BENCHMARK SITE DOCUMENTATION
04-AB (MUNDARE, ALBERTA)

SOIL QUALITY EVALUATION PROGRAM

Site Description Report

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Agriculture and Agri-Food Canada
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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 1980's in response to the sustainable agriculture issue (Mathur and Wang 1991). The popular opinion was that the value of agricultural soil resources had deteriorated, and may continue to decline, under conventional farming practices. The rate of decline was only speculative. Baseline data sets with which to make such evaluations weren't available for many regions. Information about problem soils tended to be plentiful; much less was known about the "medium to good quality" farmlands that dominate many agricultural regions.

In 1988 Agriculture and Agri-Food Canada's (AAFC) 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. The National Soil Conservation Program adopted this study nationally, in 1990, as part of the Soil Quality Evaluation Program managed by CLBRR (Acton 1994). The study was labelled Soil Quality Benchmark Sites (SQUBS).

A network of 23 benchmark-monitoring sites was established across Canada by late 1992 (Wang *et al.* 1994). Various land, soil and air characteristics were to be monitored for at least 10 years. The Mundare site, coded 04-AB, was established in October 1992. It represents Black soils of the Aspen Parkland Ecoregion. The landscape is representative of the undulating to ridged and hummocky morainal terrain that is common in central Alberta.

The purpose of this report is to chronicle the baseline features of the Mundare (04-AB) Benchmark Site, thereby providing a technical reference document in support of on-going monitoring research and reporting. Documented information includes site selection rationale, site characteristics, sampling design and analytical methods, and a preview of some of the baseline data.

This documentation report is one of a series prepared for the SQUBS sites, and the last one for Alberta's four national benchmark sites. For Alberta, three similar reports were prepared for SQUBS 03-AB (Falher; Walker and Wang 1998a), SQUBS 05-AB (Provost; Walker and Wang 1994), and SQUBS 06-AB (Bow Island; Walker and Wang 1998b) sites.

OBJECTIVES

The SQUBS study was envisaged as a "case study" approach for monitoring the trends in soil quality change. Two basic assumptions underlay 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 (i.e. predictive models) 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 – Black soils of the Aspen Parkland Ecoregion occurring on medium textured till or shallow water-laid materials with undulating to ridged or hummocky terrain – was designated for central Alberta. Characterization of complex segmented terrain and the prospect of monitoring organic matter loss, wind and water erosion, and localized impacts of salinity, were viewed as objectives for this site.

A fourth objective, fulfilling the third national objective, was added for this central Alberta site. It should co-exist with a "model conservation farm" also being established in the region. The Parkland

Agriculture Research Initiative (PARI), administered by the federal and western provincial governments, was initiated in 1992 to address concerns about soil degradation in the Parkland region of the Prairies (Sparrow 1984). Specifically, soil degradation problems associated with excessive summerfallow, intensive fall cultivation, and inappropriate crop rotations were to be addressed. One part of the PARI mandate was to establish a "conservation farm" in the parkland region of each of the three Prairie Provinces. Major objectives of the PARI conservation farm were to provide opportunities for long-term research and demonstration. These objectives were compatible with and complementary to the rationale for the SQUBS 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 of Canada. Based on the specific objectives above, the central Alberta site was to:

1. represent Black soils in the Aspen Parkland Ecoregion;
2. represent undulating to ridged glacial terrain comprised of medium-textured till, preferably with a shallow fluviolacustrine or glaciolacustrine veneer;
3. represent a cereals-oilseed-forage or pulse crop rotation, managed under both conventional tillage (i.e. multiple-pass cultivation) and direct-seeding systems;
4. be about 5-10 ha in size, and of sufficient size to adequately represent all segments of the complex landscape;
5. show potential for change in soil organic matter and structure;
6. show potential for impact by wind, water, or mechanical erosion, and by salinity; and
7. be compatible with and complementary to the long-term research and demonstration objectives of the PARI conservation farm also being established in the region.

The search for a site, based on the guidelines above, began in September 1992, mainly in the Camrose-Edmonton-Vegreville region of central Alberta. Since the search for SQUBS and PARI sites was launched at about the same time, two AAFC agencies joined forces to find a site that would suit both projects. Dr. David McAndrew, head of AAFC's former Vegreville Substation, spearheaded the search and liaised with another important partner, Ducks Unlimited Canada.

Final selection of the site was made after an extensive tour of the region and examination of several potential parcels of land. A section of land (about 600 ac.) located west of Vegreville along the Yellowhead Highway, near Mundare, met the requirements of all partners involved in the two projects. The Basilian Fathers (Order of St. Basil the Great [O.S.B.M.]), who had been renting it out for many years, owned the land. Ducks Unlimited Canada entered into a long-term lease. Hence, the PARI (or Parkland) Conservation Demonstration Farm (PCF) was launched in the fall of 1992.

The Mundare Benchmark Site (SQUBS 04-AB) was established at the same time within the cultivated area of the PCF. Site 04-AB is actually a paired site with 6.9 ha under "conventional" tillage, immediately south of the farmstead, and 6.4 ha under direct-seeding management.

Several factors affected the final decision in the selection of the site.

1. The soils, terrain and farm management system were reasonably representative of an extensive area in the targeted region. Small wetland depressions, some with waterbodies, were common – a requirement of partner Ducks Unlimited for waterfowl enhancement programs.
2. All landscape segments, from hilltops to depressions, could be adequately sampled with several short transects (50-100 m) within an area of 5-10 ha.
3. PCF management – initially Lakeland Agricultural Research Association with Farm Manager Dean Kupchenko – was fully co-operative and supportive. Integration of research and management activities was possible with the arrangement.
4. Several other organizations planned a variety of research and demonstration projects on the PCF. Integration of activities and programs was possible.
5. Location of the site along the Trans-Canada Highway (Yellowhead Route) plus planned promotional activities of PCF management offered high public profile for the site.
6. Long-term monitoring of soils under two tillage systems, conventional vs. direct seeding, added a significant new dimension to the project.

BENCHMARK SITE 04-AB (MUNDARE)

SITE LOCATION

The Mundare Benchmark Site is situated in central Alberta along the Trans Canada Highway (Yellowhead Route #16), roughly 88 km east of Edmonton, and 19 km northwest of Vegreville (Figure 1). It is located in the East half of Section 9, Township 53, Range 16, west of the 4th Meridian. Latitude and longitude co-ordinates are 53°34' N and 112°17' W. Uncorrected Nikon Total Station co-ordinates for a geodetic benchmark installed along the east side of the site are UTM Zone 12, Easting 414796.03 m and Northing 5935598.00 m, elevation 681.17 m.a.s.l.

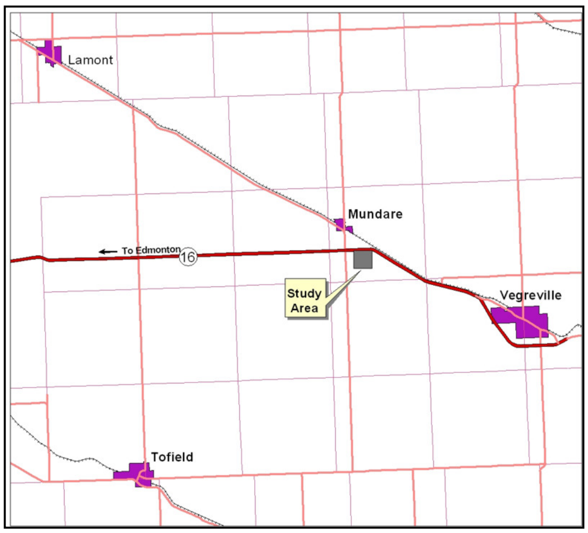

Figure 1. Location of the 04-AB (Mundare) Benchmark Site in central Alberta.

SQUBS 04-AB is comprised of two sub-sites; one managed using conventional tillage, the other using direct seeding for conservation.

Conventional Tillage (CT) Sub-site: consists of 6.9 ha located immediately south of the farmstead (yard, Figure 2). Monitoring activities here fulfil the main SQUBS objective – to provide a baseline data set for temporal assessment of soil quality change. This sub-site is highly representative of agricultural systems found in the surrounding region.

Direct Seeding (DS) Sub-site: consists of 6.4 ha and is located about 200 m directly west of the CT sub-site (Figure 2). Monitoring activities here are intended to provide a data set that will permit evaluation of soil quality change under a no-till management system and comparison with the conventionally tilled soils.

SOIL AND LANDSCAPE DESCRIPTION

Ecology and Climate

The Mundare Benchmark Site occurs in the Aspen Parkland Ecoregion of the Prairies Ecozone (Ecological Stratification Working Group 1995, Marshall *et al*. 1996). The parkland is considered transitional between boreal to the north and grasslands to the south. The area is influenced by continental climatic conditions, and has short, warm summers and long, cold winters with continuous snow cover. Large yearly and daily temperature ranges plus maximum precipitation in summer (July) attest to the continental conditions (Table 1). Temperature extremes also show the variability: the extreme maximum temperature (Vegreville CDA, 39 years of record) was 35.6ºC; the extreme minimum temperature was -51.2ºC (Environment Canada 2003).

Mean annual temperature in the Aspen Parkland is about 1.5ºC (Ecological Stratification Working Group 1995). Mean summer temperature is about 15ºC, mean winter temperature about -12.5ºC. Mean annual precipitation ranges from 400-500 mm. During its short-term record (1980-2000), the Vegreville station (Table 1) was warmer (mean annual temperature 2.3ºC) and drier (mean annual precipitation 374 mm) than the regional norms for the Aspen Parkland. The defunct Vegreville CDA station, with weather data from 1956 to 1994, was much closer to the Aspen Parkland norms – mean annual temperature of 1.7ºC and mean annual precipitation of 412 mm – based on the 1971-2000 normals (Environment Canada 2003).

The Site is located in Soil Correlation Area (SCA) 10 (Alberta Soil Information Centre 2001). Its agro-climate is classed as 2H, which signifies a slight heat limitation for the production of spring-seeded small grains (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 04-AB Benchmark Site, are:

- P-PE (May to Aug. precipitation minus potential evapotranspiration) – approximately -210.

- EGDD (effective growing degree days >5 ^{o}C, adjusted for day and growing season length) – just over 1200.

Only a small amount of wind data is available for the Vegreville station (Environment Canada 2003). Monthly and yearly means were not computed. Extreme hourly wind speeds were often in the 50 to 60 km/h range with maximum speeds (70 km/h) recorded in February and December. The most common directions of extreme hourly wind speed were W and NW.

Native vegetation of the Aspen Parkland Ecoregion is dominated by groves of trembling aspen with patches of mixed tall shrubs and intermittent fescue grasslands (Ecological Stratification Working Group 1995). In rougher terrain, numerous small lakes, ponds and sloughs, some ringed with trees and shrubs, provide important habitat for waterfowl and other wildlife. Black Chernozemic soils are characteristic of the area (Alberta Land Resource Unit 1995). Significant areas of Gleysolic soils and minor areas of Solonetzic soils also occur in the Ecoregion.

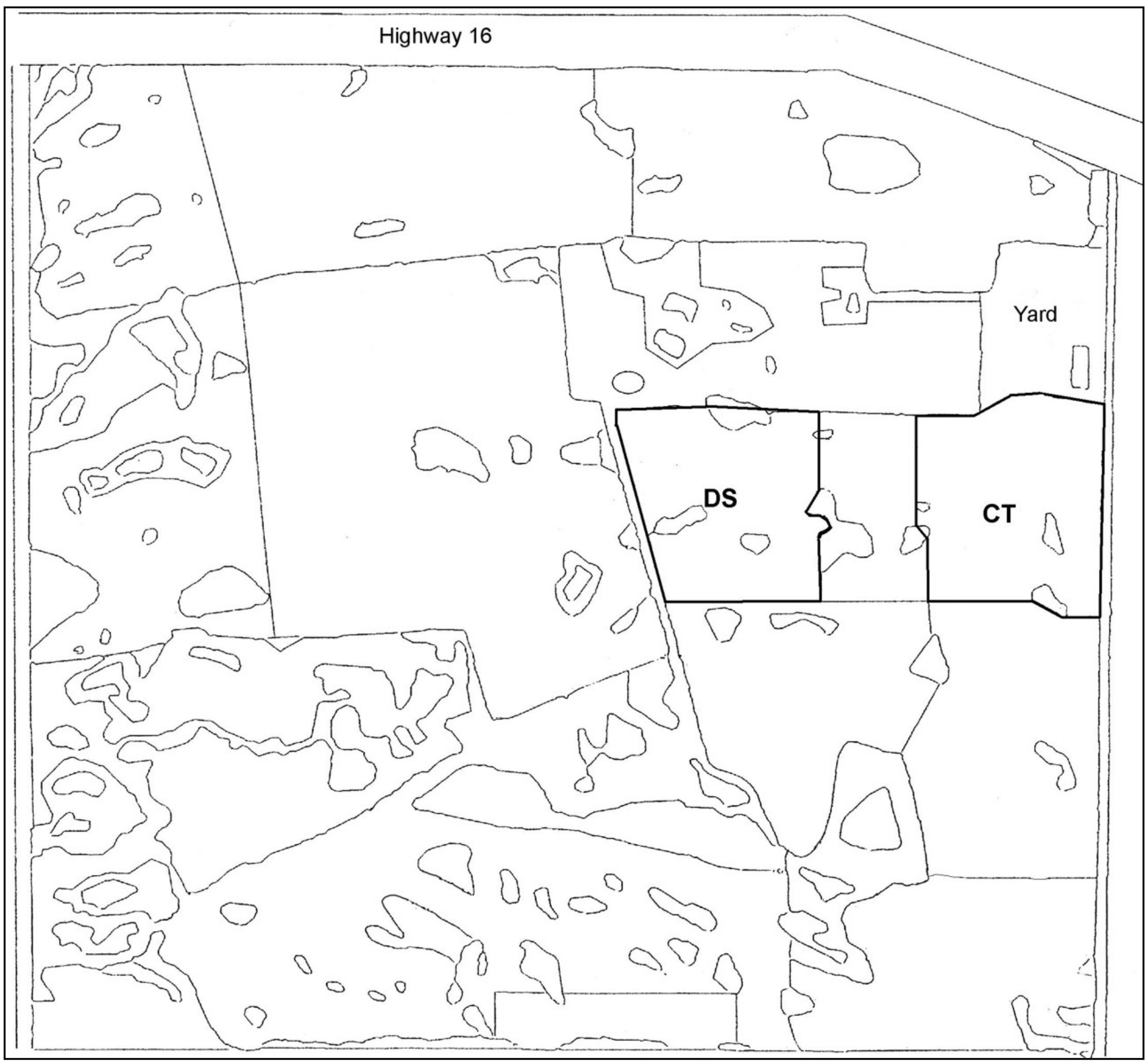

Figure 2. Parkland Conservation Farm layout in 1993, showing location of BMS sub-sites.

Table 1. Selected temperature and precipitation normals (1971-2000) for Vegreville, AB.

Month/ Year[1]	Daily Mean Temp. (°C)	Daily Max. Temp. (°C)	Daily Min. Temp. (°C)	Total Precip. (mm)	Rainfall (mm)	Snowfall (cm)	Extreme Daily Rainfall[2] (mm)
Jan.	-13.8	-9.5	-19.2	15.1	0.1	15.0	4.4
Feb.	-10.6	-5.0	-16.2	10.2	0.0	10.2	1.2
Mar.	-4.7	0.5	-9.8	14.3	0.5	13.8	2.5
Apr.	4.5	10.8	-1.9	19.5	14.7	4.8	17.6
May	10.5	17.5	3.5	37.4	34.0	3.4	32.0
June	14.5	21.3	7.8	64.1	64.1	0.0	70.0
July	16.3	22.6	10.0	79.9	79.9	0.0	56.0
Aug.	15.8	22.9	8.6	55.5	55.4	0.1	64.0
Sep.	10.2	17.0	3.5	40.0	39.8	0.2	74.0
Oct.	3.7	9.9	-2.5	11.4	6.7	4.7	8.6
Nov.	-6.4	-1.6	-11.1	12.0	1.9	10.0	5.3
Dec.	-12.5	-7.3	-17.8	14.3	0.1	14.2	1.0
Year	**2.3**	**8.4**	**-3.8**	**373.6**	**297.3**	**76.4**	N/A

[1] Weather data for Vegreville, AB, station located at 53°31'N 112°06'W, 639 m ASL (Environment Canada 2003).
[2] Period of record for this weather station – 1980 to 2002.

Most of the Aspen Parkland Ecoregion is farmland (Ecological Stratification Working Group 1995). Owing to its favourable climate and fertile Black soils, this ecoregion represents some of the most productive agricultural land in the Prairies. A wide diversity of crops, including spring wheat and other cereals, oilseeds, forages, and several specialty crops, are produced. Livestock-based farming systems, primarily cattle, are also important in the region. Dryland continuous cropping methods are prevalent in the production of agricultural crops.

Terrain

The Mundare Benchmark Site is located on the Whitford Plain, one of a series of plains and uplands that comprise the northern portion of the Eastern Alberta Plains (Pettapiece 1986). This physiographic district was further divided into Land Systems (Alberta Soil Information Centre 2001), with 04-AB Site occurring on the Inland Plain. The surficial material of this area is glaciolacustrine veneer over morainal material (till). The landform surface form is undulating to hummocky and ridged. Underlying bedrock is the non-marine Belly River Group, which consists of thick-bedded sandstone, clayey siltstone, mudstone, and concretionary ironstone beds (Hamilton *et al.* 1999).

The undulating to hummocky and ridged moraine of the Mundare Benchmark Site has distinct internal relief, as shown in the terrain relief map (Figure 5). The hillier parts have complex slope patterns, mostly of class 4 topography (5-9%) with minor class 5 (9-15%) on the steepest slopes, and class 3 slopes (2-5%) across hilltops. Lower lying localities have gentle slopes, mostly of class 2 (0.5-2%) and 3 topography. Uncultivated patches are mainly bowl-shaped wetland depressions.

The moraine is comprised of weakly to moderately calcareous, clay loam to loam textured, continental till. Underlying and principal source bedrock is the non-marine Belly River Group, which consists of sandstone, siltstone, and mudstone (Hamilton *et al.* 1999). Salinity in upper till layers is variable (E.C. from <1 to about 8 dS m^{-1}). The "saline surface" can be considered as highly variable, and does not mirror the ground surface. A thin discontinuous capping (mostly <1 m) of glaciolacustrine sediment covers the till. It is nearly continuous in the level to gently sloping, low lying segments of the landscape, but absent on the tops of most hills and ridges. Texture of the surficial material is mainly silt loam to loam.

Soil Patterns

Figures 3 and 4 show the complex soil patterns of the Mundare Benchmark sub-sites. The mapping units 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.

Table 2. Soil map legend for the SQUBS 04-AB (Mundare) Benchmark Site.

MAP UNIT[1]	DESCRIPTION
BVHB6 / H1l	**Landscape**: Prominent, low-relief (class 4 topography) hummocks. **Soils**: Mainly well drained Orthic Black Chernozemic (Beaverhills-thin A variant, BVHta; Hobbema-atypical subgroup, HBMzz) developed on medium-textured (CL-L) till and on SiL-L glaciolacustrine veneer overlying till. Soils with coarse-textured (sandy loam, loamy sand, sandy, or gravelly) layers and lenses are significant.
BVNR14 / H1l **" / R2m**	**Landscape**: Prominent, low-relief (class 4 topography) hummocks (H1l) and moderate-relief (class 4-5 topography) ridges (R2m). **Soils**: Mainly well drained Orthic Black Chernozemic (Beaverhills-thin A variant, BVHta) and Solonetzic Black Chernozemic (Norma-thin A variant, NRMta) developed on medium-textured (CL-L) till. Black Solodized Solonetzic soils (mainly Camrose, CMO) and soils with little or no topsoil occur in small patches, and are significant.
HBM1 / U1h	**Landscape**: Broad, high-relief (class 3 topography), undulating areas. **Soils**: Mainly well drained Orthic and Eluviated Black Chernozemic soils (Hobbema-atypical subgroup, HBMzz; Hobbema, HBM) developed on medium-textured (SiL-L) glaciolacustrine veneer overlying medium-textured (CL-L) till. Similar soils with very thick (>35 cm) Ap/h horizons are also common. Gleyed members of the dominant soils, till soils (e.g. BVH), soils in deeper glaciolacustrine sediments (POK), and Solonetzic-like soils (e.g. Sante, STE) occur in minor amounts.
HBST7 / U1h	**Landscape**: Broad, high-relief (class 3 topography), undulating areas. **Soils**: Mainly well drained Orthic and Eluviated Black Chernozemic soils (Hobbema-atypical subgroup, HBMzz; Hobbema, HBM) and Solonetzic Black Chernozemic soils (Sante-shallow variant, STExt) developed on medium-textured (SiL-L) glaciolacustrine veneer overlying medium-textured (CL-L) till. Black Solodized Solonetzic soils (Armena, ARM) are significant. Soils with very thick (>35 cm) Ap/h horizons are common. Gleyed members of the dominant soils, till soils (e.g. BVH, NRM), and soils in deeper glaciolacustrine sediments (POK) occur in minor amounts.
JVE1 / IUl **" / U1l**	**Landscape**: Broad, low-lying, gently sloping areas – most with low-relief (class 2-3), inclined-undulating slopes (IUl); some with low-relief (class 2), undulating slopes (U1l). **Soils**: Mainly imperfectly drained Humic Luvic Gleysolic soils (Jarvie, JVE) developed on medium-textured (SiL-L) glaciolacustrine veneer overlying medium-textured (CL-L) till. Other types of Gleysols and gleyed members of other soils occur in minor amounts.
JVEsa1 / IUl	**Landscape**: Small areas similar to JVE1/IUl but affected by saline seeps (discharge). **Soils**: Mainly imperfectly drained; various types of saline Gleysolic soils, including Humic Luvic Gleysols (Jarvie-saline, JVEsa) and Orthic Humic Gleysols. Various saline Solonetzic soils occur in minor amounts, usually near the drier margins of the discharge areas.
JVE1 / L2	**Landscape**: Level depressions (class 1-2 topography) with raised edges; usually uncultivated and ringed by willows, and sometimes aspen. **Soils**: Mainly poorly drained Humic Luvic Gleysolic soils (Jarvie, JVE) developed on medium-textured (SiL-L) glaciolacustrine veneer overlying medium-textured (CL-L) till. Other types of Gleysols occur in minor amounts. Standing water often prevails in the lowest parts of some depressions throughout much of the growing season during wet years.
PHS6 / H1m	**Landscape**: Prominent, moderate-relief (class 4-5 topography) hummocks. **Soils**: Mainly rapidly drained Orthic Black Chernozemic soils (Peace Hills, PHS) developed on coarse-textured (mainly sandy loam) glaciofluvial deposits associated with the local moraine. Even coarser textured soils (loamy sand to sand, and/or gravelly) such as Mundare (MDR) are significant. In these landscapes, soil textures often range from the coarsest at the apex of the hummocks through sandy loam to loam on the flanks.
POK1 / I3l	**Landscape**: Low-relief (class 3-4), inclined, apron-like slopes, usually flanking steeper ridges and hummocks. **Soils**: Mainly well drained Eluviated Black Chernozemic soils developed on deep (>1 m) glaciolacustrine or slopewash sediments. Orthic Black Chernozems are also common.

[1]Numerator consists of series code(s) plus number signifying typical for the series or variant (1), significant coarser-textured soils (6), significant Solonetzic soils (7), or significant "eroded" and Solonetzic profiles (14). Denominator signifies Landscape Models as used in the Agricultural Region of Alberta Soil Information Database (AGRASID, Alberta Soil Information Centre 2001).

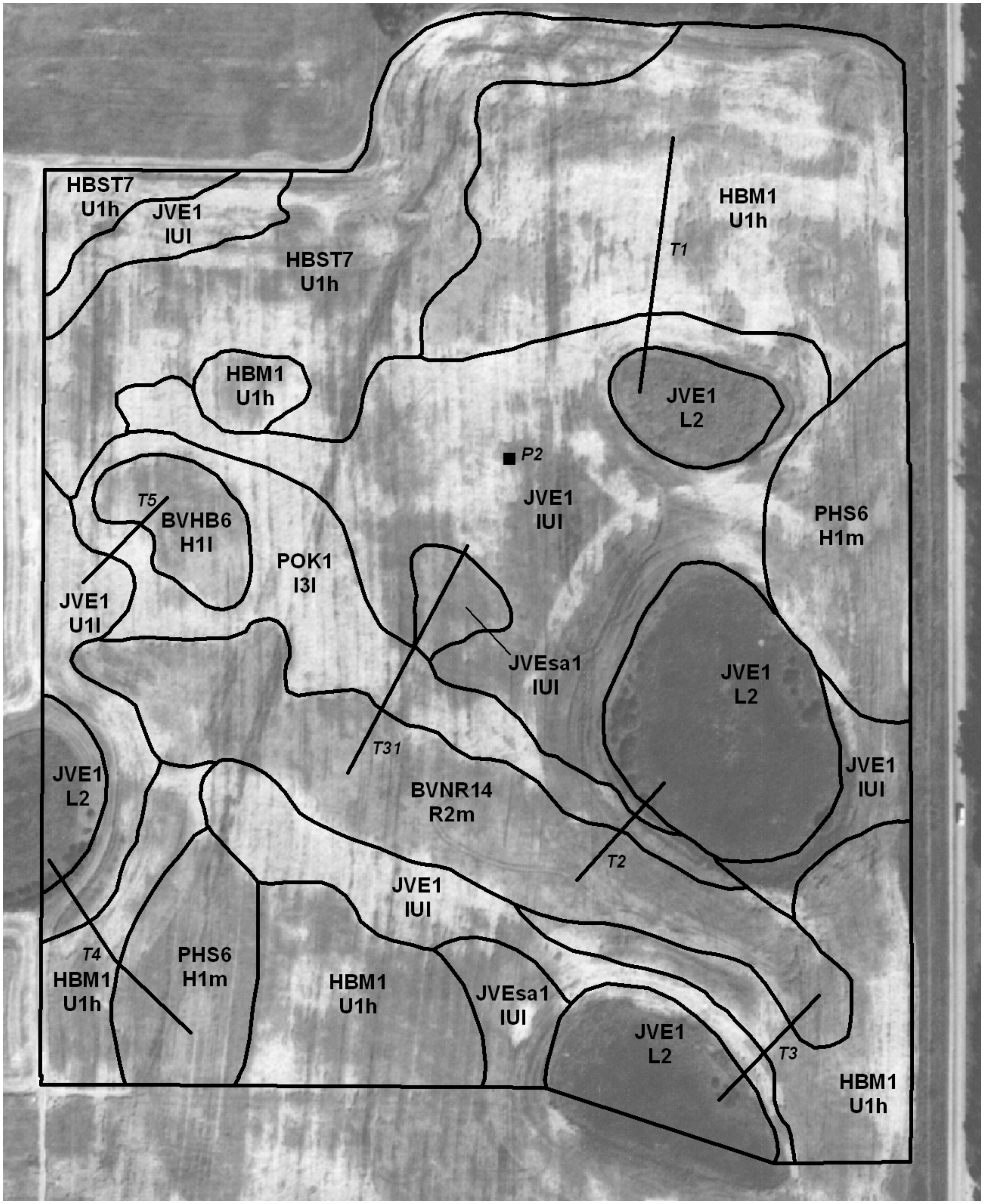

Figure 3. Detailed soil map of the CT Sub-site, with transect and pedon sampling locations.

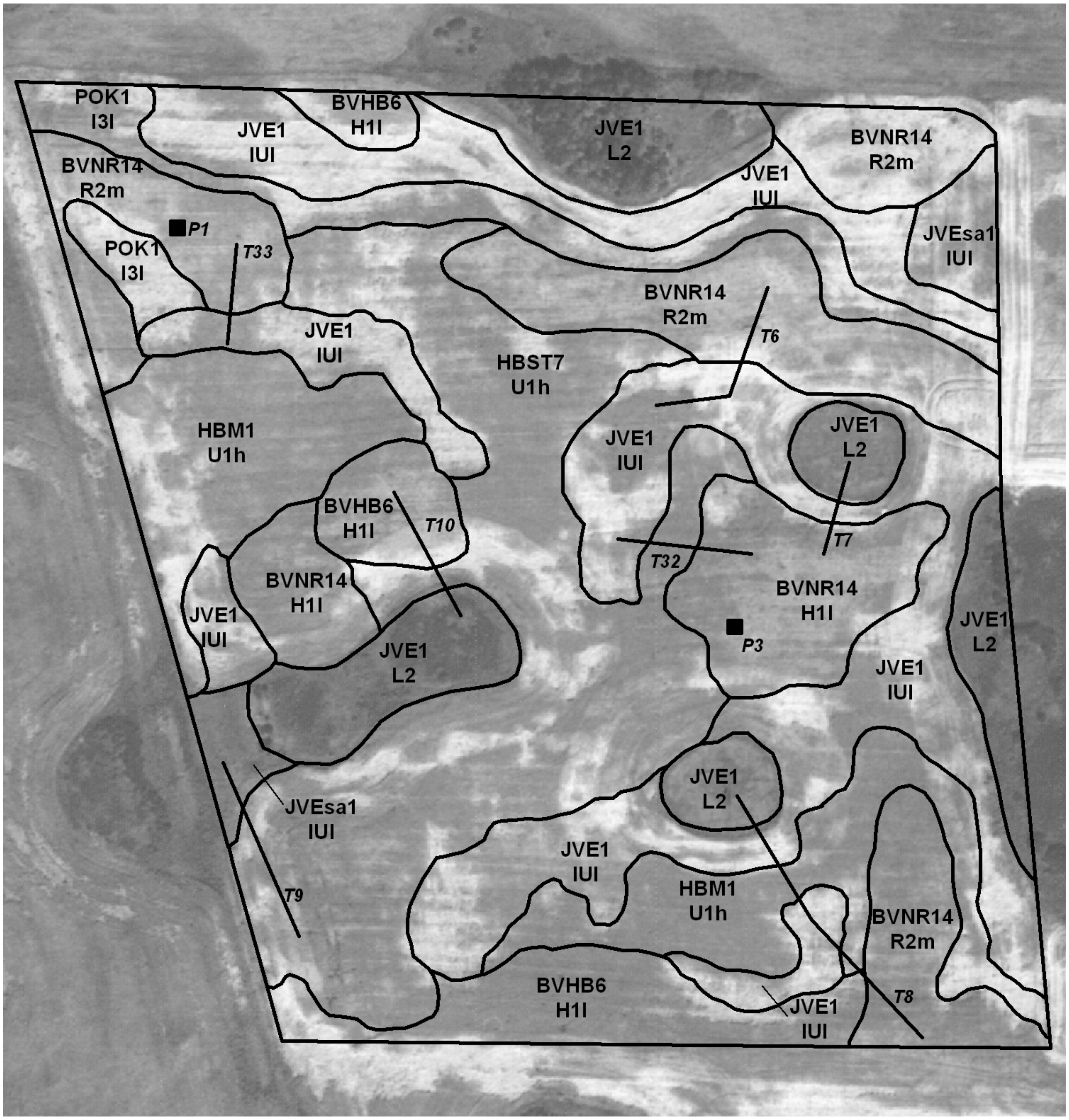

Figure 4. Detailed soil map of the DS Sub-site, with transect and pedon sampling locations.

The hillier parts of the landscape – prominent hummocks and ridges – commonly have hilltop areas with convex-shaped crests and poorly defined upper slopes. Most soils of the hilltops are developed in glacial till. The most common is classified as Orthic Black Chernozemic with abnormally thin topsoil (Beaverhills-thin A variant, BVHta). The thin topsoil is probably related to long-term cultivation and erosion. Similar Solonetzic Black Chernozemic soils, with a harder B horizon (Norma-thin A variant, NRMta), also occur on the hilltops. Their distribution is somewhat sporadic, and related to the presence of salts close to the surface in the till parent material.

This same soil pattern, dominated by BVHta and NRMta soils, extends onto the mid slope positions of the more prominent hummocks and ridges. The map unit (Figs. 3 and 4) that represents this pattern is BVNR14 occurring on either ridged (R2m) or hummocky (H1l) terrain. The "14" part of the map unit symbol recognizes 1) the importance of the thin topsoil (or eroded) variants, and 2) the occurrence of Solonetzic soils. Black Solodized Solonetzic soils (e.g. Camrose series, CMO) occur sporadically and have a Solonetzic B horizon that is even harder than that of the NRMta soil.

A few prominent hummocks feature coarse-textured soils. They may either dominate, as in the PHS6/H1m map unit, or occur as layers and lenses in the till soils, as in the BVHB6/H1l map unit.

Gentler sloping areas include undulating, inclined-undulating, and level landscapes. Better drained parts of the undulating slopes feature soils in which the parent material is layered, i.e. glaciolacustrine veneer overlying till. Orthic Black Chernozemic soils are prevalent in this layered material. Eluviated Black Chernozemic soils are also common. Often these soils also have exceptionally thick topsoil (>35 cm). Soil identifiers applied to this suite of related soils are based on the Hobbema (HBM) soil series, which is correctly applied to the Eluviated Black member. The Orthic Black member was identified as an "atypical subgroup" variant (HBMzz). Hobbema soils with very thick A horizons were identified as "thick A" variants (HBMtk or HBMzztk).

The Hobbema suite of soils dominates the HBM1/U1h map unit. Similar soils developed in deeper (>1 m) glaciolacustrine material, named Ponoka (POK), occur in a few protected areas, i.e. concave slope positions and leeward sides of ridges (POK1/I3l map unit). Solonetzic Black Chernozemic soils (Sante-shallow over till variant, STExt) are common in some areas (HBST7/U1h map unit). Black Solodized Solonetzic soils (e.g. Armena series, ARM) also occur.

Low-lying areas are dominated by Gleysolic soils developed in glaciolacustrine veneer overlying till. Humic Luvic Gleysols, named Jarvie (JVE), dominate these low-lying areas. Two general types of landscape occur.

- Depressional localities, or basins, are mostly uncultivated and dominated by some form of wetland vegetation. Poorly drained JVE soils prevail (JVE/L2 map unit).
- Lower slopes of the undulating and inclined landscapes are mostly cultivated. Imperfectly drained JVE soils characterize these areas (JVE1/IUl) map unit). Saline seeps occur in a few places, resulting in Gleysolic soils affected by salinity (JVEsa1/IUl map unit).

AGRONOMICS

Information on the agronomic history and current farming practices was obtained through interview processes using a standard questionnaire. Parkland Conservation Farm Manager Dean Kupchenko supplied information on current management practices from 1993 to 1995. An interview with the former lessee, William Gavinchuk of Mundare, provided information on the 20 years prior to the formation of the PCF. The following is a summary of the interview data.

Farm History

The land that contains the Mundare Benchmark Site was leased by Bill Gavinchuk from the Basilian Fathers in 1973. Consequently, its earliest farming history is sketchy.

The Early Years: Mr. Gavinchuk estimated that this land was cleared, broken, and first cropped in the 1910-30 time period. He also recollected that the Basilian Fathers used a 5-year cereal – 5-year forage rotation in support of their dairy (until 1969) and beef (until 1972) operations. Tillage methods were conventional for the time, relying on the plow and discer. The main fertilizer was manure. Weed control relied on mechanical methods.

Major Changes: Mr. Gavinchuk changed the rotation to a 5-year summerfallow-wheat-barley-barley-oat rotation when he took over in 1973. The Fathers had changed from plowing and discing to deep tillage (cultivator) but the year was not known. Mr. Gavinchuk continued use of the deep tillage cultivator. The Fathers also introduced chemical fertilizer (i.e. mainly 11-48-0) and herbicides but the years were not known. Mr. Gavinchuk introduced nitrogen fertilizer in 1974 and an 8-38-15 blend in 1990. He continued the use of broadleaf herbicides, switching from Estron 99 to Banvil-MCPA (K40) in 1978. The Basilian Fathers began using combines shortly after WWII, and burned straw residue at least occasionally. After 1973, Mr. Gavinchuk baled some of the wheat straw and all of the oat straw. The last crop grown by Mr. Gavinchuk, in 1992, was oats.

In 1993, the land was managed as part of the PCF. The crop rotation was changed to a 4-year peas-barley-canola-wheat rotation. The biggest change was in tillage management – the eastern sub-site (6.9 ha) remaining under conventional tillage (CT Sub-site), the western sub-site changing to zero-till or direct-seeding tillage (DS Sub-site). Changes in herbicide types and use (e.g. spring treatments with Round-up) and residue management accompanied the shift to direct-seeding management.

Co-operator Assessment: Mr. Gavinchuk felt that yields increased over the 20 years he leased the land. He felt that crop quality stayed about the same, but that yields were higher than most in the locality. Comments were that he "always had #2 wheat with up to 2% dockage". He noted that "salinity patches" scattered throughout the fields were a degradation problem, but had always been present over the years he leased the land.

Current Management Practices

Crop Rotation System: A structured peas-barley-canola-wheat rotation was adopted in 1993 when the land became part of the PCF. Both sub-sites get the same crop each year. In 1993, peas were grown. The 1994 crop was barley. The interview on agronomics and management practices took place in 1995, prior to the planting of the canola crop.

Equipment: At the time of the interview in 1995, the PCF had access to a large 4-wheel drive tractor (White 4-210) and a small 2-wheel drive tractor (International 674). Tillage equipment included a heavy-duty cultivator, a light-duty disk, and diamond harrows. A Morris Maxim air drill was used for seeding. Spraying equipment was a Versatile 50-foot sprayer. Harvesting equipment included an International 19.5-foot swather and an International 1460 combine. A 3-ton grain truck was used on the farm at that time. Much of the crop management equipment used on the farm has been provided by local farmers either on a rental or volunteer basis.

Management Procedures: Table 3 presents a year by year account of "typical" farm management activities, based on the first two years of crop production under the system introduced for the PCF in 1993. Similar activities occurred in the remaining two years of the 4-year rotation, with minor changes in fertilizer blends and herbicides to grow canola in 1995 and wheat in 1996. All operations except spring and fall cultivation and spring herbicide application are run concurrently on the CT and DS sub-sites. An annual diary of actual operational activities is being kept by the farm manager for the duration of the monitoring study.

Table 3. Tillage, crop management, and harvesting procedures for 1993 and 1994.

Crop Year	Main Activity	Time Frame	Operational Procedures
1.1993, Peas: a. CT Sub-Site:	Spring cultivation	Early May	Two passes with heavy-duty cultivator
	Planting	Mid May	Seeded with air seeder at same time as DS Sub-site
	Fertilization	Mid May	Applied 11-51-0 (40 lb./ac.) with the seed
	Spraying	Early June	Poast and Sencor applied about a week apart
	Cutting/harvesting	Early October	Swathed, then combined right behind
	Fall herbicide	Late October	Fortress application
	Fall cultivation	Late October	Finishing disc
b. DS Sub-site	Spring herbicide	Early May	Roundup applied at 0.5 L/ac.
	Planting	Mid May	Seeded with air seeder at same time as CT Sub-site
	Fertilization	Mid May	Applied 11-51-0 (40 lb./ac.) with the seed
	Spraying	Early June	Poast and Sencor applied about a week apart
	Cutting/harvesting	Early October	Swathed, then combined right behind
	Fall herbicide	Late October	Fortress application
2.1994, Barley: a. CT Sub-Site:	Spring cultivation	Early May	One pass with cultivator, one pass with disc
	Planting	Late May	Seeded with air seeder at same time as DS Sub-site
	Fertilization	Late May	Blend (40-20-10) applied at seeding in a separate band from the seed
	Spraying	Mid June	Mixture of Refine Extra with 2,4-D Ester applied
	Cutting/harvesting	August-September	Swathed in late August; combined in mid September
	Fall cultivation	Late September	Cultivated – at least one pass with cultivator
b. DS Sub-site	Spring herbicide	Early May	Roundup applied at 0.6 L/ac.
	Planting	Mid May	Seeded with air seeder at same time as CT Sub-site
	Fertilization	Mid May	Blend (40-20-10) applied at seeding in a separate band from the seed
	Spraying	Early June	Mixture of Refine Extra with 2,4-D Ester applied
	Cutting/harvesting	Early October	Swathed in late August; combined in mid September

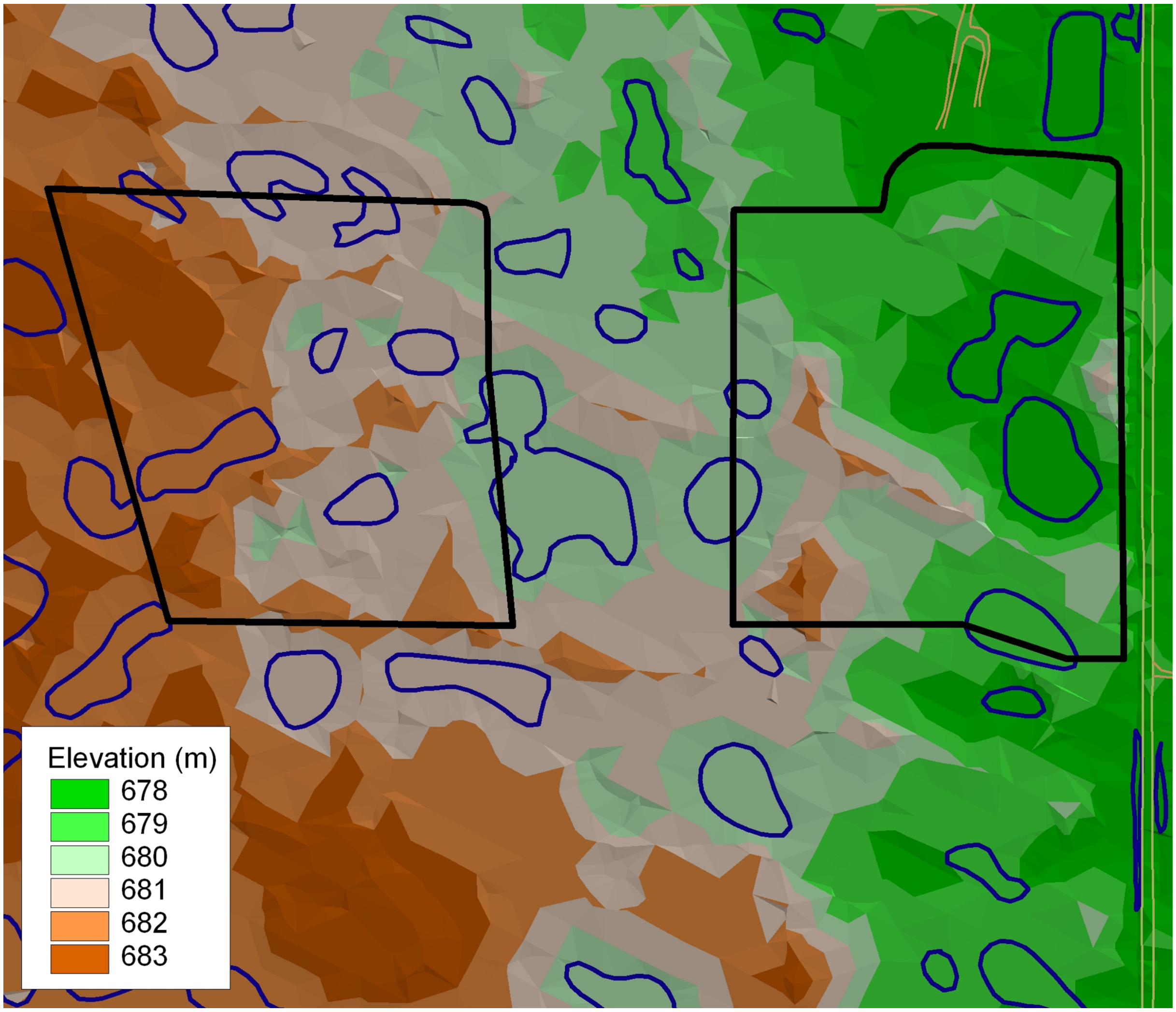

Figure 5. 3-D topographic map of the 04-AB site showing the DS (left) and CT (right) sub-sites.

SAMPLING DESIGN AND METHODOLOGY

Field Sampling Design

The Mundare BMS is characterized by undulating to ridged terrain with distinct internal relief. Soil patterns repeat in such landscapes. With the repetition comes a degree of predictability about many soil attributes.

A stratified random sampling method using transects (Wang 1982) was designed to sample the repeating landscape patterns. Orientation of each transect was perpendicular to the contour, or nearly so, stretching from the apex of a "hill" to the bottom of an adjacent depression. Samples were taken at 10m intervals along each transect. Figure 6 shows a schematic landscape profile using a "model" transect, including average transect length, rise and slope gradient information. Ten transects with a total of 68 sampling points were set-up when the site was established in 1992. Several sampling points were situated in what were then, or later became, uncultivated lower slope to depressional localities. To increase replications for future sampling, three transects with 19 new sampling points were added in 1996.

CT Sub-site Layout: Five transects (T1 to T5) with 32 sampling points were laid out initially. Another transect (T31) with 9 sampling points was added in 1996. Of the 41 total sampling points, 8 were located in what later became "permanent" depressions (sloughs), and 4 were situated in transitional localities which are not always cropped, depending mainly on spring moisture conditions. The remaining 29 sampling points are cultivated and cropped most of the time. Figure 3 shows transect locations on the soil map of the CT sub-site.

DS Sub-site Layout: Five transects (T6 to T10) with 36 sampling points were laid out in 1992. Two additional transects (T32 and T33) with 10 sampling points were set-up in 1996. Of the 46 total sampling points, 7 were located in what later became "permanent" depressions (sloughs), and 8 were situated in transitional localities which are not always cropped, depending mainly on spring moisture conditions. The remaining 31 sampling points are cropped most of the time. Figure 4 shows transect locations on the soil map of the DS sub-site.

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

Three soil profiles (pedons), representative of most of the dominant soils of the study site, were selected and excavated for detailed morphological characterization, and sampled for physical and chemical analysis. Their locations are shown as P1, P2 and P3 on Figures 3 and 4. Pedon 1 (DS sub-site) represents the Beaverhills-thin A (BVHta) variant of the Beaverhills series, an Orthic Black Chernozem (ECSS 1987) with thin topsoil developed on medium-textured till. Pedon 2 (CT sub-site) represents the Jarvie (JVE) series, a Humic Luvic Gleysol developed on shallow (<1 m), medium-textured, glaciolacustrine sediments overlying the till. Pedon 3 (DS sub-site) represents the Norma (NRM) series, a Solonetzic Black Chernozem developed on medium-textured till. They are described in Appendix B.

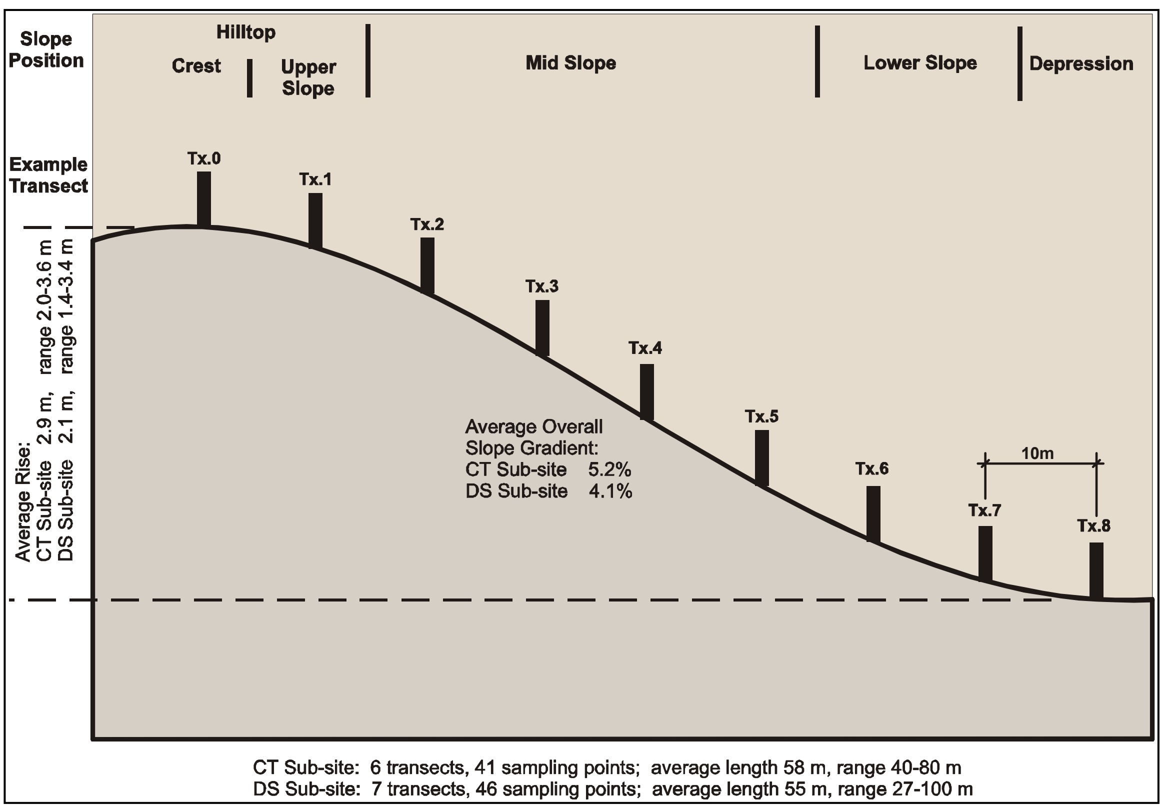

Figure 6. Schematic of transect layout depicting average topographic features.

Soil and Topographic Characterization

Topographic Data and Terrain Relief Map: A computer-generated (GIS) terrain relief map, with 1 m gradations, was created for the PCF. The two sub-sites and immediately surrounding area are shown in Figure 5. Two independent data sources were related to create the X-Y-Z digital database used to generate this map. Initially, field data was collected, using a total station instrument to measure X (easting), Y (northing) and Z (elevation) co-ordinates for all transect points and a variety of landscape features. The second dataset was derived photogrammetrically. Total station co-ordinates obtained for selected aerial photo control points were passed to Stewart Weir Land Data Inc. of Edmonton for processing to create this second dataset. Both datasets, in meters, were based on Universal Transverse Mercator (UTM) co-ordinates and elevation.

Detailed Soil Map: The soils of both sub-sites were mapped at a scale of about 1:3,300 (Fig. 3 & 4). The complex landscape was subdivided into repeating areas with similar patterns of terrain and soils. These repeating landscape units (refer to the Soil Map Legend on page 6) are identified by mapping units based on the dominant one or two series (or variant) and phase levels of classification (ECSS 1987). 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.

Baseline Sampling Activities

Six types of sampling activities, based on procedures outlined by Wang et al. (1994) for monitoring soil quality, were conducted to establish the baseline field and soil characteristics of the Mundare Benchmark Site:

1. transect point sampling for chemical and physical analyses,
2. transect point sampling for ^{137}Cs analysis,
3. pedon sampling,
4. transect point sampling for dry aggregate size distribution,
5. transect point sampling for wet aggregate stability determinations, and
6. deep sampling for soluble salt analysis.

Loose samples from 10 transects (1 and 2 above) and two pedons were collected in the fall of 1992. A third pedon (P3) was sampled in 1994. Additional baseline samples from three new transects were taken in 1996. Sampling for dry aggregate analysis was conducted in the spring of 1993, for wet aggregate stability in the spring of 1994. Deep core samples were collected in the fall of 1993.

Transect Point Sampling for Baseline Data: A bulk sample of the uppermost Ap, Apk or Ah horizon was taken at every sampling point. In addition, a bulk sample at approximately 50-60 cm depth (usually B or C horizon) was collected at every 4th sampling point. The soil profile was examined at each sampling point, and the deeper samples collected, using a truck-mounted coring machine. 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.

Transect Point Sampling for ^{137}Cs Analysis: Redistribution of surface soil, i.e. erosion, was included in monitoring activities at the Mundare Benchmark Site. The Cesium^{137} method for estimating erosion required collecting a large bulk sample (1-2 kg) of the contemporary Ap horizon, or upper Ah horizon at uncultivated locations, at every transect sampling point. For each ^{137}Cs sample, thickness of the horizon was recorded and a bulk density sample taken, collected in a 7.5 x 5.0 cm Kubiena box.

Pedon Sampling: Pits about 1 m by 2 m by 1.5 m deep were opened by backhoe at the P1, P2 and P3 locations (Fig. 3 & 4). The soil horizons of the exposed pedons were identified and described according to ECSS (1983). About 1 kg of soil was collected from each horizon. Cores (7.5 x 7.5 cm) were taken from 3 or 4 main horizons of Pedons 1 and 2 by hand operated Uhland sampler as per procedure 2.211 in McKeague (1978). Four cores were taken from the Ap horizon and three from other horizons.

Sampling for Aggregate Size Distribution and Stability: Size distribution and stability analyses of soil aggregates were considered as ways to quantify surface soil structure at the Mundare Site. Samples for dry aggregate analysis were taken in the spring of 1993. Twenty-four sampling points were selected initially, so as to have at least four points representing each slope position across both sub-sites. Unfortunately, use of this method did not foresee the benefits of paired datasets in statistical comparisons or the loss of low-lying cropland areas that reverted to wetland. Samples for wet aggregate stability analysis were collected in the spring of 1994. In this case, fifteen sampling points from each sub-site (total of 30) were selected with replicate representation focused on crest, mid and lower slope positions. In both samplings, a volume bulk sample (about 2 kg) of the soil surface to 5 cm depth was collected at each of sampling point. 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, commonly in late April or early May.

Deep Sampling for Soluble Salt Analysis: In the fall of 1993, soil samples were collected from deep cores to supplement the electromagnetic ground conductivity (EM38) measurements. Ten transect points were selected per sub-site (20 sampling points in total), spanning the full range of soil types and EM38 readings observed. A truck-mounted Giddings coring machine, using 1½-inch inside diameter tubes, was used to obtain soil cores. The cores were sampled in four intervals: 0-30, 30-60, 60-90, and 90-120 cm. The samples were immediately shipped to a laboratory facility for drying.

Field Measurements

In situ field measurements were begun at the same time as the initial sampling in the fall of 1992. Hydraulic conductivity and penetrometer measurements have been repeated many times since the site was established. Crop yield was first measured in the fall of 1993, and is planned as an annual activity for the duration of the project.

Hydraulic Conductivity (Ksat): Saturated hydraulic conductivity was measured with a Guelph Permeameter at three depths (5-10, 15-25 and 30-40 cm) using 5 and 10 cm heads per procedure 56.2.1 of Reynolds (1993). Initially, in the fall of 1992, all sampling points in transects T3 and T10 plus additional points for at least two replications per slope position per sub-site were selected – 26 sampling points in total, 13 per sub-site. In subsequent "samplings", more reps were added and measurements were usually restricted to points that were regularly cropped. Repeat "samplings" were made every 1-2 years in the early 1990's, every 3-5 years since 1995. 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 spring of 1993, measurements were made at 37 transect points – 18 in the CT sub-site and 19 in the DS sub-site. In subsequent "samplings", more reps were added and measurements were usually restricted to points that were regularly cropped. A small sample of each depth range at each sampling point was collected in a moisture tin for gravimetric determination of soil moisture. Penetration resistance and moisture measurements were made annually in the spring and fall from 1993 to 1994, in the spring only from 1995 to 1997.

Electromagnetic Ground Conductivity (EM38) Measurements: Electromagnetic inductance readings are used to provide an estimate of soil salinity. Measurements were made at all 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. These measurements were started in the fall of 1993, and repeated in 1994 and 1998, always in the fall. Initially in 1993, deep core samples were collected and analyzed for soluble-salts to supplement the EM38 readings.

Earthworm Counts: Two methods to extract earthworms from the topsoil were tested at the CT sub-site in mid May, 1996. The methods were hand sorting of the Ap horizon (Wang *et al.* 1994) vs. hot mustard powder extraction from the ground surface (Fox 2003). Three locations were tried for replication – one near Transect 1 and two near Transect 4, all on mid slope positions. The Transect 1 location, within 100 m of the farmstead boundary, yielded 62 earthworms by hand sorting and 2 by hot mustard extraction. No earthworms were extracted by either method at the other two locations. Conditions at the time were cool, and it was noted that many worms seemed to be still dormant. Soil temperatures from nearby field sensors at 2, 5, and 10 cm depths were about 8, 6, and 5°C. The consensus at the time was to not pursue this aspect of the study any further. While the hand sorting method was successful at one location, it was deemed too time consuming and destructive. In addition, few earthworms had been seen anywhere in the study area except near the farmstead. This decision was unfortunate because earthworm numbers have increased markedly based on observations made during sampling activities in the spring of 2003. While the observations were only qualitative, earthworms appear to be flourishing particularly well under direct seeding management.

Crop Yield Sampling: Crop samples to measure yield were collected every year since the Mundare BMS was established. In the early years, all transect sampling points that had crop, about 50 to 52 in total, were sampled. After the new transects were added in 1996, a few more sampling points were harvested, bringing the total to 54 to 58. Since then, the same points are selected each year. 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 were collected in large porous bags and transported to a threshing facility in Edmonton or Lethbridge. 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.

Analytical (Laboratory) Methods

Sample Handling and Preparation: Bulk samples for chemical, physical, and ^{137}Cs analyses were transported to Alberta Research Council's Soils Laboratory in Edmonton for processing. Here the samples 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 archiving. 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 aggregate 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 Alberta Agriculture, Food and Rural Development'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.

$CaCO_3$ 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: Deep-core samples (30 cm increments to 120 cm) from 20 sampling points were submitted to 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.

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, Sheldrick and Wang (1993).

Soil Moisture Retention: Undisturbed 7.5 cm diameter x 7.5 cm length cores from selected horizons in Pedons 1 and 2 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, and at $^1/_3$ bar (333 cm of water) on an aluminum oxide tension table.

Bulk Density: Two sets of bulk density values were obtained. 1) Oven-dry bulk density values, uncorrected for coarse fragment content, were determined on core samples from Pedons 1 and 2, 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.

Dry Aggregate Size Distribution: Samples were air dried and shipped in pizza-style boxes, with minimum disturbance, to AAFC'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.

Wet Aggregate Stability: Samples were collected, handled, and air dried in pizza-style boxes in order to minimize disturbance. After drying, each sample was filtered through an 8 mm sieve. Clods larger than 8 mm were gently broken apart or removed if too cemented. Loose and large coarse fragments were also removed in this process. The sample was then split into 3 or 4 sub-samples, for sieving replication, plus a sub-sample for determining moisture content (air dry to oven dry). The replicate samples were then wet sieved, using the procedure of Kemper and Chepil (1965), through a series of sieves with mesh sizes of 4, 2, 1, 0.5, 0.25, and 0.125 mm.

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

BENCHMARK SITE DATA

The Benchmark Site Database

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 continue to be made periodically.

Most of the 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. 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 04-AB Site and the other western sites should be channelled through G.M. Coen or M.D. Bock of Agriculture and Agri-Food Canada, Edmonton (contact information on title page overleaf).

Soil Variability in Complex Terrain

The variability of soil properties in landscapes of complex terrain usually does not occur randomly. This nonrandom variability is a reflection of the varying degree of intensity in slope processes occurring at "eroded" sites (Daniels *et al*. 1985). Statistical methods that use commonly pooled error terms and assume homogeneity of variance, like multiple comparison of means or analysis of variance, do not apply.

Alternatively, soil attributes can be grouped in various ways to better organize processes and reduce variability. In other words, soil attributes usually vary with some predictability in landscapes with repeating patterns. This is the premise for applying the stratified random sampling method using transects where landscape patterns repeat (Wang 1982), as at the Parkland Conservation Farm.

This sampling method offered some flexibility in analyzing the Mundare data. One way is to compare soil attributes by slope position. Table 4 lists some descriptive statistics for selected Ap/Ah horizon variables, separated into four topographic groups – hilltops (combination of crest and upper slopes), mid slopes, lower slopes, and depressions. This reduces the number of replications (n) for any particular property, but provides a picture of field variability corresponding to topographic differences, much like a manager might view it.

Unfortunately, the extreme soil variability and low predictability at the Mundare BMS still shows through in the grouped data sets (Table 4). Trends in chemical attributes like pH and organic carbon are fairly consistent with variability in similar central Alberta landscapes (Walker *et al.* 2001). On the other hand, physical attributes display significant variability, even within landform segments. This fits the patterns at other benchmark sites (Walker and Wang 1998a, 1998b, Walker *et al*. 2001) where physical parameters, especially saturated hydraulic conductivity (Ksat), tend to be more variable than chemical characteristics.

Some other trends revealed by the descriptive statistics in Table 4 include:

- Variability is greatest on the hilltops and mid slopes, and tends to diminish (i.e. improved statistics) on the lower-lying positions. This is consistent with the distribution of soil types shown in Table 5.
- The CT and DS sub-sites exhibit differences in some soil attributes despite the baseline samples having been collected at the beginning of the monitoring project, i.e. at "time zero" relative to the change in tillage management.

Table 5 illustrates the soil variability in another way. It shows that lower slopes and depressions of both sub-sites are quite uniform in terms of soil types and parent materials. That is not the case on the higher, drier portions of the landscape – mid slopes and hilltops. Here wide variation in the glacially derived parent materials, exacerbated by differential erosive processes that affected topsoil thickness, account for most of the variability. Parent material differences, while predictable in part, also had unpredictable components that were only revealed with sampling and mapping. In several cases, even adjacent parts of the same ridge or hill exhibited substantially different types of soils. Such soil variability, long recognized as an intrinsic feature of the region, presents unique challenges to research and monitoring endeavours.

Alternatives for Grouping Soil Attribute Data

The purpose of this report, to describe the baseline features of the Mundare (04-AB) Benchmark Site, includes a preview of some of the baseline data. Future analysis and reporting will compare the baseline data with results from repeat samplings in order to assess soil quality change. An issue that will have to be dealt with in those future comparisons is the variability of soil attributes.

Point-to-point variability for some parameters like Ksat is extreme, even within the topographical groupings applied in Table 4. Essentially the predictability of some soil attributes by landform (or slope) position is tenuous at this site. Great care must be taken in analyzing such data to look for management comparisons or temporal trends. How the data points are grouped, or filtered out, will be an important part of that analysis.

One alternative approach might be to analyze chronological data at selected representative sampling points. For example, sampling points with sandy or Solonetzic soils might be excluded from comparisons because they represent only a small part of the landscape. This approach would be most useful for the highly variable Ksat and penetrometer data, and might reveal some long-term trends. However, the number of useful "paired" sampling points may be too small for statistical analysis.

Table 4. Descriptive statistics for selected Ap/Ah horizon baseline attributes of the CT and DS sub-sites.

Slope Position: Variable	n	Mean	Std. Dev.	Range	Median	n	Mean	Std. Dev.	Range	Median
Hilltop (crest & upper slope):			***CT Sub-site***					***DS Sub-site***		
Ap horizon: Thickness (cm)	9	11	1	10 - 13	11	10	11	1	9 - 13	11
pH ($CaCl_2$)	9	6.0	1.1	5.0 - 7.6	5.5	10	5.4	0.7	4.6 - 6.8	5.3
Organic C (%)	9	3.06	1.72	1.07 - 5.91	2.60	10	3.43	1.11	1.50 - 4.57	3.73
Total N (%)	9	0.27	0.15	0.10 - 0.51	0.20	10	0.28	0.08	0.13 - 0.35	0.31
C:N Ratio	9	11.5	0.7	10.7 - 13.0	11.3	10	12.2	0.7	10.7 - 13.2	12.1
Available K (ug g $soil^{-1}$)	9	238	122	56 - 446	245	10	219	170	66 - 667	189
Bulk Density (Mg m^{-3})	7	1.27	0.21	0.99 - 1.60	1.26	7	1.16	0.06	1.08 - 1.25	1.16
^{137}Cs conc. (Bq kg $soil^{-1}$)	7	7.03	3.76	2.51 - 12.03	7.96	7	7.46	3.02	2.45 - 10.81	8.48
^{137}Cs mass (Bq m^{-2})	7	928	398	389 - 1429	1003	7	874	334	337 - 1157	1055
Ksat (cm h^{-1})**:** 5-10 cm depth	8	4.98	7.92	0.47 - 24.34	2.46	10	1.67	1.35	0.13 - 3.98	1.29
15-25 cm depth	25	2.81	2.98	0.03 - 10.18	1.71	31	2.23	2.40	0.01 - 9.76	1.17
30-40 cm depth	25	3.62	3.97	0.07 - 17.81	2.55	31	3.24	3.61	0.08 - 15.16	1.61
Resistance (MPa): 0-10 cm	11	0.7	0.5	0.0 - 1.9	0.8	12	0.9	0.3	0.4 - 1.5	0.8
10-20 cm	27	1.5	0.6	0.7 - 2.8	1.4	29	1.7	1.1	0.6 - 5.2	1.3
20-30 cm	26	1.6	0.9	0.7 - 4.2	1.2	29	2.5	2.0	0.6 - 8.3	1.7
30-40 cm	27	1.8	0.8	0.8 - 4.0	1.7	28	3.0	2.2	0.7 - 8.3	2.3
Mid slope:			***CT Sub-site***					***DS Sub-site***		
Ap horizon: Thickness (cm)	16	12	1	10 - 13	12	19	11	1	10 - 15	11
pH ($CaCl_2$)	16	5.6	0.5	4.9 – 6.9	5.5	19	5.5	0.4	4.9 – 6.4	5.4
Organic C (%)	16	3.68	1.33	1.28 - 5.89	3.91	19	3.68	0.82	1.97 - 5.13	3.84
Total N (%)	16	0.31	0.11	0.12 - 0.51	0.32	19	0.30	0.06	0.20 - 0.41	0.30
C:N Ratio	16	11.8	0.7	10.7 - 13.1	11.7	19	12.3	0.9	9.4 - 13.5	12.3
Available K (ug g $soil^{-1}$)	16	199	138	49 - 586	163	18	159	81	61 - 417	143
Bulk Density (Mg m^{-3})	13	1.23	0.13	1.06 - 1.48	1.16	13	1.16	0.06	1.06 - 1.27	1.16
^{137}Cs conc. (Bq kg $soil^{-1}$)	13	8.65	2.95	3.70 - 12.91	9.75	13	9.43	2.12	6.17 - 13.04	9.91
^{137}Cs (Bq m^{-2})	13	1198	345	674 - 1713	1283	13	1163	242	771 - 1675	1168
Ksat (cm h^{-1})**:** 5-10 cm depth	14	2.97	2.65	0.43 - 10.96	2.38	16	1.85	1.65	0.13 - 6.11	1.11
15-25 cm depth	35	1.77	1.07	0.01 - 4.35	1.79	36	1.27	0.85	0.00 - 3.00	1.05
30-40 cm depth	35	3.41	2.66	0.04 - 12.57	3.30	36	2.16	2.44	0.00 - 12.02	1.07
Resistance (MPa): 0-10 cm	19	0.7	0.3	0.3 - 1.3	0.7	20	0.8	0.3	0.3 - 1.4	0.9
10-20 cm	40	1.4	0.5	0.5 - 3.1	1.4	42	1.6	1.1	0.6 - 6.3	1.3
20-30 cm	40	1.4	0.5	0.5 - 3.3	1.3	42	2.0	1.2	0.4 - 5.6	1.8
30-40 cm	40	1.6	0.7	0.6 - 3.9	1.4	42	2.6	2.2	0.4 - 9.1	1.9

Slope Position: Variable	n	Mean	Std. Dev.	Range	Median	n	Mean	Std. Dev.	Range	Median
Lower slope:			***CT Sub-site***					***DS Sub-site***		
Ap/h horizon: Thickness (cm)	12	13	4	10 - 24	12	13	12	1	10 - 14	11
pH ($CaCl_2$)	12	5.7	0.5	5.0 - 6.8	5.6	13	6.4	0.7	5.3 - 7.8	6.4
Organic C (%)	12	3.97	0.76	2.86 - 5.26	3.96	13	4.72	0.52	3.64 - 5.76	4.69
Total N (%)	12	0.33	0.07	0.23 - 0.45	0.33	13	0.38	0.05	0.29 - 0.48	0.38
C:N Ratio	12	12.0	0.8	10.7 - 13.2	12.2	13	12.5	0.9	10.7 - 13.9	12.6
Available K (ug g soil^{-1})	12	311	201	73 - 686	312	13	244	126	76 - 508	204
Bulk Density (Mg m^{-3})	7	1.06	0.13	0.86 - 1.25	1.03	11	1.08	0.10	0.99 - 1.33	1.06
^{137}Cs conc. (Bq kg soil^{-1})	7	12.15	2.20	8.39 - 15.51	12.00	11	12.28	1.36	9.92 - 13.68	12.61
^{137}Cs (Bq m^{-2})	7	1595	222	1436 - 1837	1706	11	1480	229	1211 - 2046	1408
Ksat (cm h^{-1}): 5-10 cm depth	7	3.62	4.63	0.56 - 12.94	0.95	9	3.00	2.72	0.40 - 7.77	1.94
15-25 cm depth	18	0.67	0.53	0.00 - 2.09	0.53	20	1.08	1.94	0.03 - 9.16	0.59
30-40 cm depth	18	0.50	0.54	0.01 - 2.39	0.32	21	0.70	0.78	0.00 - 2.50	0.41
Resistance (MPa): 0-10 cm	6	0.5	0.4	0.1 - 1.1	0.4	11	0.2	0.2	0.0 - 0.5	0.3
10-20 cm	18	1.3	0.6	0.5 - 2.5	0.9	24	0.6	0.3	0.1 - 1.4	0.6
20-30 cm	17	2.4	2.1	0.8 - 7.5	1.6	24	0.9	0.3	0.4 - 1.7	0.9
30-40 cm	17	1.9	1.4	0.6 - 5.6	1.5	24	0.8	0.4	0.3 - 2.3	0.8
Depression:			***CT Sub-site***					***DS Sub-site***		
Ap/h horizon: Thickness (cm)	5	14	5	10 - 20	11	6	11	1	10 - 11	11
pH ($CaCl_2$)	5	5.2	0.2	4.9 - 5.4	5.2	6	6.4	0.9	4.9 - 7.5	6.5
Organic C (%)	5	5.33	0.34	4.75 - 5.59	5.40	6	4.72	0.84	3.92 - 5.69	4.42
Total N (%)	5	0.48	0.04	0.45 - 0.55	0.46	6	0.44	0.08	0.36 - 0.54	0.39
C:N Ratio	5	11.1	0.7	10.2 - 11.9	10.9	6	10.8	0.5	10.3 - 11.6	10.9
Available K (ug g soil^{-1})	5	501	110	348 - 613	528	6	192	44	142 - 258	191
Bulk Density (Mg m^{-3})	5	0.92	0.07	0.80 - 0.98	0.94	5	1.15	0.14	0.98 - 1.35	1.14
^{137}Cs conc. (Bq kg soil^{-1})	5	14.97	1.81	12.35-17.47	14.97	5	13.78	1.96	11.50-16.48	14.22
^{137}Cs (Bq m^{-2})	5	1837	566	1317 - 2485	1642	5	1655	45	1615 - 1708	1632
Ksat (cm h^{-1}): 5-10 cm depth	4	3.66	3.58	0.65 - 8.63	2.69	6	1.88	1.65	0.86 - 4.79	1.29
15-25 cm depth	4	1.47	1.04	0.75 - 3.00	1.06	7	1.05	1.41	0.01 - 3.45	0.59
30-40 cm depth	4	0.23	0.07	0.13 - 0.30	0.24	7	0.14	0.11	0.01 - 0.25	0.10
Resistance (MPa): 0-10 cm	3	0.2	0.1	0.1 - 0.2	0.2	4	0.2	0.1	0.1 - 0.3	0.2
10-20 cm	4	0.7	0.4	0.2 - 1.0	0.8	4	0.5	0.2	0.3 - 0.6	0.5
20-30 cm	4	1.0	0.5	0.5 - 1.5	1.0	4	0.9	0.9	0.3 - 1.9	0.6
30-40 cm	4	1.0	0.5	0.6 - 1.7	0.8	4	0.8	0.5	0.5 - 1.4	0.5

Table 5. A summary of selected landscape features by slope position for the Mundare BMS.

Slope Position (n)[1]	Slope Shape	Soil Groupings and Their Distribution[2]	Topsoil[3] (cm, mean and σ)
CT Sub-site:			
Hilltop (9)	Convex – 89% Concave – 11%	Orthic Black (with thin A horizon) on till – 33% Orthic Black on glaciolacustrine/till – 33% Orthic Black on sandy-gravelly material – 11% Orthic Black (with thin A) on gravelly till – 11% Solonetzic Black (with thin A horizon) on till – 11%	18 (11)
Mid slope (16)	Straight – 63% Convex – 31% Concave – 6%	Eluviated Black on glaciolacustrine/till – 19% Orthic Black on glaciolacustrine/till – 13% Gleyed Eluviated Black on glaciolacustrine/till – 13% Solonetzic Black (with thin A horizon) on till – 13% Gleyed Solonetzic Black on glaciolacustrine/till – 13% Orthic Black (with thin A horizon) on till – 6% Orthic Black on till – 6% Gleyed Eluviated Black on deep glaciolacustrine – 6% Calcareous Black on coarse-textured material – 6% Humic Luvic Gleysol on glaciolacustrine/till – 6%	31 (18)
Lower slope (12)	Straight – 83% Concave – 17%	Humic Luvic Gleysol on glaciolacustrine/till – 75% Humic Luvic Gleysol (saline) on glaciolacustrine/till – 17% Gleyed Solonetzic Black on glaciolacustrine/till – 8%	22 (5)
Depression (5)	Concave or straight	Humic Luvic Gleysol on glaciolacustrine/till – 100%	24 (7)
DS Sub-site:			
Hilltop (10)	Convex – 100%	Orthic Black (with thin A horizon) on till – 40% Orthic Black on glaciolacustrine/till – 20% Orthic Black on till – 10% Solonetzic Black (with thin A horizon) on till – 10% Solonetzic Black on till – 10% Orthic Black (with thin A) on sandy-layered till – 10%	15 (5)
Mid slope (19)	Straight – 63% Convex – 32% Concave – 5%	Solonetzic Black on glaciolacustrine/till – 21% Orthic Black (with thin A horizon) on till – 16% Orthic Black on glaciolacustrine/till – 11% Solonetzic Black (with thin A horizon) on till – 11% Black Solodized Solonetz on till or veneer/till – 11% Orthic and Solonetzic Black on till – 11% Gleyed Solonetzic Black on glaciolacustrine/till – 5% Eluviated Black on glaciolacustrine/till – 5% Eluviated Black (saline) on deep glaciolacustrine – 5% Humic Luvic Gleysol on glaciolacustrine/till – 5%	23 (11)
Lower slope (14)	Straight – 57% Concave – 36% Convex – 7%	Humic Luvic Gleysol on glaciolacustrine/till – 93% Orthic Humic Gleysol (saline) on glaciolacustrine/till – 7%	26 (7)
Depression (5)	Concave or straight	Humic Luvic Gleysol on glaciolacustrine/till – 80% Orthic Humic Gleysol (saline) on glaciolacustrine/till – 20%	20 (5)

[1] All sampling points (n) are included in this table; some may be excluded from future analyses.
[2] Soil groupings are based on subgroups (ECSS 1987) and parent materials. Soils with very thick topsoil were lumped with normal counterparts.
[3] The mean thickness of humus-rich topsoil, and standard deviation, is listed in cm. This includes the current Ap plus any underlying older Ap, uncultivated Ah or Ahe horizon. Strongly eluviated (Ae) horizons were excluded.

Another approach would involve alternative, more restrictive groupings of the data sets. More meaningful relationships might be found if the data were analyzed according to soil types, or groupings thereof, (i.e. soil series and variants), similar to those listed in Table 5. Some soil attribute variability may be related to soil type and morphology differences, which are greatest on the drier "upland" portions of the landscape. Table 5 shows that soils are much more uniform and predictable on lower and depressional slope positions than on mid slopes and hilltops.

In a test of some early Mundare BMS data, coefficients of variation were calculated for organic carbon, pH and available K data grouped in two different ways: 1) by the four slope positions used in Tables 4 and 5, and 2) by groupings of soils that differentiated sandy soils, soils with very thin A horizons, soils with very thick A horizons, soils with Solonetzic or solonetzic-like B horizons, and Gleysolic soils. Coefficients of variation were lower in all three data sets grouped by soil types as opposed to slope position. This meant that less variability in the data was attained by using soil groupings over landscape position groupings. However, the differences were small, and not statistically significant.

The drawback of using soil type groupings to deal with variability in fields like that of the Mundare BMS is a practical one. Landscape differences based on soil typing are not very visible or predictable, especially to the untrained eye. Very detailed soil maps would be required, probably compiled at substantial cost by experts. These would also need to be loaded into sophisticated, GPS-based, precision management equipment in order to be implemented on the ground.

On the other hand, topographic distinctions are fairly easy to make. A simple slope position classification, such as upper, mid, lower, and depression, can be implemented in a variety of landscapes, often with just minimal expert involvement. Further, some management decisions based on topographic segmentation can be implemented without the use of expensive and sophisticated equipment.

Other options for dealing with attribute variability like that encountered at the Mundare BMS include combining data sets and using proxy data. For example, analyzing moisture content along with the penetration resistance data might make those results more meaningful. Or crop yield data, which is not previewed in this report, may ultimately provide the "final word" on soil quality change. Fortunately, the benchmark site project was designed to be flexible and provide a host of options to address soil quality change issues.

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APPENDIX A: SOIL AND LANDSCAPE FEATURES OF SAMPLING POINTS

Selected soil and landscape characteristics of the Mundare BMS are presented in the following tables. The data is sorted by sampling point ID within slope position (4 classes; see methods). Soil subgroup codes are standard (ECSS 1987). Soil series and variant codes are based on the Alberta Soil Names File from AGRASID (Alberta Soil Information Centre 2001). The last column lists total depth of humus-rich topsoil. The current Ap plus any underlying older Ap or uncultivated Ah or Ahe were totalled; strongly eluviated (Ae) horizons were excluded.

Table 6. Selected soil and landscape characteristics of the Mundare BMS, CT Sub-site.

SLOPE POSITON	SAMPLING POINT ID	SLOPE SHAPE	SOIL SUBGROUP[1]	SOIL SERIES[2]	TOTAL Ap/Ah THICKNESS (cm)
Hilltop:	04T01.00	Convex	O.BL	Hobbema-atypical sbgp (HBMzz)	35
	04T01.01	Concave	O.BL	HBMzz	33
	04T01.02	Convex	O.BL	HBMzz	27
	04T02.00	Convex	SZ.BL	Norma-thin A (NRMta)	10
	04T03.00	Convex	O.BL	Beaverhills-thin A (BVHta)	10
	04T04.00	Convex	O.BL	Mundare-gravelly (MDRgr)	12
	04T05.00	Convex	O.BL	Beaverhills-variant (BVHtagr)	11
	04T31.00	Convex	O.BL	BVHta	11
	04T31.01	Convex	O.BL	BVHta	12
	Average:				**18**
	Std. Dev.:				**11**
Mid Slope:	04T01.03	Convex	O.BL	Hobbema-atypical sbgp (HBMzz)	34
	04T01.04	Straight	GLE.BL	Hobbema-gleyed (HBMgl)	26
	04T01.05	Straight	HU.LG	Jarvie (JVE)	23
	04T02.01	Convex	SZ.BL	Norma-thin A (NRMta)	10
	04T02.02	Straight	GLE.BL	HBMgl	50
	04T03.01	Convex	O.BL	Beaverhills (BVH)	15
	04T03.02	Straight	E.BL	Hobbema (HBM)	20
	04T04.01	Convex	CA.BL	Peace Hills-calcareous (PHSca)	34
	04T04.02	Straight	E.BL	Hobbema-thick A (HBMtk)	75
	04T04.03	Straight	E.BL	HBMtk	45
	04T04.04	Straight	GLSZ.BL	Sante-variant (STExtgl)	22
	04T05.01	Convex	O.BL	Beaverhills-thin A (BVHta)	13
	04T05.02	Straight	GLE.BL	Ponoka-variant (POKgltk)	50
	04T31.02	Straight	SZ.BL	NRMta	13
	04T31.03	Straight	O.BL	Hobbema-variant (HBMzztk)	42
	04T31.04	Concave	GLSZ.BL	STExtgl	28
	Average:				**31**
	Std. Dev.:				**18**
Lower Slope:	04T01.06[3]	Straight	HU.LG	Jarvie (JVE)	27
	04T02.03	Straight	HU.LG	JVE	24
	04T03.03	Concave	HU.LG	JVE	24
	04T03.04[3]	Straight	HU.LG	JVE	20
	04T04.05	Straight	HU.LG	JVE	20
	04T04.06[3]	Straight	HU.LG	JVE	25
	04T05.03[4]	Straight	HU.LG	JVE	30
	04T31.05	Straight	GLSZ.BL-sal.	Sante-variant (STExtsagl)	27
	04T31.06	Straight	HU.LG-saline	Jarvie-saline (JVEsa)	12
	04T31.07	Straight	HU.LG-saline	JVEsa	25
	04T31.08	Concave	HU.LG	JVE	13
	04P2	Straight	HU.LG	JVE	20
	Average:				**22**
	Std. Dev.:				**5**

SLOPE POSITON	SAMPLING POINT ID	SLOPE SHAPE	SOIL SUBGROUP[1]	SOIL SERIES[2]	TOTAL Ap/Ah THICKNESS (cm)
Depression:	04T01.07[3]	--	HU.LG	Jarvie (JVE)	20
	04T02.04[3]	--	HU.LG	JVE	35
	04T03.05[3]	--	HU.LG	JVE	17
	04T04.07[3]	--	HU.LG	JVE	24
	04T05.04[4]	--	HU.LG	JVE	25
	Average:				**24**
	Std. Dev.:				**7**

[1] Refer to the Canadian System of Soil Classification (ECSS 1987) for explanation of soil subgroup (sbgp) codes.
[2] Soil series and variant names, codes and formatting as used in the Alberta Soil Names File (Alberta Soil Information Centre 2001). Several codes have been written out to provide a preliminary guideline into the references should follow-up be an option.
[3] Most depressional and a few lower slope sampling points have not been cultivated since the benchmark site was established, and possibly not before establishment.
[4] Points 04T05.03 has been cropped frequently, 04T05.04 occasionally, when conditions are dry enough.

Table 7. Selected soil and landscape characteristics of the Mundare BMS, DS Sub-site.

SLOPE POSITON	SAMPLING POINT ID	SLOPE SHAPE	SOIL SUBGROUP[1]	SOIL SERIES[2]	TOTAL Ap/Ah THICKNESS (cm)
Hilltop:	04T06.00	Convex	O.BL	Beaverhills (BVH)	20
	04T06.01	Convex	SZ.BL	Norma (NRM)	13
	04T07.00	Convex	O.BL	Beaverhills-thin A (BVHta)	15
	04T08.00	Convex	O.BL	BVHta	11
	04T09.00	Convex	O.BL	Hobbema-atypical sbgp (HBMzz)	18
	04T09.01	Convex	O.BL	HBMzz	25
	04T10.00	Convex	O.BL	Beaverhills-variant (BVHcota)	10
	04T32.00	Convex	SZ.BL	Norma-thin A (NRMta)	13
	04T32.01	Convex	O.BL	BVHta	13
	04T33.00	Convex	O.BL	BVHta	10
	Average:				**15**
	Std. Dev.:				**5**
Mid Slope:	04T06.02	Straight	BL.SS	Camrose (CMO)	20
	04T06.03	Straight	SZ.BL	Sante-shallow variant (STExt)	30
	04T07.01	Convex	SZ.BL	Norma-thin A (NRMta)	13
	04T07.02	Straight	GLSZ.BL	Sante-variant (STExtgl)	35
	04T08.01	Convex	O.BL	Beaverhills (BVH)	20
	04T08.02	Straight	E.BL	Hobbema-thick A (HBMtk)	50
	04T08.03	Concave	SZ.BL	Sante-thick A (STEtk)	40
	04T08.07	Convex	O.BL	Hobbema-atypical sbgp (HBMzz)	25
	04T09.02	Convex	SZ.BL	STExt	12
	04T09.03	Straight	BL.SS	Armena (ARM)	28
	04T09.04	Straight	E.BL	Ponoka-saline (POKsa)	25
	04T10.01	Convex	O.BL	Beaverhills-thin A (BVHta)	10
	04T10.02	Straight	SZ.BL	STExt	12
	04T32.02	Convex	SZ.BL	NRMta	13
	04T32.03	Straight	O.BL	HBMzz	32
	04T33.01	Straight	O.BL	BVHta	13
	04T33.02	Straight	HU.LG	Jarvie (JVE)	28
	04P1	Straight	O.BL	BVHta	12
	04P3	Straight	SZ.BL	Norma (NRM)	24
	Average:				**23**
	Std. Dev.:				**11**

SLOPE POSITON	SAMPLING POINT ID	SLOPE SHAPE	SOIL SUBGROUP[1]	SOIL SERIES[2]	TOTAL Ap/Ah THICKNESS (cm)
Lower Slope:	04T06.04[4]	Straight	HU.LG	Jarvie (JVE)	28
	04T06.05[4]	Straight	HU.LG	JVE	28
	04T06.06[4]	Straight	HU.LG	JVE	24
	04T07.03[3]	Concave	HU.LG	JVE	23
	04T08.04	Concave	HU.LG	JVE	22
	04T08.05	Concave	HU.LG	JVE	28
	04T08.06	Convex	HU.LG	JVE	15
	04T08.08	Straight	HU.LG	JVE	35
	04T08.09[3]	Straight	HU.LG	JVE	20
	04T09.05[3]	Straight	O.HUG	Jarvie-variant (JVEzzsa)	40
	04T10.03[3]	Straight	HU.LG	JVE	25
	04T32.04	Straight	HU.LG	JVE	35
	04T32.05[4]	Concave	HU.LG	JVE	22
	04T33.03	Concave	HU.LG	JVE	25
	Average:				**26**
	Std. Dev.:				**7**
Depression:	04T06.07[4]	--	HU.LG	Jarvie (JVE)	15
	04T07.04[3]	--	HU.LG	JVE	25
	04T08.10[3]	--	HU.LG	JVE	15
	04T09.06[3]	--	O.HUG	Jarvie-variant (JVEzzsa)	20
	04T10.04[3]	--	HU.LG	JVE	23
	Average:				**20**
	Std. Dev.:				**5**

[1] Refer to the Canadian System of Soil Classification (ECSS 1987) for explanation of soil subgroup (sbgp) codes.

[2] Soil series and variant names, codes and formatting as used in the Alberta Soil Names File (Alberta Soil Information Centre 2001). Several codes have been written out to provide a preliminary guideline into the references should follow-up be an option.

[3] Most depressional and a few lower slope sampling points have not been cultivated since the benchmark site was established, and possibly not before establishment.

[4] Points 04T06.04, 04T06-05, and 04T06.06 have been cropped frequently, 04T06.07 and 04T32.05 occasionally, when conditions are dry enough.

APPENDIX B: PEDON DESCRIPTIONS

Pedons representing the two major soils of the site were described and sampled in detail when the site was established in 1992. A third pedon was added in 1994. Locations of all three pedons are shown in Figs. 3 and 4. 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, and soil moisture retention and bulk density from core samples.

PEDON 1: Beaverhills-thin A (BVHta) variant

ID and Location:	04-AB, Pedon 1 (P1, Figure 4); NE9-53-16-W4
Described by:	B.D. Walker; October 23, 1992
Classification	Orthic Black Chernozemic (ECSS 1987)
Parent material:	Moderately fine textured (fine loamy), moderately calcareous, weakly saline till
Landscape:	Mid slope of a ridge with moderate slope (9%) towards the southeast
Drainage:	Well drained
Land use:	Oat stubble; last year of summerfallow-wheat-barley-barley-oat rotation

Horizon	Depth (cm)	Description
Ap	0-12	Black (10YR 2/1 m), very dark gray (10YR 3/1 d); loam; moderate, medium to coarse, subangular blocky and weak, very fine to fine subangular blocky; slightly hard; abundant, very fine roots; many, very fine pores; 5% gravels, cobbles, & stones; abrupt, wavy boundary; 10-15 cm thick; medium acid.
Bt1	12-32	Dark brown (10YR 3/3 m), brown (10YR 4/3 d); clay loam; weak, fine to medium, prismatic and weak to moderate, fine, subangular blocky; firm; plentiful, very fine roots; many, very fine to fine pores; 5% gravels, cobbles, & stones; gradual, wavy boundary; 15-25 cm thick; slightly acid.
Bt2	32-62	Very dark grayish brown (10YR 3/2 m), brown (10YR 4/3 d); loam; weak to moderate, medium to coarse, prismatic and weak to moderate, fine, subangular blocky; firm; plentiful, very fine roots; many, very fine to fine pores; 5% gravels, cobbles, & stones; abrupt, wavy boundary; 25-35 cm thick; neutral.
Ck	62-100	Very dark grayish brown (2.5Y 3.5/2), dark grayish brown (2.5Y 4/2 d); loam; moderate, fine to medium, angular & subangular blocky; firm; few, very fine roots; many, very fine to fine pores; moderate effervescence; 5% gravels, cobbles, & stones; gradual, wavy boundary; 30-45 cm thick; mildly alkaline.
Cks	100-120	Olive brown (2.5Y 4/3 m); loam; massive breaking to moderate to strong, medium to coarse, angular blocky; friable; few, very fine roots; many, very fine pores; common gypsum nodules; weak effervescence; 5% gravels, cobbles, & stones; moderately alkaline.

Table 8. Selected chemical and physical characteristics of the BVHta profile (Pedon 1).

Horizon	Depth (cm)	pH ($CaCl_2$)	Organic C (%)	Total N (%)	$CaCO_3$ Equiv. (%)	E.C. ($dS\ m^{-1}$)	Sand (%)	Silt (%)	Clay (%)
Ap	0-12	5.8	3.29	0.28		Nd*	42	35	23
Bt1	12-32	6.4	0.91	0.09		Nd	39	33	28
Bt2	32-62	6.9	0.63	0.06	0.04	Nd	44	31	25
Ck	62-100	7.8	0.59	0.05	6.29	Nd	45	32	23
Cks	100-120	7.9	0.53	0.04	5.57	Nd	45	32	23

* Nd – not determined

PEDON 2: Jarvie (JVE) Series

ID and Location: 04-AB, Pedon 2 (P2, Figure 3); NE9-53-16-W4
Described by: B.D. Walker; October 24, 1992
Classification Humic Luvic Gleysol (ECSS 1987)
Parent material: Medium textured glaciolacustrine material overlying medium textured till
Landscape: Lower part of a long inclined-undulating slope (1.5%), oriented southeast
Drainage: Imperfectly drained
Land use: Oat stubble; last year of summerfallow-wheat-barley-barley-oat rotation

Horizon	Depth (cm)	Description
Ap1	0-10	Very dark gray (10YR 3.5/1 d); silt loam; weak to moderate, fine to medium, subangular blocky grading to weak, very fine, subangular blocky; soft; abundant, very fine, fine and medium roots; clear, smooth boundary; 9-12 cm thick; medium acid.
Ap2	10-20	Dark gray (10YR 4/1 d), very dark gray (10YR 3/1 m); silt loam; massive breaking to weak to moderate, fine to medium, subangular blocky; hard; plentiful, very fine & medium roots; many, very fine pores; abrupt, smooth boundary; 9-11 cm thick; strongly acid.
Ae	20-25	White (10YR 8/1 d); loam; weak, fine platy; hard; few, very fine roots; many, very fine & fine pores; abrupt, broken boundary; 0-9 cm thick; medium acid.
Btg	25-48	Very dark grayish brown (2.5Y 3/2 m); clay loam; many, fine & coarse, prominent, reddish brown (5YR 4/4 m) mottles; weak, medium to coarse, columnar grading to moderate, medium, subangular blocky; firm; continuous, thin clay films in all voids/channels and on all ped faces; plentiful, very fine & medium roots; common, very fine pores; 1-2% gravels; gradual, wavy boundary; 15-27 cm thick; slightly acid.
2Btg1	48-90	Dark grayish brown (2.5Y 4/2 m); loam; many, medium & coarse, prominent, reddish brown (5YR 4/4 m) mottles; weak to moderate, medium, subangular blocky; friable; continuous, thin clay films in all voids/channels and on all ped faces; few, very fine roots; common, very fine pores; 5% gravels, cobbles and stones; diffuse, smooth boundary; 38-50 cm thick; slightly acid.
2Btg2	90-120	Dark grayish brown (2.5Y 4/2 m); loam; many, medium & coarse, prominent, strong brown (7.5YR 4/6 m) mottles; moderate, fine to medium, subangular blocky; very friable; continuous, very thin clay films in many voids/channels and on some ped faces; few, very fine roots; common, very fine & fine pores; 5% gravels, cobbles and stones; neutral.

Comments: Reported colors are exped except for the Ae (crushed) and 2Btg2 (matrix).

Table 9. Selected chemical and physical characteristics of the JVE profile (Pedon 2).

Horizon	Depth (cm)	pH ($CaCl_2$)	Organic C (%)	Total N (%)	$CaCO_3$ Equiv. (%)	E.C. ($dS\ m^{-1}$)	Sand (%)	Silt (%)	Clay (%)
Ap1	0-10	5.6	3.18	0.29		Nd*	33	51	16
Ap2	10-20	5.4	2.74	0.26		Nd	35	51	14
Ae	20-25	5.8	0.38	0.05		Nd	38	45	17
Btg	25-48	6.1	0.49	0.06		Nd	38	28	34
2Btg1	48-90	6.3	0.30	0.04		Nd	43	33	24
2Btg2	90-120	6.7	0.28	0.03	0.04	Nd	48	30	22

* Nd – not determined

PEDON 3: Norma (NRM) Series

ID and Location:	04-AB, Pedon 3 (P3, Figure 4); NE9-53-16-W4
Described by:	B.D. Walker; October 12, 1994
Classification	Solonetzic Black Chernozemic (ECSS 1987)
Parent material:	Moderately fine textured (fine loamy), moderately calcareous, weakly saline till
Landscape:	Mid slope (4%) of a hummock; oriented southwest
Drainage:	Moderately well drained
Land use:	Barley stubble

Horizon	Depth (cm)	Description
Ap	0-12	Black (10YR 2/1 m); loam; weak to moderate, fine to medium, subangular blocky and weak, very fine to fine subangular blocky; very friable; plentiful, very fine roots; many, very fine pores; 1% gravels; abrupt, smooth boundary; 10-14 cm thick; strongly acid.
Ah	12-24	Very dark brown (10YR 2/2 m); loam; weak, fine to medium, subangular blocky; very friable; plentiful, very fine roots; many, very fine pores; 2-5% gravels & cobbles; abrupt, wavy boundary; 10-30 cm thick; strongly acid.
Btnj	24-47	Dark brown (7.5YR 3/2 m); clay loam; weak to moderate, fine to medium, prismatic grading to moderate to strong, fine to medium, subangular blocky; firm; continuous, thin clay films in all voids/channels and on all ped faces; plentiful, very fine roots; many, very fine pores; 2-5% gravels & cobbles; clear, wavy boundary; 17-30 cm thick; slightly acid.
Bt	47-75	Dark yellowish brown (10YR 3/4 m); clay loam; weak, fine to medium, prismatic grading to moderate, fine to medium, subangular blocky; firm; few, many, thin clay films in many voids/channels and on some ped faces; very fine roots; many, very fine & fine pores; 2-5% gravels & cobbles; abrupt, wavy boundary; 19-40 cm thick; mildly alkaline
Csak	75-95	Olive brown (2.5Y 4/4 m); loam; massive breaking to moderate, coarse, subangular blocky; friable; many, thin clay films in many voids/channels and on some ped faces; many, very fine & fine pores; many, medium, oblong & irregular, very pale brown (10YR 8/3), salt nodules; weak effervescence; 2-5% gravels & cobbles; clear, wavy boundary;; moderately alkaline.
Csk	95-110	Olive brown (2.5Y 4/4 m); loam; massive; friable; many, very fine & fine pores; common, medium, oblong & irregular, very pale brown (10YR 8/3), salt nodules; weak effervescence; 2-5% gravels & cobbles; moderately alkaline.

Comments: Reported colors are for the soil matrix, except for Btnj and Bt (exped).

Table 10. Selected chemical and physical characteristics of the NRM profile (Pedon 3).

Horizon	Depth (cm)	pH ($CaCl_2$)	Organic C (%)	Total N (%)	$CaCO_3$ Equiv. (%)	E.C. (dS m^{-1})	Sand (%)	Silt (%)	Clay (%)
Ap	0-12	5.4	1.97	0.21		Nd*	Nd*	Nd*	Nd*
Ah	12-24	5.3	4.14	0.35		Nd	Nd	Nd	Nd
Btnj	24-47	6.5	0.78	0.14		0.5	Nd	Nd	Nd
Bt	47-75	7.8	0.49	0.11	Nd*	3.5	Nd	Nd	Nd
Csak	75-95	8.2	0.48	0.11	5.60	7.0	Nd	Nd	Nd
Csk	95-110	8.1	0.21	0.10	5.49	6.0	Nd	Nd	Nd

* Nd – not determined