion;

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

3. represent a wheat-oilseed-specialty crop rotation managed under irrigated, conventional tillage;

4. be about 5-10 ha in size; and

5. show potential for change in soil organic matter, structure, or salinity, and be affected by wind erosion.

The search for a site, based on the guidelines above, began in June 1991, mainly in the Taber to Medicine Hat area of southern Alberta. Dr. Ross McKenzie of Alberta Agriculture, Food and Rural Development in Lethbridge provided valuable guidance on the landscapes and farm operators throughout the area. The final selection was shortly after a tour through the region. A site about half way between Bow Island and Foremost, on land owned and managed by Tony Crooymans and sons, was selected. Several factors affected the final decision.

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

2. The nearly level landscape could be sampled within an area of 5-10 ha.

3. The farm operators, Tony Crooymans and his three sons, were fully cooperative and supportive. They are a family with a long history and good standing in the community, and offered a stable farm operation.

4. Alberta Agriculture, Food and Rural Development (AAFRD) were in the process of establishing research and trial plots, which included a full meterogical station, within about 4 km (2.5 mi.).

5. The potential to monitor salinity and nitrate change at depth in the irrigated soils was a bonus attraction.

BENCHMARK SITE 06-AB (BOW ISLAND)

SITE LOCATION

The Bow Island Benchmark Site is situated in southeastern Alberta, over 550 km (350 mi.) southeast of Edmonton, roughly half way between Lethbridge and Medicine Hat. It is located in Legal Survey Division (LSD) 2 and the SE quarter of Section 4, Township 9, Range 11, west of the 4th Meridian. The GPS-corrected coordinates for the NW corner of the site are 49°42'8" N latitude and 111°26'17" W longitude; UTM Zone 12, Easting 468436.48 m and Northing 5505628.71 m; elevation 826 m.a.s.l. From the town of Bow Island, the site can be reached by traveling 6 km (3.7 mi.) west along Highway No. 3 and 16 km (10 mi.) south on Highway No. 789 (Fig. 1).

SAMPLING DESIGN AND METHODOLOGY

Field Sampling Design

Terrain at the Bow Island site is nearly level but with discernible internal relief in places. While the overall slope gradient (southeast-northwest) is only 0.4%, some short slopes are as steep as 1.5-2.0%. An area 275 x 275 m, totalling 7.6 ha (18.7 ac) in size, was selected to represent this landscape. A grid design with 100 sample points spaced 25 m apart (east-west and north-south) was setup within this area. The north-south "columns" of points were labelled A to J; the east-west "rows" were tagged 0 to 9 (Fig.2), much as in a spreadsheet layout. Thus each sampling (or grid) point is identified by the intersection of a column letter and a row number, i.e. grid point "F3".

Each grid point was described, during sampling activities, in terms of slope shape, soil taxonomy, and other pertinent landscape features.

Two soil profiles (pedons), representative of the dominant soils of the study site, were selected and excavated for detailed characterization, and sampled for physical and chemical analysis. Their locations are shown as P1 and P2 on Figure 2. Pedon 1 belongs to the Travers (TVS) series, a Calcareous Brown (Chernozemic Order, ECSS 1987) developed on medium-textured till. Pedon 2 represents the Cranford (CFD) series, an Orthic Brown developed on shallow (<1 m), medium-textured, glaciolacustrine sediments overlying the till. They are described in Appendix A.

Soil and Topographic Characterization

Topographic Data and Contour Map: A detailed contour map, with a 0.2 m interval, was created for the site (Fig. 2). A Nikon Total Station was used to measure X (easting), Y (northing) and Z (elevation) co-ordinates, in meters, for each grid point and other selected points at the site. The initial coordinates for this survey were estimated from 1:50,000 series NTS maps. In the fall of 1995, an attempt was made to correct this dataset with topographic data collected by a Differential Global Positioning System (DGPS) at several "benchmarks" located around the site (within 1 km). This new data has not yet to been evaluated.

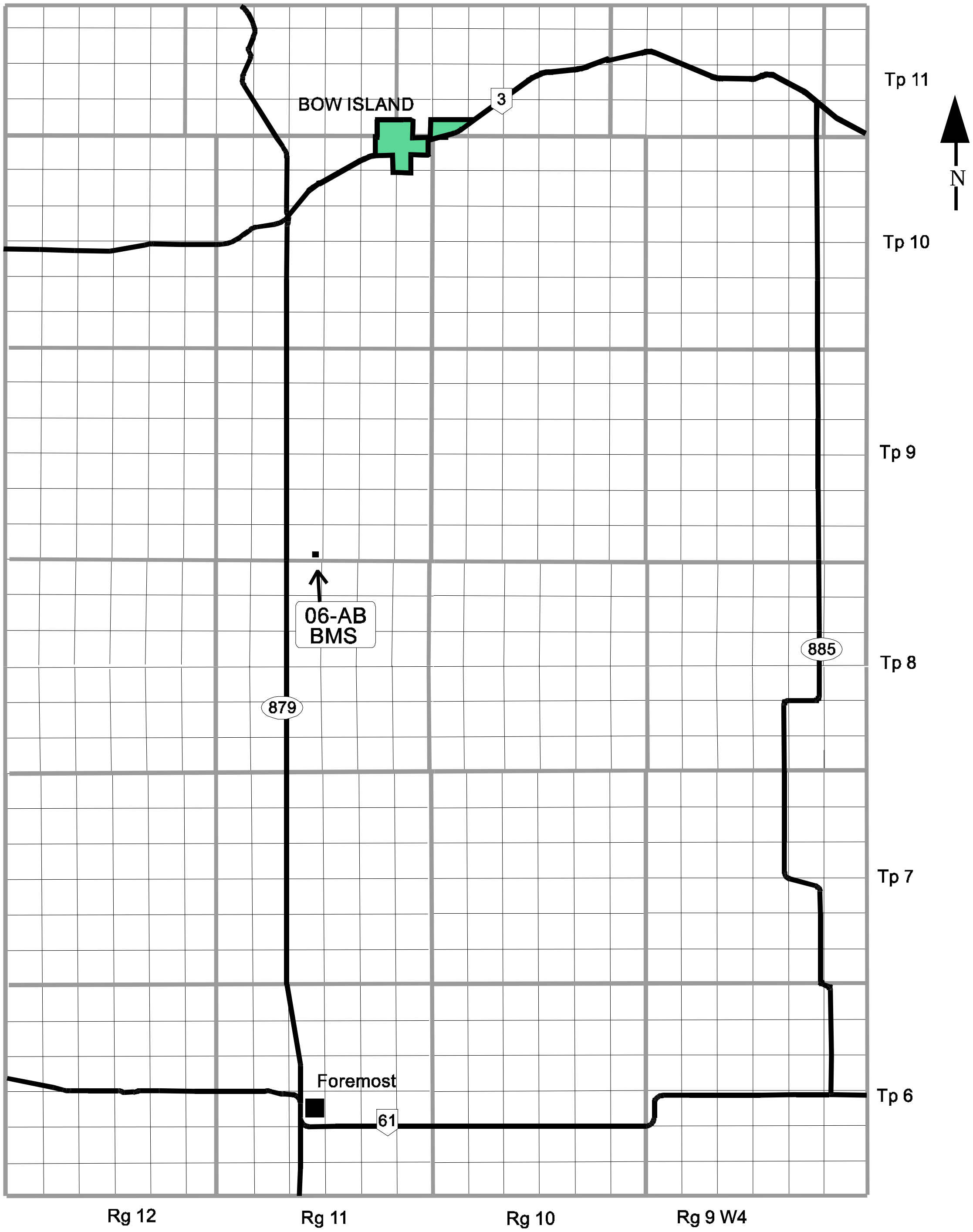

Figure 1. Location of the 06-AB (Bow Island) Benchmark Site in southeastern Alberta.

Detailed Soil Map: During the sampling activities, the morphological features of the soils at all 100 grid points were examined, and they were classified according to the Canadian system (ECSS 1987). A soil map (Fig. 3) was made from this data, with simple mapping units based on combinations of the two dominant soil series. Delineations were made in the field, mainly by distinguishing the convexities from concavities in this low-relief terrain.

Sampling Activities

Four types of sampling activities were conducted to establish the baseline field and pedological characteristics of the Bow Island Benchmark Site. Bulk sampling and pedon sampling for lab analysis were conducted in the fall of 1991. Sampling for aggregate analysis, and for salts and nitrates at depth, were conducted in the spring of 1992. Sampling occurred on cultivated stubble after a wheat crop.

Grid Point Sampling for Baseline Data: A bulk sample of the contemporary Ap horizon was taken at every sampling point. In addition, a sample at approximately 50-60 cm depth (usually a C or 2Ck horizon) was collected at 20% of the sampling points. These were selected in a stratified random manner so as have 2 per column and 2 per row. 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 (1983). About 1 kg of soil was collected from each horizon. Cores (7.5 x 7.5 cm) were taken from 4 main horizons of each pedon by hand operated Uhland sampler as per procedure 2.211 in McKeague (1978). Five cores were taken from the Ap horizon and three from other horizons.

Sampling for Dry Aggregate Size Distribution: The size distribution of dry aggregates was considered a means of quantifying surface soil structure at the Falher Site. Fifteen grid points were selected for sampling in a stratified random manner, so as to be well dispersed across the site and split evenly between the two map units. A volume bulk sample (about 2 kg) of the soil surface to 5 cm depth was collected at each of these points. Timing was judged critical to provide some standardization for temporal comparisons. Thus sampling was done after spring thaw (1992), before the first cultivation, when the soil was reasonably dry.

Deep Sampling for Nitrate and Soluble Salt Analyses: Periodic collection of soil samples from deep cores was chosen as an acceptable compromise methodology for monitoring the potential nitrate-N and soluble salt accumulation at depth in irrigated soils.. Ten grid points were selected, in a stratified random manner, so that 5 were scattered throughout each map unit. Through the efforts of AAFRD (Lethbridge) personnel and equipment, large diameter (3-4 inch) cores to a depth of 210 cm were extracted at each of these points. The cores were logged and sampled in nine intervals: 0-15, 15-30, 30-45, 45-60, 60-90, 90-120, 120-150, 150-180, and 180-210 cm. The samples were immediately shipped to a laboratory facility for drying.

Field Measurements

The baseline set of *in situ* field measurements was begun prior to spring tillage in 1992. The hydraulic conductivity and penetrometer measurements have been repeated two to four times since the site was established. Yield was first measured in late summer, 1992, and will be collected annually if feasible.

Hydraulic Conductivity (Ksat): Saturated hydraulic conductivity was measured with a Guelph Permeameter at two depths (15-25 and 30-40 cm) using 10 cm heads per procedure 56.2.1 of Reynolds (1993). Measurements were made at 30 grid points, selected in a stratified random manner with 15 in each map unit. Results were calculated and recorded in cm/hr, and placed in classes as defined by McKeague *et al.* (1986).

Penetration Resistance and Soil Moisture: Resistance to penetration was measured at 4 depth ranges (0-10, 10-20, 20-30, and 30-40 cm) using the Centre-Cone Penetrometer, operated manually per the user's manual (Star Quality Samplers 1990). Reported results, in MPa, are the averages of five readings per depth per sampling point. Initially, in the fall of 1991, measurements were made at 40 grid points, selected in a stratified random manner, with 20 per map unit. Measurements were repeated in the spring of 1992 at half of these points. Small samples, one from each depth at 30-40% of the selected points, 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.

Crop Yield Sampling: Crop samples to measure yield have been collected every year since the Bow Island Site was established, except in 1995. For the first crop sampling in 1992, twenty grid points were selected in a stratified random manner, with 10 in each map unit. These same points were used for crop sampling in subsequent years. In 1996, four more grid points were added for a total of 24. At the selected points, all above-ground crop material within a 1 m^2 area was clipped at about 1-3 cm above the soil surface. The samples are collected in large porous bags and transported to a threshing facility operated by Alberta Agriculture, Food and Rural Development (AAFRD) near Edmonton. After air drying, the crop samples were threshed to separate grain and residue (straw). Weights of both, expressed as kg ha^{-1}, harvest index (grain weight as % of total dry matter weight) and residue-grain ratio were calculated and recorded.

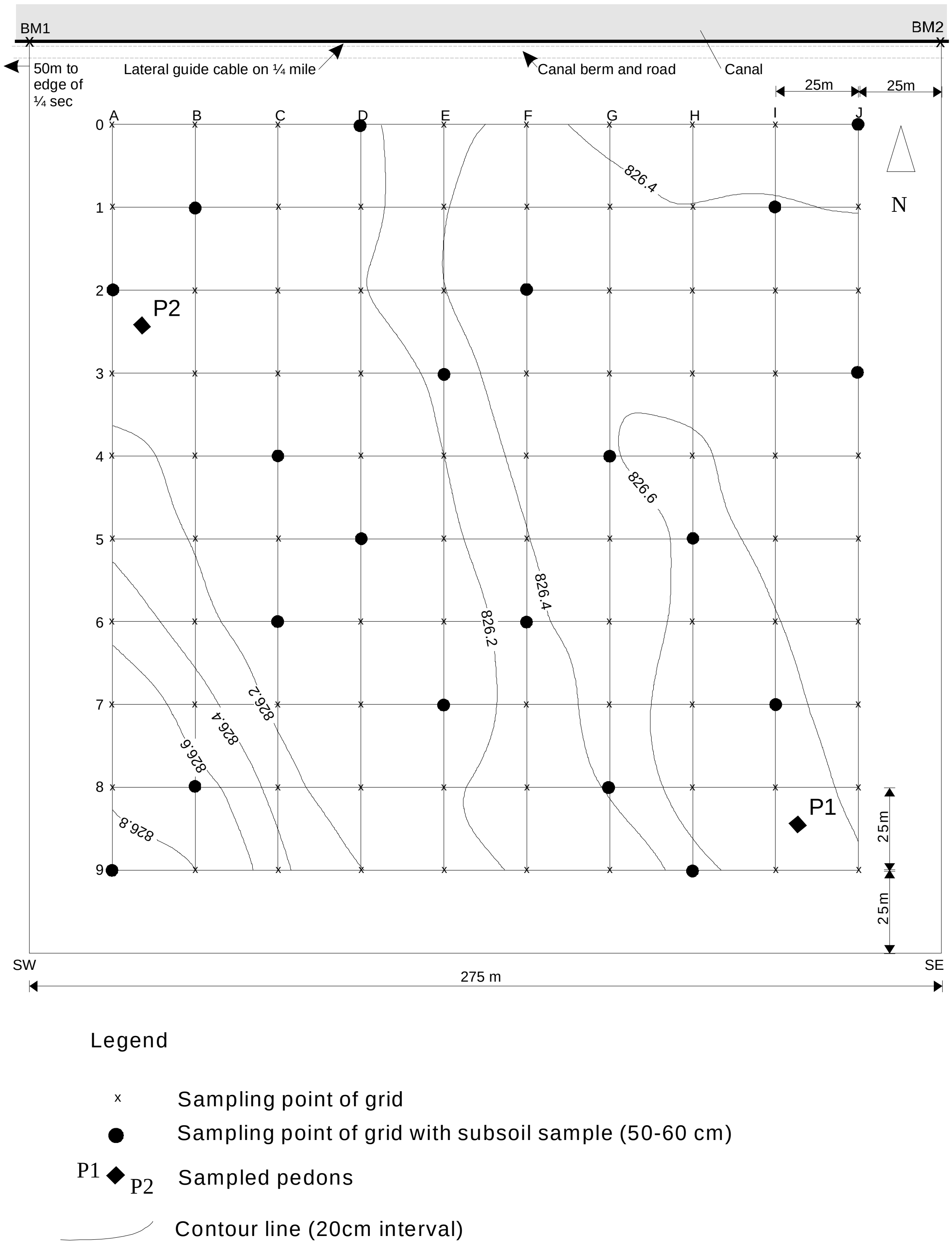

Figure 2. 06-AB Benchmark Site grid plan with pedon locations and contours (interval 0.2 m).

Analytical (Laboratory) Methods

Sample Handling and Preparation: Bulk samples for chemical and physical analyses were air-dried and roller-ground to separate the fine earth fraction (<2mm) from coarse fragments as per procedure 1.2 (McKeague, 1978). Pedon and field samples, after preparation 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 Saskatchewan Land Resource Unit, Saskatoon, for rotary sieve analysis. Samples from the deep cores were dried as soon as possible after collection, ground to separate the fine earth fraction, and shipped to AAFRD's Soils and Animal Nutrition Laboratory (ASANL) in Edmonton for 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, 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 (AOAC 1955) using Se-K_2SO_4 (Keltabs) as the catalyst. Ammonium-N in the distillate was detected colorimetrically with a Kjeltec nitrogen analyzer.

$CaCO_3$ Carbonate 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 <5.5 — 2M NaCl method, per procedure 84-004 in Sheldrick (1984). Cation replacement is by Na, thus Na cation and CEC were not determined. Exchangeable Al and permanent charge CEC (the sum of Ca, Mg, K and Al) were determined on some samples, with detection by atomic absorption spectrophotometry.
- pH 5.5-6.4 — 1M, buffered (pH 7), NH_4OAc steam distillation method (USDA Soil Conservation Service 1984).
- pH ≥6.5 (calcareous soils) — 1M, buffered (pH 7), NH_4Cl steam distillation method (USDA Soil Conservation Service 1984).

Total exchange capacity – the sum of exchangeable Ca, Mg, K, and Na if measured – was also calculated and recorded in the benchmark data sets.

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 HN_4F + 0.025 M HCl), extractable P determined using ammonium molybdate solution, per procedure 84-018 of 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, 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, 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: Selected pedon and grid samples plus deep-core samples below 30 cm were submitted to AAFRD's Soils and Animal Nutrition Laboratory (ASANL) 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.

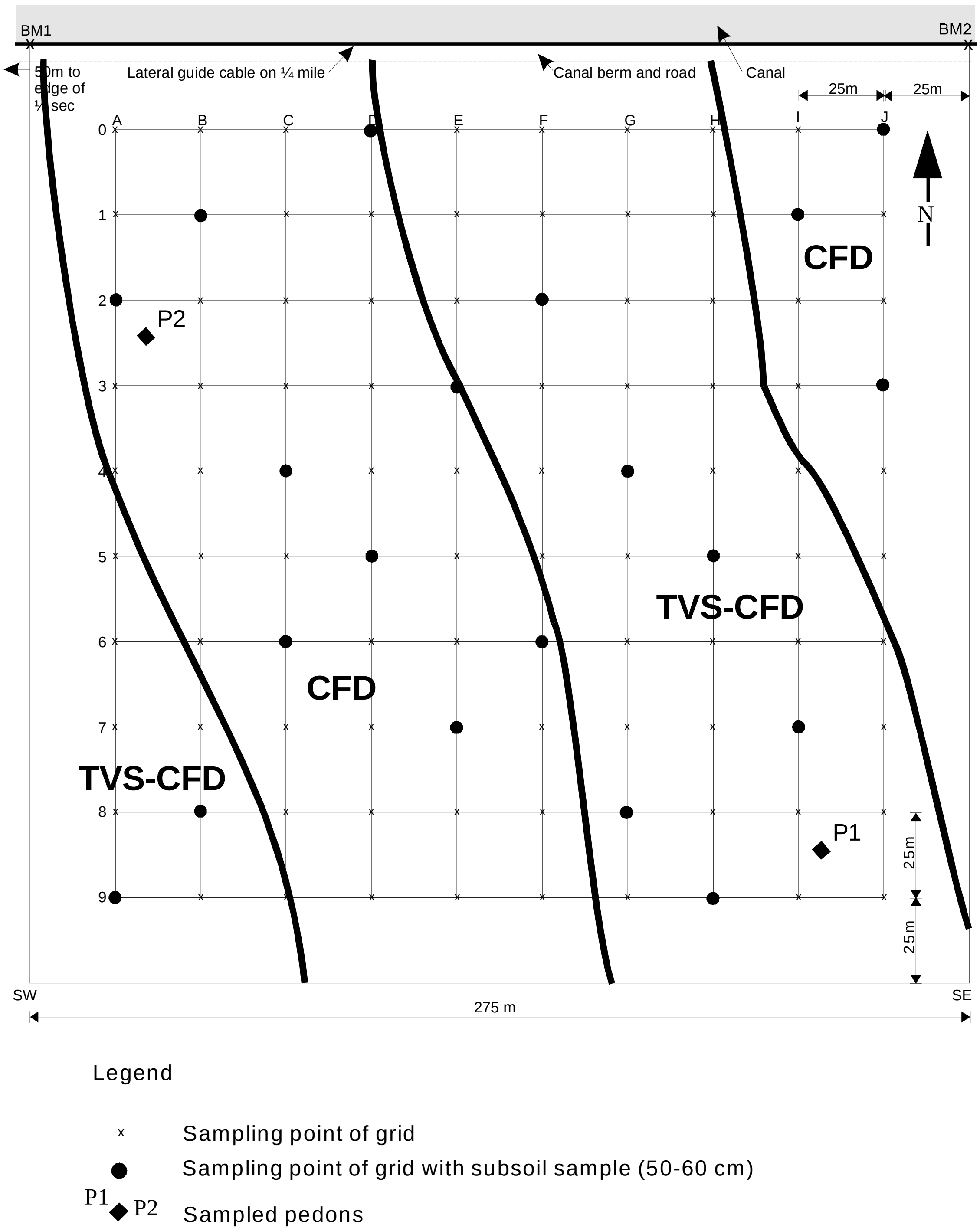

Figure 3. Soil map of 06-AB Benchmark Site (CFD – mainly Cranford series; TVS-CFD – combination of Travers and Cranford soils; see descriptions on page 12).

Nitrate-N Analysis: "Plant-available" or extractable nitrogen (NO_3-N) was measured on all deep-core samples using a standard ASANL test based on ASA Method 33-8.3 (Page *et al*. 1982) and Technicon Industrial Systems (1972, 1973) methods 158-71W and 100-70W. Nitrate was extracted by an NH_4F-H_2SO_4 solution, reduced to nitrite in a copper-cadmium reductor column, reacted with sulfanilimide under acidic conditions, and measured colorimetrically by a Technicon GTpc AutoAnalyzer.

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, glycerolated 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 were recorded.

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 similar to procedure 53.4 by Topp *et al.* (1993).

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

Bulk Density: Only one set of bulk density values was obtained during the baseline sampling at the Falher Site. 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).

Dry Aggregate Size Distribution: Samples were air dried and shipped in pizza-style boxes, with minimum disturbance, to Agriculture and Agri-Food Canada's Saskatchewan Land Resource Unit for rotary sieve analysis. Aggregate distribution was determined, per the procedure of White (1993), using a rotary sieve with screen openings of 53.53, 34.58, 17.51, 7.20, 2.58, 1.30, and 0.50 mm.

AGRONOMICS

Information on the agronomic history and current farming practices was obtained through an interview process using a standard questionnaire. The owner/operator, Tony Crooymans, and his son, Andrew, were interviewed about the Bow Island Site. The following is a summary of the interview data.

Farm History

The land that contains the Bow Island Benchmark Site was purchased from a neighbor in 1972. Consequently, its early farming history is sketchy.

The Early Years: Mr. Crooymans recollected that this land was in a dryland wheat-fallow rotation for many years. A few years prior to changing hands, a flax- or mustard-fallow rotation was adopted. It is likely that fertilizers and pesticides were not used much prior to 1972, and tillage was mainly by one-way discer.

Major Changes: The wheat-fallow rotation was reintroduced after the land changed hands in 1972. The wheat was grown for seed. Chemical pesticides (2-4-D herbicide and seed treatments Dualtreat and Vitavax) were used, perhaps for the first time. The Crooymans also began, at this time, to purposely maintain good residue cover, and incorporate more residues into the soil. They felt that low fertility and erosion had degraded this land.

In 1980, a large lateral-move irrigation system was installed in the field. This allowed a wider diversity of crops, continuous cropping, better residue production, and perhaps the first application of fertilizers. After observing ponding on some parts of the field, it was "subsoiled", in 1982, to a depth of about 46 cm (18 in.) using a home-modified cultivator. This implement was equipped with spikes on shanks spaced about 0.8-0.9 m (2.5-3.0 ft.) apart. While this action did not cause major disruption of the soil horizons, the effects can still be seen in the B horizons.

Cooperator Assessment: The Crooymans were concerned about this piece of land when they purchased it. They felt that fertility was low, and that erosion was an escalating problem. To address these issues, they began with residue management, and later added irrigation and fertilizer into the management. As a result, they felt that yields had increased on this land, and that the yields were now higher than others in the locality. Crop quality stayed about the same – the Crooymans Farm produces high quality registered seed and has won several awards.

Current Management Practices

Crop Rotation System: Through the 1980s and early 1990s, the crop rotation was a fairly structured wheat-wheat-sugar beets-wheat-wheat-canola (flax or beans) rotation. In the sixth year, canola, flax or beans could be grown. Later, in the mid 1990s, sugar beets were dropped from the rotation; they were last grown in 1989. So in 1995, when sugar beets would have normally been grown, the field was planted in small plots to develop a canola hybrid for seed. The 1991 crop was wheat, the 1992 crop canola, and 1993 and 1994 crops wheat.

Equipment: At the time of the interview in 1992, power equipment used on the Crooymans Farm included a large 4-wheel drive tractor (John Deere 8450) and three 2-wheel drive tractors, the largest with front-wheel assist (John Deere 4850, 4640 and 4240). Equipment used for tillage and seeding included: a John Deere cultivator with sweeps and a harrow-packer unit behind, a Melroe cultivator with spikes, an Alloway 12-row cultivator, an International Vibra-shank cultivator with harrows and John Deere hoe drill behind, a John Deere tandem disk, a John Deere 6-bottom plow, a Flexicoil harrow-packer, a land floater/leveler, and a home-built subsoiler. A Vicon field sprayer and a Kirchner 12-row band sprayer were used to apply herbicides. A Zimmatic Lateral-Move irrigation system, comprised of a ½ mi. long series of sprinkler booms with electrically driven wheels about every 50 m and powered by a diesel engine-pump-generator assembly, delivered water from an irrigation canal beneath it to fields totaling ½ mi. wide by 1 mi. long. Harvesting equipment included a John Deere self-propelled swather, a Versatile pull-type swather, John Deere and International pull-type combines, a Speedy bean cutter (6-row), an Alloway defoliator, a John Deere 3-row beet digger, and a Heston 4-row beet digger. Two trucks, International 3-ton and tandem units, were used at that time.

Management Procedures: Table 1 presents a year by year account of "typical" farm management activities based on the rotation in use at the time of the interview (1992). Since then, sugar beets have been dropped from the rotation. An annual diary of actual operational activities is being kept by the farm operator for the duration of the monitoring study.

SOIL AND LANDSCAPE DESCRIPTION

Ecology and Climate

The Bow Island Benchmark Site occurs in the Mixed Grassland Ecoregion of the Prairies Ecozone (Ecological Stratification Working Group 1995, Marshall *et al*. 1996). This semiarid grassland ecoregion forms part of the shortgrass prairie in the Great Plains of North America. The area is influenced by continental climatic conditions, and has cold winters with limited snow cover and warm, semiarid summers (Ecoregions Working Group 1989). Large yearly and daily temperature ranges plus maximum precipitation in summer (June) attest to the continental conditions (Table 2). Temperature extremes also show the variability: the extreme maximum temperature (Medicine Hat A, 108 years of record) was 42.2ºC, the extreme minimum temperature was -46.1ºC (Environment Canada 1998).

The mean annual temperature in this part of the Mixed Grassland Ecoregion is over 5.0ºC (5.5ºC at Medicine Hat, Table 2). Mean summer temperature exceeds 16ºC, and the mean winter temperature is less than -10ºC. Annual precipitation in this area is approximately 300 mm (Table 2). A late summer moisture deficit, caused by low precipitation and high evapotranspiration, is the most striking climatic feature (Ecoregions Working Group 1989).

The Site is located in Soil Correlation Area (SCA) 1 (Alberta Soil Series Working Group 1993). Its agro-climate is classed as 3A, which signifies a moderate moisture limitation for the production of spring-seeded small grains under dryland conditions (Agronomic Interpretations Working Group 1995). Selected climate indices or factors, computed from climate normals (Agronomic Interpretations Working Group 1995) and extrapolated for the general area of the 06-AB Benchmark Site, are:

- P-PE (May to Aug. precipitation minus potential evapotranspiration) – approximately -375.

- EGDD (Effective growing degree days >5 ^{o}C, adjusted for day and growing season length – very close to 1600.

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

Crop Year	Main Activity	Time Frame	Operational Procedures
1. Wheat: and **4. Wheat:**	Spring cultivation	Mid April start	Cultivator with harrow and packer, one pass
	Planting	Late April – early May	Vibra-shank cultivator, harrow and hoe drill, one-pass cultivation and seeding
	Spraying	Early June	Hoe Grass/Triumph for wild oat and broadleaf control
	Irrigation	Mid June – mid August	Lateral-move irrigates slowly length of ½ section
	Cutting/harvesting	Mid Aug. – early September	Swathed, then combined soon after
	Fall cultivation	Mid Sept. on	Disked; then spiked (cultivator) after fall irrigation
	Fall irrigation (optional)	Mid Sept. – early Oct.	More water applied <u>if needed</u>
	Fall fertilization	Late October	26-13-0 broadcast and worked in with harrow-packer
2. Wheat: and **5. Wheat:**	Same activities as above, <u>unless</u>:	Same time frame as above, <u>unless</u>:	Same procedures as above <u>unless sugar beets are grown the next year</u>
	Preparation for sugar beets	Late October	No fertilizer used; land floater/leveler used to smooth the field surface
3. Sugar Beets (Not grown since 1989)	Spring cultivation	Mid April start	Cultivator with harrow and packer, one pass
	Spring fertilizer	Mid April	26-13-0 broadcast and worked in
	Planting	Late April	Row-crop seeder – 56 cm (22 in.) spacing
	Summer cultivation	Late May – early August	Row-crop cultivator, usually three passes (last in early August)
	Spraying	Mid June	Betanol/Betanex for broadleaf weed control
	Irrigation	Late June – late September	Lateral-move irrigates slowly length of ½ section
	Cutting/harvesting	Early – mid Oct.	Defoliator mulches leaves; digger digs beets and loads to trucks
	Fall cultivation	Mid – late Oct.	Cultivator with spikes; spiked 13-15 cm (5-6 in.) deep
	Fall fertilizer	Late October	26-13-0 broadcast and worked in with harrow-packer
4. Canola Flax or **Beans**	Spring cultivation	Mid April start	Cultivator with harrow and packer, one pass
	Planting (1)	Late April – early May	<u>Canola or flax</u> – hoe drill
	Planting (2)	Mid – late May	<u>Beans</u> – row-crop seeder
	Spraying	Mid June	Post-emergent herbicides (Poast + Butril-M + 2-4-D on flax; Basagran on beans) used if needed
	Summer cultivation	Mid June – early August	**Beans only** – row-crop cultivator, usually three passes (last in early August)
	Irrigation	Mid June – mid August	Lateral-move irrigates slowly length of ½ section
	Cutting/harvesting	Early September	Swath and combine canola or flax; undercut, rodweed and combine beans
	Fall cultivation	Late September	Spike cultivate canola or beans; burn or plow (usually plow) flax
	Fall fertilizer	Late October	26-13-0 broadcast and worked in with harrow-packer

Wind is an important part of the regional climate, based on data from the AES climate station at Medicine Hat A (Environment Canada 1998). Mean yearly wind speed is 15 km/h, with only slight variation month to month. The most frequent direction is clearly SW in all months. Extreme hourly wind speeds are often in the 65 to 80 km/h range with a clear October maximum (105 km/h).

Extreme gust speeds over 100 km/h were recorded for all months, with records of 145 km/h or more in two months.

The natural vegetative cover of the Mixed Grassland Ecoregion is dominated by spear grass, blue grama grass and wheat grass (Ecological Stratification Working Group 1995). June grass and dryland sedge are significant associates. Blue grama and spear grass predominate on drier sites, along with dwarf sedges. A variety of shrubs and herbs also occurs, but sagebrush is most abundant. On the driest sites, yellow cactus and prickly pear can be found. The Brown Chernozemic soil group is characteristic of the area (Alberta Land Resource Unit 1995). However, significant areas of Solonetzic soils can also be found in the Ecoregion.

About half of the region is cultivated; the remainder is used for pasture or rangeland (Ecological Stratification Working Group 1995). Most of the cultivated area is in dryland cropping, using mainly a cereal-fallow rotation because of the dry conditions. However, significant areas near rivers and other large water storage projects have been developed for irrigated crop production. Here cereals, oilseeds, forages, and a variety of specialty crops can be grown because of the favorable heat units (EGDD).

Table 2. Selected temperature and precipitation normals (1961-90) for Medicine Hat A, AB (50°01'N 110°43'W, 717 m ASL) (Environment Canada 1998)

Month/ Year	Daily Mean Temp. (°C)	Daily Max. Temp. (°C)	Daily Min. Temp. (°C)	Total Precip. (mm)	Rainfall (mm)	Snowfall (cm)	Extreme Daily Rainfall[1] (mm)
Jan.	-10.7	-5.1	-16.4	17.3	0.5	20.9	5.1
Feb.	-6.8	-1.1	-12.7	10.3	0.2	12.5	5.1
Mar.	-1.2	4.7	-7.1	16.0	2.9	15.0	24.9
Apr.	6.3	13.0	-0.4	26.0	12.5	14.3	24.6
May	12.4	19.3	5.5	42.3	40.0	2.3	40.1
June	17.1	24.0	10.1	56.4	56.4	0.0	71.6
July	19.8	27.3	12.2	40.9	40.9	0.0	57.4
Aug.	19.2	26.8	11.4	30.6	30.6	0.0	121.9
Sep.	13.0	20.3	5.6	36.3	34.2	2.1	118.6
Oct.	7.3	14.4	0.2	15.5	8.7	7.1	42.4
Nov.	-2.1	3.8	-8.1	14.8	2.3	14.8	22.1
Dec.	-8.6	-3.0	-14.3	16.2	0.8	19.3	11.2
Year	5.5	12.0	-1.2	322.6	230.0	108.2	N/A

[1] Highest recorded rainfall over the period of record (1883 to 1990).

Terrain

The Bow Island Benchmark Site is located on the Etzikom Plain, the southern-most of a series of plains that comprise the Eastern Alberta Plains (Pettapiece 1986). This physiographic district was further divided into Land Systems (McNeil *et al*. 1994), with 06-AB Site occurring on the Yellow Lake Plain. The surficial material of this area is glaciolacustrine blanket to veneer over morainal material (till). The landform surface form is level to undulating (McNeil *et al*. 1994). Underlying bedrock is the non-marine Judith River Formation, Foremost member, which consists of sandstone, siltstone and mudstone (Irish 1968, Green 1972, Eberth and Ryan 1992).

The nearly level to undulating topography at the Bow Island Benchmark Site has some discernible internal relief. The site diagram (Fig. 2) shows this terrain in plan view. While the overall slope gradient (southeast-northwest) is only 0.4%, some short slopes are as steep as 1.5-2.0%. The higher, or convex, parts of the terrain, coincident with the TVS-CFD soil pattern in Fig. 3, have exposed till and thin glaciolacustrine sediment overlying the till. Lower lying or concave localities, coincident with the CFD soil areas in Fig. 3, have nearly level (slightly concave) slopes and marginally thicker glaciolacustrine sediment with no exposed till.

The glacial till is loam-silt loam (L-SiL) textured, and of continental origin. At depths of over 1m, it is weakly calcareous (3-5% $CaCO_3$ equivalent) and weakly saline (4-6 dS m^{-1}). Carbonate content of upper till layers, just below the soil solum, tends to be much higher (5-12% $CaCO_3$ equivalent). Salinity in the till layers above 1m is low (E.C. <1-2 dS m^{-1}).

The shallow layer of glaciolacustrine sediment caps the till across most of the site. At its thickest it ranges from 50-90 cm (occasionally 100 cm) in the CFD area (Fig. 3). It is much thinner and discontinuous in the TVS-CFD area, commonly ranging from 0-60 cm thick. This virtually stone-free material is SiL textured, moderately calcareous (5-15% $CaCO_3$ equivalent), and non-saline.

Soil Patterns

Figure 3 shows the relatively simple soil pattern of the Bow Island Benchmark Site. A description of the map units follows.

The **CFD soil unit**, in the lower-lying parts of the site, is dominated by the Cranford (CFD) soil series. This series is defined as an Orthic Brown Chernozemic soil developed on shallow (30-100 cm thick), medium textured, glaciolacustrine sediments overlying till. A description of the sampled pedon (P2) is given in Appendix A. Other soils found in this unit are similar to CFD: Calcareous Brown, with a Bmk horizon; Chin (CHN) series, where the glaciolacustrine material exceeds 100 cm in thickness (barely); and some fine textured variants, with SiCL-SiC layers at depth. Till soils were not found here.

The **TVS-CFD soil unit**, on the upper (convex) parts of the site, is dominated by the Travers (TVS) soil series. CFD is subdominant, and occurs mainly on the slopes of the unit. The TVS series is defined as a Calcareous Brown Chernozemic soil developed on till. Most other soils found in this unit are similar to either TVS or CFD. These included Maleb (MAB) series, an Orthic Brown on till, and the Calcareous Brown variant of CFD.

No gleyed or Gleysolic soils were found on the site, even though there is occasional ponding resulting from irrigation. In addition, Solonetzic or solonetzic-like soils were not found on the site, despite the presence of salts at depth in the till.

BENCHMARK SITE DATA

Copious amounts of baseline and reference data have been collected on the benchmark sites. This has been followed up with repeat sampling, on about a five-year frequency, to look for potential changes in soil quality. In addition, on-going measurements on yield and some *in situ* field properties are being made.

Most of this data has been compiled and entered into a rudimentary relational database. 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 tables (files) developed in dBase IV. Each file contains similar types of data on similar kinds of soil and landscape entities. The files can be linked to perform analyses across data types. As in the table below, data on a particular site can be extracted from the database and analyzed according to soil or map unit types, terrain entities, horizons or depth ranges, dates, years, crop types, and so on. Requests for data from the 06-AB Site (Bow Island) and the other western sites should be channeled through Dr. G.M. Coen at the Lethbridge Research Centre.

One way to analyze the Bow Island data is to compare soil attributes according to the two map units, CFD and TVS-CFD. Table 3 lists some descriptive statistics for selected soil properties, separated into these two groups. This reduces the number of replications (n) for any particular property, but provides a picture of field variability corresponding to the subtle topographical differences, perhaps much like a manager might view it.

Note that there are analytical data for only three B horizon samples taken at grid points. The methodology – collecting subsoil samples from about 50-60 cm depth at 20 grid points (see page 4) – was a factor in this outcome. Ck or 2Ck horizons were commonly encountered at this depth, except for the three occurrences of B horizon, all in the CFD soil unit where thicker soil sola were often found.

Table 3. Descriptive statistics for selected soil attributes of the Bow Island Benchmark Site.

Variable	n	Mean	Std. Dev.	Range	Median	Mode
Ap horizon: **CFD soil unit**	all topsoil samples from grid points and CFD pedon					
Thickness (cm)	52	14	2	12 - 20	14	13
pH ($CaCl_2$)	52	7.0	0.4	6.3 - 7.7	7.1	7.4
Organic C (%)	52	1.15	0.07	0.96 - 1.40	1.14	1.16
Total N (%)	52	0.12	0.01	0.09 - 0.14	0.12	0.12
Total Exch. Cap. (cmol kg^{-1})	52	20.7	3.0	15.4 - 28.1	20.1	20.1
Available K (ug g $soil^{-1}$)	52	511	121	250 - 771	521	396
Sand (%)	6	22	3	19 - 26	22	N/A
Silt (%)	6	56	2	52 - 59	57	N/A
Clay (%)	6	22	2	19 - 24	22	24
Ap horizon **TVS-CFD soil unit**	all topsoil samples from grid points and TVS pedon					
Thickness (cm)	50	14	2	10 - 19	14	12
pH ($CaCl_2$)	50	7.4	0.3	6.2 - 7.7	7.5	7.6
Organic C (%)	50	1.16	0.09	0.82 - 1.43	1.15	1.11
Total N (%)	50	0.12	0.01	0.11 - 0.14	0.12	0.12
Total Exch. Cap. (cmol kg^{-1})	50	25.5	2.7	17.8 - 28.9	26.7	27.6
Available K (ug g $soil^{-1}$)	50	412	83	234 - 596	405	319
Sand (%)	6	27	2	24 - 30	27	27
Silt (%)	6	53	2	51 - 55	53	51
Clay (%)	6	20	3	16 - 23	20	N/A
B horizon (Bm): **CFD soil unit**	sampled from about 40-60 cm depth at selected grid points					
pH ($CaCl_2$)	3	7.2	0.3	7.0 - 7.5	7.1	N/A
Organic C (%)	3	0.89	0.08	0.81 - 0.95	0.93	N/A
Total N (%)	3	0.08	0.01	0.07 - 0.08	0.08	0.08
Total Exch. Cap. (cmol kg^{-1})	3	22.9	0.6	22.3 - 23.4	23.0	N/A
Available K (ug g $soil^{-1}$)	3	187	48	146 - 239	175	N/A
Parent material (Ck, 2Ck): **CFD soil unit**	sampled from about 40-70 cm depth at selected grid points					
pH ($CaCl_2$)	8	7.9	0.1	7.7 - 8.0	7.8	7.8
Organic C (%)	8	0.77	0.15	0.97 - 1.53	0.74	N/A
Total N (%)	8	0.06	0.01	0.05 - 0.07	0.06	0.05
$CaCO_3$ Equivalent (%)	8	11.06	2.09	7.17 - 14.42	10.73	10.49
Total Exch. Cap. (cmol kg^{-1})	8	26.4	4.5	21.8 - 34.7	25.5	N/A
Available K (ug g $soil^{-1}$)	8	103	27	68 - 149	100	100
Parent material (Ck, 2Ck): **TVS-CFD soil unit**	sampled from about 40-70 cm depth at selected grid points					
pH ($CaCl_2$)	9	8.0	0.1	7.8 - 8.1	7.9	7.9
Organic C (%)	9	0.67	0.15	0.48 - 0.90	0.71	N/A
Total N (%)	9	0.05	0.01	0.04 - 0.07	0.04	0.04
$CaCO_3$ Equivalent (%)	9	9.64	2.69	6.21 - 13.30	9.77	N/A
Total Exch. Cap. (cmol kg^{-1})	9	28.3	2.2	24.1 - 31.6	28.0	N/A
Available K (ug g $soil^{-1}$)	9	103	13	85 - 130	102	N/A
Selected in situ field measurements: **CFD soil unit**	measured at standard depths at selected grid points					
Ksat (cm h^{-1}): 15-25 cm depth	42	0.99	0.78	0.08 - 4.26	0.81	0.75
30-40 cm depth	42	1.31	0.68	0.10 - 2.95	1.20	0.75
Resistance (MPa): 10-20 cm	33	1.1	0.4	0.2 - 2.1	1.0	1.0
20-30 cm	33	1.1	0.3	0.4 - 2.1	1.1	1.0
30-40 cm	33	1.2	0.6	0.4 - 4.1	1.1	1.1

Table 3 continued.

Variable	n	Mean	Std. Dev.	Range	Median	Mode
Selected in situ field measurements: **TVS-CFD soil unit** measured at standard depths at selected grid points						
Ksat (cm h^{-1})**:** 15-25 cm depth	48	1.05	0.66	0.18 - 3.11	0.86	1.00
30-40 cm depth	48	1.59	0.95	0.26 - 4.76	1.47	1.50
Resistance (MPa): 10-20 cm	46	1.0	0.4	0.3 - 1.7	0.9	0.9
20-30 cm	46	1.0	0.4	0.3 - 1.9	1.0	1.2
30-40 cm	46	0.9	0.4	0.2 - 2.0	0.9	0.7
Crop yield measurements: **CFD soil unit** one m^{-2} cuts at selected grid points						
Wheat (3 yr.): Grain (kg ha^{-1})	32	6333	937	4574 - 8126	6416	5520
Residue (kg ha^{-1})	32	7433	1187	5248 - 9803	7245	6412
Harvest Index (%)	32	46.1	4.9	36.0 - 52.4	45.9	44.6
Residue-Grain Ratio	32	1.20	0.25	0.91 - 1.78	1.19	1.24
Canola (1 yr.) Grain (kg ha^{-1})	10	2702	530	1912 - 3814	2591	N/A
Residue (kg ha^{-1})	10	8659	1355	7020 - 11153	8257	N/A
Harvest Index (%)	10	23.8	2.6	19.4 - 26.8	24.2	N/A
Residue-Grain Ratio	10	3.26	0.49	2.73 - 4.16	3.16	N/A
Crop yield measurements: **TVS -CFD soil unit** one m^{-2} cuts at selected grid points						
Wheat (3 yr.): Grain (kg ha^{-1})	32	6200	1056	3993 - 8425	6111	N/A
Residue (kg ha^{-1})	32	7347	1086	5323 - 9063	7409	8632
Harvest Index (%)	32	45.7	4.6	38.4 - 52.9	44.9	42.4
Residue-Grain Ratio	32	1.21	0.22	0.89 - 1.60	1.23	1.36
Canola (1 yr.) Grain (kg ha^{-1})	10	2598	544	1715 - 3271	2634	N/A
Residue (kg ha^{-1})	10	8098	1396	6476 - 10544	7732	N/A
Harvest Index (%)	10	24.2	2.5	20.5 - 28.5	23.9	N/A
Residue-Grain Ratio	10	3.17	0.43	2.51 - 3.87	3.20	N/A
Selected deep core sample results: **CFD soil unit** sampled at selected grid points						
EC (dS m^{-1}): 60-90 cm	5	0.6	0.3	0.4 - 1.1	0.5	0.5
90-120 cm	5	0.9	0.5	0.5 - 1.8	0.7	0.7
120-150 cm	5	1.4	1.6	0.4 - 4.3	0.8	N/A
150-180 cm	5	1.5	2.1	0.4 - 5.2	0.7	0.4
180-210 cm	5	2.2	1.9	0.5 - 5.4	1.7	N/A
NO_3-N (ppm): 0-15 cm	5	10	6	5 - 21	9	N/A
15-30 cm	5	8	4	5 - 14	7	N/A
45-60 cm	5	3	3	0 - 6	1	1
90-120 cm	5	2	1	0 - 3	2	2
150-180 cm	5	4	5	0 - 12	4	0
180-210 cm	5	5	7	0 - 17	2	0
Selected deep core sample results: **TVS-CFD soil unit** sampled at selected grid points						
EC (dS m^{-1}): 60-90 cm	5	1.8	1.3	0.9 - 3.9	1.0	0.9
90-120 cm	5	4.8	0.9	4.0 - 6.2	4.7	N/A
120-150 cm	5	5.5	0.6	5.0 - 6.6	5.2	5.2
150-180 cm	5	5.8	0.5	5.0 - 6.4	5.8	5.8
180-210 cm	5	5.4	0.3	5.0 - 5.8	5.4	5.4
NO_3-N (ppm): 0-15 cm	5	11	4	8 - 18	10	N/A
15-30 cm	5	14	11	8 - 33	9	9
45-60 cm	5	15	10	2 - 30	17	17
90-120 cm	5	4	3	1 - 8	3	3
150-180 cm	5	9	17	0 - 40	2	0
180-210 cm	5	11	20	0 - 46	0	0

From a more academic point of view, meaningful relationships might also be found if the data were analyzed according to the soil series found at each grid point. For example, NO_3-N tends to be much higher in the TVS-CFD map unit that in the CFD unit, even though the data sets have mediocre statistical distributions. Perhaps small cracks and channels, commonly found in till soils such as TVS, convey water and NO_3-N to deeper layers in the soil. Analyzing the data by CFD vs. TVS soil series might clarify or crystallize potential relationships, and improve the statistical distribution of this data. The Benchmark Site database can contribute to this need.

Similarly, adding moisture content to the analysis of penetration resistance data would likely make those results more meaningful. In addition, the wheat yield data summary above combines the results for two varieties. The statistical distribution may improve if they were analyzed independently. In summary, the Benchmark Site database was designed to serve a variety of demands such as illustrated here.

REFERENCES

Agronomic Interpretations Working Group. 1995. Land suitability rating system for agricultural crops: 1. Spring-seeded small grains. W.W. Pettapiece (ed.). Agriculture and Agri-Food Canada, Centre for Land and Biological Resources Research, Ottawa, ON. Tech. Bull. 1995-6E, 90 pp. + maps.

Alberta Land Resource Unit. 1995. Soil group map of Alberta. Agriculture and Agri-Food Canada and Alberta Agriculture, Food and Rural Development, Edmonton, AB. Map.

Alberta Soil Series Working Group. 1993. Alberta soil names: Generation 2. User's handbook. L.J. Knapik and J.A. Brierley (eds.). Alberta Research Council, Publications, Edmonton, AB. 142 pp. + map.

AOAC (Association of Official Agricultural Chemists). 1955. Official methods of analysis. Eighth ed. Washington, D.C.

Bascombe, C.L. 1961. Calcimeter for routine use on soil samples. Chem. Ind., Part II: 1826-1827.

Cihacek, L.J. and Bremner, J.M. 1979. A simplified ethylene glycol monoethyl ether procedure for assessment of surface area. Soil Sc. Soc. Am. J. 43:821-822.

Day, J.H. (ed). 1983. The Canada Soil Information System (CanSIS). Manual for describing soils in the field. Expert Committee on Soil Survey. 1982 revised ed. Agric. Can., Research Br., L.R.R.I. Contribution No. 82-52. 97 pp. + appendices.

Eberth, D.A. and M. Ryan. 1992. Stratigraphy, depositional environments and paleontology of the Judith River and Horseshoe Canyon Formations (Upper Cretaceous), Southern Alberta, Canada. Field trip guide book. American Assoc. of Professional Geologists. 107 pp.

Ecological Stratification Working Group. 1995. A national ecological framework for Canada. Agriculture and Agri-Food Canada, Centre for Land and Biological Resources Research and Environment Canada, State of the Environment Directorate, Ottawa, ON. 125 pp. + map.

Ecoregions Working Group. 1989. Ecoclimatic regions of Canada, first approximation. Ecoregions Working Group of the Canada Committee on Ecological Land Classification. Env. Can., Canadian Wildlife Service, Ottawa, ON. Ecological Land Classification Series, No. 23, 119 pp and map.

ECSS (Agriculture Canada Expert Committee on Soil Survey). 1987. The Canadian system of soil classification. 2nd ed. Agric. Can. Publ. 1646. 164 pp.

Environment Canada, Atmospheric Environment Services. *Canadian Climate Normals 1961-1990* [Online]. (1998, February 12). Available HTTP: http://www.cmc.doe.ca/climate/normals/ALTAP005.HTM. [April 1, 1998].

Green, R. 1972. Geological map of Alberta. Research Council of Alberta, Map 35.

Irish, E.J.W. 1968. Geology-Foremost, Alberta. Geological Survey of Canada. Map 22-1967.

Knudsen, D., Peterson, G.A. and Pratt, P.F. 1982. Lithium, sodium, and potassium. Pages 225-246 in A.L. Page (ed.) Methods of soil analysis part 2 chemical and microbiological properties, 2nd edition. American Society of Agronomy. Madison, Wisconsin.

Kodama, H., Scott, G.C. and Miles, N.M. 1977. X-ray quantitative analysis of minerals in soils. Research Branch, Agriculture Canada, Ottawa, ON.

Marshall, I.B., Smith, C.A. and Selby, C.J. 1996. A national framework for monitoring and reporting on environmental sustainability in Canada. Environmental Monitoring and Assessment 39: 25-38.

Mathur, S.P. and Wang, C. (eds). 1991. Soil quality in the Canadian context. Research Branch, Agric. Can., LRRC Contrib. No. 89-12, 62 pp.

McKeague, J.A. (ed.) 1978. Manual on soil sampling and methods of analysis, 2nd edition. Can. Soil Sci. Soc.

McKeague, J.A., Wang, C. and Coen, G.M. 1986. Describing and interpreting the macrostructure of mineral soils - a preliminary report. Tech. Bull. 1986-2E, Research Branch, Agric. Can., Ottawa. 47 pp.

McNeil, R.L., Howitt, R.W., Whitson, I.R., and Chartier, A.G. 1994. Soil survey of the County of Forty Mile No. 8, Alberta. Alberta Research Council, Environmental Research and Engineering Department, Edmonton, AB. Alberta Soil Survey Report No. 54. 82 pp. + 8 maps.

Page A.L., Miller, R.H. and Keeney, D.R. (eds.). 1982. Methods of soil analysis part 2 chemical and microbiological properties, 2nd edition. American Society of Agronomy, Madison, Wisconsin.

Pettapiece, W.W. 1986. Physiographic subdivisions of Alberta. Agric. Can., Research Br., L.R.R.C. Map.

Reynolds, W.D. 1993. Saturated hydraulic conductivity: field measurement. Pages 599-613 in M.R. Carter (ed.). Soil sampling and methods of analysis. Lewis Publishers, Boca Raton, Florida.

Sheldrick, B.H. 1984. Analytical methods manual. LRRI Contrib. No. 84-30, Research Br., Agric. Can., Ottawa.

Sheldrick, B.H. and Wang, C. 1993. Particle-size distribution. Pages 499-511 in M.R. Carter (ed.). Soil sampling and methods of analysis. Lewis Publishers, Boca Raton, Florida.

Star Quality Samplers. 1990. Centre Cone Penetrometer. Use and interpretation information. Edmonton, AB. 7 pp.

Technicon Industrial Systems. 1972. Nitrate and nitrite in water and seawater. Industrial Method No. 158-71W/Tentative.

Technicon Industrial Systems. 1973 Nitrate and nitrite in water and wastewater. Industrial Method No. 100-70W.

Topp, G.C., Galganov, Y.T., Ball, B.C., and Carter, M.R. 1993. Soil water desorption curves. Pages 569-579 in M.R. Carter (ed.). Soil sampling and methods of analysis. Lewis Publishers, Boca Raton, Florida.

USDA (United States Department of Agriculture) Soil Conservation Service. 1984. Procedures for collecting soil samples and methods of analysis for soil survey. Soil Survey Investigations Rpt. No. 1, 68 pp.

White, W.M. 1993. Dry aggregate distribution. Pages 659-662 in M.R. Carter (ed.). Soil sampling and methods of analysis. Lewis Publishers, Boca Raton, Florida.

APPENDIX A: PEDON DESCRIPTIONS

Pedons representing the two major soils of the site were described and sampled in detail when the site was established. Locations of the two pedons are shown in Fig. 2. 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: TRAVERS SERIES (TVS)

ID and Location:	06-AB, Pedon 1 (P1, Figure 2); LSD2-SE4-9-11-W4
Described by:	B.D. Walker; October 22, 1991
Classification	Calcareous Brown Chernozem (ECSS 1987)
Parent material:	Medium textured (coarse loamy), weakly calcareous, weakly saline till
Landscape:	Nearly level; upper part of “knoll” with gentle slope (1.0%) towards the southeast
Drainage:	Well drained
Land use:	Irrigated cropland; wheat-wheat-sugar beets-wheat-wheat-canola (flax or beans) rotation

Horizon	Depth (cm)	Description
Apk	0-16	Brown to dark brown (10YR 4/2.5 m), brown to grayish brown (10YR 5/2.5 d); silt loam; weak, very fine to coarse, subangular blocky; very friable; plentiful, micro & very fine, random roots; many, micro to fine pores; moderate effervescence; 2% gravels & cobbles; clear, wavy boundary; 12-20 cm thick; alkaline.
Bmku	16-32	Dark brown (10YR 3/3 m); silt loam; very weak, medium & coarse, subangular blocky and very weak, medium, prismatic; friable; plentiful, micro & very fine, random roots; few, micro to fine pores; moderate effervescence; 2% gravels & cobbles; abrupt, wavy boundary; 10-21 cm thick; alkaline.
Ck1	32-63	Brown (10YR 5/3 m); loam; very weak, medium & coarse, subangular blocky; friable; few, micro to very fine roots; few, micro & very fine pores; strong effervescence; many, medium & coarse, very friable, pale brown (10YR 6/3), random streaks and irregular spots of secondary carbonate; 2% gravels & cobbles; clear, irregular boundary; 28-50 cm thick; alkaline.
Ck2	63-102	Olive brown (2.5Y 4/3 m) to brown (10YR 5/3 m); loam; very weak, medium, coarse & very coarse, subangular blocky; friable; few, micro & very fine roots; common, micro & very fine pores; moderate effervescence; 5% gravels & cobbles; abrupt, irregular boundary; 31-120 cm thick; alkaline.
Csk	102-175	Olive brown (2.5Y 4/3 m); silt loam; weak, medium, coarse & very coarse, subangular blocky; friable; few, micro & very fine roots; common, micro & very fine pores; many, medium & coarse, light gray (10YR 7/2), irregular, gypsum nodules throughout matrix; moderate effervescence; 5% gravels & cobbles; alkaline.

Other features: Bmk**u** horizon disrupted by deep ripping (“subsoiled” in 1982 with spikes on shanks spaced 2.5-3.0 ft. apart);
rooting penetration depth 120 cm;
carbonate spots and streaks only visible in lower part of Ck1 horizon.

Table 4. Selected chemical and physical characteristics of the Travers (TVS) profile (Pedon 1).

Horizon	Depth (cm)	pH ($CaCl_2$)	Organic C (%)	Total N (%)	$CaCO_3$ Equiv. (%)	E.C. (dS m^{-1})	Sand (%)	Silt (%)	Clay (%)
Apk	0-16	7.6	1.13	0.11	2.14	0.4	30	51	19
Bmku	16-32	7.7	1.10*	0.11	Error	0.4	32	53	15
Ck1	32-63	7.9	1.53	0.09	7.53	0.4	34	43	23
Ck2	63-102	8.1	1.18	0.05	3.80	0.4	34	44	22
Csk	102-175	7.9	0.50*	0.03	Error	4.3	35	54	11

* Estimated values – the $CaCO_3$ data for this profile is suspect and has affected the Organic C calculation. Organic C contents of subsurface horizons in Pedon 2 are much closer to expected values. The $CaCO_3$ analysis will be redone on the affected samples.

PEDON 2: CRANFORD SERIES (CFD)

ID and Location:	06-AB, Pedon 2 (P2, Figure 2); LSD2-SE4-9-11-W4
Described by:	B.D. Walker; October 22, 1991
Classification	Orthic Brown Chernozem (ECSS 1987)
Parent material:	Medium textured (coarse loamy), moderately calcareous, glaciolacustrine veneer overlying medium textured (coarse loamy), weakly calcareous, weakly saline till
Landscape:	Level; lower-lying (slightly concave) area sloping slightly (0.5%) towards the southwest
Drainage:	Well drained
Land use:	Irrigated cropland; wheat-wheat-sugar beets-wheat-wheat-canola (flax or beans) rotation

Horizon	Depth (cm)	Description
Ap	0-14	Dark grayish brown (10YR 4/2 m), brown (10YR 5/3 d); silt loam; weak, very fine to coarse, subangular blocky; very friable; plentiful, micro & very fine roots; many, micro to fine pores; clear, wavy boundary; 11-18 cm thick; alkaline.
Bmu	14-34	Brown (10YR 4/3 m) to dark brown (10YR 3/2.5 m); silt loam; very weak, medium & coarse, subangular blocky; friable; plentiful, micro & very fine roots; common, micro to fine pores; clear, wavy boundary; 17-24 cm thick; alkaline.
Bm	34-41	Dark brown (10YR 3/3 m); silt loam; many, very weak, medium & coarse, subangular blocky; very friable; plentiful, micro & very fine roots; common, micro to fine pores; abrupt, wavy boundary; 5-14 cm thick; alkaline.
Ck1	41-49	Brown (10YR 5/3 m); silt loam; very weak, medium & coarse, subangular blocky; very friable; plentiful, micro to very fine roots; many, micro to fine pores; strong effervescence; homogenous secondary carbonate areas; abrupt, wavy boundary; 3-13 cm thick; alkaline.
Ck2	49-65	Olive brown (2.5Y 4/3 m); silt loam; very weak, medium & coarse, subangular blocky; very friable; plentiful, micro & very fine roots; many, micro & very fine pores; moderate effervescence; abrupt, wavy boundary; 4-18 cm thick; alkaline.
2Ck1	65-110	Olive brown (2.5Y 4/3 m); loam; massive; firm; few, micro & very fine roots; many, micro & very fine pores; moderate effervescence; many, medium, friable, pale brown (10YR 6/3), irregular spots of secondary carbonate; 5-10% gravels; gradual, irregular boundary; 30-65 cm thick; alkaline.
2Ck2	110-160	Dark grayish brown (2.5Y 4/2 m); loam; massive grading to weak, medium blocky; firm; few, micro & very fine roots; common, micro & very fine pores; moderate effervescence; 5-10% gravels; clear,wavy boundary; 35-55 cm thick; alkaline.
2Csk	160-175	Dark grayish brown (2.5Y 3.5/2 m); loam; massive grading to weak, medium blocky; firm; few, micro & very fine pores; many, medium & coarse, very pale brown (10YR 7/3), plate-like, gypsum nodules and slat veins throughout matrix; strong effervescence; 5-10% gravels; alkaline.

Other features: Bm**u** horizon disrupted by deep ripping ("subsoiled" in 1982 with spikes on shanks spaced 2.5-3.0 ft. apart);
rooting penetration depth 160 cm;

Table 5. Selected chemical and physical characteristics of Cranford (CFD) profile (Pedon 2).

Horizon	Depth (cm)	pH ($CaCl_2$)	Organic C (%)	Total N (%)	$CaCO_3$ Equiv. (%)	E.C. (dS m^{-1})	Sand (%)	Silt (%)	Clay (%)
Ap	0-14	7.2	1.15	0.12	0.08	5.2*	21	58	21
Bmu	14-34	7.1	0.93	0.09	0.04	0.3	21	58	21
Bm	34-41	7.4	0.89	0.09	0.32	0.3	16	62	22
Ck1	41-49	7.7	0.88	0.08	15.03	0.3	15	71	14
Ck2	49-65	7.8	0.74	0.06	7.89	0.3	24	63	13
2Ck1	65-110	7.9	0.65	0.05	10.36	0.4	31	49	20
2Ck2	110-160	8.1	0.53	0.03	5.1	0.4	42	39	19
2Csk	160-175	7.8	0.47	0.02	3.83	3.9	41	39	20

* Sample should be re-analyzed due to higher than expected value (note pH).