Soil Management Guide

REVISED 2008

COVERING NEW GROUND
Manitoba Agricultural Sustainability Initiative

Manitoba

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Understanding the Soil Landscapes of Manitoba

Introduction

Soil management, or soil conservation, deals with some aspect of protecting soil resources and using soils in a sustainable manner. Effective soil conservation in agriculture hinges on five basic principles:

1. **Keeping soil in place by reducing tillage practices**
2. **Maintaining or improving soil quality parameters, such as organic matter, bulk density, earthworms, desirable soil structure, etc.**
3. **Managing and protecting water supplies**
4. **Planning a crop rotation system made up of crops that are profitable and protect soil quality**
5. **Applying only the amount of inputs needed to achieve reasonable crop production targets**

This publication focuses on the first three principles. Additional information on items #4 and #5 are found in the *Soil Fertility Guide, Field Crop Production Guide* and *Guide to Crop Protection* published by Manitoba Agriculture, Food and Rural Initiatives and in other agronomy-related publications.

To fully appreciate and understand the principles of soil management, one must understand the soil itself. The first part of the guide deals with how soils are formed and classified. The latter section uses these principles to identify certain soils (under certain conditions) that would benefit the most from a particular soil conservation practice.

What is soil?

Soils comprise the uppermost layer of the earth's surface. They were developed by the action of climate on rock and sediments under the influence of organic life. The first interest in the soil was related to its ability to produce plants for food and fibre. In this context, soil is defined as **the collection of natural bodies on the earth's surface supporting or capable of supporting plants** (Brady, 1984).

Why are soils important?

Soils are required for food production and for filtration of water. However, only 1/16 of the earth's surface has soil that is suitable for growing crops. Of the 160 million acres (65 million hectares) in Manitoba, only 19 million acres (7.7 million hectares) have potential for agriculture. Much of this land has been settled over time, and is either being lost to urbanization or being mismanaged so that erosion, salinity, compaction and organic matter losses have made the soil less productive. **Over a 10 year period from 1991 to 2001, approximately 36,600 acres (14,640 hectares) of land in Manitoba has been subdivided into building lots for non-agricultural land uses (Land Use Planning Group, 2003).**

Table 1.1. Relative area of various segments of Manitoba

	Million Acres (approx.)	Million Hectares (approx.)
Total Area – Manitoba	160	65
Total Land Surface - Manitoba	136	55
Total Land Area – Agro-Manitoba	26	10.5
Land in Farms – Agro-Manitoba	19	7.7
Improved Land (Crops, Fallow, Pasture)	13	5.3
Unimproved Pasture	4	1.6
Other (e.g. yard sites, etc.)	2	0.8

(Source: Manitoba Agriculture Yearbook 2003).

Table 1.2. Land use data within agro-Manitoba as based on satellite imagery from 1999-2002 (Manitoba Conservation – Manitoba Remote Sensing Centre, 2002).

Land use	Total (ac)	Total (ha)
Agricultural Cropland	12,161,607	4,921,648
Trees	6,279,339	2,541,167
Water Bodies	620,708	251,193
Grassland/Rangeland	6,001,550	2,428,751
Wetlands	2,222,681	899,491
Forages	1,038,032	420,078
Urban & Transportation	828,344	335,220
Total	**29,152,261**	**11,797,548**

> **"In the past, many industrial developments were put on poor soils because the land was (inexpensive), but in the future information on soils and the environment must be considered much more carefully to avoid repeating past mistakes. Many of our (waste disposal) problems can be solved and mistakes avoided by increased use of soil maps together with other environmental information."**
>
> **(Olson, 1984).**

The first step in sustainable soil management is ensuring that the soil will support the land use activity. For example, only the better agricultural soils in Manitoba will support grain and vegetable production, while more marginal agricultural soils will support forage and pasture-based production. For this reason, agricultural development should only occur in areas where the soil resource will support the agricultural activity. The only way to do this is to understand the soil resource that is available.

Soil variation

Soils vary significantly in their properties. They may be deep in some places, shallow in others, black or gray in colour, sandy or clayey in texture. Although the soil mantle covering Manitoba is far from uniform, all soils have some common factors. For example, all soil is a mixture of organic and mineral material plus water and air. While the major components remain the same, the proportion of each component in this mixture varies from soil to soil.

Every farm may consist of several types of soil. To date, over 1,000 different soil types have been recognized in Manitoba, about 550 of which can be found in agro-Manitoba. They are not scattered randomly, but occur in definite geographic areas and in certain patterns. Significant differences set apart the soil of a poorly drained pothole from the adjacent well-drained ridge or hilltop while relatively small differences occur between adjacent soils on level fields of uniform texture.

Why are there so many different soils found throughout Manitoba?

Soils are a product of their environment. The addition, loss, translocation and transformation of materials in soils determine the way soils form. Soils form and progressively develop under the influence of several environmental factors.

How were soils formed?

Soils form and progressively develop under the influence of four *soil forming factors* acting over time:

1. Parent material
2. Relief (topography and drainage)
3. Climate
4. Organisms (vegetation, animals, man)

1. Parent Material - the original material from which soils develop. It is based on type of bedrock and method of deposition. In Manitoba, soils contain some combination of granite, limestone or shale. These rocks break down over time through weathering to form sand (from granite) or clay (from shale). Limestone can break down into sand, silt and clay-sized particles.

Figure 1.1. Distribution of types of bedrock in Manitoba

Table 1.3. Modes of deposition and examples of their location

Mode of Deposition	Description	Examples
Till	Glacier-deposited material; usually stony, mixed material	Interlake Southwest Manitoba
Lacustrine	Lake-deposited material; usually well-sorted, non-stony material	Red River Valley
Fluvial	River or stream-deposited material	Assiniboine River Valley Pembina Valley
Outwash	Gravels deposited by rapidly flowing waters	Brandon area Birds Hill Park
Eolian	Wind-deposited materials (sand dunes)	Spruce Woods Park Sandilands Park
Organic deposits	Accumulation of peat from dead vegetation in poorly drained sites in cooler climatic regions	North Interlake Southeast Manitoba

2. Relief - The land surface of Manitoba is not perfectly flat. In Manitoba landscapes, areas of higher and lower elevation can be found within a given field and across the province. These areas respond differently to the addition of moisture through precipitation.

Water tends to run off higher areas and collect in lower areas. As a result, the tops of knolls are usually the driest part of the landscape, with thin stands of vegetation and a shallow layer of topsoil. Erosion also removes topsoil from knolls and steep slopes. Deeper soils develop on midslopes and lower slopes which receive and retain most of the precipitation, resulting in heavier stands of vegetation. Soils on lower slopes and in depressions may have the deepest topsoil because of the deposition of eroded material from upslope. Excess water in depressional areas causes ponding, stimulates the growth of aquatic vegetation and may contribute to saline conditions.

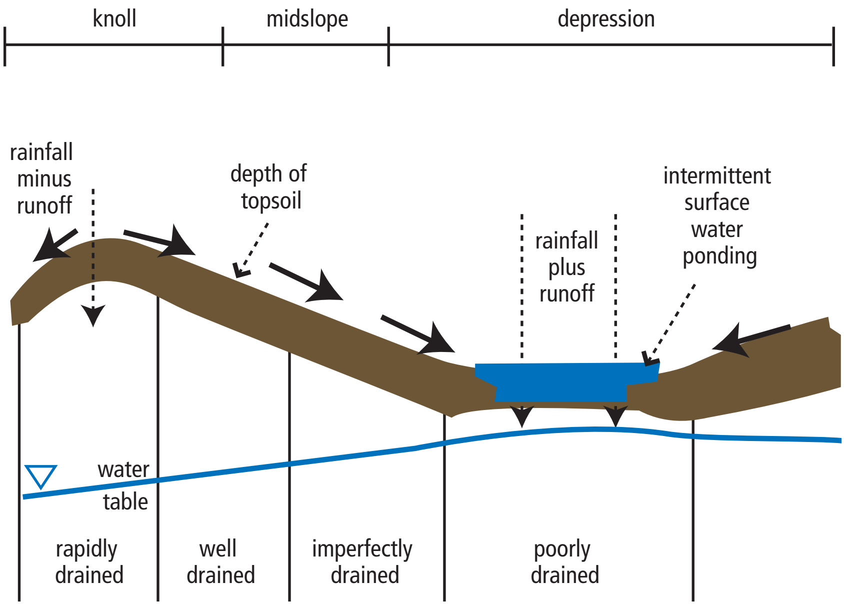


Figure 1.2. Effect of relief on water movement and the development of soils

3. Climate - Moisture and temperature play a major role in determining the rates of mineral weathering, leaching, vegetation establishment and topsoil development. Compared to other parts of the world, Manitoba's climate is considered to be relatively cool and dry. The climate becomes cooler and wetter moving from southwest to northeast Manitoba. The main result is soils in the southwest, formed under more arid conditions, tend to be less developed and have shallower topsoil layers than similar soils to the north and east.

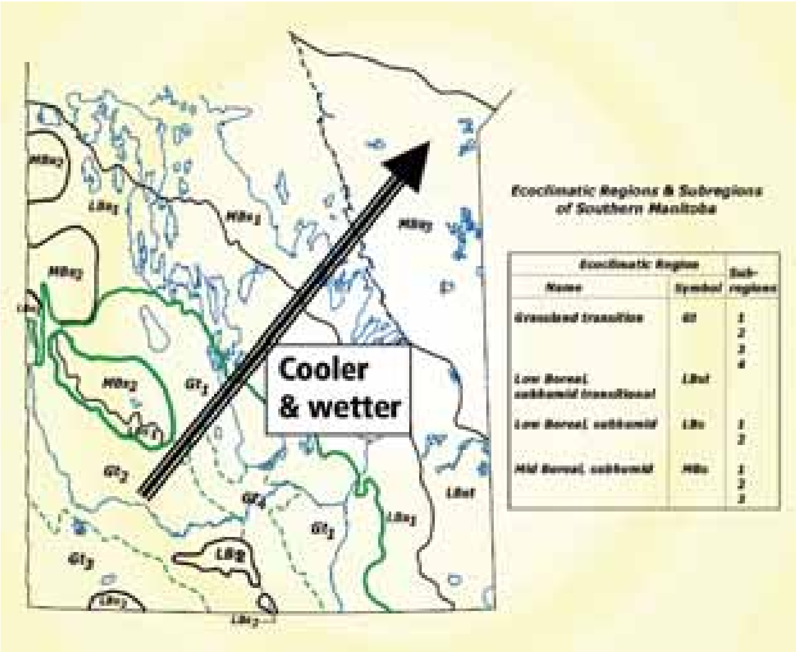


Figure 1.3. Ecoclimatic regions and subregions of southern Manitoba

4. Organisms – Soon after the parent material is exposed to the effects of climate, living plants become established and take part in the development of the soil. Bacteria, algae and lichens are the first organisms to establish on bedrock. Over time, more complex plants become established and contribute to the accumulating organic matter. Gradually, the decomposing bedrock is changed into layers of topsoil and subsoil, increasing in thickness as the process continues.

In southwest and southern Manitoba where temperatures are moderate and fairly large amounts of water are evaporated from the surface, the native vegetation is mainly grass. Most of the biomass from grassland vegetation is found below the surface, resulting in the addition of large amounts of organic matter into the soil, producing black topsoil.

In the cooler, more humid conditions of eastern and central Manitoba, where evaporation is less, the native vegetation is trees. Most of the biomass from forest vegetation is found on the surface, from leaf fall, stem decay and decomposition of mosses. Little organic matter is incorporated into the soil, resulting in gray topsoil.

Human activities such as agriculture have influenced soil formation by modifying large areas of natural vegetation through cultivation. Removing vegetative cover increases water runoff and alters the moisture and temperature status of the soil. Removing excess water through drainage also changes the moisture conditions in the soil. The removal of natural vegetation and mixing of soil layers can adversely alter the properties of the soil. However, through proper management and soil conservation practices, soil erosion, degrading soil quality and loss of natural fertility can be minimized.

What are the basic soil properties?

1. Texture
2. Structure
3. Colour
4. Bulk Density
5. Drainage
6. Calcium Carbonate Content

1. Texture

Soil texture is the relative proportion of sand, silt and clay particles. The texture of a soil cannot be altered. In agriculture, soil texture is determined by measuring the size and distribution of particles less than 2.0 mm in diameter. Particles larger than 2.0 mm in diameter, such as gravel and stones, are included in the textural description only if present in significant amounts (e.g. gravelly sand (GrS)).

- Sand (S) = 2.0 - 0.05 mm in diameter (coarse material) – referred to as "light" soils, since they are easily tilled (not because of the soil's weight).
- Silt (Si) = 0.05 - 0.002 mm (medium material).
- Clay (C) = <0.002 mm (fine material) – referred to as "heavy" soils, because of their difficult workability.
- Loams (L) are medium textured soils made up of a mixture of sand, silt and clay.
- Gravel and stones are particles > 2.0 mm in diameter.

Figure 1.4. Particle size comparison

Sands (S), loamy sands (LS) and sandy loams (SL) are dominantly composed of sand particles. For these soil textures, sand particles are further broken down into subclasses:

Very coarse sand (VCoS) = 2.0 - 1.0 mm in diameter

Coarse sand (CoS) = 1.0 - 0.5 mm

Medium sand (S) = 0.5 - 0.25 mm

Fine sand (FS) = 0.25 - 0.10 mm

Very fine sand (VFS) = 0.10 - 0.05 mm

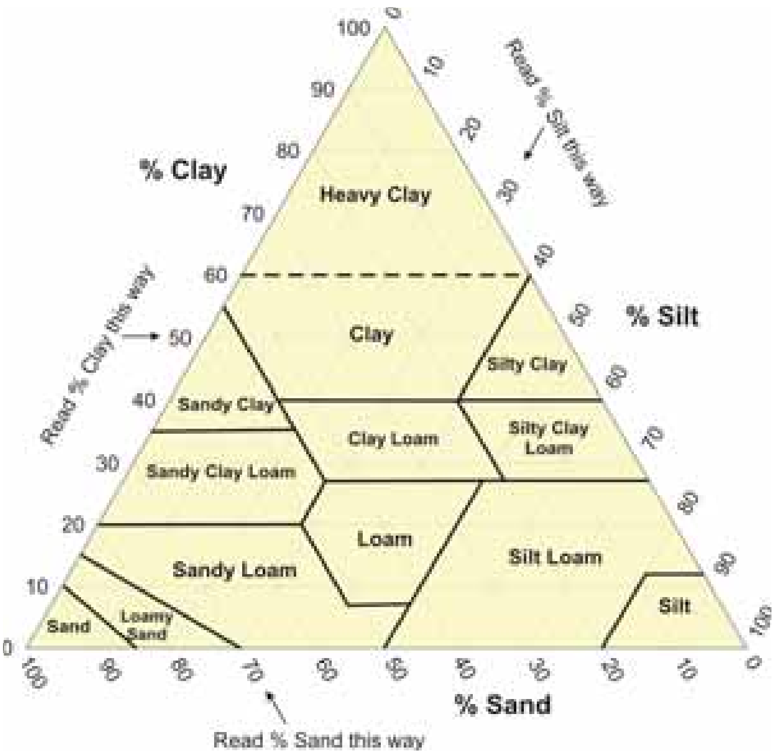


Figure 1.5. Soil textural triangle

Table 1.4. Textural groups and classes

Texture Group	Texture Class	Texture Class Symbol
Very Coarse	Very coarse sand	VCoS
	Coarse sand	CoS
	Medium sand	S
Coarse	Fine sand	FS
	Loamy coarse sand	LCoS
	Loamy sand	LS
	Loamy fine sand	LFS
Moderately Coarse	Very fine sand	VFS
	Loamy very fine sand	LVFS
	Coarse sandy loam	CoSL
	Sandy loam	SL
	Fine sandy loam	FSL
Medium	Very fine sandy loam	VFSL
	Loam	L
	Silt loam	SiL
	Silt	Si
Moderately Fine	Sandy clay loam	SCL
	Clay loam	CL
	Silty clay loam	SiCL
Fine	Sandy clay	SC
	Silty clay	SiC
	Clay	C
Very Fine	Heavy clay (>60 %)	HC

2. Structure

Soil structure refers to the way in which soil particles cling together to form aggregates. Clay particles tend to cling tightly together and resist separation more than sand particles. As organic matter decomposes to humus, a variety of compounds are released which "glue" soil particles together.

When individual soil particles are aggregated, they form larger, relatively stable primary structures. If the individual aggregates are distinct and clearly separated from one another, the soil is said to have *well-developed* structure. But if the fine clay and organic particles are dispersed throughout the soil, the result may be a *poorly developed* structure. If there are no visible aggregates at all, the soil is structureless, described as either single grain (as found in some sands) or massive (as found in some heavy clays).

Types of soil structure include: prismatic, columnar, angular blocky, subangular blocky, platy and granular. Most agricultural soils have either blocky or granular structure. Forest soils usually have a platy structure at or just below the soil surface. Prismatic and columnar structures develop in soils with significant amounts of sodium present in the subsoil.

Structure has a significant effect on soil water properties and the ability of a soil to resist erosion. Good soil structure increases porosity, aeration, drainage and permits easier root penetration, all of which are important on soils with limited internal drainage, such as clays. Conversely, poor soil structure in the topsoil produces hard, massive clods, which makes a poor seedbed for germinating crops. Poor structure in the subsoil results in dense, compact properties which limit root and moisture penetration.

The natural structural properties of surface soil horizons can be changed by tillage, crop rotation, artificial drainage and applications of manure. As a result, it is important to maintain a desirable soil structure to ensure optimum crop production. For example, massive clay soils are difficult to till when dry and are not easily accessible for field equipment when wet. Poorly structured sandy soils are easily pulverized by tillage, making them prone to erosion.

3. Colour

Soil conditions such as drainage and salinity, and constituents such as organic matter, iron and carbonates, impart characteristic colours to the soil profile. These colours are measurable and are used as part of the soil classification criteria. Light coloured topsoil indicates either low organic matter content or a concentration of carbonates or soluble salts. Dark coloured topsoil, by contrast, indicates high organic matter content. Subsoil colour is an indicator of drainage that is often more reliable than the actual moisture conditions at the time a soil is examined. Bright colours, such as light brown, yellow or reddish subsoil, is characteristic of a well-drained profile. Dull gray, bluish-green or rust colours indicate a poorly drained profile.

4. Bulk Density

Bulk density is the apparent density of a soil, measured by determining the oven-dry mass of soil per unit volume. The volume of soil is determined using sampling cores and is measured before soil is oven-dried to avoid any changes in volume due to drying. Bulk density is usually expressed in g/cm^3 or Mg/m^3.

Bulk density tends to be higher in sandy soils than in clays. A typical clay soil has a bulk density around 1.1 g/cm^3; a sandy soil's bulk density is approximately 1.3 g/cm^3; compacted soils may have a bulk density as high as 1.8 g/cm^3.

5. Drainage

Soil drainage is the speed and extent of water removal from the soil by runoff (surface drainage) and downward flow through the soil profile (internal drainage). It also refers to the frequency and duration when the soil is not saturated.

Drainage classes:

A. *rapid/excessive* - water is removed rapidly in relation to supply – very coarse textured soils in higher landscape positions have rapid internal drainage.

B. *well (and moderately well)* - water is removed readily in relation to supply - development of a B horizon is evidence of well to moderately well internal drainage.

C. *imperfect* - water is removed somewhat slowly in relation to supply to keep the soil wet for a significant part of the growing season – a B horizon may not be present; an AC horizon and the possible presence of some mottles (gleying) at depth are indicators of imperfect drainage.

D. *poor (and very poor)* - water is removed so slowly that the soil remains wet or the water table is near the soil surface for a large part of the time - extensive mottling, peat buildup and blue-grey colors indicative of saturated conditions are prevalent.

- **Mottles - rust-coloured spots in the subsoil formed from alternating wetting and drying conditions.**
- **Gleying – a soil-forming process which occurs under poor drainage conditions, resulting in the production of gray colours and mottles.**

In general, drainage is primarily influenced by soil texture and relief. Coarse-textured, porous soils allow excess water to pass through the soil whereas finer-textured, compact clay materials tend to restrict water movement. Nevertheless, texture and drainage are independent factors, with relief having a greater influence on the drainage class of a soil than its texture. For example, sands in low-lying areas with high water tables are poorly drained, and clays in relatively higher portions of the landscape can be well-drained.

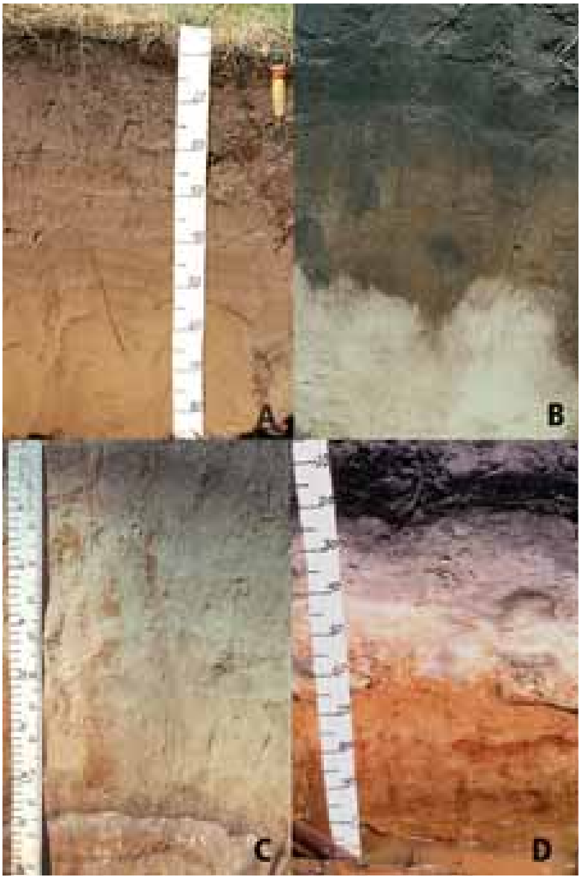


Figure 1.6. Soil drainage classes on four sandy soils

A. Shilox (rapid)
B. Stockton (well)
C. Long Plain (imperfect)
D. Lelant (poor)

6. Calcium Carbonate Content

Calcium carbonates (and, to a lesser extent, magnesium carbonates) are common to most agricultural soils in Manitoba. They are derived mostly from fragments of limestone rocks. Over time, carbonates dissolve and move in the soil water.

The calcareous nature of Manitoba soils is basically what maintains their neutral to high pH. Adequate levels of calcium and magnesium, both essential nutrients for plant growth, are usually present in calcareous soils. Since most of the agricultural soils in Manitoba are calcareous, the addition of lime to raise the pH is not a required practice.

Soil surveyors use dilute hydrochloric acid (HCl) to check for the presence of carbonates. Calcium and magnesium carbonates react with HCl to produce carbon dioxide (CO_2) which can be identified by bubbling and fizzing in the area where the HCl was applied. The greater the carbonate content of the soil, the more aggressive the reaction is with HCl.

The depth at which dilute HCl reacts with calcium carbonate ($CaCO_3$) gives an indication of internal soil drainage and soil development. Over time, soils with good internal drainage have had significant amounts water infiltrate and percolate through the soil. Provided they have not been affected by wind, water, or tillage erosion, they will be free of $CaCO_3$ in the surface layer and the subsoil layer below the surface horizon. In these soils, dilute HCl will not fizz until it comes into contact with the $CaCO_3$ below the subsoil layer. With the exception of leached micro depressions, less infiltration and percolation of water in imperfectly drained soils is reflected in the presence of $CaCO_3$ at the surface or in the subsoil layer below the surface layer. Very low infiltration and percolation of water in poorly drained soils (with the exception of leached depressions) usually results in calcareous ($CaCO_3$) surface layers. Therefore, dilute HCl will fizz nearer to or at the surface in imperfectly and poorly drained soils.

Calcium carbonate content is expressed as the "calcium carbonate equivalent," and can range from 0% in extremely leached soil profiles to over 40% in the high lime tills found in the Interlake region of Manitoba.

How do we organize and classify soils?

Soil surveyors are able to distinguish differences in soil properties and group soils according to their mode of formation. This is done by digging holes and inspecting the layers, as well as examining the surrounding landscape features.

The origin of the materials and the soil properties are examined in each layer of soil. Each layer, or horizon, of soil is classified according to properties and designations highlighted in Table 1.5. The sequence of horizons makes up the soil profile. A is the topsoil horizon, B is the middle or subsoil horizon and C is the designation of the parent material. The A and B horizons make up the solum. Each horizon is further described using the lower-case suffixes in Table 1.5.

> **Soil Horizon - a layer of soil running approximately parallel to the land surface and differing from vertically adjacent layers in terms of physical, chemical and biological properties such as color, structure, texture, pH, etc.**
>
> **Repeating or alternating layers of different colors, textures, etc. in the soil profile are referred to as a *stratified* profile. This is referred to as a *cumulic* profile in soil survey reports.**

Table 1.5. Soil horizon designations

Organic Horizons – contain more than 30% organic matter by weight	
O	an organic horizon developed mainly from mosses, rushes and woody materials
Of	fibric horizon (least decomposed)
Om	mesic horizon (intermediate decomposition)
Oh	humic horizon (most highly decomposed)
LFH	organic horizons developed from leaves, twigs and woody materials
Mineral Horizons – contain less than 30% organic matter by weight	
A – surface horizon (topsoil)	Leaching (removal) of materials in solution and suspension Maximum accumulation of organic matter
B – middle horizon (subsoil)	Enrichment in clay, iron, aluminum, organic matter, sodium Change in color or structure from horizons above or below
C – parent material	Unaffected by soil forming processes except for gleying and the accumulation of carbonates and soluble salts
AB, BC, and AC	transitional horizons

Lower case suffixes used to further describe mineral horizons	
h	horizon enriched with organic matter (eg. Ah, Ahe, Bh, Bhf)
e	eluviated (leached) horizon of clay, iron, aluminum, organic matter (eg. Ae, Ahe)
p	plow layer; disturbance by man's activities, such as cultivation (Ap)
b	buried horizon (Ab)
m	modified by hydrolysis, oxidation or solution to give a change in color or structure (Bm, Bmk)
t	horizon enriched with clay at least 5 cm (2 in.) thick. (Bt, Btg, Bnt)
n	high Na (sodium) horizon – ratio of exchangeable Ca to Na is 10 or less Prismatic or columnar structure that is hard to very hard when dry (Bn, Bnt)
g	gray colors or mottles, indicative of permanent or periodic intense reduction (wet conditions) (Bg, Bgj, Ckg, Ckgj)
f	enrichment with non-crystalline Fe and Al combined with organic matter (Bf, Bfh)
j	weak (juvenile) expression of soil processes (Btj, Ckgj)
k	presence of carbonates, visible by effervescence when dilute HCl is added (Bmk, Ck)
ca	layer of carbonate accumulation that the exceeds the amount present in the parent material (Cca)
s	soluble salts present (Cks)
z	frozen horizon (permafrost)

Soils in Canada are classified using *The Canadian System of Soil Classification*, by Agriculture and Agri-Food Canada. This classification system is similar to the hierarchical classification system used to classify the plant and animal kingdoms. The system goes from very broad to very detailed classifications:

I. Order
II. Great Group
III. Subgroup
IV. Association
V. Series
VI. Phase

Table 1.6. Classification criteria of soils vs. automobiles

Classification Category	Soils	Automobiles
I. Order	Chernozemic	General Motors
II. Great Group	Black	Car
III. Subgroup	Orthic Black	Chevrolet
IV. Association	Fine loamy, mixed, cool, subhumid	4-door Sedan
V. Series	Newdale	Impala
VI. Phase	NDL/xcxs	loaded, good condition

I. Soil Orders – based on properties that reflect the effects of the dominant soil-forming processes.

Chernozemic – most grassland, agricultural soils in Manitoba (high organic matter in A horizon)

Gleysolic – poorly drained soils (saturated, reduced, mottles)

Luvisolic – forest soils (Ae and Bt horizons)

Regosolic – young soils along rivers, slopes, sand dune areas (weak horizon development)

Solonetzic – sodium-affected soils (sodium in B horizon)

Vertisolic – heavy clay soils with high shrink-swell potential (cracks and shear planes)

Brunisolic – catch-all category (weak B horizon)

Cryosolic – frozen soils

Podzolic – B horizon with Fe, Al, organic matter

Organic – more than 30% organic matter by weight

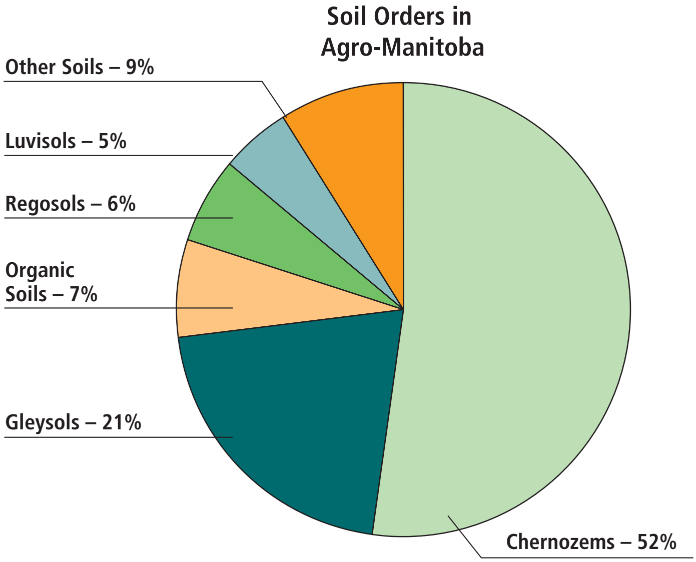


Figure 1.7. Relative abundance of soil orders found in agro-Manitoba

Figure1.8. Mineral soil orders found in agro-Manitoba:

1. Chernozem
2. Luvisol
3. Gleysol
4. Regosol

Table 1.7. Comparison of four mineral soil orders in Manitoba

Factor	Chernozem	Luvisol	Gleysol	Regosol
Native vegetation	Grassland	Forest	Moisture-loving grasses	Limited vegetative growth
Moisture regime	Normal	Normal	Wet	Variable to dry
Formative processes	Vegetation puts bulk of biomass production below ground	Vegetation puts bulk of biomass production above ground	Moist or saturated conditions affect decomposition process	Relatively young soils not fully stabilized by vegetation
Distinguishing features	Thick topsoil horizon (Ah)	Strongly leached horizon (Ae)	Dull, blue-gray colours and mottles (Bg or Cg)	Little soil profile development due to droughtiness, erosion, or deposition
Typical landscape position	Midslope	Upper slopes	Depressions	Upper slopes

II. Great Group – broad separations of soil zones based on climate and native vegetation patterns. The five soil zones recognized across the prairies are: Brown, Dark Brown, Black Dark Gray Chernozems; and Gray Luvisol (Figure 1.9). Climate and vegetation have determined the organic matter levels in the topsoil over time, resulting in darker colors with increasing organic matter content in cooler, wetter regions.

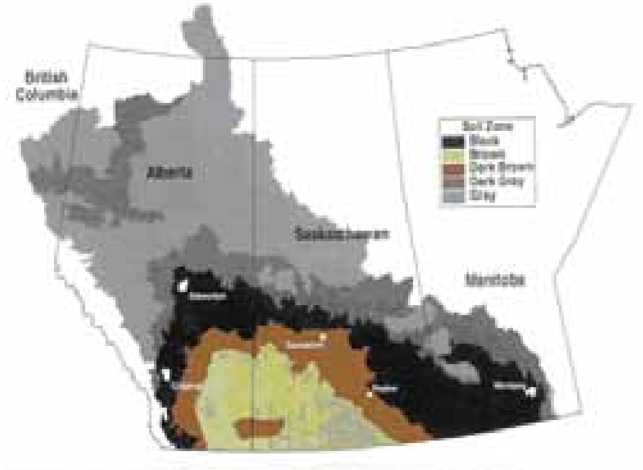


Figure 1.9.
Soil zones of the Canadian prairies (courtesy PFRA). Scale is 1 inch = 230 miles (1: 14,572,800)

III. Subgroup – subdivisions of each great group. For the Chernozem great group, the subgroups are:

- **orthic:** typical A, B, C profile
- **rego:** no B horizon
- **calcareous:** carbonates (k)
- **eluviated:** Ae/Bt horizons present
- **solonetzic:** Bn, Bnt horizons present
- **gleyed:** presence of mottles, or gleying (g), in B and/or C horizon
- **vertic:** horizon disruption or mixing caused by shrinking and swelling.

IV. Soil Association (or Catena) - a sequence or family of related soils located in the same climatic zone formed from similar parent material under different landscape positions resulting in different profile characteristics. These soils are adjacent to one another from hilltop to depression. Variation in soil horizons from hilltop to depression is caused by the amount of water available at each point along the slope as a function of infiltration, runoff, run-on and proximity to the water table. Each soil type located along the slope is a soil series (e.g. The Newdale association includes six soil series: Newdale, Rufford, Varcoe, Angusville, Penrith and Drokan).

Soil Series	Soil Classification	Drainage
Rufford	Rego Black Chernozem	Well
Newdale	Orthic Black Chernozem	Well to Moderately Well
Angusville	Gleyed Eluviated Black Chernozem	Imperfect
Varcoe	Gleyed Rego Black Chernozem	Imperfect
Penrith	Humic Luvic Gleysol	Poor
Drokan	Rego Humic Gleysol	Poor

Soils of the Newdale Association and their Position in the Landscape

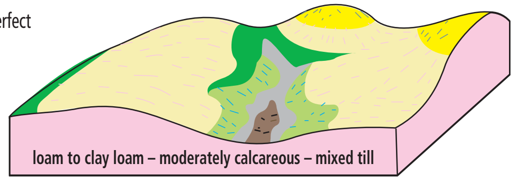


Figure 1.10.
Soils of the Newdale Association

V. Soil Series - an individual soil type, with a particular kind and arrangement of soil horizons developed on a particular type of parent material and located in a particular soil zone. The properties of a particular soil series are determined by moisture influences and landscape position. As a result, an individual soil series can usually be found in a specific part of a given field.

A soil series name is often derived from a town or landmark in or near the area where the series was first recognized (e.g. Newdale soil series).

VI. Soil Phases - variations of a soil series because of factors such as erosion, topography (slope), stones, salinity, improved drainage and peaty layers. This type of information is only found in detailed soil survey reports.

i) Degree of Erosion:

x = non-eroded or minimal

1 = slightly eroded (25-75% of A horizon removed)

2 = moderately eroded (>75% of A and part of B horizon removed)

3 = severely eroded (all of A and B horizons removed)

o = overblown (subsoil deposited over topsoil)

ii) Slope Class:

x = 0 - 0.5% (level)

b = 0.5 - 2% (nearly level)

c = 2 - 5% (very gently sloping)

d = 5 - 9% (gently sloping)

e = 9 - 15% (moderately sloping)

f = 15 - 30% (strongly sloping)

g = 30 - 45% (very strongly sloping)

h = 45 - 70% (extremely sloping)

iii) Stoniness:

x = nonstony (<0.01% of surface covered)

1 = slightly stony (0.01 - 0.1%)

2 = moderately stony (0.1 - 3%)

3 = very stony (3-15%)

4 = exceedingly stony (15 - 50%)

5 = excessively stony (>50%)

iv) Degree of Salinity:

x = non-saline (0-4 dS/m)*

s = weakly saline (4-8 dS/m)

t = moderately saline (8-15 dS/m)

u = strongly saline (>15 dS/m)

*Sensitive crops may exhibit negative effects of salinity at levels <4 dS/m - this is a general salinity rating for traditional annual crops (wheat, canola) which are not significantly affected by soil salinity levels below 4 dS/m.

Other rating systems (refer to *Manual for Describing Soils in the Field*) evaluate salinity with greater detail using the following classes:

1 - Nonsaline (0-2 dS/m)

2 - Slightly saline (2-4 dS/m)

3 - Weakly saline (4-8 dS/m)

4 - Moderately saline (8-15 dS/m)

5 - Strongly saline (>15 dS/m)

2
Using Soil Survey Information

Figure 2.1. A soil surveyor inspecting a saline area

What is soil survey?

Soil survey is an inventory of the properties of the soil (such as texture, internal drainage, parent material, depth to groundwater, topography, degree of erosion, stoniness, pH, and salinity) and their spatial distribution over a landscape (often portrayed in a map). Soils are grouped into similar types and their boundaries are delineated on a map. Each soil type has a unique set of physical, chemical and mineralogical characteristics and has similar reactions to use and management. The information assembled in a soil survey can be used to determine potential uses and limitation of soils. As such, soil surveys can be used to plan the development of new lands or to evaluate the conversion of land to new uses. Soil surveys also provide insight into the kind and intensity of land management that will be needed.

What are soil survey reports?

A soil survey describes the characteristics of the soils in a given area, classifies the soils according to a standard system of classification, plots the boundaries of the soils on a map, and makes predictions about the behavior of soils. The different uses of the soils and how management affects them are considered in designing and carrying out the survey. The information collected in a soil survey helps in the development of land-use plans and evaluates and predicts the effects of land use on the environment (adapted from the USDA definition of "soil survey").

Soil survey reports contain two parts. The first component is a soils map or series of maps at a particular scale with coding for soil types. Soil survey reports also include a supporting document that contains background information, how the soil survey was conducted, an explanation of interpretive criteria and a summary of the area occupied by various soil types.

Map Information

Soil Polygon - an area (which can be any shape) which contains a specific soil condition that is identified by a symbol(s).

In addition to the limitations of map scale, the boundaries of the soil map polygons imply there are abrupt changes in soil types within the landscape. In reality, however, ***soil varies continuously across the landscape.*** It must be recognized that, although the map lines imply abrupt changes, the soil grades from one type to the next and the lines on the map are only approximations of where these transitions occur.

Map Units - symbols on soil survey maps that represent the type of soil(s) found within a particular polygon. A simple map unit designates a single soil series on a detailed soils map. A complex map unit includes as many as three soil series on a detailed map, or as many as two soil associations on a reconnaissance soil map. Other information on the soil phase, such as extent of erosion, slope gradient, stoniness and salinity, may be included within the map unit.

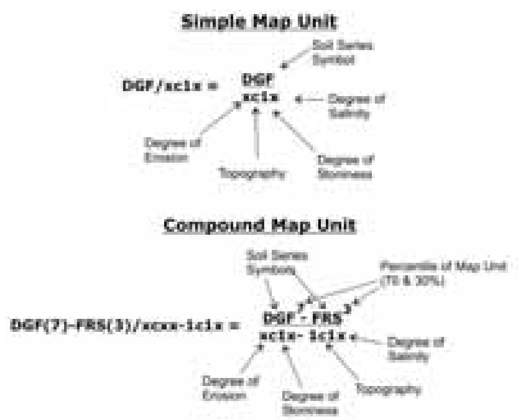


Figure 2.2. Derivation of map unit symbology

Why is map scale important?

Reconnaissance (general) soil surveys of Manitoba were started in 1926 as the first step in the development of a basic program of soil research, education, conservation and utilization for the province. The scale of these maps is approximately 1:125,000, or 1/2 inch to 1 mile. In recent years, many developments have occurred in agriculture that have created demand for soils information that is beyond the scope of detail provided in reconnaissance surveys, such as:

- research trials
- manure application and nutrient management
- precision farming
- soil productivity for production insurance ratings
- land use planning
- suitability for irrigation and drainage
- tax assessment
- watershed management

Figure 2.3. Current availability of detailed soils information for complete rural municipalities of agro-Manitoba

Note: There are several municipalities in other parts of Manitoba that have a portion of their area surveyed at a detailed level. Many of these areas surround town sites and were conducted for the purpose of assessing soil suitability for sewage lagoons. Contact your local Manitoba Agriculture, Food and Rural Initiatives office for a complete list of current and on-going detailed soil survey activities.

The first large-scale, or detailed, soil survey in Manitoba was published in 1972 for the Portage la Prairie area at a scale of 1:20,000. **Detailed soil surveys identify more of the variation in soil types across smaller landscapes (Figure 2.4). Detailed soil survey maps are much more accurate and reliable for making decisions at the farm-level (Table 2.1).** Field inspection sites for a 1:20,000 map scale (3.2 inches to 1 mile) requires 25-30 inspection sites per section of land (Figure 2.5). Semi-detailed maps at 1:50,000 scale, or 1.5 inches to 1 mile, require 16 inspections per section. A two-person crew usually maps 1 section per day. Mapping costs are approximately $3.00-7.50/acre, but this is a one-time cost, as most soil properties remain unchanged over a lifetime.

Table 2.1. Intended uses for maps according to scale

Generalized 1:1 000 000	**Reconnaissance 1:125 000**	**Detailed 1:50 000**	**Detailed 1:20 000**
Provincial overview	General soils awareness	On-farm decisions Municipal decisions	On-farm decisions Municipal decisions
N/A	~6 inspections per section	~16 inspections per section	~30 inspections per section
General soil comparisons (soil orders) National scope	General soil comparisons (subgroup/family/ association level) National scope Starting point for more detailed soils data collection	Field scale comparisons (series level) Watershed management Land use assessment	Field scale comparisons (phase level) Precision agriculture Irrigation assessment Potato suitability Nutrient management Land use assessment

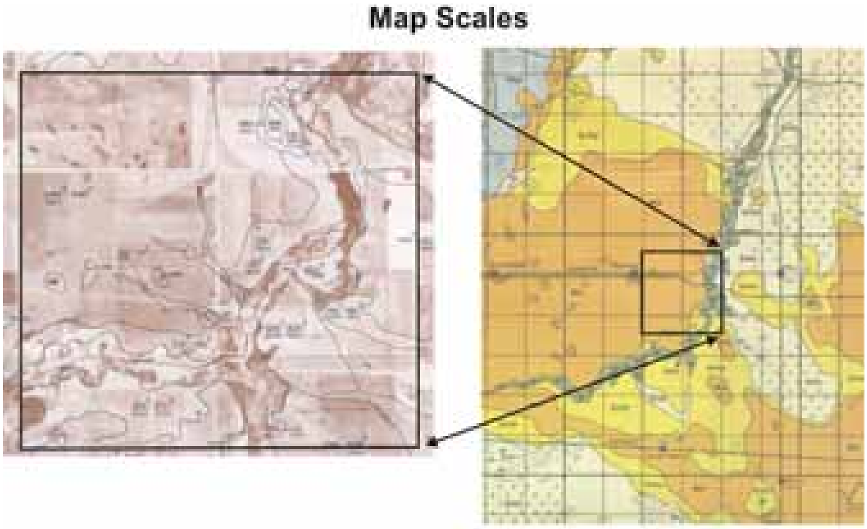


Figure 2.4. Comparison of soils information on same land parcel at detailed (1:20 000) scale (left) versus reconnaissance (1:126 720) scale (right)

Figure 2.5. Typical soil sampling and inspection pattern for a detailed soil survey

Why are detailed soil survey reports required for in-field assessments?

Soil survey maps are not without limitations. Although the map may say that a discrete area of land contains a certain soil type, it must be understood that the reliability of that information is a function of the *map scale*. All soil delineations (called polygons) contain small areas of dissimilar soils that are not identified (called inclusions). The smaller the scale of the map (or the more general the map), the more frequently this occurs. Small-scale, reconnaissance or general soil surveys give only a broad picture of the dominant types and distribution of soils that occur over relatively large areas. The landscape may actually include fairly significant areas of different soils that are not identified on the map. As such, reconnaissance soil surveys are best suited to making general comparisons of soil capabilities and limitations on a regional, national or even worldwide scale. They are not reliable for making on-farm decisions as they lack the detail necessary to describe the variation in the soil types on the farm (Table 2.1).

Recent translation of soils information in reconnaissance areas into digital maps and an interpretive data base (eg. as agriculture capability) looks like detailed soil series information. However, this data has not been verified by field inspections to the same extent as detailed soil surveys. As a result, these maps are not as reliable at the farm level as detailed soil survey information. This data should only be used for general soils information purposes or coupled with detailed soils data from field visits; it should not be relied on solely for on-farm decisions.

Options for data collection when detailed soil survey information is unavailable

When detailed soil survey data is needed but unavailable, on-site investigations are necessary. On-farm soil survey can be designed for a specific purpose or general purpose. A specific, or single purpose survey may be appropriate when there is only one, well-defined objective (such as siting a livestock operation). In this instance, only the information required to meet the single objective may need to be collected. The major advantage to a single purpose survey is decreased cost. A general-purpose survey, on the other hand, contains a wider range of information. Although more information is more costly to collect, the general-purpose soil survey may have more value over the long-term as it can be interpreted in a variety of ways and can be reused for many purposes.

As detailed soils information is not available in all parts of Manitoba, some information about the soil types present in the landscape can be gleaned from aerial photos, yield maps, infrared maps, etc. Coupled with the landowners' knowledge of the area, several interpretations can be made:

- Scale and acreage determination
- Identify major features such as roads, rail lines and yard sites

- Identify soil features such as knolls, depressions and saline areas
- Using personal experience, yield maps or strip trial data, locate crop features (i.e. Where are best yields, poorest yields usually found?)
- What management decisions can be made? Or is more information needed? Is a field investigation warranted?

The reliability of the field data and its interpretation is largely dependent on the experience and ability of the surveyor. Data collection should always follow standardized procedures and should only be carried out by those who have received training in soil survey.

An example of soil survey interpretation is the evaluation of a given land base for manure application. The type of soil and its associated characteristics determine the crops that can be grown, their yield potentials, the quantities of nutrients that are needed and the field practices that will be necessary to maintain optimum soil conditions for plant growth. As well, soil data on permeability (the rate at which water moves through a soil), depth to groundwater, flooding, slope gradient, soil texture and depth to bedrock can be useful in determining the risk of groundwater contamination due to leaching or surface water contamination due to runoff and erosion.

Interpretive maps

The following conceptual model depicts the information required to make on-farm land use and land management decisions that are objective, consistent and technically sound.

Detailed Soils Info (Baseline Data)	+	**Standardized Interpretive Criteria**	=	**Appropriate Land Use and Management**
E.g. LOP/xcxx		E.g. agriculture capability - 4M		E.g. most suitable for improved forage or pasture under dryland conditions

Agriculture capability for Manitoba

Agriculture capability is a 7 class rating of mineral soils based on the severity of limitations for dryland farming. This system does not rate the productivity of the soil, but rather its capability to sustain agricultural crops based on limitations due to soil properties and landscape features and climate. This system is usually applied on a soil polygon basis and the individual soil series are assessed and maps portray the condition represented by the dominant soil in the polygon. Class 1 soils have no limitations, whereas class 7 soils have such severe limitations that they are not suitable for agricultural purposes. In general, it takes about 2 acres (0.8 hectares) of class 4 land to equal production from 1 acre (0.4 hectares) of prime (class 1) land. (From *Land: The Threatened Resource*).

- Class 1: Soils in this class have no important limitations for crop use. The soils have level to nearly level topography; they are deep, well to imperfectly drained and have moderate water holding capacity. The soils are naturally well supplied with plant nutrients, easily maintained in good tilth and fertility; soils are moderately high to high in productivity for a wide range of cereal and special crops (field crops).
- Class 2: Soils in this class have moderate limitations that reduce the choice of crops or require moderate conservation practices. The soils have good water holding capacity and are either naturally well supplied with plant nutrients or are highly responsive to inputs of fertilizer. They are moderate to high in productivity for a fairly wide range of field crops. The limitations are not severe and good soil management and cropping practices can be applied without serious difficulty.
- Class 3: Soils in this class have moderate limitations that restrict the range of crops or require moderate conservation practices. The limitations in Class 3 are more severe than those in Class 2 and conservation practices are more difficult to apply and maintain. The limitations affect the timing and ease of tillage, planting and harvesting, the choice of crops and maintenance of conservation practices. Under good management, these soils are fair to moderate in productivity for a fairly wide range of field crops.
- Class 4: Soils in this class have significant limitations that restrict the choice of crops or require special conservation practices or both. These soils have such limitations that they are only suited for a few field crops, the yield for a range of crops may be low or the risk of crop failure is high. These soils are low to moderate in productivity for a narrow range of field crops but may have higher productivity for a specially adapted crop or perennial forage.
- Class 5: Soils in this class have severe limitations that restrict their capability to producing perennial forage crops and improvement practices are feasible. These soils have such serious soil, climatic or other limitations that they are not capable of use for sustained production of annual field crops. However, they may be improved by the use of farm machinery for the production of native or tame species of perennial forage plants.
- Class 6: Soils in this class are capable only of producing perennial forage crops and improvement practices are not feasible. Class 6 soils have some natural sustained grazing capacity for farm animals, but have such serious soil, climatic or other limitations as to make impractical the application of improvement practices that can be carried out on Class 5 soils. Soils may be placed in this class because their physical nature prevents the use of farm machinery or because the soils are

not responsive to improvement practices.

- Class 7: Soils in this class have no capability for arable culture or permanent pasture because of extremely severe limitations. Bodies of water too small to delineate on the map are included in this class. These soils may or may not have a high capability for forestry, wildlife and recreation.

Agriculture capability subclasses identify the soil properties or landscape conditions that may limit use. A capital letter immediately following the class number identifies the limitation (eg. 2W, 3N, etc.).

Subclasses:
C – adverse climate (outside the boundaries of agro-Manitoba)
D – dense soils (undesirable soil structure/low permeability)
E – erosion damage
I – inundation (flooding) by streams and lakes
M – moisture (droughtiness) or low water holding capacity
N – salinity
P – stoniness
R – consolidated bedrock
T – topography (slopes)
W – excess water other than flooding (inadequate soil drainage or high water table)
X – two or more minor limitations

How does agriculture capability compare to the crop insurance Soil Productivity Index ratings?

Crop insurance coverage is based on a 10-category classification system for cultivated land based on **soil productivity as determined by crop yields**. The ratings are from A to J with A being the most productive and J the least. Each quarter section receives a single rating and the ratings are calculated based on moving average cropping data, temperature, precipitation and soil factors such as organic matter, sub-surface material, texture, drainage, depth of topsoil, topography, salinity and erosion. Ratings are modified to account for local risk factors such as frequency of drought, frost, flooding and other natural hazards. As a result, a quarter section with several soil polygons will have several agriculture capability ratings, but will always have one soil productivity index rating.

Irrigation suitability

Irrigation suitability is a general suitability rating for irrigated crop production. This classification system considers soil and landscape characteristics such as texture, drainage, depth to water table, salinity, geological uniformity, topography and stoniness and ranks them in terms of their sustained quality due to long term management under irrigation. It does not consider factors such as water application, water availability, water quality or economics of this type of land use. Classes are *excellent, good, fair* and *poor*.

Soil suitability for irrigated potato production

Deep, well-drained, sandy loam to loam soils exhibit favourable properties for the production of high quality potatoes. This rating is a 5-class evaluation of soil properties and landscape features that are important for irrigated production of potatoes for processing, with Class 1 soils most suitable and Class 5 soils least desirable for this use. Texture, drainage, salinity, sodicity, topography and stoniness are considered.

Other assessment ratings

Detailed soil survey reports include assessment criteria for several other non-agricultural uses that may be of value to engineers, land use planners and the general public. These suitability ratings include soil assessments for:

- source of top soil
- source of sand and gravel
- source of road fill
- permanent buildings with basements
- local roads and streets
- sanitary trench
- landfill area
- cover material
- sewage lagoon
- septic field
- playground
- picnic area
- camp area
- path and trails
- permanent buildings without basements

Table 2.2. Dryland agriculture capability guidelines for Manitoba

Based on the Canada Land Inventory Soil Capability Classification for Agriculture (1965, Rev. 2001), with modifications made for soil application at larger mapping scales.

Subclass Limitations	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7
	No significant limitations in use for crops	Moderate limitations that restrict the range of crops or require moderate conservation practices	Moderate severe limitation that restrict the range of crops or require special conservation practices	Severe limitations that restrict the range of crops or require special conservation practices or both	Very severe limitations that restrict soil capability to produce perennial forage crops, and improvement practices are feasible	Soils are capable only of producing perennial forage crops, and improvement practices are not feasible	No capability for arable culture or permanent pasture
Climate (C)	All Ecodistricts[1] within ARDA boundary not explicitly listed under 2C and 3C	Ecodistricts: 664, 666, 668, 670, 671, 672, 674, 675, 676, 677, 714, 715, 716	Ecodistricts: 356, 357, 358, 359, 363, 366, 663, 665	None within ARDA boundary			
Consolidated Bedrock (R)				50-100 cm	20-50 cm	< 20 cm	Surface bedrock Fragmental over bedrock
Moisture limitation[2] (M)		Stratified loams Moderate moisture holding capacity	Loamy Sands Low moisture holding capacity	Sands Very low moisture holding capacity	Skeletal sands Very severe moisture deficiency	Stabilized sand dunes	Active sand dunes
Topography[3] (T)	x, a, b (0-2%)	c (>2-5%)	d (>5-9%)	e (>9-15%)	f (>15-30%)	g (>30-45%) Eroded slope complex	h (>45 - 70%) i (>70 - 100%) j (> 100%)
Structure and/or Permeability (D)	Granular clay	Massive clay or till soils[4] Slow permeability	Solonetzic intergrades Very slow Permeability	Black solonetz Extremely slow Permeability			

Salinity[5] (N) a.00-60cm depth b.60-120cm depth	NONE (x) < 2dS/m < 4ds/m	WEAK (x) 2-4 dS/m 4-8 dS/m	MODERATE (s) 4-8 dS/m 8-16 dS/m	STRONG (t) 8-16 dS/m 16-24 dS/m	VERY STRONG (u)[6] 16-24 dS/m >24 dS/m		Salt Flats
Inundation[7] (I)	No overflow during growing season	Occasional overflow (1 in 10 years)	Frequent overflow (1 in 5 years) Some crop damage	Frequent overflow Severe crop damage	Very frequent (1 in 3 years) Grazing > 10 weeks	Very frequent Grazing 5-10 weeks	Land is inundated for most of the season
Excess Water (W)	Well and Imperfectly drained		Loamy to fine textured Gleysols with improved drainage	Coarse textured Gleysols with improved drainage	Poorly drained, no improvements	Very Poorly drained	Open water, marsh
Stoniness (P)	Nonstony (x) and Slightly Stony (1)	Moderately Stony (2)	Very Stony[8] (3)	Exceedingly Stony (4)[9]		Excessively Stony (5)	Cobbly Beach Fragmental
Erosion[10] (E)		Moderate erosion (2)	Severe wind or water erosion (3) lowers the basic rating by one class to a minimum rating of Class 6[11].				
Cumulative minor Adverse Characteristics (X)	Use only for soils with no other limitation except climate. The subclass represents soils with a moderate limitation caused by the cumulative effect of two or more adverse characteristics which are singly not serious enough to affect the rating. Because the limitation is moderate, soils may only be downgraded by one class from their initial climate limitation. Therefore, a soil with a climate limitation of 2c and 2 or more minor adverse characteristics will be rated as 3X. This symbol is always used alone.						

1 Smith, R.E., H. Veldhuis, G.F. Mills, R.G. Eilers, W.R. Fraser, M. Santry, 1996. Terrestrial Ecoregions and Ecodistricts of Manitoba, An Ecological Stratification of Manitoba's Natural Landscapes. Agriculture and Agri-Food Canada, Research Branch, Brandon Research Centre, Manitoba Land Resource Unit, Winnipeg, MB. Report and Provincial Map at scale of 1:1.5m.

2 With the exception of class 2, ratings as indicated are based on the assumption of a single parent material, using the most readily drained representative of each textural class. Prevailing climatic conditions within the Ecodistrict, soil drainage and stratification will affect the moisture limitation accordingly.

3 Topographic classes are based on the most limiting slope covering a significant portion of an area of complex, variable slopes. Map units with long, unidirectional slopes may be considered equivalent, or one class worse due to an increased erosion hazard.

4 Extremely calcareous loamy till soils with a high bulk density (>1.7 g/cm^3) are rated 3D.

Continued on next page

5 Soil Salinity is reported in DeciSiemens/metre (dS/m). Soil will be classed according the the most saline depth. For example, if a soil is non-saline from 0-60 cm but moderately saline from 60-120 cm, the soil will be classed as moderately saline (3N).

6 Strongly saline (u) soils are rated 5N with the exception of poorly and very poorly drained soils, which are rated 6NW.

7 Inundation may be listed as a secondary subclass for some fluvial soils. In this case, inundation is not class determining, but may become a limitation if the soil is otherwise improved.

8 Extremely calcareous loamy till soils with a high bulk density (>1.7 g/cm^3) and stony 3 are rated 4DP (4RP if depth to bedrock is 50 - 100 cm).

9 Stony 4 soils will be rated 4P unless their primary physical composition is sandy skeletal or their parent material is till. In either or both of these cases, the soil will be rated 5P.

10 If erosion is moderate, a subclass of E is assigned as a secondary limitation, but the basic rating is not lowered. If erosion is severe, the basic soil rating is downgraded by one class, and E becomes the primary limitation. For example, if a soil has a basic rating of 4T, the presence of moderate erosion will result in a rating of 4TE. If erosion is severe, the rating will be lowered to 5ET. Erosion will be the sole limitation only if the basic rating has a subclass of X. For example, a soil with a rating of 3X will be assigned a rating of 3E if moderate erosion is present.

11 The rating is not lowered from class 6 based on erosion. A rating of 6TE indicates a soil with g topography and either moderate or severe erosion.

Table 2.3. Land use data based on satellite imagery from 1993-94

Agriculture Capability Class	Total (ac)	Total (ha)
1	660,782	267,523
2	7,318,412	2,962,920
3	6,039,123	2,444,989
4	4,256,620	1,723,328
5	2,555,235	1,034,508
6	1,658,669	671,526
7	512,920	207,660
Organic	1,912,652	774,353
Urban & Trans.	679,311	282,312
Water	493,094	199,633
Total	26,104,817	10,568,752

Table 2.4. Agriculture capability data based on 1:1,000,000 Canada Land Inventory map information

Agriculture Capability Class	Limitation	Within Limits of CLI Boundary	
		Acres	Hectares
1	**Total Class 1**	**453,000**	**183,401**
2	I - Inundation (flooding)	153,000	61,943
	P - Stoniness	68,000	27,935
	T - Topography	1,645,000	665,992
	W - Wetness (W, WP, WI)	1,874,000	758,704
	X - accumulation of two or more factors	2,569,000	1,040,081
	Other	2,000	810
	Total Class 2	**6,311,000**	**2,555,061**
3	I - Inundation (I, WI-IW)	78,000	31,579
	P - Stoniness (P, FP, MP, PM, WP)	537,000	217,409
	T - Topography (T, TE)	1,110,000	449,393
	W - Wetness (W, WD, WS)	2,471,000	1,000,405
	M - Deficient soil moisture (M, TM)	1,846,000	747,368
	Other	282,000	114,170
	Total Class 3	**6,324,000**	**2,560,324**
4	I - Inundation (I, WI)	197,000	79,757
	P - Stoniness (P, FP, PV, R, SP)	3,127,000	1,265,992
	T - Topography (T)	798,000	323,077
	W - Wetness (W, WP, WD, WS, WF)	996,000	403,239
	M - Deficient soil moisture (M, TM, FM, MP)	950,000	384,615
	Other	285,000	115,385
	Total Class 4	**6,353,000**	**2,572,065**
5	**Total Class 5**	**5,556,000**	**2,249,393**
6	**Total Class 6**	**5,338,000**	**2,161,134**
7	**Total Class 7**	**3,096,000**	**1,253,441**
Total		**33,431,000**	**13,534,817**

Provincial soil concept

Soil is one of our most valuable natural resources. To ensure that we do not take this resource for granted, soils need to be protected and managed in a sustainable manner. Designation and proclamation of a provincial soil is one way to increase public awareness and create a greater appreciation for soils.

The concept of provincial soils is practiced to a limited extent in Canada and universally in the United States. As of 2000, every state in the United States (including Guam, Puerto Rico and the US Virgin Islands) has designated a state soil. Of these, 13 have received official proclamation by their state legislature (USDA-NRCS, 2000 State Soil Planning Guide).

Table 2.5. Current status of provincial soils in Canada

Province / Territory	Provincial Soil	Classification
New Brunswick	**Holmesville proclaimed Feb. 1997**	**Orthic Humo-Ferric Podzol**
Prince Edward Island	**Charlottetown proclaimed Nov. 1998**	**Orthic Humo-Ferric Podzol**
British Columbia	TBA	Humo-Ferric Podzol
Alberta	Breton designated	Orthic Gray Luvisol
Manitoba	Newdale designated	Orthic Black Chernozem
Quebec	Ste. Rosalie designated	Orthic Humic Gleysol
Nova Scotia	Pugwash designated	Orthic Humo-Ferric Podzol

Newdale Series (NDL)

The Newdale series is characterized by an Orthic Black Chernozem solum on moderately to strongly calcareous, loamy (L, CL) morainal till of limestone, granitic and shale origin. These soils are moderately well to well-drained and occur in mid to upper slope positions of undulating to hummocky landscapes. Surface runoff is moderate to moderately rapid; permeability is moderately slow. Most of these soils are presently cultivated; they have formed under intermixed aspen grove and grassland vegetation.

The Newdale solum has a very dark gray Ah horizon, commonly 10 inches (25 centimetres) thick and ranging from 6 to 14 inches (15 to 35 centimetres), a dark brown Bm horizon, 4 to 12 inches (10 to 30 centimetres) thick, and a transitional BC horizon, 1 to 6 inches (3 to 15 centimetres) thick. A lime carbonate horizon, 4 to 6 inches (10 to 15 centimetres) thick is often present in shallower soils but is not evident in deeper profiles. Its solum depth averages 23 inches (58 centimetres) and ranges from 10 to 35 inches (25 to 90 centimetres).

Table 2.6. Newdale soil analysis

Horizon	Depth cm	pH $CaCl_2$	Organic Carbon %	Organic Matter %	$CaCO_3$ %	Extracteable Cations meq./100gm					CEC meq./100gm	Very Fine Sand %	Total Sand %	Total Silt %	Total Clay %	Texture Class
						Ca	Mg	Na	K	H						
Ap	0 - 15	7.2	4.5	7.8	1	24	10	0.3	1.0	3	39	9	30	36	34	Clay loam
Ah	15 - 25	7.2	3.0	5.2	1	19	8	0.3	0.9	0	29	12	42	30	28	Clay loam
Bm	25 - 45	7.3	1.0	1.7	1	18	9	0.3	0.8	0	25	9	34	35	31	Clay loam
BC	45 - 55	7.6			15	18	9	0.1	0.5	0	21	10	35	34	31	Clay loam
Ck	55 - 100	7.9			20	12	16	0.7	0.7	0	20	10	36	36	26	Loam

3

Water Use and Moisture Management

In addition to supporting our agricultural needs, we rely on the soil to regulate the flow of rainwater and to act as a filter for drinking water. With such a tremendously important role, it is imperative that we manage our soils for their long-term productivity, sustainability and health.

Soil data on available water holding capacity, permeability (the rate at which water moves through a soil), depth to groundwater, flooding, slope gradient and depth to bedrock can be useful in determining the risk of groundwater contamination due to leaching or surface water contamination due to runoff and erosion.

Soil moisture definitions for plant growth

- *Saturation* is the moisture content at which all soil pores are completely water-filled.
- *Field capacity* (FC) is the maximum amount of water held in a soil, measured a few days after it has been thoroughly soaked and allowed to drain freely. (Note: FC is difficult to determine for heavy clay soils because water drains so slowly through these soils.)
- *Permanent wilting point* (PWP) is the soil water content at which water is no longer available to plants, which causes them to wilt because they cannot extract enough water to meet their requirements.
- *Available water* (AW) is the amount of water held in a soil that plants can use. The maximum amount of available water held in a soil is the difference between the PWP and FC, expressed in inches or millimetres of water per unit depth of soil.
- *Air Dry* is the amount of water remaining in soil after drying at room temperature for several hours. Only water that is tightly held to the soil particles (hygroscopic water) remains.

Table 3.1. Moisture contents (by weight) for selected soil types and depths

	Gas Tank Analogy:	**Soil Moisture Content (%)**					
		Stockton (FS)		**Newdale (CL)**		**Red River (HC)**	
		0-6″ (0-15 cm)	**0-30″ (0-76 cm)**	**0-6″**	**0-30″**	**0-6″**	**0-30″**
Saturation*	Tank is Overflowing	37	31	42	36	56	50
Field Capacity	Tank is Full	15	14	29	27	45	43
Permanent Wilting Point	Tank is Empty	4	4	12	9	18	18
Available Water	Size of the tank	11	10	17	18	27	25
Air Dry	N/A	1-2	1-2	2-3	2-3	3-4	3-4

* *Saturation is the moisture content when lack of oxygen will adversely affect plant growth and may induce denitrification. Note that saturation (on a weight basis) occurs well below 100% and even below 50% on most soils.*

Plants cannot extract all the available water between field capacity and permanent wilting point with equal ease. Soil water is more readily available to plants when soils are near field capacity and less so as soil moisture content approaches the permanent wilting point.

Table 3.2. Determining available soil moisture by feel or appearance

% Available water remaining	Coarse (VCoS – LFS)	Light (VFS – FSL)	Medium (L – SiCL)	Heavy (SC – HC)
0 (PWP or drier)	Dry, loose, single grained, flows through fingers	Dry, loose, flows through fingers	Powdery, dry, sometimes slightly crusted but easily breaks down into powdery condition	Hard, baked, cracked, sometimes has loose crumbs on surface
<50	Still appears to be dry; will not form a ball with pressure	Still appears to be dry; will not form a ball	Somewhat crumbly but will hold together from pressure	Somewhat pliable, with ball under pressure
50-75	Still appears to be dry; will not form a ball with pressure	Tends to ball under pressure but seldom will hold together	Forms a ball, somewhat plastic, will sometimes slick slightly with pressure	Forms a ball, will ribbon out between thumb and forefinger
75 to FC	Tends to stick together slightly, sometimes forms a very weak ball under pressure	Forms weak ball, breaks easily, will not slick	Forms a ball and is very pliable, slicks readily if relatively high in clay	Easily ribbons out between fingers; has a slick feeling
At FC	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand
Above FC	Free water appears when soil is bounced in hand	Free water will be released with kneading	Can squeeze out free water	Puddles and free water forms on surface

Soil moisture definitions for other purposes

- *Liquid Limit* is the moisture content at which a soil begins to flow and behave like a liquid.
- *Plastic Limit* is the moisture content at which a soil sample changes from a semi-solid to a plastic state (This is the point at which travel on the soil becomes difficult, if not impossible).
- *Oven Dry* occurs when soil has been dried at 105°C for 24 hours so that no water remains. Oven drying of soil is done to determine the total amount of water present in a soil prior to oven drying for moisture content determination.

Table 3.3. Moisture contents (by weight) for selected soil types and depths

		Soil Moisture Content (%)					
		Stockton (FS)		**Newdale (CL)**		**Red River (HC)**	
	Gas Tank Analogy:	**0-6″ (0-15 cm)**	**0-30″ (0-76 cm)**	**0-6″**	**0-30″**	**0-6″**	**0-30″**
Liquid Limit	N/A	N/A	N/A	46	42	65	68
Plastic Limit	Tank is ~½ full	N/A	N/A	26	22	25	27
Oven dry	Tank is Empty (no fumes)	0	0	0	0	0	0

Reporting soil moisture

Soil moisture content can be expressed on either a weight basis (gravimetric) or on a volume basis (volumetric).

$$\text{Gravimetric soil moisture (W\%)} = \frac{\text{wt. (wet soil)} - \text{wt. (oven dry soil)}}{\text{wt. (oven dry soil)}} \times 100\%$$

Volumetric soil moisture (Θ%) = gravimetric soil moisture x bulk density

It is important to measure soil moisture content when monitoring soil nutrient changes over time.

Available Water Holding Capacity (AWHC) describes how much available water a fixed amount of soil can hold for plant uptake. It is largely determined by soil texture and to a limited degree by soil structure and organic matter content.

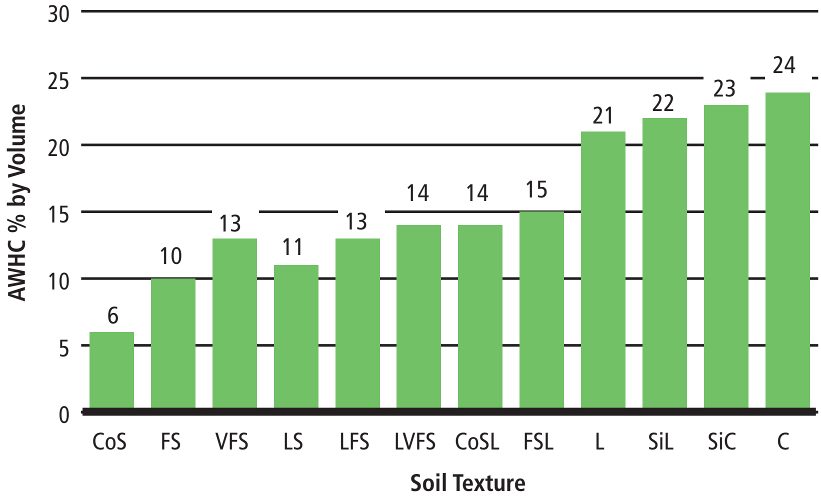


Figure 3.1. Relationship between soil texture and available water holding capacity (AWHC)

Water movement through soil

Infiltration is the entry of water into soil. The rate of infiltration can be relatively fast, especially as water enters into pores and cracks of dry soil. As the soil wets up and becomes saturated, the infiltration rate slows to the point where water ponding and runoff may occur.

Hydraulic conductivity is the rate at which water can pass through a soil material, usually measured under saturated conditions (i.e. when a small volume of soil has been sufficiently saturated) to ensure water is moving through the soil via gravity and positive head pressure. Saturated hydraulic conductivity (K_{sat}) provides the simplest and most consistent means of measuring the rate of water movement through soils.

The rate of water movement through a given soil is largely determined by the texture. Large soil particles (sands) create large pore spaces between the particles, allowing water to move through these pores relatively quickly and with little adhesion to soil particles. Small soil particles (clays) pack together more tightly, producing numerous small pore spaces that represent a larger volume than the pore volume of sandy soils, but allow the transmission of water at a much slower rate. Movement of water through clay soils is restricted by the small pore size and the significant adhesive forces between water and soil particles.

Other factors affecting water movement through soil are the internal drainage, depth to water table, soil structure, amount of organic matter present and the presence of soluble salts (salinity).

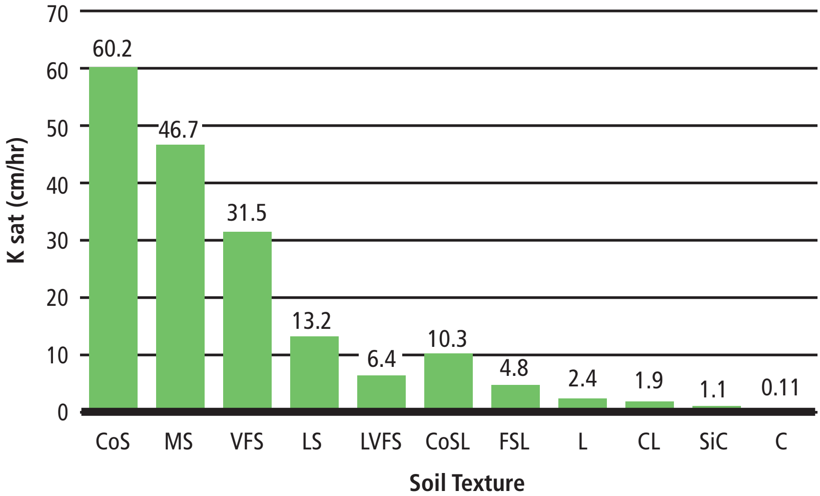


Figure 3.2. Relationship between hydraulic conductivity and soil texture

Basic water movement principles and rules of thumb

- Water flows more quickly through large pores (sandy soils) than small pores (clay soils); water is held more tightly in small pores (clay soils) than in large pores (sandy soils).
- Water moves from wet areas to dry areas (not necessarily by gravity) due to forces of adhesion and cohesion. This is called matric flow.
- Water will not move from small soil pores to large soil pores unless conditions are saturated. This phenomenon explains why coarser layers in the soil subsurface, or cracks or root channels that have been cut off from the soil surface by tillage, actually restrict the downward movement of water until the moisture content of the surrounding area becomes saturated (i.e. the "check valve" phenomenon).

How far will an inch (25 millimetres) of water move into a soil profile?

Several concepts need to be discussed to understand how to calculate the depth of water infiltration.

Soil porosity is the percentage of a given volume of soil that is made up of pore spaces. Soils are oven-dried to measure bulk density, so porosity is a measure of air-filled pore space.

Bulk density is the apparent density of a soil, measured by determining the oven-dry mass of soil per unit volume. The volume of soil is determined using sampling cores and is measured before soil is oven-dried to avoid any changes in volume due to drying. Bulk density is usually expressed in g/cm^3 or Mg/m^3.

Table 3.4. Typical bulk densities for various soil series

Soil Series	Bulk Density (g/cm^3) 0-6" depth (0-15 cm)
Stockton fine sand	1.34
Newdale clay loam	1.26
Red River heavy clay	1.07
Most rocks	2.65
Compacted soil	1.80

Particle density is the grain density, or the mass per unit volume of the soil particles. Pore spaces found in bulk soil samples are excluded. Particle density is usually expressed in g/cm^3 or Mg/m^3, and the particle density for most agricultural soils is 2.65 g/cm^3.

These three factors are used to calculate the depth an inch of precipitation moves into a given soil.

The distance an inch (25 millimetres) of water (precipitation) moves into the soil depends on several factors including initial soil moisture content, amount of water lost as runoff, texture, structure, organic matter content and porosity. A general estimate can be calculated for dry soil using the following formulae:

% Porosity = [1-(bulk density ÷ particle density)] x 100

where particle density = 2.65 g/cm^3

Depth of water infiltration for dry soil
~ [depth of water ÷ (% porosity/100)]

E.g. 1) A sandy soil with a bulk density of 1.2 g/cm^3:
% Porosity = [1 – (1.2 ÷ 2.65)] x 100
= 55%

Depth of water infiltration
~ [1 inch ÷ (55/100)] = 1 inch ÷ 0.55 = 1.8 inches

Therefore, an inch of precipitation will move **1.8 inches (4.5 centimetres)** in a dry sandy soil.

E.g. 2) A clay soil with a bulk density of 0.9:
% Porosity = [1 – (0.9 ÷ 2.65)] x 100
= 77%

Depth of water infiltration
~ [1 inch ÷ (77/100)] = 1 inch ÷ 0.77 = 1.3 inches

Therefore, an inch of precipitation will move **1.3 inches (3.25 centimetres)** in a dry clay soil.

Table 3.5. Relative crop suitability on various soil types

Texture	Coarse (sand)			Medium (loam, clay loam)			Fine (clay)		
Drainage	Well	Imp.	Poor	Well	Imp.	Poor	Well	Imp.	Poor
Crops:									
Cereals	✓	✓	W	✓	✓	W	✓	W	W
Flax, canola	M	M	W	✓	✓	W	✓	✓	W
Peas, lentils	M	✓	W	✓	✓	W	W	W	W
Field beans	✓	✓	W	✓	W	W	W	W	W
Sunflowers	✓	✓	W	✓	✓	W	✓	✓	W
Soybeans	M	M	W	✓	✓	✓	✓	✓	W
Faba beans	M	M	W	✓	✓	W	✓	✓	W
Corn	✓	✓	W	✓	✓	W	✓	W	W
Buckwheat	✓	✓	✓	✓	✓	W	✓	W	W
Canary seed	M	✓	W	✓	✓	W	✓	✓	W
Potatoes	✓	✓	W	✓	✓	W	H	H	W
Hybrid poplar	M	✓	W	✓	✓	W	✓	W	W
Forages:									
Alfalfa	M	✓	W	✓	✓	✓	✓	W	W
Drought tolerant grasses*	✓	✓	✓	✓	✓	W	✓	W	W
Flood tolerant grasses**	M	M	✓	✓	✓	✓	✓	✓	✓
Orchardgrass	M	M	✓	✓	✓	✓	✓	W	W

* = tame species of wheatgrasses, wild rye, etc.
** = reed canarygrass, meadow foxtail, fescues, etc.
✓ = suitable most years
M = moisture challenges in normal-dry years; suitable in wet years
W = wetness challenges in normal-wet years; suitable in dry years
H = harvestability challenges (i.e. potatoes on clay)

- **1 inch (25 millimetres) of precipitation = 22,500 gallons/acre (252,675 litres/hectare) of H_20**
- **actively growing plants transpire approx. 1/3 inch (8.3 millimetres) of water per day (which is 7500 gallons/acre/day or 84,225 litres/hectare/day).**

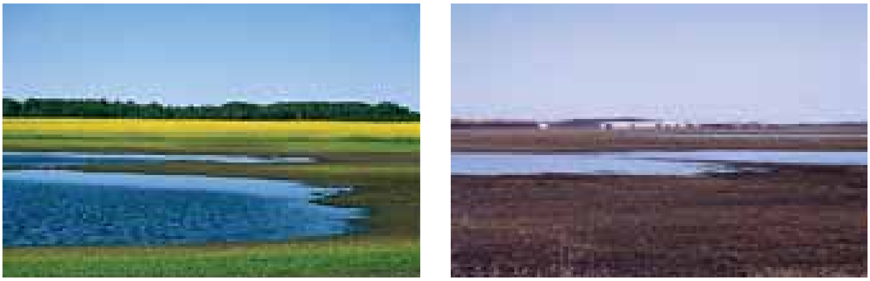
Water management strategies

A. Droughty soils (soils with an agriculture capability modifier "**M**") require moisture conservation practices, which may include the following:

Figures 3.3 and 3.4. Examples of soils with drought limitiations.

- Avoiding summer fallow – summer fallow does a poor job of conserving moisture, reduces soil organic matter, increases soil salinity, and leaves soil prone to erosion (spring moisture conditions in Manitoba are usually adequate for continuous cropping)
- Adopting reduced tillage, leaving more crop residues on the surface to reduce evaporation
- Avoiding unnecessary tillage – each tillage pass removes approximately ½" (12.7 millimetres) of water from the soil
- Snow management – leave standing stubble, plant shelterbelts or annual barriers, or leave trap strips of stubble

B. Wet soils (soils with an agriculture capability modifier "**W**") require moisture removal, which includes the following practices:



Figures 3.5 and 3.6. Examples of soils with excess water limitations.

- Drainage - systems should be designed to have sufficient capacity to remove excess water before crop damage occurs
- Tillage – although each tillage pass removes approximately ½" (12.7 millimetres) of soil water, avoid tilling soils that are wet to avoid compaction problems.

Yield losses are greatest on clay soils during periods of excess water in July, regardless of crop (Rigaux & Singh, 1977).

Table 3.6. Indicator weeds of soil moisture problems
(Organic Gardening Staff, 1978)

Dry Soils ("M" limitation)	Poorly Drained Soils ("W" limitation)
Tumble mustard	Buttercup
Stinking mayweed	Field mint
Thyme-leaved sandwort	Horsetail
Stork's bill	Silverweed
Purslane	Coltsfoot
Prostrate pigweed	Bindweed
	Comfrey
	St. John's wort
	Swamp smartweed

Table 3.7. Cropping and management strategies

Droughty soils and drier weather conditions	Wet soils and wetter weather conditions	Soils with both moisture (M) and wetness (W) limitations
• Moisture conservation • Increase soil organic matter for water retention • Reduced/zero tillage • Irrigation • Cereals > oilseeds • Pulses: peas > field beans (i.e. peas are more drought tolerant than field beans) • Forages: millet, crested wheatgrass, russian wildrye, sweetclover, alfalfa	• Drainage • Increase soil organic matter for improved infiltration • Cereals: Oats > wheat > barley • Pulses: Fababeans > soybeans >>> field beans > peas • Forages: grasses > legumes birdsfoot trefoil > alfalfa reed canarygrass > timothy > orchardgrass	• Drainage AND moisture conservation • Forage mixtures • Diverse crop rotations • Increase soil organic matter

4
Nutrient Management

Why is nutrient management necessary?

Managing nutrients properly offers both economic and environmental benefits to producers and the rest of society. Efficient use of nutrients from commercial fertilizers, manure or other sources reduces input costs for crop production and minimizes the risk of nutrient loss to ground and surface water. With rising fertilizer and fuel prices, as well as concerns for environmental stewardship, sound nutrient management is increasingly important for the sustainability of crop and livestock operations. Soil testing and crop nutrient requirements are the cornerstone of nutrient management. Detailed information on these topics can be found in the Manitoba Agriculture, Food and Rural Initiatives *Soil Fertility Guide*.

Heavy applications of crop nutrients, either from fertilizers or livestock manures, can exceed the nutrient requirements of crops, resulting in the buildup of nutrients in the soil. Some nutrients may be carried downward through the soil by excess water and enter the groundwater. Nutrients that are surface applied and not worked into the soil can be washed off by heavy rains or snowmelt, particularly on sloping land. These nutrients can then enter ditches, streams and other surface watercourses. If significant amounts of nutrients build up in the soil and water over time, the quality of these resources may be affected.

Nutrient management requires an understanding of how various crop nutrients behave in the landscape, how they are utilized by crops and how they may be lost to the environment. Knowing which soils may be at a higher of risk of nutrient loss can assist producers in managing nutrients more efficiently and in protecting the environment. Adjustments in the rate, placement method and timing of fertilizer and manure applications, along with maximizing crop nutrient removal, may significantly reduce the risk of nutrient losses.

Leaching of nitrate-nitrogen to groundwater

Nitrogen fertilizers, livestock manures, municipal sewage sludges, compost and soils high in organic matter are all sources of nitrogen. Regardless of their forms, once nitrogen fertilizers are applied to soil, most of the nitrogen is converted by microorganisms in the soil to nitrate (NO_3^-), which is readily taken up by plants. Nitrate is also highly mobile in the soil because it is soluble in water. As a result, loss of nitrate to groundwater can be significant in soils with coarse textures (agriculture capability subclass **M**), shallow bedrock (agriculture capability subclass **R**) and coarse textured soils with shallow water tables (agriculture capability subclass **MW**), especially when large amounts of nitrates are present in the soil prior to major precipitation events.

Nitrate leaching becomes a problem when nitrates have moved beyond the root zone so that future crops will be unable to extract nitrates from the soil. This is confirmed by deep soil sampling for nitrates and finding more than 20 lb/ac of nitrate-nitrogen in ANY 12-inch (30-centimetre) depth below 4 feet (1.2 metres). However, very coarse textured soils rarely have elevated levels of nitrate-nitrogen present for long enough periods of time to be detected by soil testing. These soils represent a greater risk to water quality than soils in which elevated levels of nitrate-nitrogen remain long enough to be measured by soil testing *and* to be retrieved by upcoming cropping practices.

The guideline upper limit for nitrate-nitrogen in drinking water is 10 parts per million (ppm). Above this limit, there is concern over the development of a condition called Blue Baby Syndrome in infants who drink water high in nitrates. While serious, the risk of Blue Baby Syndrome, based on past incidents in Manitoba, is extremely low. To ensure that groundwater in Manitoba is not contaminated with nitrates, producers can limit the amount of nitrate-nitrogen in the soil by following soil test recommendations and adjusting nitrogen fertilizer application rates, placement and timings. For more information on sampling techniques for a representative soil test, refer to the Manitoba Agriculture, Food and Rural Initiatives *Soil Fertility Guide*.

Phosphorus runoff into surface waters

Phosphorus is an essential plant and animal nutrient that can impair surface water quality when present in excess. Phosphorus occurs naturally and is commonly found in fertilizers, manure, detergents, municipal and domestic sewage, and industrial waste. Phosphorus must be carefully managed to minimize the impact on surface water quality.

A small amount of phosphorus in water is essential for aquatic life. However, phosphorus can quickly become a problem when present at excessive levels. Such an increase in phosphorus and other nutrients in surface water is called **eutrophication**. As eutrophication occurs, both plant and algae growth can increase to a harmful level for aquatic life. When these plants and algae die, their decomposition uses a great deal of the water's oxygen which may result in fish kills. As well, blooms of some blue-green algae may release toxins into surface water that can harm wildlife, livestock and humans if they drink the water. Phosphorus levels greater than 0.05 mg/L in surface water can result in eutrophication.

Unlike nitrogen, phosphorus is not very mobile in the soil because it binds easily with calcium and magnesium in the soil. However, phosphorus can move in the environment in two forms: dissolved P and particulate P. Dissolved P moves in runoff water and is very difficult to manage. Dissolved P levels increase as soil test P levels increase, therefore soil test levels should not be allowed to increase to excessive levels. Particulate P is attached to soil particles and is transported during soil erosion events.

The following are recommended practices to reduce P entry into surface water:

- minimize erosion to limit the amount of particulate P entering surface waters
- use incorporation or banding to place P fertilizers beneath the surface, reducing the risk of P entering surface waters via runoff
- establish buffer strips (Table 4.1) to intercept P. Manitoba studies suggest vegetated buffer strips (VBS) are often ineffective in reducing P losses since most occurs during snowmelt when vegetation is not growing and the ground is still frozen, and waters flow right over the VBS. However, in those circumstances where the primary P loss mechanism is soil erosion caused by spring and summer rainfall, VBS have been shown to be effective in reducing P losses to waterways.

Producers can limit the amount of phosphorus in runoff by fertilizing according to soil test recommendations and adjusting phosphorus fertilizer application rates, placement and timings. For more information on sampling techniques for a representative soil test, refer to the Manitoba Agriculture, Food and Rural Initiatives *Soil Fertility Guide.*

Loss of phosphorus can be significant on soils with sloping topography (agriculture capability subclass **T**), soils with a considerable risk of flooding (agriculture capability subclass **I**), wet soils where water ponding occurs (agriculture capability subclass **W**) and on soils with clay surface textures. Phosphorus losses are most likely to occur during spring snowmelt or during the growing season from precipitation events that generate runoff in the landscape.

Table 4.1. Effectiveness of buffer strips from various scientific papers (Journal of Soil and Water Conservation and Journal of Environmental Quality)

	% Reduction in Constituent			
	Runoff	Sediment	Total N	Total P
6 ft (2 m) Vegetated Filter Strip				31
15 ft (4.6 m) grass	81		67	
23 ft (7 m) switchgrass	58	95	80	78
23 ft (7 m) switchgrass + 43 ft (13 m) woody vegetation	82	97	94	91
130 ft (40 m) buffer strip @ 4% slope	67		84	

Stream and drain order criteria

The relative size of streams or drains in a watershed may determine the need for and extent of the adoption of certain management practices. For example, buffer strips may be more important and need to be wider adjacent to major waterways than adjacent to small, intermittent waterways. Other practices, such as water storage and erosion control, may be more beneficial to implement in the upper headwaters of a watershed than in the lower portions at the mouth of the watershed.

To help understand, discuss and explore similarities and differences between streams in a watershed and drain networks, classification systems have been developed to rank streams/drains according to their relative position within the drainage system of a watershed. The two most common classification systems are the Strahler sytem and the Shreve system.

In the Strahler system, the smallest headwater tributaries are called *first-order streams*. Where two first order streams join, a second-order stream is created; where two *second-order streams* join, a *third-order stream* is created; and so on. Most biologists prefer this classification system, but this approach is only useful if the order number in question is proportional to the channel dimensions, size of the contributing watershed and stream/drain discharge at each point in the system. These proportions are verified using a number of mathematical equations (Environmental Hydrology, 2004).

In the Shreve system, the smallest headwater tributaries are also called *first-order streams* and the orders increase with increasing size. However, in this system, the orders are additive, much like the flow from two converging streams is additive. This approach is preferred by most hydrologists because it appears to correlate better with most hydrologic processes. The most obvious difference in the Shreve system over the Strahler system is more frequent changes to stream orders for larger tributaries.

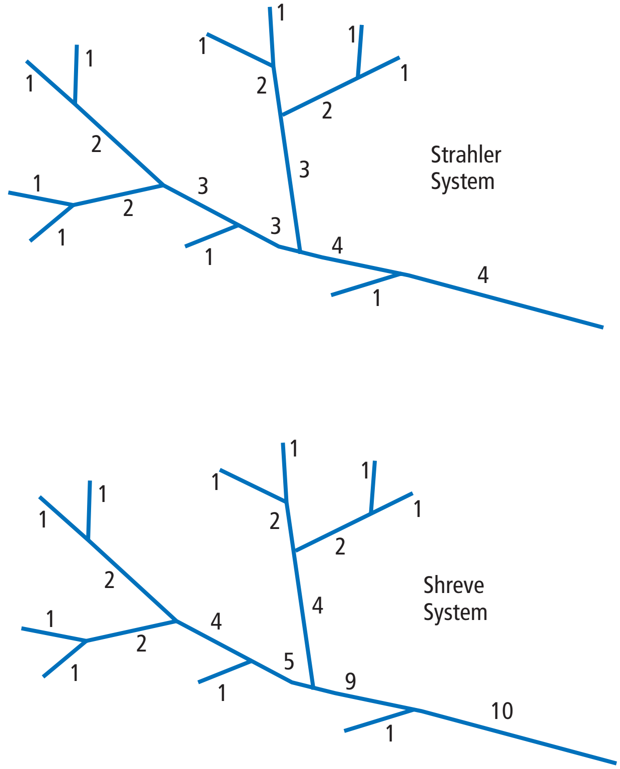


Figure 4.1.
Comparison of Strahler and Shreve stream ordering systems

Regulation of Manure Nutrient Management in Manitoba

Currently, nutrient management legislation in Manitoba pertains to the application of livestock manure to crop land. Manure nutrient management is regulated on the basis of both nitrogen and phosphorus through the Livestock Manure and Mortalities Management Regulation under *The Environment Act*. Table 4.2. lists nitrate-nitrogen limits (residual and any other time of year) that are based on Agriculture Capability ratings for soils. Table 4.3. contains soil phosphorus regulatory thresholds that trigger P-based manure application requirements, irrespective of soil type. Table 4.4 summarizes required manure management practices for Special Management Areas (SMAs).

Table 4.2. Residual and any other time of year soil nitrate-nitrogen limits (lb/ac in the 0 to 24 inch depth), as stated in the Livestock Manure and Mortalities Management Regulation.

Agriculture Capability Class	Residual[1] nitrate-N maximum	Any other time of year[2] nitrate-N maximum
Class 1, 2, 3 (except 3M and 3MW)	140	280
Class 3M, 3MW and 4	90	180
Class 5	30	60
Class 6, 7 and unimproved organic soils	No manure application[3]	No manure application[3]

1 "Residual nitrate-nitrogen" means the amount of nitrate-N that remains in the soil after the production of a crop.

2 No person shall apply livestock manure to land in a manner or at a rate that results in the concentration of nitrate-N within the top 24" (0.6 m) of soil at any one time being more than twice the amount of residual nitrate-N allowed for that particular soil class.

3 This section does not apply to a livestock operation in existence on March 30, 2004, unless the agricultural operation is modified or expanded after that day or unless the operator is otherwise notified by a Director of the Department of Manitoba Conservation.

Table 4.3. Soil phosphorus regulatory thresholds (ppm in the 0 to 6 inch depth) for livestock manure application on crop land in Manitoba, as stated in the Livestock Manure and Mortalities Management Regulation (2006).

Soil Test P Threshold (Olsen P)	Intent of Threshold	Manure P Application
Less than 60 ppm P	No restriction on P application	Apply on the basis of crop nitrate nitrogen (N) requirements. Soil N concentrations are subject to section 12 of the Livestock Manure and Mortalities Management Regulation
Between 60 and 119 ppm P	Control soil P accumulation rate	Apply P up to 2 times the crop removal rate of P_2O_5
Between 120 and 179 ppm P	Prevent further increase in soil P concentration	Apply P up to 1 times the crop removal rate of P_2O_5
180 ppm or greater P	Depletion at a rate controlled by crop removal	No manure application without written consent of the Director

For more information on the regulation of manure nutrient management, refer to: manitoba.ca/conservation/envprograms/livestock/index.html

Table 4.4. Summary of manure management practices required for Special Management Areas (SMAs), as stated in the Livestock Manure and Mortalities Management Regulation (2006).

SMA	Manure Management Practices	Manure Application Setbacks (m)	
		Injection/low level application with incorporation	**High level broadcast application/low level application with no incorporation**
Red River Valley or Flood plains of other designated rivers	Prohibition on all winter application (no later than November, 2013); Incorporation within 48 hours or injection of fall applied manure on tilled soils (as of September, 2007)		
Lakes	Injection or low-level application followed by immediate incorporation	15 m setback, consisting of 15 m permanently vegetated buffer	20 m setback
	High-level broadcast or low-level application without incorporation	30 m setback, including 15 m permanently vegetated buffer	35 m setback
Rivers, creeks and large unbermed drains, designated as an Order 3 or greater drain on a plan of Manitoba Water Stewardship, Planning and Coordination, that shows designations of drains	Injection or low-level application followed by immediate incorporation	3 m setback, consisting of 3 m permanently vegetated buffer	8 m setback
	High-level broadcast or low-level application without incorporation	10 m setback, including 3 m permanently vegetated buffer	15 m setback
All other types of surface water or surface watercourses	No manure application allowed		

Basics of nutrient management

1. Soil testing – a prudent soil sampling strategy is required to produce an accurate depiction of nutrients available in the soil for crop growth. From this, a recommendation for an appropriate amount of supplemental nutrients to add as fertilizer is provided. Refer to the *Soil Fertility Guide* for more information on soil testing.

Figure 4.2. Soil sampling

2. Manure testing – estimating the amount and availability of nutrients in manure provides information needed to calculate an application rate based on crop nutrient requirements. This step details the nutrient content of the manure, similar to the chemical analysis of a commercial fertilizer.
3. Realistic crop yield targets – higher crop yields are usually the result of increased nutrient uptake provided by additional fertilizer. However, other limitations from soil, weather, pests and management practices can limit yield potential even with an adequate nutrient supply. Use field and farm records to determine target yields that are reasonable and attainable most years. Use crop insurance data if farm records are unavailable.
4. Realistic crop nutrient requirements – apply the appropriate amount of nutrients to achieve an economic yield response and a reasonable return for the fertilizer. Increased nutrient applications to elevate protein content or increase straw are not recommended if there is no economic return to justify the practice.
5. Calibration, timing and placement of nutrients – ensure the application equipment applies the product at or near the target application rate. Apply nutrients as close as possible to the time of crop nutrient uptake to minimize the risk of nutrient loss to the environment. Banding fertilizers below the soil surface is consistently more effective than broadcasting fertilizer. If fertilizers must be broadcast, incorporate into the soil as soon as possible.
6. Record keeping – documentation improves producers' ability to manage nutrients in a way that maximizes the economic benefits while minimizing the environmental risks. Information pertaining to the fields receiving nutrients, the soils, the fertilizers, the crops being grown, the equipment used and the weather conditions at application, should all be recorded.

Figure 4.3. Manure application by injection

For more information on manure management, refer to the *Tri-Provincial Manure Application and Use Guidelines* (Manitoba version).

Figure 4.4. Example of a soil test.

Challenges to nutrient management

- Fall application of nutrients is a desirable practice because of historically lower fertilizer costs, more time, drier field conditions, etc. However, soils with higher risks for leaching and runoff may be less suitable for fall applications.
- The N:P balance of manure does not match N:P removal by crops. Meeting the N requirements of a crop with manure may result in an over-application of P, which can cause problems if the practice is repeated over time. Allowing N losses to occur during the storage and application of manure requires increased application rates to meet N requirements, which results in greater buildup of P in soil.
- Agronomic thresholds do not always prevent environmental impacts, nor do environmental limits always allow for agronomic responses that are beneficial and economically sound.
- Banding nutrients below the soil surface is more efficient (in terms of utilizing nutrients by the crop) than broadcasting nutrients on the surface. However, surface applications of nutrients in zero tillage and forage systems are generally required to maintain seedbed quality and plant viability.
- Over-application of manure has historically been the result of applying too much product on too few acres. A shortage of land suitable for manure application and prohibitive transportation costs often discourage producers from relying on manure fertilizer to meet the nutritional needs of the crop.
- Winter application of manure by smaller, older livestock operations that do not have sufficient storage capacity is allowed but not recommended. It is best to avoid applying manure to frozen and/or snow-covered soils because of the higher risk of nutrient losses in spring runoff. When winter application of manure is necessary, setbacks from watercourses must be adhered to by the operator.

Riparian management

Proper management of uplands (those areas in the landscape where crops are grown and crop inputs are applied) is the first step in ensuring nutrients and other constituents stay in the target areas as much as possible. In an agricultural landscape, these areas represent the majority of the land base. However, there are small (in terms of their area) but dynamic portions of the landscape adjacent to water courses that, if properly managed, serve as another line of defense in keeping nutrients and other potential contaminants out of our water resources. These latter portions of the landscape are called riparian areas.

The riparian area serves as a buffer strip that filters runoff before it enters a surface watercourse. Maintaining or rejuvenating healthy riparian areas is crucial to protecting surface water quality and preserving the agricultural land base. Riparian areas can be assessed in terms of their "health" - factors such as degree of erosion, type of vegetation present, health of this vegetation, etc. are considered.

By managing or restricting access of grazing or confined livestock to riparian areas, vegetation is allowed to grow and hoof traffic is minimized so that river banks are stabilized.

In landscapes used for annual cropping, conducting farm operations in roadside ditches and right up to stream banks is discouraged. Even with no livestock present, buffer zones are still needed to prevent soil erosion and filter nutrients, sediments, etc. before they enter surface watercourses.

Refer to the website **www.riparianhealth.ca** for more information on riparian areas and their management.

5
Soil Salinity

Background

Soil salinity limits plant growth due to the presence of soluble salts in soils which hold water more tightly than the plants can extract it. As a result, many plants will exhibit symptoms of droughtiness, but the soil is often relatively moist.

Salinity can develop naturally *(primary salinity)* or be human-induced *(secondary salinity)*. Naturally-occurring salinity results from the long term continuous discharge of saline groundwater. Human-induced salinity is the result of human activities that have changed the local water movement patterns of an area. Soils that were previously non-saline have become saline due to changes in saline groundwater discharge.

Figures 5.1 and 5.2. Examples of saline soils and the resulting reductions in crop growth

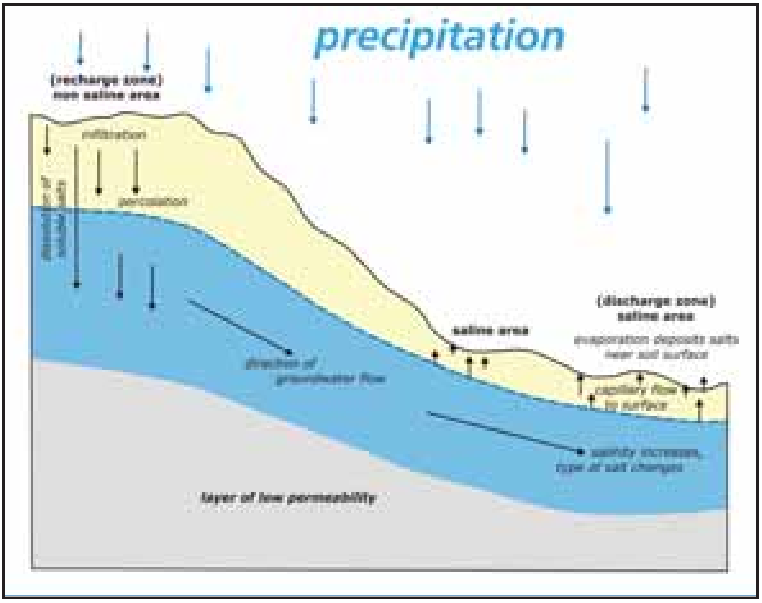


Figure 5.3. Development of soil salinity

In the landscape, soil salinity develops as excess water from well-drained recharge zones moves to and collects in imperfectly to poorly drained discharge zones. The buildup of excess water brings dissolved salts into the root zone of the discharge area. The concentration of these salts reduces the amount of available water, so that crops trying to grow in salt-affected areas cannot extract enough water to grow.

Soil salinity can be difficult to notice from one season to the next because it is influenced by moisture conditions. In wet years, there is sufficient leaching and dissolving of salts so that they are not visible on the soil surface and some crop growth may be possible. However, the excess water received in wet years contributes to the overall salinity problem over time. In dry years, increased evaporation dries out the soil and draws salts up to the soil surface, producing white crusts of salt. In dry years, producers become more concerned with salinity because salts are highly visible and little to no crop growth occurs in the affected areas.

Salt-affected soils can occur locally (only a few square feet in size, scattered over a given landscape) or regionally (large areas several acres in size). Depending on moisture conditions, these areas can increase in size or intensify in salt concentration. Overall outcomes are primarily dependent on the movement, salt content and depth of groundwater.

Recharge zone – an area where water infiltration exceeds the storage capacity of the soil and moves downward to the zone of saturation (groundwater). In recharge areas, well, imperfect and poorly drained soils may have well developed A (leached) and B (clay accumulation) horizons which indicate net movement of water is downward. The surface and subsoil are usually non calcareous.

Discharge zone – an area where the zone of saturation is at or near the surface and the net movement of water is towards the ground surface. Discharge may be focused in areas such as springs, weeping embankments and baseflow discharge, or it may be diffuse over larger areas of the landscape. These areas may be characterized by soils that are calcareous, imperfectly or poorly drained and have a build-up of salts.

Conditions required for soil salinity

- presence of soluble salts in subsoil, groundwater or both
- high water tables (within 6 feet (1.8 metres) of the soil surface) that can result in soluble salts moving into the root zone of the soil through the upward movement of water (ie. capillary rise, wicking). Capillary rise increases as the texture of the soil becomes finer.

Table 5.1. Estimated capillary rise of water above a water table in soils (*Handbook of Drainage Principles*, OMAF, Publication 73)

Soil Type	Capillary Rise
Very coarse sand (VCoS)	0.8" (2.0 cm)
Coarse sand (CoS)	1.6" (4.1 cm)
Medium sand (S)	3.2" (8.1cm)
Fine sand (FS)	6.8" (17.3 cm)
Very fine sand (VFS)	16.0" (40.6 cm)
Silt (Si)	40.0" (101.6 cm)
Clay (C)	>40.0" (>101.6 cm)

Salinity can occur in several different forms. The most common type of salinity is due to any type of salt present in excess in the soil, limiting the availability of water to plants. This results in high electrical conductivities.

Electrical Conductivity (EC) – a measure of soluble salts within the soil. As the concentration of soluble salts increases, the EC of the soil extract increases. EC is expressed in dS/m, mS/cm, or mmho/cm (all equal).

Electrical conductivity is directly related to the total dissolved solids in the soil.

Total Dissolved Solids (TDS) – a measure of soluble salt content in water extracted from the soil sample, expressed in mg/L.

$TDS = 0.7 \times 1000 \times EC$ or $EC = 1.4 \times 0.001 \times TDS$
(assumes bulk density of 1.1 g/cm^3, saturated moisture content of 40% by weight and soil depth of 0-12")

Another form of salinity occurs if *sodium* salts are the dominant type of salts present. A relatively small amount of sodium salts can negatively affect soil structure and create a sodic soil condition but may not necessarily have high electrical conductivities. Producers often refer to these conditions as "alkali", "gumbo", etc.

Figure 5.4.
Clods from a sodic soil

The concentration of sodium relative to calcium and magnesium in the soil is called the sodium adsorption ratio (SAR). SAR is a measure of soil sodicity.

Sodium Adsorption Ratio (SAR) – a measure of the ratio of sodium (Na) to calcium (Ca) and magnesium (Mg) in a soil water extract, calculated as:

$SAR = [Na^+]/[[Ca^{++} + Mg^{++}]/2]^{0.5}$ where cation concentration units are mmol(+)/L.

Soil water extracts with SAR values >13 are indicative of a soil with a sodium problem. Even at SAR values >8, there are instances when relatively high concentrations of Na relative to Ca and Mg results in dispersion of clay particles, soil structural breakdown, and soil pore blockage which reduces infiltration rates and increases erosion potential.

Table 5.2. Diagnosis of non-saline and salt-affected soils

	Crop	Soil Condition	Field Observations
Non- saline	Pulses and vegetable crops	EC < 2* SAR <13	Normal crop growth
	All other crops	EC < 4 SAR <13	
Saline	Pulses and vegetable crops	EC >2 SAR < 13	Salt crystals at or near soil surface when dry; little or no plant growth
	All other crops	EC >4 SAR <13	
Sodic	All crops	EC < 4 SAR >13	Shiny black when wet; dull grey, hard and cracked when dry; little or no plant growth; pH may be > 8.6
Saline-sodic	All crops	EC > 4 SAR > 13	Any combination of the above features may be present

*dS/m = mS/cm=mmho/cm

The above values should be used as a guide for determining the presence and intensity of salinity in soil. As EC or SAR values approach these critical values, impacts on crop performance may occur. The effects of soil salinity are affected somewhat by soil texture, organic matter content, soil moisture, etc.

Crop response to salinity

Some crops are more sensitive to salinity than others. Crops such as pulses, row crops and special crops are particularly sensitive to salinity (Table 5.3). The salt tolerance of some crops changes with growth stages (Table 5.4).

Sensitive crops may exhibit negative effects of salinity at levels <4 dS/m. An EC of 4 is a general salinity rating for traditional annual crops (wheat, canola) which are not significantly affected by soil salinity levels below 4 dS/m. Other rating systems (refer to *Manual for Describing Soils in the Field*) evaluate salinity with greater detail using the following classes:

1 - Nonsaline (0-2 dS/m)

2 - Slightly saline (2-4 dS/m)

3 - Weakly saline (4-8 dS/m)

4 - Moderately saline (8-15 dS/m)

5 - Strongly saline (>15 dS/m)

Table 5.3.
Relative salt tolerance of Manitoba crops (adapted from McKenzie, 1988)

EC Tolerance* (dS/m)	Field Crops	Forages	Vegetables	Trees/shrubs
High (16)		Tall wheatgrass Russian wildrye Slender wheatgrass		Sea buckthorn Silver buffalo-berry
Moderate (8)	6-row barley 2-row barley Fall rye Winter wheat Spring wheat Oats Flax Canola	Birdsfoot trefoil Sweetclover Alfalfa Bromegrass Crested wheatgrass Intermediate wheatgrass Meadow fescue Reed canarygrass	Garden beets Asparagus Spinach Tomatoes Broccoli Cabbage	Russian olive Poplar Apple
Low (4)	Sunflowers Soybeans Corn Peas Field beans	Timothy White Dutch clover Alsike clover Red clover	Potatoes Carrots Onions Strawberries Raspberries	Common lilac Manitoba maple Colorado blue spruce Cottonwood Birch

*Crops within a box are ranked from top to bottom as most to least tolerant

Table 5.4. Salt tolerance at two stages of growth (Soils '84)

Crop	Growth Stage	
	Germination	Established
Barley	Good	Good
Fall rye	Good	Fair
Wheat	Fair	Fair
Alfalfa	Poor	Fair
Corn	Fair	Poor
Field beans	Very poor	Very poor

Consult soils report for indicators of soil salinity

Using detailed soils information (if available), look for indicators of salinity:

- Possibility of salinity in soil series description
- N subclass in agriculture capability rating for salinity
- Sodic soils also have a D subclass in agriculture capability
- Saline phases on map: xxx**s**, xxx**t**, xxx**u**. Note the fourth position in the denominator of the soil code refers to the degree of salinity.

xxx**x** = non-saline (0-4 dS/m)*
xxx**s** = weakly saline (4-8 dS/m)
xxx**t** = moderately saline (8-15 dS/m)
xxx**u** = strongly saline (>15 dS/m)

Example:
BWO/xcxx = Barwood, 2-5% slopes, non-saline
BWO/xcxs = Barwood, 2-5% slopes, weakly saline

Figure 5.5. Topsoil with "t" salinity (xxxt) = 13 dS/m

Site visit

Salinity tends to be a localized problem such that a site visit is recommended regardless of the availability of detailed soils information.

Field symptoms

Check for poor crop growth, light gray or white colors on soil surface, areas that take longer to dry and growth of salt-tolerant weeds (foxtail barley, kochia, Russian thistle, etc.)

Measuring salinity in the field

1. Determine whether or not the problem is salinity by soil sampling both affected and unaffected areas. See Table 5.2 to compare soil test data with field observations.

Composite soil sampling may not provide an accurate measurement of the overall salinity level of a field. To assess a suspicious area of a field for salinity, take soil samples to 2 feet (0.6 metres) from the affected area and an adjacent non-affected area. If you wish to map an entire field for its salinity status, there are indirect measurements using specialized equipment that can be used.

2. Determine the source of salinity. Dig a pit in the soil of both the affected and unaffected areas, check for salt particles and check for carbonates using dilute hydrochloric acid (HCl) – see Figure 5.6. Since soluble salts are more mobile than carbonates, this can be used to determine the net direction of water movement.
3. Install observation wells and piezometers to identify recharge and discharge areas.

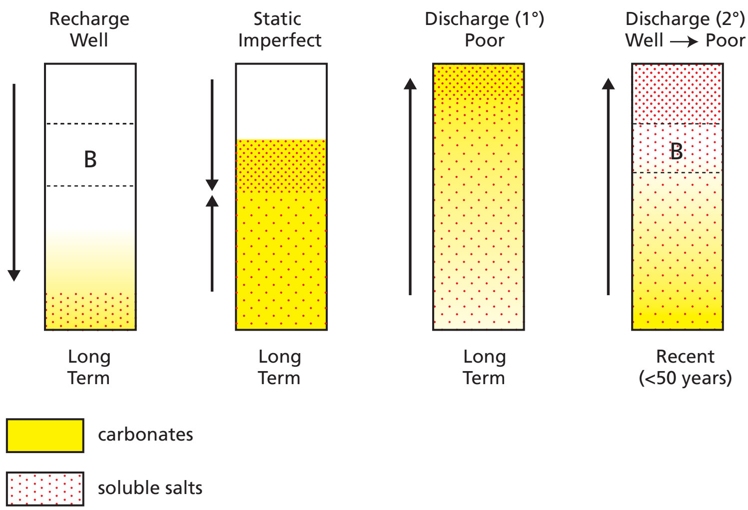


Figure 5.6. Diagnosing soil salinity using visual soil properties

The first profile represents a typical well-drained, non-saline soil profile in a recharge area. Net movement of water is downward through the profile, with the development of a B horizon verifying this process. Carbonates are found only in the parent material (C horizon); salts are either absent or found further down the profile than the carbonates.

The second profile represents imperfectly drained soils found in lower areas of the landscape where the net movement of water is relatively static. Salts and carbonates are found approximately at the same depth, which is below the soil surface but closer to the surface than in the well-drained scenario.

The third profile represents a saline soil as the result of primary (1°) salinity. The net upward movement of water in poorly drained, low-lying, groundwater discharge areas produces the highest concentration of salts and carbonates at or near the soil surface.

The fourth profile represents a saline soil that has recently become saline through the reversal in groundwater movement from net downward to net upward. Previously non-saline, like those conditions represented in the first box, changes in management have raised the water table and transported salts into the root zone. The presence of a B horizon and salts near the soil surface, coupled with the absence of near-surface carbonates, indicates this is the result of secondary (2°) salinity.

Salinity can be measured indirectly using inductive electromagnetic (EM_{38}) meters. These meters measure the apparent conductivity of the ground in mS/m in the 0 to 4 feet (0 to 120 centimetres) depth in the vertical mode and the 0 to 2 feet (0 to 60 centimetres) depth in the horizontal mode. Measuring a 4 foot (120 centimetre) depth of soil with uniform salinity should result in readings from the vertical mode twice as large as readings in the horizontal mode. Deviations from this ratio indicate salts are concentrated either at the 0 to 2 ft (0 to 60 cm) depth or the 2 to 4 ft (60 to 120 centimetres) depth.

Because the EC values obtained from the EM_{38} are affected by soil texture, soil moisture and soil temperature, calibration of these values with EC values from saturated pastes is required for each salinity investigation site (McKenzie, 1988).

Table 5.5. Correlation comparison of EM_{38} data from field investigations on soybean performance (September, 2002)

		Laboratory Analysis		In-Field Measurement
Soil Texture	**Soybean Performance**	**Depth (ft)**	**Laboratory EC (dS/m)**	**EM_{38} Reading (horizontal/ vertical)**
Clay Loam	Good	0-2 0-4	0.7 1.4	80 100
Clay Loam	Marginal	0-2 0-4	1.0 4.7	110 150
Clay Loam	Poor (saline area)	0-2 0-4	3.3 10.1	170 230
Clay Loam	Poor (wet area)	0-2 0-4	1.7 9.3	100 115
Heavy Clay	Good	0-2 0-4	3.9 6.6	230 240
Heavy Clay	Marginal	0-2 0-4	4.9 5.7	270 270

Based on the data in Table 5.5, one can conclude:

i) salinity is increasing with depth in most cases

ii) comparisons of absolute EM readings between soil textures are not appropriate because other factors affect the EM readings (eg, 230 in the clay loam is saline (10.1 dS/m) and 230 in heavy clay is non-saline (3.9 dS/m)).

EM readings allow for relative comparisons within a field of the same soil texture at a given point in time. Revisiting the site requires re-calibration of the equipment to account for changing moisture and temperature conditions. If calibration is not done, changing readings may not reflect a change in salinity, but rather changes in moisture.

Another tool for measuring salinity in the field is the VERIS meter. Similar in operation to an EM_{38}, the VERIS meter can be pulled behind a truck and driven across an entire field. Data loggers and GPS characterize changes in salinity over the landscape. Soil samples must still be analyzed for equipment calibration and for data comparison with other fields and future monitoring.

Measuring salinity in the laboratory

When sending soil samples away for laboratory analyses, request the following information:

pH, EC, SAR, CEC and exchangeable cations (Ca, Mg, Na).

- pH > 8.6 indicates a sodic condition
- EC - increasing EC values indicate increasing salinity. EC values <2 are considered non-saline. Sensitive crops may exhibit negative effects when EC values are >4

(NOTE: Most commercial soil testing laboratories use a 1:1 soil:water mixture to analyze for electrical conductivity. Although faster and less expensive to conduct than the saturated soil paste method, the 1:1 method produces EC values approximately that of the saturated paste method, depending on soil texture. Multiply EC values from 1:1 method by 2 to approximate EC values from saturated paste).

- SAR > 13 indicates sodic soil
- Ratio of Ca to Na should be 10:1 or greater; ratios less than 10:1 mean sodium may begin to cause soil structural problems

Recommendations for managing soil salinity

"The only real reclamation procedure for saline soils is to drain the excess water off the bottom and pour fresh water on the top to flush the salts out and away."

Les Henry, 1990

There are no quick or easy solutions to soil salinity. Saline soils can only be reclaimed by rinsing the salts down and out of the root zone. Preventing capillary rise involves adopting water management practices which improve drainage, lower the water table and promote the downward movement of salts in a saline soil.

Primary salinity:

Saline soils due to primary salinity often have high EC values. These soils are not suited to crop production. The best course of action for primary salinity is to leave the affected area in its natural state. If the land has been tilled, salt-tolerant vegetation should be established.

Secondary salinity:

Saline soils due to secondary salinity may have lower EC values and may be improved with management. In order to optimize production in saline, discharge areas, water must be utilized in the adjacent, non-saline recharge areas (Table 5.6). This will decrease the movement of excess water from recharge areas to discharge areas.

Table 5.6. Management options for secondary salinity

Control Types	Recharge Areas	Discharge Areas
Vegetative	• high moisture use crops • continuous cropping	• salt tolerant crops
Mechanical	• surface drainage	• tile drainage • salt leaching

The following are additional recommendations for managing secondary salinity:

1. Eliminate summerfallow – this reduces evaporation which draws water and salts to the soil surface.
2. Improve drainage to lower the water table and minimize the upward movement of salts.

3. Crops that use large amounts of soil water (such as alfalfa, perennial grasses, corn, sunflowers, winter wheat) should be planted in recharge areas – this reduces the amount of excess water that percolates through the soil and prevents the water table from rising in discharge areas.
4. Select salt tolerant crops to grow in discharge areas in order to reduce evaporation and maximize soil water use. Since crops will not root into the water table (saturated soil), drainage may be required for crops to establish.
5. Seed shallow and early when soils are moist and most favourable for germination.
6. Use recommended fertilizers according to soil test information. **There are no quick chemical fixes to cure soil salinity.**
7. Use manure and crop residues to provide additional organic matter to the soil. Although increased organic matter does not cure salinity, it reduces evaporation, improves water infiltration, water holding capacity and tilth of the soil. Apply 20 to 30 tons/acre (45 to 67 tonnes/hectare) of solid manure once every three to four years to saline areas.
8. Avoid deep tillage *on saline soils* because it will bring salts up to the soil surface. Zero tillage should be considered for strongly saline soils. For *sodic soils*, deep tillage may be beneficial to break up the hardpan and improve infiltration, as well as to bring any calcium salts present in the subsoil to the surface. A field investigation should be conducted before attempting deep tillage.
9. Establish forage buffer strips (at least 10 to 20-feet (3 to 6-metres) wide) immediately adjacent to municipal ditches, field drains and depressional areas to reduce the encroachment of soil salinity into the field (see the Manitoba Agriculture, Food and Rural Initiatives *Field Crop Production Guide*).

Forages are usually high water users and tend to be more salt tolerant than annual crops. Recommended forage mixture for saline soils (see the Manitoba Agriculture, Food and Rural Initiatives *Field Crop Production Guide*):

A. Hay mixture:
   - 5 lb/ac (5.6 kg/ha) tall wheatgrass
   - 5 lb/ac (5.6 kg/ha) slender wheatgrass
   - 3 lb/ac (3.4 kg/ha) alfalfa
   - 3 lb/ac (3.4 kg/ha) sweetclover

B. Hay mixture:
   - 5 lb/ac (5.6 kg/ha) tall fescue
   - 3 lb/ac (3.4 kg/ha) alfalfa
   - 3 lb/ac (3.4 kg/ha) sweetclover

C. Pasture mixture:
- 4 lb/ac (4.5 kg/ha) creeping foxtail
- 2 lb/ac (2.2 kg/ha) alfalfa
- 2 lb/ac (2.2 kg/ha) birdsfoot trefoil
- 2 lb/ac (2.2 kg/ha) sweetclover
- 2 lb/ac (2.2 kg/ha) slender wheatgrass

D. Pasture mixture:
- 4 lb/ac (4.5 kg/ha) tall fescue
- 2 lb/ac (2.2 kg/ha) sweetclover
- 2 lb/ac (2.2 kg/ha) slender wheatgrass
- 2 lb/ac (2.2 kg/ha) creeping foxtail
- 1 lb/ac (1.1 kg/ha) alfalfa
- 1 lb/ac (1.1 kg/ha) birdsfoot trefoil

Follow-up monitoring

Keep annual records of crop yields and growing season precipitation. Using GPS technology, establish benchmark sites for repeated soil testing to monitor changes in soil salinity. If inspection wells or piezometers are installed, monitor water table levels throughout the growing season to determine if water tables are being lowered. If salinity levels do not decrease, then other management strategies may need to be considered.

6
Drainage Management

Background

Improving drainage on agricultural land not only enhances crop production but also has a role in soil conservation. Agricultural drainage improvement can help reduce year-to-year variability in crop yield, which helps reduce the risks associated with crop production. Improved field access through enhanced drainage also extends the crop production season and reduces damage to equipment and soil that can occur under wet conditions. Maintaining existing agricultural improvements and improving the drainage on wet agricultural soils presently in agricultural production helps minimize the need for producers to convert additional land to agricultural production. The main objective of agricultural drainage is to remove excess water quickly (within 24 to 48 hours) and safely to reduce the potential for crop damage.

Drainage is important to avoid excess water stress to the crop. Excess water has been shown to decrease yields of wheat, oats, barley and flax by an average of 14, 18, 23 and 4 bu/ac respectively (Rigaux and Singh, 1977). Other benefits of drainage include: earlier spring seeding (see Table 6.1), warmer soils in spring, increased soil air in root zone, increased availability of nutrients, reduced risk of delayed harvesting, less damage to equipment, less overlapping of inputs during field operations and more effective weed control.

Table 6.1. Effect of delayed planting on Manitoba crop yields (MASC)

Planting Date	% Yield Reduction			
	Corn	Canola	Flax	Peas
1st week May	-	-	-	-
2nd week May	5	-	-	5
3rd week May	10	5	5	15
4th week May	20	10	15	20
1st week June	30	20	25	30

The use of surface and subsurface drainage improvements is not limited to agricultural lands. Many residential homes use subsurface drainage systems, similar to those used in agriculture, to prevent water damage to foundations and basements. Golf courses make extensive use of both surface and subsurface drains. Houses, streets and buildings in urban areas depend heavily on surface and subsurface drainage systems for protection. These generally are a combination of plastic or metal gutters, and concrete pipes or channels.

There are two principle types of field drainage – surface drainage and tile (or subsurface) drainage. In general, surface drainage is conducted on heavier-textured soils and tile drainage, along with surface drainage, is used on lighter-textured soils.

A. Surface Drainage

The purpose of using surface drainage is to minimize crop damage from water ponding after a precipitation event, and to control runoff without causing erosion. To accomplish this, one must follow a few drainage design standards:

- Proper grades are 0.1 - 0.3%. Grades >0.2% should have grassed bottom and sides.
- Side slopes of ditches should be <10%.
- For deep, permanent ditches and major landscaping, topsoil should be removed first and stored separately until earth moving is complete. Topsoil should be added back on the surface with minimal mixing of subsoil to ensure crop productivity is protected.

Shortcomings of surface drainage include: erosion and filling in of ditches (which requires ongoing maintenance), increased risk of salinization in areas affected by artesian pressure, and potential water quality impacts because water is not filtered through soil.

B. Tile Drainage

The purpose of installing tile drainage is to lower the water table in order to increase the productivity of the drained land. Water tables that are close to the surface in the spring restrict seeding operations and impede crop growth and development. Rising water tables during the growing season can damage actively growing crops, resulting in yield losses. Capillary rise can carry salts into the root zone and contribute to soil salinity. In Manitoba, tile drainage has a particular fit in the wet, sandy soils used to produce high value crops. However, for tile drainage to be effective, a network of properly designed and maintained surface drains must also be in place.

- Some common concerns and explanations regarding tile drainage:
    1. **Overdraining (drying out) soils** - tile drains are only able to remove excess water that flows by gravity (i.e. water above field capacity) from the portion of the soil profile that is above the depth of the tile drain. This water is unavailable for plant uptake and restricts oxygen availability. Available water (between field capacity and permanent wilting point) is held in the soil under tension and cannot enter tile drains until conditions become saturated (refer to Chapter 3 on moisture management). If soils do experience droughtiness after drainage, these are usually soil types that have both wetness (W) and moisture (M) limitations. Tiling as shallow as possible (30 to 36 inches, or 90 to 105 centimetres) should address the wetness issues on these soils; producers should implement moisture conservation practices and, if necessary, irrigation to address droughtiness issues.

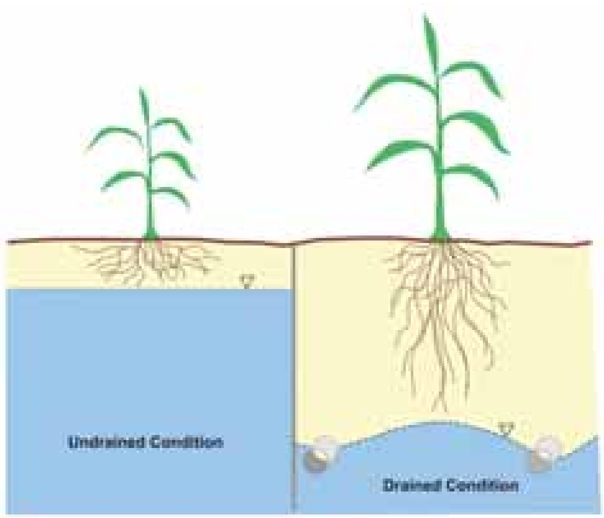


Figure 6.1. Comparison of water table and root development in tiled and untiled conditions (Sands, 2001)

Table 6.2. Benefits of tiling wet, sandy soils

	Untiled	Tiled
Soil moisture in root zone	Saturated throughout	Field capacity above tile, saturated below tile
Potential for water uptake by crop	Negligible	Full
Oxygen availability	Negligible	Full

In summary, a soil that is tiled has **less total water** but more water available to the plant because the depth of the rooting zone is greater than the same soil in the untiled condition (Figure 6.1). Tiled soils also have increased capacity for storing water in the profile, since soil moisture is usually less than field capacity with a growing crop, rather than above field capacity or at saturation.

2. **Downstream flooding** - conceptually, if large acres of land were tiled overnight, the drainage water could overwhelm existing municipal drains. However, with proper design of tile drainage systems and municipal drains, water leaving agricultural lands (as surface runoff or through tile drains) in the summer would be tempered because:

   a. a soil that is tile drained has more water storage capacity (i.e. soil moisture is usually less than field capacity with a growing crop, rather than above field capacity or at saturation);

   b. a healthy, actively growing crop will utilize any subsequent precipitation that brings soil moisture up to field capacity;

   c. water must flow through the soil and enter the tile before it leaves the property, rather than as overland flow directly into surface drains (exceptions would include very coarse textured soils or soils with deep, extensive cracks and root channels).

   The use of small dams in specific watercourses and designated selected lands as wetlands or water storage areas would provide additional buffer to minimize downstream flooding. In sensitive areas, tile drains could be closed at crucial times of the year.

3. **Surface water quality** - water that moves vertically through the soil may pick up dissolved salts, nitrates, etc. and these constituents may reach surface watercourses at the tile outlet. These soils require more intensive nutrient management practices, including soil testing, nutrient applications based on reasonable crop yield targets and nutrient budgets. Improving the water management of a field should result in more stable or improved crop yields, greater nutrient uptake and reduced risk of nutrient losses to the environment.

4. **Cost-Benefit** - installation costs for tile drainage systems can be $400 to $600 per acre or higher. For high value crops such as potatoes and other vegetable crops on coarse-textured soils susceptible to wetness limitations, the payback from increased crop yields and reduced yield variability could be realized in only a few years, especially when compared to payback from irrigation infrastructure.

5. **Proper design** - depending on field conditions, tile drains placed 30 to 36 inches (90 to 105 centimetres) deep (and properly spaced according to soil type) are effective in keeping the water table below the portion of the soil profile with the most root activity and most crucial for crop growth. Tiles placed deeper may drain more water or can be spaced further apart, but response time to heavy precipitation events may be too slow to prevent crop damage due to wetness.

6. **Drain maintenance to prevent freezing** - tiles need to be "dry" in the fall and the outlets unobstructed so that the drainage system is able to drain water early in the spring. Wet fall seasons will increase the risk of frozen tiles in the spring. If tiles freeze, they may be damaged and have their useful life reduced. In addition, frozen tiles will be unable to enhance drainage during spring thaw, but they should thaw in time to reduce the negative impacts of precipitation events later in the growing season, which may be the most harmful to crop performance.

Consult soils report when assessing lands for improved drainage

Clearly distinguish between wet land, which can be managed by drainage, cultivation and cropping systems, and wetlands, which should be conserved. "True" wetlands, like bogs, marshes and swamps, have saturated soil conditions over a sustained period of time during the year to maintain water-loving vegetation (rushes, cattails, sedges, willows) and wildlife habitat. These areas, once their benefit is assessed, should be protected from development.

Wetlands are valuable for groundwater recharge, nutrient filtering and recycling and supporting wildlife habitat. Water control through backflood irrigation and proper management when haying or grazing wetlands can have multiple, long term benefits.

Figure 6.2 Wet land

Figure 6.3 A wetland

Table 6.2. Distinguishing wet land from wetlands using agriculture capability ratings of soils

Limitation	Wet Land	Wetlands
Wetness (W)	• Imperfectly drained soils (Class 2W-4W) • Poorly drained gleysols (Class 5W) • Soils with agriculture capability subclasses 3MW and 4MW; water tables within 1-2 m (3-6 ft) during the growing season as stated in soil series description	• Very poorly drained soils (Class 6W) • Marsh (Class 7W) • Open water (coded "ZZ" in soil survey reports)
Salinity (N)	• Soils that display secondary (human-induced) salinity.	• Soils with primary (natural) salinity • Very strong (u) salinity (Classes 5N and 6N) • Salt flats (Class 7N)
Inundation (I)	Land inundated relatively infrequently (Class 2I, 3I)	Land inundated most of the season (Class 7I)

"Wet land" is agricultural land in production that has some crop limitations due to wetness limitations (see Table 6.2).

Drainage of wet land by soil texture:

i. *Clays* - poorly drained soils (such as Osborne soils) have their agriculture capability upgraded from 5W to 3W through properly designed surface drainage.

ii. *Wet sands* - imperfectly drained soils (such as Almasippi soils) benefit from properly designed surface and tile drainage when the drainage infrastructure is sufficient for effective field outlets.

Site visit

- Acquire elevation data for the selected field to assist in determining the design capacity of the drainage system.
- Consider soil texture, natural soil drainage, hydraulic conductivity, depth to water table, flooding frequency, depth to impermeable barrier, depth to bedrock, % slope, nature of the surface runoff, location of outlets before proceeding with drainage enhancement.
- Confirm the occurrence of soil salinity in previously non-saline soils using dilute hydrochloric acid (HCl) and observing salt-tolerant plant species (such as foxtail barley and kochia) and established alfalfa growth patterns (refer to Chapter 5 on soil salinity).

Other factors to consider are: size of area, location in ecosystem, relative size and productivity compared to other areas considered for agricultural development and/or wildlife conservation.

Laboratory analysis

A variety of factors are required to determine the appropriate drain spacing for a given soil type. Soil texture, permeability and depth to water table, along with possible changes of these properties with depth, can influence the drain spacing and overall cost of the project.

If a project becomes too expensive to have drains spaced relatively close together, the drains could be placed deeper in the subsoil or the overall capacity of the drainage system may have to be reduced with wider drain spacing.

Recommendations when considering a drainage project

A. Surface drainage:

1. Determine purpose/goal
2. Obtain a detailed topographic survey (elevation map) of selected field(s)
3. Conduct a detailed cost/benefit analysis
4. Obtain a drainage license from Manitoba Water Stewardship, which will include obtaining sign-off from those impacted (private and/or municipal)
5. Stake out drainage path beforehand
6. Start at outlet and work backwards, maintaining proper grade
7. Establish buffer strips/grassed waterways of deep-rooted, perennial plants (forages, trees, shrubs) to control erosion and salinity; incorporate other appropriate erosion prevention and control measures as needed
8. Consider outlet control to reduce runoff velocity or to control outflow timing

B. Tile drainage:

1. Determine purpose/goal
2. Obtain a detailed topographic survey (elevation map) of selected field(s)
3. Identify site criteria to confirm tile drainage is the most appropriate solution
4. Conduct a detailed cost/benefit analysis
5. Obtain a drainage license from Manitoba Water Stewardship
6. Tile drainage design:

i) The outlet should be higher than lowest point in municipal ditch to drain water from the field without pumping into the ditch. (Manitoba Water Stewardship generally allows a maximum of one 16 inch (40 centimetre) diameter outlet per quarter section.)

ii) An appropriate alternative use to consider is runoff collection on private land and other uses such as irrigation.
iii) The tiles must be deep enough to prevent damage from tillage and keep costs down (spacing can be further apart), but shallow enough to respond quickly to precipitation events
iv) Grade - >0.05% (depends on achieving correct flow velocity, depth, reasonable cost, etc.)
v) Flow velocity - greater than 0.5 cu.ft./sec (14 L/sec) to prevent sedimentation, but less than 1.4 cu.ft./sec (40 L/sec) to prevent blowouts and erosion
vi) **Spacing** – 40 to 50 feet (12 to 15 metres) is a general recommendation. However, the suggested spacing between tile laterals based on soil permeability conditions (modified from Beauchamp, 1955) is as follows:
   - Muck and peat: 50 to 200 feet (15 to 61 metres)
   - Sandy loam: 100 to 300 feet (30 to 91 metres)
   - Silt and silty clay loam: 60 to 100 feet (18 to 30 metres)
   - Clay and clay loam: 30 to 70 feet (9 to 21 metres)

   It is recommended that producers consider the cost and benefits of installing tile drainage while designing their drainage system. Well-drained, higher areas of the field may not require tile drainage and spacing the tiles closer together than necessary is an unwarranted cost.
vii) Installation - use a laser level to remove minor humps and dips in the landscape
viii) **Design and installation of tile drainage systems should only be conducted by trained individuals.** (Workshops offered by University of Minnesota Extension Service and courses offered by the University of Manitoba are available on this subject).

Follow-up monitoring of drained fields

- Keep records of crop yields, noting any changes in yield variability and stability prior to drainage improvements.
- Construct nutrient budgets for N and other nutrients to compare the amount of nutrients applied with the amount of nutrients taken up by the crop and remaining in the soil.
- Monitor water quality from drainage outlets at various times of the year. Compare with surface runoff water quality.
- Use soil testing for salinity and nutrients.
- Keep records of growing season precipitation events. If possible, monitor changes in water table levels over the growing season.
- Be aware of downstream effects and options to minimize the effects, such as controlled release of runoff during critical times.
- Be a good neighbor who is considerate of the effects of water on landowners downstream.

7

Soil Erosion

A loss of topsoil can result in a significant loss in productivity, largely due to losses of organic matter and nutrients as well as deterioration of physical soil properties.

> **"It was found that yields generally decreased as the amount of topsoil removed increased. Data indicated yields to be severely depressed on all topsoil removal treatments where no fertilizer was applied. …On the coarse textured soils, even twice the recommended rate of fertilizer was not able to bring the yields back to that of the control."**
>
> **(Kapoor and Shaykewich, 1990; Kenyon and Shaykewich, 1987).**

A. Wind erosion

Background

Wind erosion is the detachment, movement and removal of soil from the land surface by wind. It can occur naturally, without human intervention, or can be accelerated through human activities such as excessive tillage.

Soils most susceptible to wind erosion by texture:
sands > clays > loams

Soils most susceptible to wind erosion by structure:
single-grained (structureless) > crumbly or cloddy

Quick facts

- Maximum tolerable loss: 5 tons/acre/year (10 tonnes/hectare/year) = 0.03 inches (0.75 millimetres) thickness of topsoil on a well-developed soil.
- Pulse crops and potatoes usually do not leave enough residue on the surface to prevent erosion once these fields are cultivated – these crops are usually grown on the most erodible soil types.
- A 30 mph (48 km/h) wind has more than 3 times the erosive power than a 20 mph (32 km/h) wind.
- Wind erosion increases as soil dries (eg. air-dry soil erodes 1.3 times faster than soil at permanent wilting point).

- The most susceptible period for soil erosion by wind is early spring and after fall tillage.
- Soil particles move by wind in one of three ways: *surface creep* (rolling or sliding along surface); *saltation* (bouncing and dislodging other particles on impact); and *suspension* (continuously carried in the air).

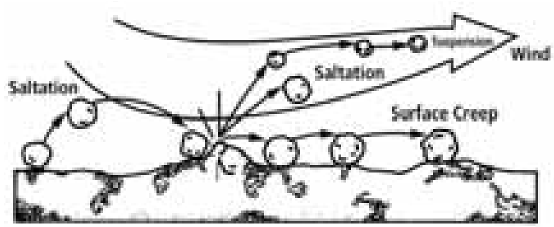


Figure 7.1. Three types of movement of soil particles by wind erosion: surface creep, saltation and suspension

Consult soils report to assess risk of wind erosion

Look for items that indicate soil susceptibility to erosion:

- texture (see above)
- agriculture capability subclass E (erosion limitation)
- Eroded phases on map: **1**xxx, **2**xxx, **3**xxx, **o**xxx. Note the first position in the denominator of the soil code refers to the degree of erosion.

  xxxx = non-eroded or minimal erosion

  1xxx = slightly eroded (25-75% of A horizon removed)

  2xxx = moderately eroded (>75% of A and part of B horizon removed)

  3xxx = severely eroded (all of A and B horizons removed)

  oxxx = overblown (subsoil deposited over topsoil)

Example:

DRN/xxxx = Durnan; no erosion

DRN/1xxx = Durnan, slightly eroded

Conduct site visit to assess risk/evidence of wind erosion

- Identify visual effects of past wind erosion events – blow banks, light colored knolls, etc.
- Check the depth of black topsoil to determine if erosion or deposition has occurred
- Identify any sandblasting of crops
- Estimate or measure crop residue cover

Method for measuring crop residue cover:

- Use any line, rope or tape that is equally divided into 100 parts at 6- or 12-inch (15- or 30-centimetre) spacings.
- Choose representative locations in the field.
- Stretch the line diagonally across the rows.
- Select a point on one edge of the line markings, and observe that point at each mark.
- Look straight down at that point. Do not count residue smaller than 1/8 inch (3 millimetres) diameter.
- Walk the entire length of the line. Count the total number of marks with residue under them. That count will be the per cent cover for the field.
- Repeat the procedure at least 5 times in different areas of the field and average the findings.

Figure 7.2
10% crop residue cover

Figure 7.3
35% crop residue cover

Figure 7.4
65% crop residue cover

Recommendations

a) Prevention:

- Maintain adequate crop residue cover (at least 35% cover just after seeding for most soils, and at least 65% cover for soils highly susceptible to soil erosion)
  - standing stubble is 1.6 times more effective at controlling wind erosion than flat stubble.
- Establish cover crops – these crops should be solid seeded at the appropriate time and seeding rate (Table 7.1).
- If it is not feasible to plant a cover crop on the entire field, plant on headlands (field perimeter), or on/beside the most susceptible areas.

Table 7.1. Cover crop establishment criteria

Cover Crop	Seeding Date	Seeding Rate (lb/ac)
Fall rye	August 15 – September 12	11-23
Small grain	August 15 – September 1	25-30
Millet	July 15 – August 15	10-15
Sweet clover	May 1 – 15	6-10
Alfalfa	May 1 – 15	6-8
Red clover	May 1 – 15	4-6

- annual barriers of corn or sunflowers should be planted perpendicular to prevailing spring winds to reduce wind erosion after erosion-susceptible crops are harvested.

Table 7.2. Annual barrier establishment criteria

Crop	Barrier width (ft)	Barrier spacing (ft)	Seeding date
Corn/ Sunflowers	5 – 12 (1.5-3.6 m)	60 (18 m)	Normal seeding date

Shelterbelts reduce wind velocity in the area behind the shelterbelt for a distance up to 30 times the height of the trees. Plant shelterbelts perpendicular to prevailing winds. If planting shelterbelts in the middle of a field is not feasible due to equipment access, consider planting shelterbelts on the north and west edges of the field perimeter to reduce the effects of prevailing winds. Contact Prairie Farm Rehabilitation Administration for more information on shelterbelt design and establishment.

b) Control of blowing soils:

- Emergency tillage of heavier textured soils roughens the land surface to reduce wind velocity and trap drifting soils; creates or brings to the surface aggregates or clods large enough to resist wind erosion.
- Additions of:
  a) crop residues (1700 to 2000 lb/ac (1910 to 2247 kg/ha) of cereal straw on highly erodible soils) – the straw may have to be wet or anchored to the soil by packing. Potential drawbacks include the introduction of weed seeds and the immobilization of nitrogen due to high C:N ratios in the straw (see Table 8.6).
  b) manure (solid or liquid) may be effective, but avoid excessive nutrient applications and nutrient losses to water sources via leaching and runoff;
  c) irrigation water – add enough to moisten topsoil to prevent movement (this is a short term fix only, and may not be feasible if water supplies are limited)

B. Water Erosion

Background

Water erosion is the detachment, movement and removal of soil from the land surface by precipitation leaving the landscape as runoff. It can occur naturally, without human intervention, or can be accelerated through human activities such as insufficient residue cover on soils prone to runoff.

Soil erodibility is affected by surface texture, organic matter content, size and shape of soil aggregates and the permeability of the least permeable horizon.

Susceptibility to soil erosion by texture:

clays or loams > sands

Susceptibility to soil erosion by structure:

single-grained (structureless) > crumbly or cloddy

Rainfall quantity, intensity and duration influence the extent of water erosion. Intense rainstorms of more than 1 inch per hour (2.5 centimetres per hour) exceed most soils' capacity to absorb water, creating runoff conditions which lead to water erosion on unprotected fields.

The degree of soil erosion is affected by slope length and steepness - doubling the length of a slope increases soil losses by 1.5 times; doubling the incline of a slope increases soil losses by 2.5 times

$$\% \text{ slope} = \frac{\text{rise}}{\text{run}} \times 100\%$$

Quick facts

- Maximum tolerable loss: 5 tons/acre/year (10 tonnes/hectare/year) = 0.03 inches (0.75 millimetres) thickness of topsoil on a well-developed soil.
- Pulse crops and potatoes usually do not leave enough residue on the surface to prevent erosion once these fields are cultivated – these crops are usually grown on the most erodible soil types.
- The most susceptible period for soil erosion by water is during spring snowmelt and May-June, after seeding but before canopy cover.
- Flat stubble is more effective at preventing water erosion than standing stubble.

Consult soils report to assess risk of water erosion

Look for:

- T subclasses in the agriculture capability rating for a given soil series or phase, indicating a slope limitation. The exception to this would be with sandy soils, or soils with an M (moisture) limitation. Water infiltrates faster than it can run off on coarse textured soils, reducing the risk of water erosion regardless of slope.
- agriculture capability subclass E (erosion limitation)
- "rapid surface runoff" in soil series description
- Slope phases on map: x**b**xx to x**h**xx. Note the second position in the denominator of the soil code refers to the slope phase.

  x = 0 - 0.5% (level)
  b = 0.5 - 2% (nearly level)
  c = 2 - 5% (very gently sloping)
  d = 5 - 9% (gently sloping)
  e = 9 - 15% (moderately sloping)
  f = 15 - 30% (strongly sloping)
  g = 30 - 45% (very strongly sloping)
  h = 45 - 70% (extremely sloping)

Example:

MXS/xxxx = Manitou; level slope
MXS/xbxx = Manitou, 0.5-2% slopes
MXS/xcxx = Manitou, >2-5% slopes
MXS/xdxx = Manitou, >5-9% slopes
MXS/xexx = Manitou, >9-15% slopes

Table 7.3. Using per cent slope to make management decisions to prevent soil erosion by water

% Slope	Description	Recommended Use	% Cover Required*
0-5%	Level to very gentle slopes	Annual and row crop production	35
>5-9 (“d” slope in soil survey reports)	Gentle slopes	Annual crop production	35-50
>9-15 (“e”)	Moderate slopes	Crop rotation: 2/3 forage production 1/3 annual crop production	50-70
>15-30 (“f”)	Steep slopes	Forage production	
> 30 (“g”)	Very steep slopes	Native production	

*Flat cereal residue required for effective erosion control

Conduct site visit to assess risk/evidence of water erosion

- Identify visual effects of past water erosion events – in-field channels, gullies, etc.
- Check the depth of black topsoil to determine if erosion or deposition has occurred.
- Estimate or measure crop residue cover

Recommendations

Crop management to minimize water erosion:

forages > cereals > row crops

Buffer strips of forages in sensitive areas may be appropriate.

- Establish grassed waterways with side slopes no more than 25% (1 unit rise to 4 units run); > 16 feet (4.8 metres) wide, > 6 inches (15 centimetres) deep.
- Manage riparian areas appropriately in order to minimize streambank erosion.
- Adopt conservation tillage practices (i.e. any tillage and planting system that leaves at least 30% of the soil surface covered by the previous year’s crop residue after planting).
- Consider the establishment of permanent cover – sensitive areas may be taken out of annual crop production for forage production, pasture production, or as a set aside for non-agricultural uses. It may be most beneficial to establish permanent cover on headlands or at points where soil and water are likely to exit the property.

C. Tillage Erosion

Background

Tillage erosion is the progressive downslope movement of soil by tillage causing soil loss on hilltops (knolls) and soil accumulation at the base of slopes (depressions). Tillage erosion is described in terms of erosivity and landscape erodibility. Large, aggressive tillage implements, operated at excessive depths and speeds are more erosive, with more passes resulting in more erosion. Landscapes that are very topographically complex (with many short, steep, diverging slopes) are more susceptible to tillage erosion.

Visual evidence of tillage erosion includes: loss of organic rich topsoil and exposure of subsoil at the summit of ridges and knolls; and undercutting of field boundaries, such as fence lines, on the downslope side and burial on the upslope side.

Tillage erosion has only recently been recognized as a form of soil erosion. Studies across North America and Europe have concluded that tillage erosion is the major cause of the severe soil loss and crop yield loss observed on hilltops.

The soil loss on hilltops resulting from tillage erosion reduces crop productivity and increases field variability. Rates of soil loss on these slope positions are often more than ten times what is considered to be tolerable for sustainable production. Consequently, yield losses associated with these areas are as high as 30 to 50%.

This type of erosion occurs subtly as compared to wind and water erosion and usually results in a redistribution of topsoil within the field (i.e. the net soil loss from the field is roughly zero, but the net loss in soil productivity on the knolls can be dramatic). This concept is reinforced from wheat yields in Idaho (Norris and Comis, 1982).

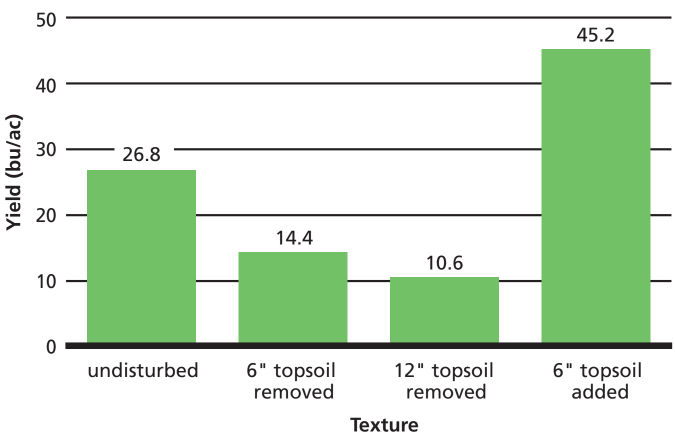


Figure 7.5. Effect of topsoil on wheat yields in Idaho

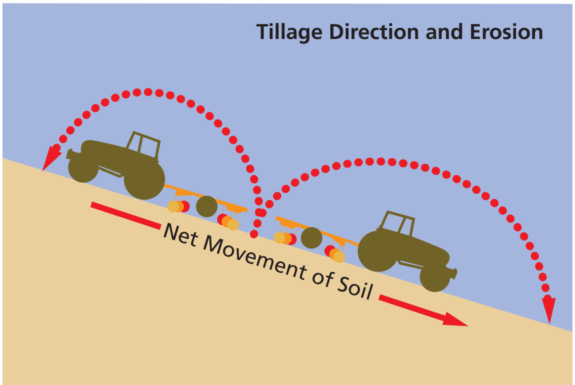


Figure 7.6. Movement of soil by tillage erosion

Quick facts

- Tillage erosion occurs only during tillage operations.
- All field operations that disturb the soil cause some tillage erosion, even operations such as seeding, row crop cultivation, root crop harvesting, manure injection, etc.
- The heavy duty cultivator moves 10 pounds of soil per foot width of tillage (15 kilograms of soil per metre) on level land, but moves 17 to 20 pounds (25 to 30 kilograms) when tilling down a 15 to 20% slope and less than 3.5 pounds (less than 5 kilograms) when tilling up that slope.
- Root crop harvesting can cause more tillage erosion than plowing.
- The majority of soil moved by tillage is only moved 6 to 12 inches (15 to 30 centimetres), but some soil will be dragged as far as 6 to 10 feet (2 to 3 metres) and greater distances when tilling down slope.
- The soil lost from hilltops by tillage erosion is not lost from the field; it simply accumulates at the bottom of the hills.
- The soil that accumulates at the bottom of the hills is not degraded by the erosion process.
- Tillage erosion moves soil down slope to areas where water erosion is most intense, so tillage erosion is linked to water contamination.
- Maximum tolerable loss: 5 tons/acre/year (10 tonnes/hectare/year) = 0.03 inches (0.75 millimetres) thickness of topsoil on a well-developed soil.

Figure 7.7.
An undisturbed landscape prior to the effects of tillage erosion

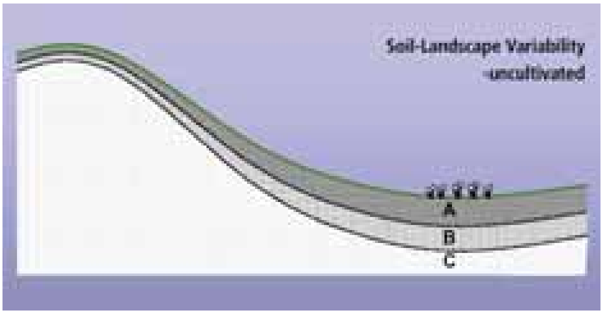


Figure 7.8.
A cultivated landscape showing the short-term effects of tillage erosion. Topsoil is being removed from the knolls and accumulating in the depressions.

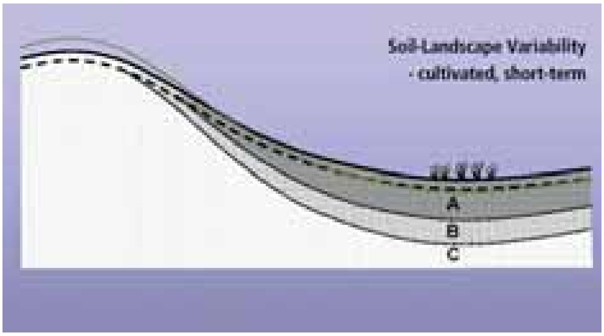


Figure 7.9.
Medium-term effects of tillage erosion, typical of many prairie landscapes in their current condition. Topsoil is almost completely removed from knolls and depressions have thick layers of topsoil due to accumulation. Yield variability across the landscape is significant.

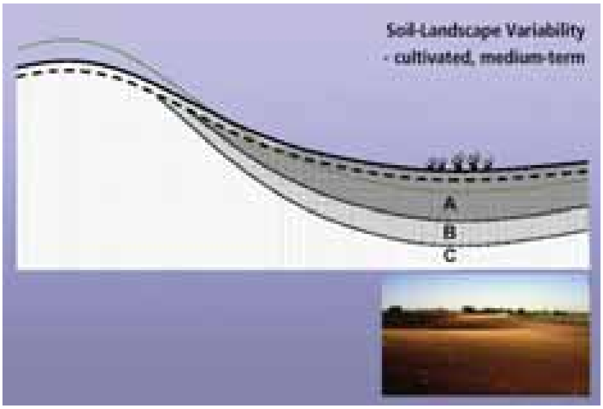


Figure 7.10. Landscape restoration – the practice of moving some of the accumulated topsoil from depressions back onto the knolls at a depth of 4 to 6 inches (10 to 15 centimetres) – is recommended to restore productivity to the knolls and reduce crop yield variability in the field.

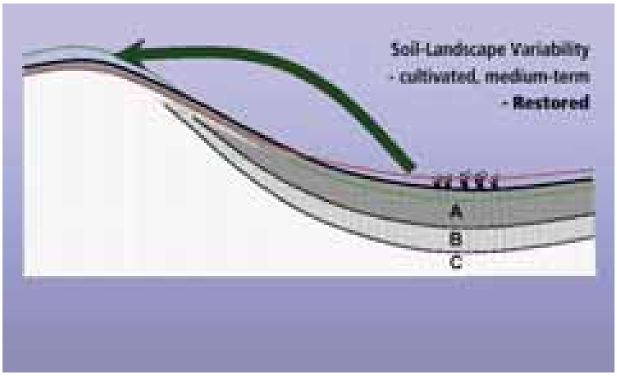
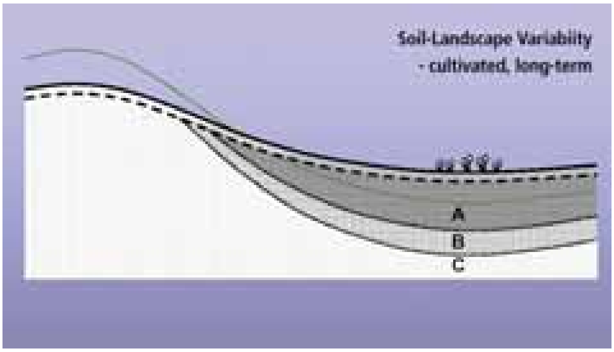


Figure 7.11. Long-term effects of tillage erosion. If allowed to continue, tillage erosion will move subsoil from the knolls onto the depressions, burying the topsoil and reducing yield productivity in these areas as well.



Consult soils report to identify areas prone to tillage erosion

Tillage erosion has only been recently recognized and, therefore, it is not clearly reflected in soils reports. However, there is information in these reports that does help in the identification of areas prone to tillage erosion as well as wind and water erosion.

- E subclass in the agriculture capability rating for a given soil series or phase, indicating an erosion limitation.
- T subclass in the agriculture capability rating for a given soil series or phase, indicating a slope limitation. Land with steep slopes will have greater rates of both water and tillage erosion.

- Eroded phases on maps: **1**xxx, **2**xxx, and **3**xxx often indicate soil loss by tillage erosion, particularly when those eroded phases appear on hilltops (see examples under wind and water erosion).
- Slope phases on maps: x**b**xx to x**h**xx (see examples under water erosion). Steeper slopes have greater rates of tillage erosion. As steepness of slope increases, the difference in the amount of soil moved down slope by downslope tillage and up slope by upslope tillage increases.

Site visit to identify areas prone to tillage erosion

- Land that is hilly is sensitive to tillage erosion. Fields with many small hills are more prone to tillage erosion than fields with a few large hills. Hummocky land is more sensitive to tillage erosion than undulating land and is much more sensitive than rolling land.
- Land that has shallow topsoil or has areas where topsoil is shallow, like hilltops, is most sensitive to any form of soil erosion.
- Even land that is considered to be flat can suffer from tillage erosion. Tillage erosion is probably the major cause for the infilling of surface drains in cultivated lands.

Recommendations to reduce tillage erosion

1. Reduce tillage frequency

All unnecessary tillage operations should be eliminated from a tillage system. Tillage should be done when soil conditions are suitable to avoid correctional tillage. If possible, a reduced- or zero-tillage system should be adopted.

2. Reduce tillage intensity

The depth and speed at which a tillage implement is operated affect its intensity and, therefore, its erosivity. Tillage implements should be operated at minimum recommended depths and speeds.

3. Reduce tillage speed and depth variability

Operators should try to maintain a constant tillage depth and tillage speed, even in hilly landscapes. Variability in tillage depth and speed contributes to tillage erosion.

To maintain constant operating depth and speed in hilly landscapes requires more power from a tractor than would be recommended for a specific tillage implement by an equipment manufacturer or dealer. Implements are rated for required horsepower assuming that they will be operated on level ground.

Operation in excess of recommended depth and speed results in greater variation in soil movement, and, consequently, results in greater tillage erosion.

4. Reduce the size of tillage implements

The larger the implement is relative to the size of the hills, the more rapid the landscape is leveled. Tillage implements which are very long and/or very wide should be avoided on landscapes which are highly susceptible to tillage erosion. Some large implements have flexible frames which allow them to conform to the shape of the landscape and, therefore, are less erosive.

5. Use contour tillage

Where possible, tillage should be conducted along the contour of the landscape. This will reduce the variation in tillage depth and speed and, consequently, reduce tillage erosion.

6. Use a reversible moldboard plow

Where tillage is conducted on the contour, a reversible/rollover/two-way moldboard plow can be used to throw the furrow upslope, leaving a back furrow on the uppermost slope position. This works against the progressive downslope movement of soil by other tillage implements (Foster, 1964).

The most effective way to arrest tillage erosion is to eliminate tillage; however, it is not always desirable to do so. Where tillage is used, there are practices which can be used to reduce tillage erosion. Improvements to tillage practices should be made immediately. Practices which require the purchase of equipment may or may not provide short-term economic benefits. Individual Beneficial Management Practices (BMPs) to reduce tillage erosion may or may not reduce soil loss to tolerable levels.

There are a few additional considerations regarding the reduction of tillage erosion:

- Where the soil degradation from tillage erosion is a problem and it is not possible to implement BMPs to reduce tillage erosion to a tolerable level, it may be advisable to take the land out of crop production which requires tillage.
- Where it is feasible, areas which are severely degraded by tillage erosion should be restored by returning the topsoil which has accumulated downslope and/or by applying amendments such as livestock manure. This should be followed by the implementation of BMPs to reduce tillage erosion.
- Field boundaries such as fences and terraces compound soil losses by tillage erosion and careful consideration should be given to their placement within the landscape.

Follow-up monitoring

- Measure tillage depth and the amount of surface area disturbed, taking particular note of depths during upslope tillage and downslope tillage. Keep records.
- Monitor the speed of all operations that disturb soil, taking particular note of speeds during upslope tillage and downslope tillage. Keep records.
- Conduct soil testing for organic matter and nutrient status. Compare results from hilltops to those from the back of hills and at the bottom of hills. Track changes over time.
- Use a crop yield monitor and maps to compare results from hilltops to those from the back of hills and at the bottom of hills. Track changes over time.

8

Tillage, Organic Matter and Crop Residue Management

A. Tillage

Defining Tillage Systems

There are two main types of tillage systems: conventional tillage and conservation tillage. ***Conventional tillage*** is a system that traditionally uses moldboard plows or chisel plows with sweeps, followed by disking, harrowing or other secondary tillage operations to incorporate residue, prepare a seedbed and control weeds. ***Conservation tillage*** systems, which include reduced tillage and zero tillage, produce benefits such as soil quality enhancement (increased soil organic matter levels over time), moisture conservation, erosion control, reduced use of fossil fuels and reduced labor requirement. Weed control in these systems may require increased use of herbicides. There are a variety of conservation tillage systems, as described below.

Reduced tillage systems involve the removal of one or more tillage operations to increase residue cover on the soil, reduce fuel costs and to use standing stubble to trap snow to increase soil moisture and permit the winter survival of winter wheat. Three examples of reduced tillage systems:

- ***Direct seeding*** is a type of reduced tillage where the only tillage operation occurs at seeding. Maximum surface residue is maintained until seeding, at which time high disturbance seed openers are used for seedbed preparation, residue management and weed control.

- ***Ridge till*** is a type of reduced tillage where row crops (such as corn) are planted on pre-formed ridges. During the planting operation, crop residues are cleared from the row area and moved to the furrow between rows. The planted rows are on a raised ridge 3 to 5 inches (7.6 to 12.7 centimetres) above furrows between rows. Ridge height is maintained with cultivation. Weeds are controlled with cultivation and/or herbicides.
- ***Minimum tillage*** is a type of reduced tillage that employs a reduction in one or more tillage operations from conventional practices (such as no fall tillage) and uses low disturbance seed openers.

Zero tillage (or no-till) is a type of cropping system in which crops are planted into previously undisturbed soil by opening a narrow slot of sufficient width and depth to obtain proper seedbed coverage. No tillage operation *for the purpose of weed control* is conducted, but this allows for tillage with low disturbance openers (knives, spikes, etc) for fall banding of fertilizer, filling in ruts, and the use of heavy harrows for crop residue management.

Zero tillage is often thought of as the "ultimate" in conservation tillage. The use of narrow, low disturbance openers (knives, discs) on the seeder results in minimal seedbed disturbance. All of the other tillage systems produce higher soil disturbance, either from wider, high disturbance openers (sweeps, spoons) or from the inclusion of a tillage operation for the purpose of weed control.

Regardless of the type of conservation tillage system, all will result in lower seedbed disturbance/fewer passes than in a conventional tillage system.

Table 8.1. Comparisons of various tillage systems*.

Tillage System			Fall Tillage	Spring Tillage	Soil Disturbance	
					Seed openers	Overall System
Conventional tillage			Yes	Yes	Low or High	High
Conservation tillage	Reduced Tillage	Direct seeding	No	No	High	Moderate
		Ridge tillage	Yes	No	Ridge planters	Moderate
		Minimum tillage	Spring OR Fall		Low	Moderate
	Zero tillage		No	No	Low	Low

*Adapted from Definition and Verification of Tillage Systems Used for Pilot Emissions Reductions, Removals and Learnings Initiative (PERRL), 2004 Draft.

Low disturbance openers are narrow openers such as knives, narrow spoons, narrow hoes and slightly offset discs (not including a discer). The openers should not disturb more than 33% of the soil surface area (eg. If the opener row spacing is 9 inches (22.9 centimetres), then the width of disturbance created by a single opener should not exceed 3 inches (7.6 centimetres).

High disturbance openers are medium and wide openers, such as wide hoes, narrow sweeps or shovels, wide spoons, wide shovels and discers. These openers disturb more than 33% of the soil surface.

For more information refer to the *Zero Tillage Production Manual* and *Advancing the Art* by the Manitoba-North Dakota Zero Tillage Farmers Association.

B. Organic Matter Depletion

Organic matter is an important component of soil that supplies plants with nutrients, holds soil particles together to prevent erosion, and improves soil tilth, which refers to the degree to which the soil is aggregated together and suitable for agriculture. Organic matter also improves water infiltration and water-holding capacity while controlling the decomposition and movement of some pesticides. Biological processes of plant growth and human activities, such as tillage, have affected the present state of soil organic matter.

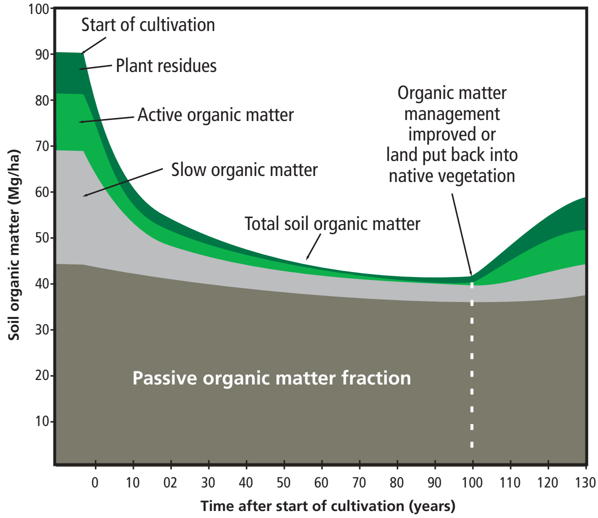


Figure 8.1. Trends in soil organic matter content (Brady, 1999)

Typically, soils in agro-Manitoba range from 2 to 7% organic matter. These lands in a native state, prior to settlement and cultivation, had organic matter levels in the range of 10 to 15%. For the first 25 to 50 years, little to no commercial fertilizer was added to the soil because the nutrients released in the decomposing organic matter were ample to grow a crop. The decomposing organic matter resulted in depleting soil organic matter levels. The rate of depletion has now leveled off and organic matter levels are relatively stable, but fertilizers are invariably required most years on agricultural soils to provide sufficient nutrients to grow a crop.

The trend in organic matter depletion is variable and site specific. Practices such as conservation tillage, forages in the crop rotation, and the addition of crop residues and livestock manure can maintain or increase soil organic matter content over time. However, row crop and special crop production, such as potatoes and edible beans, results in more tillage, less plant residue produced by crops and less residue returned. This may deplete soil organic matter levels.

Soils with increased organic matter have desirable structure that tends to crumble and break apart easily and is more suitable for crop growth than hard, cloddy structure.

Consult soils report

It is important to ask the following questions when considering adoption of any conservation tillage practices:

- What are the texture and drainage of the soils at the site in question?
- What are main agriculture capability limitations?
- What soil conservation practice(s) would most likely benefit the soil type in question?

Agriculture capability ratings from the soils report have implications for which, if any, conservation tillage practice should be adopted.

Table 8.2. Agriculture capability limitations and implications for conservation tillage practices

Ag Cap	Effect of tillage
E	Tillage increases susceptibility of soil to all types of erosion
M	These are typically sandy soils that would benefit from conservation tillage
N	Salt affected soils are worsened by tillage as salts are brought to the surface
T	Tillage on slopes results in tillage erosion and increases the risk of water erosion

Site Assessment

- Determine the equipment used for: primary tillage, secondary tillage, seeding, spraying, harvesting, chaff and straw management
- Determine crop residue cover
- Earthworm populations are an indicator of soil quality. Earthworms generally increase soil microbial activity, increase soil chemical fertility and enhance soil physical properties. About 10 earthworms per square foot (100 per square metre) of soil is generally considered a good population in agricultural systems (Soil Quality Test Kit Guide, 1998).

Recommendations

1. Adopt some form of conservation tillage.
2. Consider chaff and straw management equipment options (contact Prairie Agricultural Machinery Institute for individual equipment assessment). Keep in mind that standing stubble is 1.6 times more effective at controlling wind erosion than flat stubble.
3. Tillage can easily dry out the soil profile (eg. 1 tillage pass removes 0.5 inches (12.7 millimetres) of water) and increase the risk of wind erosion. Tillage when soils are too wet can result in soil compaction.
4. Moving 4 to 6 inches (10 to 15 centimetres) of topsoil upslope from the lower areas of the field and placing it back onto the eroded knolls (*landscape restoration*) has restored yield potential to affected portions of fields that could not be achieved by simply adopting zero tillage techniques (Dr. David Lobb, Department of Soil Science, University of Manitoba, personal communication).

Follow-up monitoring

- Keep records of crop yields
- Soil test for organic matter, nutrient status, etc.
- Measure earthworm populations. Earthworm populations are patchy within a field and vary with time of year. Count earthworms in spring and fall and use the averages to gauge changes from year to year *(Soil Quality Test Kit Guide, 1998)*.
  - i) Measure a square foot and dig down 12 inches (30.5 centimetres) with a shovel or trowel, minimizing the number of cuts to avoid damage to the earthworms. Dig the hole first, then sort for earthworms. Make sure the bottom of the hole is level.
  - ii) Sort the samples against a pale-colored background to help locate the earthworms. Separate and count the number of earthworms.
  - iii) To extract deep burrowing earthworms, add 2 L of mustard solution (2 tbsp. mustard powder + 2 L tap water) to the hole. Deep burrowing earthworms should appear within 5 minutes. Count the number of worms.

iv) Record total number of earthworms found at the inspection site. Rinse earthworms in clean tap water and return to hole.

v) Repeat.

C. Crop Residue Management

Depending on the climatic conditions and soil type, the amount of crop residue produced may vary from place to place and over time. In times of drought and on soils prone to erosion, maximizing the amount of crop residue produced is beneficial. In wet years and on heavy clays, large amounts of crop residue can be difficult to incorporate and results in cold, wet soils in the spring. As a result, many producers resort to burning the crop residue, but this destroys soil organic matter, removes nutrients and causes problems from the smoke generated. On these soils, producing less crop residues is preferred.

The following management practices should be considered.

Spring:

- Cereal variety selection – straw height and lodging rating should be considered. Refer to *Seed Manitoba* crop variety data for more information.
- Soil test for N (0 to 24 inches (0 to 60 centimetres)) – excessive amounts of nitrogen produces higher vegetative growth and increases the susceptibility to lodging. Follow recommendations based on reasonable and attainable target yields – refer to the *Soil Fertility Guide* for more information.
- Earlier seeding usually results in shorter straw.

Table 8.3. Estimating straw yield from grain yield of selected crops

Grain	Pounds of straw per bushel of grain
Wheat	100
Barley	48
Flax	70
Canola	110
Peas	100

(e.g. A 40 bu/ac (2700 kg/ha) wheat crop produces approximately 4000 lb/ac (4500 kg/ha) of straw.)

Summer:

Harvest Options

- The amount of crop entering the combine depends on harvest method, each of which has its benefits and drawbacks:
  - *swathed wheat crop*: 85% straw, 15% chaff entering combine
  - *straight-cut wheat crop*: 70% straw, 30% chaff entering combine
  - *stripper header*: even less residue entering combine than the above methods, resulting in faster harvesting time, but a separate pass may be required to manage the straw, along with challenges of straw flattened by equipment traffic
- Ensure optimum combine straw chopper performance
- Keep knives sharp - if possible, avoid harvesting a crop when straw is wet because it requires more power to chop and does a poorer job of chopping straw into short pieces
- Set fins for maximum spread – spreading straw 70% of the width of cut is recommended (eg. In a 30 foot (9 metre) swath, spread straw 21 to 24 feet (6 to 7 metres))
- Consider upgrading to a "fine cut" chopper – finely chopped straw requires 30 to 40 hp from the combine
- Consider opportunities for baled straw:
  - livestock bedding and feed
  - composting ingredient
  - alternate uses (heating fuel, erosion control, building material, etc.)
  - Manitoba Agriculture, Food and Rural Initiatives has a free hay listing service where producers submit hay and straw they have available for posting on the internet. Those looking for hay or straw can search the database and contact the producer directly. web2.gov.mb.ca/agriculture/haysearch/index.php
- Crop reside burning should be avoided using other management practices, such as those listed above. However, if you must burn, crop residue burning daily authorizations begin August 1 – consult Manitoba Agriculture, Food and Rural Initiatives' website: manitoba.ca/agriculture/news/burn/index.html

  Daily authorizations are also sent to radio stations, RCMP detachments and to the offices of Manitoba Agriculture, Food and Rural Initiatives, Manitoba Conservation and Manitoba Health throughout agro-Manitoba by 11:00 am.

Fall:

- Fall-applied liquid hog manure, at agronomic application rates, may increase the decomposition rate of crop residues (MacLeod et al, 2002)
  - Stubble height after harvest should be similar to the shank spacing of the equipment used for the next field operation (fall or following spring).
  - Heavy harrows should be set for maximum tine angle (as vertical as possible) without causing bunching.
  - Tillage options are presented in Table 8.4.

Table 8.4. Amount of straw buried per pass of selected tillage implements

Implement	Amount of straw buried per pass (%)
Heavy harrows (steel tooth, >12")	5
Wide blade cultivator (sweeps > 3 ft)	10
Heavy duty cultivator (sweeps 8-12")	20
One-way disc	40-50
Heavy tandem or offset discs	40-60
Moldboard plow	90-100

Table 8.5. Cost of fuel and equipment per fall tillage pass (Farm Machinery Rental and Custom Rate Guide, 2001)

Equipment	Cost
300 hp 4WD tractor	$2.05 – 2.45/ac
Fuel	$0.95 – 1.23/ac
Heavy duty cultivator	$1.05 – 1.30/ac
Total	**$4.05 - 4.98/ac**

Note: Residue management may differ for winter wheat survival. For winter wheat to survive the winter, an adequate layer of snow cover is required to keep the crop insulated.

Snow Trapping Potential (STP)

"The most successful way to maintain adequate snow cover is to retain the greatest possible height and density of standing stubble. Harvest the preceding spring crop as high as possible and thoroughly spread the harvested straw and chaff. Special attention must be paid to maintaining standing stubble in high traffic areas such as field approaches and headlands. Use the snow trapping potential index to measure your snow trapping potential:

$$\textbf{STP = [stubble height (cm)} \times \textbf{stubble stems per m}^2\textbf{]/100}$$

A snow trapping potential index greater than 20 is acceptable; less than 20 indicates a high risk of winter injury, particularly for winter wheat and triticale. Based on the stubble disturbance of your seeding equipment, you may need to set pre-seed STP targets of 40 or more. For reference, cereal stubble typically has pre-seed STP's of 80 or higher, while canola and flax are normally in the range of 30-50, depending on stubble height."

(Winter Cereals Canada, Winter Cereal Production Reference Guide).

If You Must Burn

- Account for nutrient losses from burning straw. Straw that is removed by baling transfers the nutrients in straw for use in another area – straw removed by burning removes nutrients from the field with no subsequent economic benefit and destroys organic matter from intense heating. This emphasizes the need to maximize the use of straw in the field or at least recognize the economic value of straw in terms of its nutrient content.
- Drop straw in tight, narrow swaths for burning.
- Use fire-guards - consider tillage in between swaths or burning in moist conditions to avoid burning the entire field.
- Follow daily crop residue burning authorizations, **which are based on suitability of weather conditions for smoke dispersion.**
- Fires must be supervised at all times.
- Consider wind speed and direction before burning.
- Consider the health and safety of neighbours and nearby traffic before burning.

Table 8.6. Nutrient content in pounds per tonne of straw and resulting ash (Heard et al, 2001)

Crop	Nutrient	lb/t of straw		
		Straw	Ash	% lost
Wheat (assumed Yield = 1 t/ac)	C	911	85	91%
	N	24	0.4	98%
	P	3	2.6	18%
	K	32	26	24%
	S	2.4	0.8	70%
	Ca	4.4	3	30%
	Mg	2.3	1.7	27%
Oats (assumed Yield = 1 t/ac)	C	918	34	96%
	N	11	0.14	98%
	P	1.7	1.4	17%
	K	52	33	37%
	S	4.9	2.4	72%
	Ca	4.6	3	33%
	Mg	3.8	2.7	31%
Flax (assumed Yield = 0.5 t/ac)	C	1003	31	97%
	N	31	0.06	99%
	P	1.5	1	36%
	K	5.2	2.9	44%
	S	1.2	0.15	82%
	Ca	10.3	6.7	34%
	Mg	3	1.9	36%

From the above table, the C:N ratios for crop residues are 38:1 for wheat, 83:1 for oats and 32:1 for flax. All three crop residues have high C:N ratios which favour immobilization of soil N as the straw is decomposed by soil microbes.

Winter:

Crop Residue Burning authorizations cease on Nov. 15. From Nov. 16 to July 31, burning of crop residues may proceed between sunrise and sunset, subject to health and safety considerations. **Nighttime burning of crop residues is banned year-round.**

Spring (Year 2):

The following issues must be considered when seeding into high residue conditions:

- **Plugging** – match stubble height to the shank spacing of the equipment used for the **next** field operation (fall or following spring) to reduce the risk of equipment plugging with straw. Coulters and disc openers are less likely to plug than hoe openers, and knives are less likely to plug than sweeps, but less plugging also means less soil disturbance and cooler spring soil temperatures.
- **Soil temperature** – cooler soil temperatures may result in delayed emergence and increased risk of frost injury; however, this may not impact crop yield.
- **Moisture** – higher soil moisture may result in improved seeding conditions in a dry spring, but delayed seeding, plugging problems and increased compaction may occur in a wet spring.
- **Disease potential** – there is no evidence that burning straw reduces the incidence of crop diseases. Crop rotations and environmental conditions are the major factors determining disease pressures.

9

Soil Compaction

Background

Figure 9.1. Evidence of compaction from equipment traffic

Soil compaction is the squeezing together of soil particles, reducing the space available for air and water. Compaction increases the density of the soil, which hampers infiltration of water, soil air movement, seedling emergence, root growth and ultimately reduces yield. Soil aeration is likely to become limiting to plant growth when air-filled porosity in the soil falls below 10%.

There are two types of soil compaction: natural and human-induced. In Manitoba, naturally compacted soils contain extremely high levels of carbonates (>40%) or high levels of sodium, with bulk densities greater than 1.8 g/cm^3 (these are the soils designated with a D limitation in their agriculture capability rating). Human-induced soil compaction is usually caused in two ways: by excessive tillage and untimely field operations on wet soils (*tillage induced*), or by wheel tracking in intensive cropping systems (*traffic induced*). Under favorable conditions, winter freezing and thawing of the soil can correct human-induced compaction problems up to a depth of 2 to 3 feet (60 to 90 centimetres).

Most compaction caused by wheel traffic occurs to a depth of 1 to 3 feet (30 to 90 cm) on the first pass over a field. The first pass accounts for up to 80% of the compaction that four passes would cause on the same spot.

Soils most susceptible to compaction:

- moist (nearing field capacity) – Moist soils are more susceptible to compaction than saturated soils because saturated soils have their pores completely filled with water. Since water cannot be compacted and fields are usually not accessible when saturated, compaction is usually less of a problem than when soils are moist.
- low organic matter and low crop residue – Organic matter helps soil particles resist compaction.
- poor soil structure – Eroded soils with massive soil structure are more likely to be compacted than soils with blocky structure.

Figure 9.2. Ruts caused by field traffic

Moderate surface compaction sometimes increases yield on lighter textured soils with limiting water holding capacity under dry conditions (less than 12 inches or 300 millimetres of rainfall). The opposite is true of clay soils under wet conditions (more than 16 inches or 400 milllimetres of rainfall).

Consult the soils report to assess compaction

- Check soil texture - compaction is influenced by soil texture and moisture status. Compaction is often more difficult to manage on heavier textured soils.
- Check agriculture capability - soils with a D limitation indicate existing compaction, high density or structure problems.
- In addition to the soils report, check recent aerial photos for wheel track patterns.

Conduct a site visit to assess compaction

- The following weeds may be indicators of compaction: silverweed, tansy, plantains, pineappleweed, camomiles, horsenettle, morning-glory, field bindweed, field mustard, stinkweed and quackgrass.
- Identify and confirm compaction problems with a soil penetrometer, shovel and inspection of plant roots.
- Impacts of limited plant root growth can be identified as roots begin to grow horizontal instead of vertical; limited root growth can be the result of poor water infiltration, poor aeration, presence of a hardpan, etc.
- For an accurate measure of compaction, collect bulk density cores (pp. 363-367, in *Methods of Soil Analysis, Part 1* (2nd edition)) from the area in question and compare to "normal" areas of the field. Some typical bulk densities for various soil textures are found in Table 9.1.
- Bulk density (BD) calculation:

  BD = wt of oven-dry soil (g)/volume of soil core (cm^3)

Table 9.1. Typical bulk densities for various soil series

Soil Series	**Bulk Density (g/cm^3)** 0-6" depth (0-15 cm)
Stockton fine sand	1.34
Newdale clay loam	1.26
Red River heavy clay	1.07
Most rocks	2.65
Compacted soil	1.80

Recommendations to prevent and correct soil compaction

Healthy plants will be better able to compensate for the stress caused by soil compaction.

Prevention:

- Do not overballast a tractor.
- Run tires at rated pressures (7 to 10 psi (48 to 69 kPa) for radials; no less than 14 psi (97 kPa) for bias ply tires); do not exceed recommended loads for tires; wheel slippage under load should be 10 to 15% for 2-wheel-drive tractors and 8 to 12% for 4-wheel-drive tractors.
- Use duals, triples or larger tires to lower tire pressure - overall, properly inflated radial tires give the best overall performance and value in terms of traction, flotation, efficiency and costs.
- Wheel tractors cause more soil compaction than track-type tractors when tire pressure is high (24 psi or 166 kPa) but wheels cause less soil compaction than tracks when tire pressure is low (7 psi or 48 kPa).
- Soil packing pressure on seeding equipment should be kept to a minimum (approx. 75 pounds (34 kilograms) per wheel) for optimum crop establishment under direct seeding systems. Packing improves stand establishment under dry conditions, but may impede crop emergence under wet conditions. However, this does not necessarily translate into yield differences that are significant to producers (PAMI, Research Update #749).

Correction:

There are two extremely different approaches to dealing with soil compaction:

a) *develop a system to mitigate compaction* - use alfalfa, sunflowers or other deep rooted crops with taproot systems to penetrate hardpan and dry out soil; minimize the number of tillage passes across the field; minimize the area compacted by equipment traffic on the field (tramlines, common tracks, etc.); use manure to improve soil structure and organic matter levels.

b) *treat compaction using deep ripping/subsoiling* - use tillage equipment capable of penetrating beyond depth of soil hardpan; do not use this method when soils are moist/wet; do not use if deep tillage will bring salts, rocks and carbonates to the soil surface that may negatively impact crop production.

- Deep ripping may be most effective on headlands (headlands often get tracked four to five times per tillage operation).

Figure 9.3.
A subsoiler/deep ripper

Follow-up monitoring

- Keep records of tillage operations, such as number of passes, depth, and direction. View aerial photos to see any track patterns in the field.
- Keep records of precipitation and soil moisture content.
- Examine crop rooting patterns.
- Keep records of crop yields.

References:

- PAMI, Research Update #749
- *Methods of Soil Analysis, Part 1* (2nd edition)
- Organic Gardening Staff, 1978
- PAMI report #726
- PAMI report #742
- Hofman, 2001

10

Soils Information for Planning Purposes

Introduction

Soils information can be used for a variety of planning purposes including land use planning, environmental farm planning and watershed management planning. All of these planning processes attract a range of stakeholders that are interested in the activities that take place in their communities. Often there are a number of land uses, including agriculture, industry, residential areas and recreation that compete for a limited land base.

In Manitoba, land use planning is principally a local process, where local people and their representatives make decisions about allocating land, providing appropriate services, promoting a good quality of life for residents, ensuring orderly development and the prudent use of natural resources. To ensure that development occurs in ways that are compatible with the environment and adjacent land uses, municipal development plans and by-laws are often developed. The intent of these is to designate and protect land for certain purposes in order to promote development, avoid land use conflicts, protect property values, provide efficient servicing, promote healthy and safe living environment and protect natural resources.

The Environmental Farm Plan (EFP) is a voluntary process in Manitoba that producers can participate in to assess environmental risks and benefits associated with their land base and management practices. The first step of the EFP is to evaluate the farm's land assets and to identify any sensitive areas within the land base. Once these areas are identified, any risks to the environment associated with their management, is determined. Finally, an action plan is developed that addresses the environmental risks in a manner that makes a field or the whole farm more productive and cost-efficient.

Watershed management planning is also gaining popularity in Manitoba. A watershed management plan is the prescribed use of a watershed in accordance with predetermined objectives. A watershed is an area of land that sheds water to a common point or the area of land drained by a given watercourse. It does not follow political boundaries and can include multiple municipalities and cross international borders. Therefore, watershed management planning often has the extra challenge of involving multiple agencies having responsibility for various activities in the watershed. Normally, all stakeholders located within the watershed are invited to participate in their watershed management plan.

A. Land Use Planning

The ultimate authority to regulate land use in Manitoba is vested with municipalities. In accordance with *The Planning Act*, municipalities may enact development plans and zoning by-laws to plan for and regulate land use and the location and operation of developments. The Provincial Land Use Policies are adopted as a Regulation (184/94) under *The Planning Act* and outline the broader provincial and public interests in land use and are used as a guide for municipalities when creating their land use plans. The Provincial Land Use Policies Regulation encompasses development policies in nine broad policy areas (including agriculture).

Manitoba Agriculture, Food and Rural Initiatives is just one stakeholder in land use planning. From a provincial standpoint, there is a need to protect our food production potential and the role of agriculture in the local, provincial and national economy. Agriculture depends upon productive soil and therefore, it makes long-term economic and environmental sense for land use plans to encourage the protection of both prime agricultural lands and viable lower class lands that are used for agriculture and the conservation of soil. In order to do this, reliable detailed soil survey information is used in order to determine the agricultural capability of the soil in an area. Prime *agricultural lands* are defined as land composed of mineral soil to be of dryland agricultural capability class 1, 2 or 3 and includes a land unit of one quarter section or more, or a river lot, 60% or more of which is comprised of land of dryland agricultural capability class 1, 2 or 3. The province and local governments have recognized that prime agricultural lands need to be protected for food production, agricultural diversification, and value-added opportunities by minimizing the subdivision and wasteful use of this land and protecting farms from encroachment and disturbance by other land uses which may be incompatible with normal farming operations.

Dependable Agricultural Land

Source: Environment Canada 1982, Lands Directorate, CGIS Database.

Statistics Canada 1999, Environment Accounts and Statistics Division, Environmental Information System (EIS) Database.

> **“Comprehensive regional planning with soils maps is essential to allocate soil resources for the future. Urban sprawl not only occupies the best soils, but also creates pressures on other soils that have severe limitations. Thus… comprehensive community planning, with detailed soils maps of large areas, will help to prevent some of the land abuse of the past. The future must be given higher priority than it has been given in the past, if peace, progress and prosperity is to be achieved.”**
>
> **(Olson, 1984, p.140)**

For more information on land use planning and land use policies, contact the Land Use Planning Branch in Manitoba Agriculture, Food and Rural Initiatives.

B. The Environmental Farm Plan

As agricultural producers strive to increase efficiency on their farms, there is also mounting pressure on producers to ensure the environment is being protected. In any given farm operation, “sensitive areas” may exist that present an increased risk to surface or groundwater through leaching, runoff and/or erosion. These areas often also provide inconsistent or continuously poor yields and lower economic returns. Therefore, it makes both environmental and agronomic sense that they should be managed differently from the more productive areas of the farm.

Producers that complete an Environmental Farm Plan (EFP) do a self-assessment of their farm in order to identify sensitive areas and natural risks. They use this assessment to prepare an action plan to address those risks. The identification of sensitive areas and natural risks provides the farm managers (whether it is the producer, landowner, agronomist or custom applicator) with additional information that they can use to voluntarily adjust their management practices in a manner that makes economic sense and minimizes any impacts on the quality of soil, water, air or biodiversity. The EFP process demonstrates how the agriculture industry is finding solutions to managing environmental risks without the onus of regulation.

Section A of the EFP uses aerial photographs, published soils information as well as the producer’s knowledge of the land to identify the sensitive areas on the farm. Once identified, sensitive areas can be managed separately to improve their productivity and minimize any impacts on water quality. Soil sampling and crop scouting these areas separately from the rest of the field prevents biasing composite sampling procedures meant to represent the majority or “average” portions of the field, and allows for the determination of the yield-limiting factors in the sensitive areas and their appropriate management.

By combining various sources of information (such as aerial photographs, cropping history, yield records, yield maps and soils maps) with the producers' experience and agronomic knowledge, the EFP makes it possible for producers to conduct a thorough assessment of the type, location, extent and severity of limitations on their farms.

Recommendations

1. Evaluate your farmstead for the potential risks of runoff and leaching.
2. Examine aerial photos of your fields and identify any sensitive areas.
3. Use the agriculture capability table (Table 2.2) and your experience to assess the type and severity of the limitations in each field.
4. Based on what you know about your fields, consult soil survey reports to confirm or re-assess your lands.
5. Fill out the summary chart (Table 10.1) to record field information for your farm. Keep this information available as you complete the other worksheets.
6. Use this information to help you choose agronomic practices that will decrease the potential for environmental degradation.
7. Consult the appropriate agricultural extension specialist for additional information and support.

Table 10.1. Compilation of field assessments and risks using agriculture capability codes

Lower Risk (1) = No risks or only stoniness (P) identified. Stoniness is an agronomic limitation but presents little or no risk to the environment.

Higher Risk (4) = Some risks identified – R (bedrock), M (sand or gravel), T (slope), I (flooding), W (wetness including clayey soils with improved drainage), N (salinity) or E (erosion)

Field Information			Environmental Risks								Agronomic Limitations		Little or No Limitations
			Leaching		Runoff			Soil Degradation					
Current Land Use or Legal Land Description	Field Grouping	Size (acres)	Bedrock (R)	Sandy/ Gravelly (M)	Slope (T)*	Flooding (I)	Wetness (W) (including clay soils**)	Water Erosion (E)	Wind Erosion (E)	Salinity (N)	Stones (P)	Other (e.g. peat)	Lower
			Higher	Higher	Higher	Higher	Higher	Higher	Higher	Higher	Lower		
Risk Rating			Higher	Higher	Higher	Higher	Higher	Higher	Higher	Higher	Lower		Lower
Total Acres (by category)													
% of Total Acres													

* Sloping lands increase the risk to the environment from runoff. The exception to this is sandy/gravelly soils because water can infiltrate these soils before runoff occurs.

** Heavy clay soils with improved surface drainage present a risk to the environment from runoff. Although some of these soils are our most productive agricultural soils, they would be bumped from the green (little or no limitations) column to the blue (runoff risk).

*** Should there be more than one risk factor on the same acreage, it should be noted (i.e. slope and stones). Therefore, total acres may not equal farme acres.

C. Integrated Watershed Management Planning

Community-based watershed management is a process for managing water resources that involves engaging stakeholders in making and implementing management decisions that are sustainable and appropriate for local conditions. In Manitoba, *The Water Protection Act* specifies the basic content of an integrated watershed management plan including the requirement for consultation with various parties through a local watershed authority. Through this process, agricultural producers are working together with other local stakeholders to develop strategies to protect and enhance the quality of water within their watershed with positive impacts downstream.

Local knowledge, combined with technical information from provincial and federal government departments and other agencies, is considered throughout the planning process. Information related to the study area is first compiled into a state of the watershed report (a resource inventory). It often includes soils information such as soil texture, agriculture capability and areas prone to wind and water erosion. This inventory is then used to identify areas where improvements could be made through a change in management practices.

Community consultations occur at various times during the planning process in several communities throughout the watershed. At these meetings, additional information is sought from the public on watershed resource issues and on the proposed watershed management plan.

The integrated watershed management plan addresses how implementation will occur and provides a mechanism to measure future progress on meeting resource goals and objectives. The plan allows the watershed authority to set programming agendas and direct annual funding to watershed priorities. The watershed management plan must also be considered in the municipal development plan in order to avoid potential conflicts with existing or future development in the watershed.

An integrated watershed management plan helps to ensure that the resources in the watershed are managed in a sustainable manner. The input and support of local stakeholders results in solutions that are customized to the area and are therefore more likely to be implemented because of the community support received.

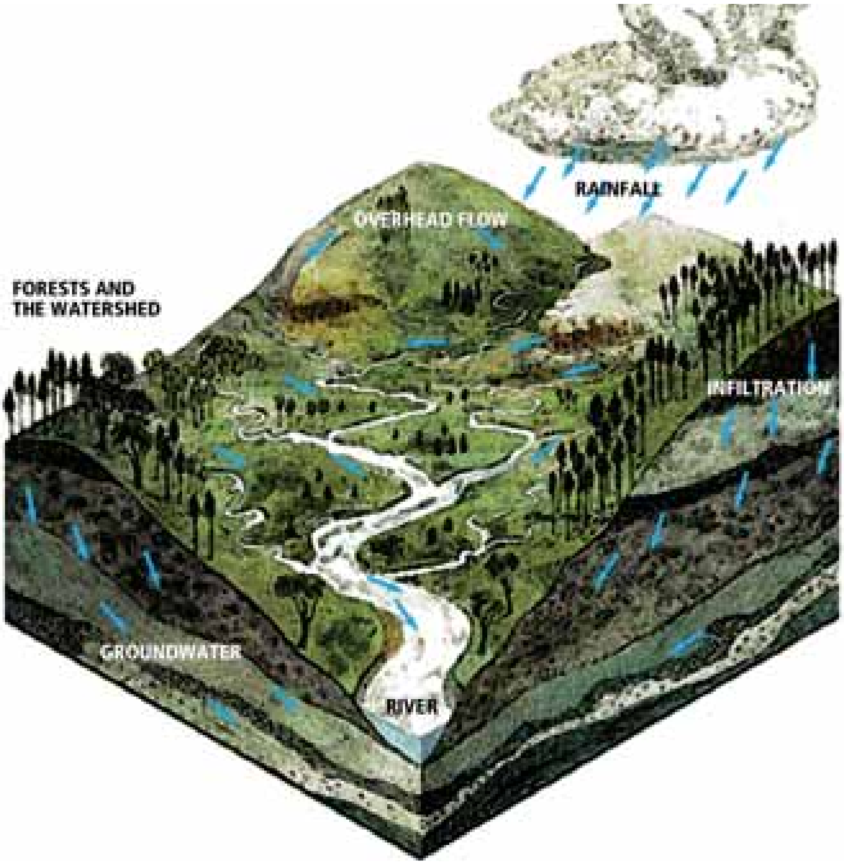


Figure 10.1.
Example of a watershed

11

Greenhouses Gases in Agriculture

What is climate change?

The term "climate change" is commonly used interchangeably with "global warming" and "the greenhouse effect", but is a more descriptive term. Climate change refers to the buildup of man-made gases in the atmosphere that trap the sun's heat, causing changes in weather patterns on a global scale. The effects include changes in rainfall patterns, sea level rise, potential droughts, habitat loss and heat stress. (National Safety Council, Environmental Health Centre Glossary, www.nsc.org/ehc/glossary.htm#c.)

Predicted changes for agriculture in Manitoba due to climate change include (Province of Manitoba, manitoba.ca/est/climate/affect_mb/index):

- More frost-free days would yield a longer growing season, lessen cold stress and reduce winterkill and open up opportunities for new crops. On the other hand, crops could be exposed to more damaging winter thaws, while warmer winter temperatures could decrease the amount of protective snow cover.
- Drought and flooding caused by climate change could increase soil erosion due to wind and water. Loss of protective snow cover would increase the exposure of soils to wind erosion during the winter, while more frequent freeze-thaw cycles could also increase soil erosion.
- Warmer temperatures could lead to increased crop damage from heat stress, as well as an improved breeding environment for a variety of weeds, insects and pests. Droughts, floods and storms could affect the reliability of water for irrigation.
- There would be an increased likelihood of severe drought and increased aridity in semiarid zones of Manitoba.
- Drought, heat waves and the increased frequency of extreme weather events (such as hurricanes, blizzards and ice storms) would affect livestock operations.

The most significant anthropogenic greenhouse gases (GHGs) are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Although these gases are found naturally in the atmosphere, it is their accelerated increase in concentration due to human activities, most notably burning fossil fuels, that is the concern. Carbon dioxide is the most common GHG but it is not the most potent: CH_4 and N_2O have 23 and 296 times the global warming potential of CO_2, respectively (IPCC, 2001).

What are the agricultural contributions to climate change?

Farming activities in Manitoba, excluding the burning of fossil fuels for heating homes and operating machinery, accounted for about 30% of Manitoba's total GHG emissions in 2005 (Figure 11.1). This is second only to the GHG emissions arising from the transportation sector. From 1990 to 2005, agriculture-related emissions increased by 36%.

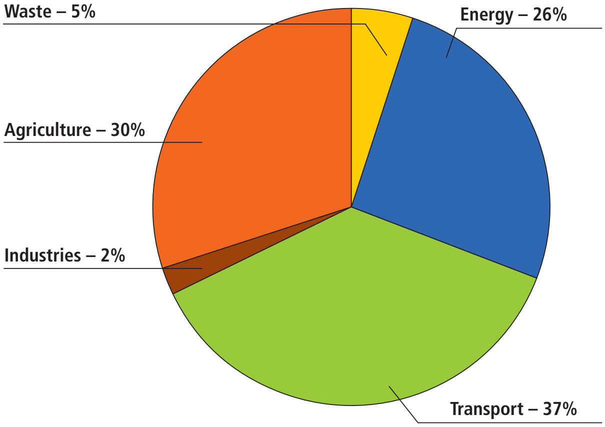


Figure 11.1 2005 greenhouse gas emissions in Manitoba by sector (Environment Canada, 2007).

Agriculture produces CO_2, CH_4 and N_2O. While CO_2 is the primary gas emitted by most other industries, the primary greenhouse gases emitted by agriculture are CH_4 and N_2O. Table 11.1 provides a breakdown of GHGs emitted by agriculture and their sources and causes. It includes home heating and farm machinery as sources of CO_2 emissions from fossil fuel burning, *although when governments quantify the contributions from agriculture, the gases from these processes are often considered separately.* It does not include CO_2 produced in the manufacture of nitrogen (N) fertilizers, which is a significant source of GHG.

On-farm CO_2 comes from burning fossil fuels to heat homes and run farm machinery, decomposition of organic matter from intensive tillage operations and summerfallow, and crop residue burning.

On-farm CH_4 comes from digestive process of ruminant livestock (cattle, sheep and goat burps), anaerobic (without oxygen) decomposition of organic matter in wet soils, riparian areas, wetlands and manure storages.

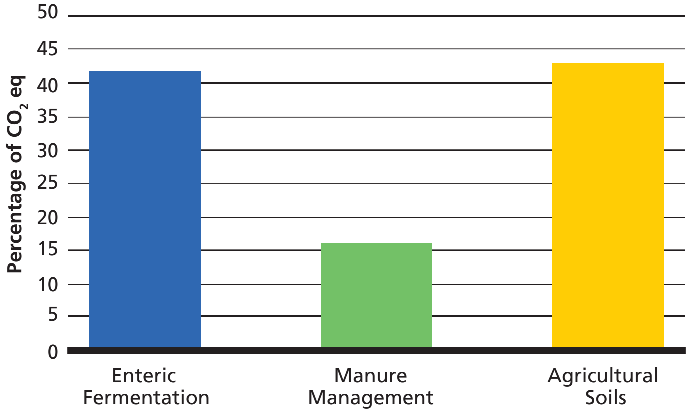
On-farm N_2O comes from nitrification in soil (when ammonium is converted to nitrate in soil), denitrification in soil (anaerobic respiration in soil due to wet soil conditions or high microbial activity where both carbon and nitrate are present) and in the manure storage.

Table 11.1 Greenhouse gases and their global warming potential, agricultural sources and causes. Adapted from the Climate Change Connection, 2007.

Greenhouse Gas	Global Warming Potential[1]	Agricultural Sources	Causes
Carbon dioxide (CO_2)	1:1 (CO_2 equivalent)	• Soils • Fossil fuel combustion	• Tillage • Soil drainage • Crop residue burning • Operating farm machinery • Heating farm buildings
Methane (CH4)	23:1 (23 times more potent than CO_2)	• Ruminant livestock • Manure • Soils • Wetlands	• Digestion of feeds by ruminants (enteric fermentation) • Decomposition of manure during storage and application • Anaerobic (without oxygen) decomposition of organic matter in poorly drained soils and wetlands
Nitrous oxide (N_2O)	296:1 (296 times more potent than CO_2)	• Soil • Manure	• Nitrification in soil • Denitrification in soil • Indirect GHG production due to N losses from leaching, run-off and NH_3 volatilization • Excess N fertilizer • Decomposition of manure during storage and application

1 Global warming potentials (GWPs) are used to compare the abilities of different greenhouse gases to trap heat in the atmosphere. These estimates are from the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2001).

Of Manitoba's agricultural emissions in 2005 (Figure 11.2), it is estimated that 43% came from agricultural soils (mostly N_2O), 41% from enteric fermentation (CH_4) and 16% from manure management (CH_4 and N_2O).
These estimates do not include indirect GHG emissions from fertilizer production.



Source: National Inventory Report (Environment Canada, 2007)

Figure 11.2 Relative proportions of greenhouse gases produced by agriculture (excluding fossil fuel burning for home heating and farm machinery).

What are "Carbon Sinks"?

Farmers are in the fortunate position of being able to reduce greenhouse gas emissions by increasing their carbon sinks. Carbon sinks are processes that remove greenhouse gases from the atmosphere and store them long-term in another form. On farms, CO_2 can be stored as carbon in perennial vegetation (such shelterbelts and woodlots) and in soil as organic matter. Many of the farming practices that reduce greenhouse gases also improve soil quality and productivity, protect water quality and promote profitability.

Land management to reduce greenhouse gas emissions

Marginal lands (agriculture capability classes 4, 5 and 6) do not have the yield potential of higher class agricultural lands (see agriculture capability explanation in Chapter 2). Some class 6 and 7 lands have such severe limitations that they are either not profitable or not suited to agriculture. By planting unproductive marginal and often fragile lands to perennial cover, farmers can improve profit margins, create a carbon sink and provide natural habitat (Soil Conservation Council of Canada, 2003).

Agroforestry is a land management approach that combines the production of trees with other crops and/or livestock. Trees, like growing crops, remove CO_2 from the air, storing it as carbon in trunks, branches, leaves and roots. By blending agriculture and forestry, particularly on marginal lands, agroforestry can optimize economic and environmental benefits.

Although wetlands are a source of CH_4 and N_20, all of their advantages should be considered when assessing their ecological value on the farm. Wetlands can remove CO_2 from the atmosphere, help to clean water, provide wildlife habitat and reduce downstream flooding. Drained areas of the field that remain less productive due to excess moisture for significant portions of the year (agriculture capability classes 5W, 6W and 7W) may provide more ecological value if they were restored back to wetlands.

When soils become saturated, soil microbes use nitrate-N to respire instead of oxygen through a process called denitrification. This process results in a loss of N fertilizer to the air as N_2O and N_2 gases. Improving the drainage on lands with mild to moderate wetness limitations (agriculture capability classes 2W, 3W and 4W) can reduce greenhouse gas emissions by decreasing denitrification and increasing plant uptake of CO_2 by healthier more vigorous crops. Unfortunately, drainage is not without some risk to water quality. Tile drainage and surface drains must be managed in a way that reduces the risk of nutrient transfer to surface water. As well, improving drainage on some lands may increase the oxidation of organic matter and release of CO_2.

Soil management to reduce greenhouse gas emissions

Agricultural soil is dynamic biological system that both stores and releases greenhouse gases. Whether or not the soil acts as a net source of CO_2 or a net sink for CO_2 can be influenced by soil management. By increasing soil organic matter levels – a process called carbon sequestration – the farmer can decrease CO_2 emissions and increases the soil carbon sink.

Soil organic matter levels can be increased by producing healthier crops and reducing tillage operations. Healthy crops not only produce more harvestable material for the farmer but they also decrease greenhouse gases by trapping more carbon in their roots, some of which will be converted to more stable soil organic matter. Conservation tillage systems increase soil organic matter levels by decreasing the amount of organic matter that is oxidized and released to the atmosphere as CO_2. In conservation tillage, crops are planted into the previous year's stubble with minimum or no tillage. In addition to increasing soil organic matter levels, this practice also reduces fossil fuel consumption and reduces the risk of soil erosion by wind, water and tillage. It is estimated that conservation tillage, along with reduced use of summerfallow, can store from 0.3 to 0.5 tonnes of carbon per hectare per year in the soil, depending on weather and moisture conditions (Soil Conservation Council of Canada, 2006).

The use of perennial forages in crop rotations reduces GHG emissions by increasing carbon storage (sequestration) in agricultural soils. For example, perennial forages can sequester 2 to 3 more tonnes of CO_2 per hectare per year than annual crops (Grant et al. 2004). Alfalfa can also fix its own atmospheric N, thereby eliminating the need for commercial fertilizer applications in the years following establishment. This is an additional GHG reduction benefit because both the production and application of N fertilizer involve the burning of fossil fuels.

Nutrient management to reduce greenhouse gas emissions

The use of N fertilizers, whether commercial inorganic fertilizer or manure, increases GHG emissions from soil. When ammonium is added to soil, it is converted to nitrate by soil microorganisms through a process called nitrification. This process requires oxygen and releases small amounts of N_2O. In anaerobic soils, nitrate is converted to N gases through a process called denitrification. Denitrification occurs in the absence of oxygen, requires both carbon and nitrate and gives off N_2 and N_2O.

Good nutrient management practices help to reduce GHG emissions. Fertilizer type, application rate, timing and placement have been shown to influence the amount of N_2O released to the atmosphere from some soils in some years (Burton et al. 2007). Improved fertilizer efficiency represents an economic savings for the producer and will reduce the amount of excess N fertilizer that can be lost to the atmosphere or to surface or groundwater. Any reduction in commercial N fertilizer use has the added benefit of reducing the greenhouse gases emitted during its manufacture.

The first step towards improving fertilizer efficiency is determining how much fertilizer N the crop requires. Nitrogen application rates should take into account how much available N is already in the soil and any additional N requirements should target realistic crop yields. This is achieved through annual soil testing for residual soil nitrate levels. Targeted N application rates will minimize the amount of nitrate that is remaining in the soil after the crop has been harvested. This excess nitrate is at increased risk of being lost to the atmosphere as N_2O the following spring when soils are saturated during snowmelt. Additional benefits of targeted N application rates include optimal crop response, reduced crop lodging, reduced risk of nitrate leaching to groundwater and decreased fertilizer costs.

Manure is an excellent source of nutrients for crop production and can replace the requirement for commercial fertilizer. Like fertilizer, manure should be applied at rates that meet crop nutrient requirements. Unlike commercial fertilizer, however, manure is a heterogeneous mix of nutrients, organic matter and water. The only way to know the nutrient concentration of manure is through laboratory analysis of a representative, composite manure sample. Similar to commercial fertilizer, spring applications of manure are ideal but are not always practical. Winter applications of manure should be eliminated to prevent runoff, leaching and volatilization of ammonia. To ensure the target application rate of commercial fertilizer or manure is applied, application equipment must be calibrated.

The N in manure and ammonium-based fertilizers is at increased risk of being lost to the atmosphere as ammonia (NH_3) gas. These losses can result in *indirect* GHG emissions when the ammonia is re-deposited on land elsewhere and lost as N_2O. Injection or immediate incorporation of manure and ammonium-based fertilizers can reduce or eliminate volatilization of NH_3. This not only reduces indirect GHG emissions, but it can represent a significant savings for the producer in N fertilizer.

Ideally, fertilizers should be applied as close as possible to the time that plants need them. Applications of fertilizers in the spring after snowmelt reduce the risk of losses to the environment during spring snowmelt. During the snowmelt period, denitrification rates can be high if nitrate and carbon are present in the soil because the soil is often also saturated. Late fall applications of ammonia-based N, when soils are cool, are also acceptable as much of the N is not converted to nitrate until the soils warm again the following spring after snowmelt. One of the most efficient methods of fertilizing annual crops is banding the fertilizer at seeding. If banding is not possible, then incorporation as soon as possible after application will reduce the risk of losses to the environment. Some long-season, wide row crops such as corn and potatoes permit in-season application of N, which may be the most efficient time to apply N fertilizer.

Slow release N fertilizers supply N more slowly over the growing season when the crop can use it and reduce the risk of N loss to the environment. Slow release fertilizers are more expensive, however, so economics may limit their use. Urease and nitrification inhibitors improve the efficiency of N uptake and are more affordable than slow-release fertilizers. Urease inhibitors prevent volatilization of surface-applied urea and indirect GHG emissions. Nitrification inhibitors slow the conversion of ammonium-N to nitrate-N and have been shown to reduce N_2O emissions in some soils.

Inclusion of leguminous cover crops or green manure crops in crop rotations could also decrease GHG emissions. The more gradual release of the N from these crops over the subsequent growing season may result in less N in the soil at any one time that is susceptible to loss as N_2O following precipitation events. As well, crediting the N from these crops reduces the requirement for commercial N fertilizer for the next crop. The reduction in N fertilizer use means that less greenhouse gases are emitted from N fertilizer manufacture.

Composting manure to reduce greenhouse gas emissions

Composting manure is the controlled, accelerated decomposition of manure into a more stable organic form. Composting solid manure reduces the volume for land application by up to 50% thereby decreasing application costs for the producer and possibly reducing the use of fossil fuels.

The addition of compost to soil improves soil quality. Compost improves soil organic matter levels, decreases bulk density and increases fertility, aeration and water holding capacity. The use of compost may reduce the need for commercial fertilizers.

The overall benefits of composting manure for greenhouse gas reduction are promising although reduction estimates are variable and depend on the method of composting and type of manure. More research in this area is required before these benefits can be quantified.

12

Other Applications of Soils Information

There are many other applications of soil information to agronomic principles that have not been addressed in this publication, such as management of organic (peat) soils, yield correlations with soil types, soil variability and precision agriculture, sequential soil testing for on-farm agronomy trials and land uses other than agriculture for soil types. Understanding the principles and sources of additional information provided in this guide should lay the groundwork for future applications of soils information.

13

Summary

The purpose of this guide has been to provide the appropriate background and technical information required for managing soils in a sustainable fashion. Most of the information provided hinges on the following main points:

- **Use detailed *soil survey* information, where available, to confirm soil type, dominant processes and limitations.**
- **Determine your *crop yield potential* and use the most appropriate Beneficial Management Practices (such as appropriate amount of tillage, crop choices and crop rotation, etc.) to try to reach that potential.**
- **Conduct *soil testing* to at least the 2 feet (60 centimetres) depth for nitrogen and to 6 inches (15 centimetres) for phosphorus and potassium from representative areas of the field for proper nutrient assessment over time.**
- **Establish *buffer strips* of perennial forages, with or without shelterbelts adjacent to sensitive areas to minimize runoff, wind and water erosion, compaction, moisture problems, overlap of inputs, salinity, pesticide drift, etc.**

Contact your local Manitoba Agriculture, Food and Rural Initiatives farm production advisor or soil specialist for more information on soil management issues.

14
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15
Glossary

Agriculture capability is a 7 class rating of mineral soils based on the severity of limitations for dryland farming. This system does not rate the productivity of the soil, but rather its capability to sustain agricultural crops based on limitations due to soil properties and landscape features and climate. This system is usually applied on a soil polygon basis and the individual soil series are assessed and maps portray the condition represented by the dominant soil in the polygon. Class 1 soils have no limitations, whereas class 7 soils have such severe limitations that they are not suitable for agricultural purposes.

Air dry is the amount of water remaining in soil after drying at room temperature for several hours.

Available water holding capacity (AWHC) describes how much available water a fixed amount of soil can hold for plant uptake. It is largely determined by soil texture and to a limited degree by soil structure and organic matter content.

Available water (AW) is the amount of water held in a soil that plants can use. The maximum amount of available water held in a soil is the difference between the permanent wilting point and field capacity, expressed in inches or millimeters of water per unit depth of soil.

Bulk density is the apparent density of a soil, measured by determining the oven-dry mass of soil per unit volume. The volume of soil is determined using sampling cores and is measured before soil is oven-dried to avoid any changes in volume due to drying. Bulk density is usually expressed in g/cm^3 or Mg/m^3.

Catena is a sequence or family of related soils located in the same climatic zone formed from similar parent material under different landscape positions resulting in different profile characteristics.

Conservation tillage systems include reduced tillage and zero tillage and produce benefits such as soil quality enhancement (increased soil organic matter levels over time), moisture conservation, erosion control, reduced use of fossil fuels and a reduced labour requirement. Weed control in these systems may require increased use of herbicides.

Conventional tillage is a system that traditionally uses moldboard plows or chisel plows with sweeps, followed by discing, harrowing or other secondary tillage operations to incorporate residue, prepare a seedbed and control weeds.

Detailed soil survey maps (see also Soil Survey and Reconnaissance Soil Surveys) identify more of the variation in soil types across smaller landscapes. Detailed soil survey maps are much more accurate and reliable for making decisions at the farm-level. Maps prepared at a 1:20,000 scale (3.2 inches to 1 mile) require 25-30 inspection sites per section of land whereas semi-detailed maps at 1:50,000 scale, or 1.5 inches to 1 mile, require 16 inspections per section.

Direct seeding is a type of reduced tillage where the only tillage operation occurs at seeding. Maximum surface residue is maintained until seeding, at which time high disturbance seed openers are used for seedbed preparation, residue management and weed control.

Discharge zone is an area where the zone of saturation is at or near the surface and the net movement of water is towards the ground surface. Discharge may be focused in areas such as springs, weeping embankments and baseflow discharge, or it may be diffuse over larger areas of the landscape. These areas may be characterized by soils that are calcareous, imperfectly or poorly drained and have a build-up of salts.

Electrical conductivity (EC) is a measure of soluble salts within the soil. EC is expressed in dS/m, mS/cm or mmho/cm (all equal). Electrical conductivity is directly related to the total dissolved solids in the soil.

Eutrophication is the enrichment of water bodies by nutrients, particularly nitrogen and phosphorus. Phosphorus is the nutrient that most commonly limits plant growth in fresh water bodies. Excess P entering water can result in increased production of algae and other aquatic plants, thereby affecting the quality of water and the diversity of organisms present.

Field capacity (FC) is the maximum amount of water held in a soil, measured a few days after it has been thoroughly soaked and allowed to drain freely.

Gleying is a soil-forming process which occurs under poor drainage conditions, resulting in the production of gray colours and mottles.

Gravimetric soil moisture (W%) = $\dfrac{\text{wt. (wet soil)} - \text{wt. (oven dry soil)}}{\text{wt. (oven dry soil)}} \times 100\%$

High disturbance openers are medium and wide openers, such as wide hoes, narrow sweeps or shovels, wide spoons, wide shovels and discers. These openers disturb more than 33% of the soil surface.

Hydraulic conductivity is the rate at which water can pass through a soil material usually measured under saturated conditions.

Infiltration is the entry of water into soil. The rate of infiltration can be relatively fast, especially as water enters into pores and cracks of dry soil.

Irrigation suitability is a general suitability rating for irrigated crop production. This classification system considers soil and landscape characteristics such as texture, drainage, depth to water table, salinity, geological uniformity, topography and stoniness and ranking them in terms of their sustained quality due to long term management under irrigation.

Liquid limit is the moisture content at which a soil begins to flow and behave like a liquid.

Loams are medium textured soils made up of a mixture of sand, silt and clay.

Low disturbance openers are narrow openers such as knives, narrow spoons, narrow hoes and slightly offset discs (not including a discer). The openers should not disturb more than 33% of the soil surface area.

Map units are symbols on soil survey maps that represent the type of soil(s) found within a particular polygon. A simple map unit designates a single soil series on a detailed soils map. A complex map unit includes as many as three soil series on a detailed map, or as many as two soil associations on a reconnaissance soil map.

Minimum tillage is a type of reduced tillage that employs a reduction in one or more tillage operations from conventional practices (such as no fall tillage) and uses low disturbance seed openers.

Mottles are rust-coloured spots in the subsoil formed from alternating wetting and drying conditions.

No-till – See zero tillage.

Organic matter is an important component of soil that supplies plants with nutrients, holds soil particles together to prevent erosion, and improves soil tilth. Organic matter also improves water filtration and water-holding capacity while controlling the decomposition and movement of some pesticides. Biological processes of plant growth and human activities, such as tillage, have affected the present state of soil organic matter.

Oven dry occurs when soil has been dried at 105°C for 24 hours so that no water remains.

Parent material is the original material from which soils develop. It is based on the type of bedrock and method of deposition.

Particle density is the grain density, or the mass per unit volume of the soil particles. Pore spaces found in bulk soil samples are excluded. Particle density is usually expressed in g/cm^3 or Mg/m^3, and the particle density for most agricultural soils is 2.65 g/cm^3.

Permanent wilting point (PWP) is the soil water content at which water is no longer available to plants, which causes them to wilt because they cannot extract enough water to meet their requirements.

Plastic limit is the moisture content at which a soil sample changes from a semi-solid to a plastic state.

Primary salinity or naturally-occurring salinity results from the long term continuous discharge of saline groundwater.

Recharge zone is an area where water infiltration exceeds the storage capacity of the soil and moves downward to the zone of saturation (groundwater). In recharge areas, well, imperfect and poorly drained soils may have well developed A (leached) and B (clay accumulation) horizons which indicate net movement of water is downward. The surface and subsoil are usually non calcareous.

Reconnaissance (general) soil surveys of Manitoba were started in 1926 as the first step in the development of a basic program of soil research, education, conservation and utilization for the province. Reconnaissance soil surveys are best suited to making general comparisons at the regional scale. The scale is approximately 1:125,000, or ½ inch to 1 mile. (See also Soil Survey and Detailed Soil Survey Maps.)

Reduced tillage systems involve the removal of one or more tillage operations to increase residue cover on the soil, reduce fuel costs and to use standing stubble to trap snow to increase soil moisture and permit the winter survival of winter wheat.

Ridge till is a type of reduced tillage where row crops (such as corn) are planted on pre-formed ridges. During the planting operation, crop residues are cleared from the row area and moved to the furrow between rows. The planted rows are on a raised ridge 3 to 5 inches (7.6 to 12.7 cm) above furrows between rows.

Saturated hydraulic conductivity (K_{sat}) provides the simplest and most consistent means of measuring the rate of water movement through soils.

Saturation is the moisture content at which all soil pores are completely water-filled.

Secondary salinity or human-induced salinity is the result of human activities that have changed the local water movement patterns of an area.

Sensitive areas are areas where productivity is lower (such as eroded knolls or saline areas), and/or in areas that have heightened risk of impacts to soil and water if traditional activities are allowed to continue (such as creeks, potholes, ditches, springs, wells or rapidly permeable areas).

Snow trapping potential (STP) refers to an index which quantifies the amount of standing stubble (height and density) used to capture snow. A snow trapping potential index greater than 20 is acceptable; less than 20 indicate a high risk of winter injury, particularly for winter wheat and triticale. For reference, cereal stubble typically has pre-seed STPs of 80 or higher, while canola and flax are normally in the range of 30-50, depending on the stubble height.

Sodium adsorption ratio (SAR) is the concentration of sodium relative to calcium and magnesium in the soil. SAR is a measure of soil sodicity.

Soil compaction is the squeezing together of soil particles, reducing the space available for air and water. Compaction increases the density of the soil, which hampers infiltration of water, soil air movement, seedling emergence, root growth and ultimately reducing yield.

Soil drainage is the speed and extent of water removal from the soil by runoff (surface drainage) and downward flow through the soil profile (internal drainage).

Soil horizon is a layer of soil running approximately parallel to the land surface and differing from vertically adjacent layers in terms of physical, chemical and biological properties such as colour, structure, texture, pH, etc.

Soil is defined as the collection of natural bodies on the earth's surface supporting or capable of supporting plants.

Soil phases are variations of a soil series because of factors such as erosion, topography (slope), stones, salinity, improved drainage and peaty layers.

Soil polygon is an area (which can be of any shape) which contains a specific soil condition that is identified by symbol(s).

Soil porosity is the percentage of a given volume of soil that is made up of pore spaces. Soils are oven-dried to measure bulk density, so porosity is a measure of air-filled pore space. % Porosity = [1-(bulk density / particle density)] x 100

Soil salinity is a limitation where plant growth is reduced due to the presence of soluble salts in soil which holds water more tightly than the ability of plants to extract water from the soil.

Soil series is the name given to an individual soil type, with a particular kind and arrangement of soil horizons developed on a particular type of parent material and located in a particular soil zone.

Soil structure refers to the way in which soil particles cling together to form aggregates.

Soil survey is an inventory of the properties of the soil (such as texture, internal drainage, parent material, depth to groundwater, topography, degree of erosion, stoniness, pH and salinity) and their spatial distribution over a landscape (often portrayed in a map).

Soil texture is the relative proportion of sand, silt and clay particles.

Tillage erosion is the progressive downslope movement of soil by tillage causing soil loss on hilltops and soil accumulation at the base of slopes. It is described in terms of erosivity and landscape erodibility. Large, aggressive tillage implements, operated at excessive depths and speeds are more erosive, with more passes resulting in more erosion. Landscapes that are very topographically complex (with many short, steep diverging slopes) are more susceptible to tillage erosion.

Total dissolved solids (TDS) is a measure of soluble salt content in water extracted from a soil sample, expressed in mg/L.

Volumetric soil moisture (Θ) = gravimetric soil moisture x bulk density

Water erosion is the detachment, movement and removal of soil from the land surface by precipitation leaving the landscape as runoff. It can occur naturally, without human intervention, or can be accelerated through human activities such as insufficient residue cover on soils prone to runoff.

Watershed management is the planned use of drainage basins in accordance with predetermined objectives.

Wind erosion is the detachment, movement and removal of soil from the land surface by wind. It can occur naturally, without human intervention, or can be accelerated through human activities such as excessive tillage.

Zero tillage is a type of cropping system in which crops are planted into previously undisturbed soil by opening a narrow slot of sufficient width and depth to obtain proper seedbed coverage. No tillage operation for the purpose of weed control is conducted, but this allows for tillage with low disturbance openers (knives, spikes, etc.) for fall banding of fertilizer, filling in ruts, and the use of heavy harrows for crop residue management.

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Appendices

A. Detailed Soil Survey Protocol (1:20 000 scale)

1. Acquire as much of the existing background information as possible for the area to be surveyed. Reconnaissance soil maps, elevation maps and aerial photographs are all good starting points.
2. Delineate landform boundaries on twin air photos viewed with stereo glasses. Aerial photographs will serve as the base map.
3. Investigate soil variability within landforms by soil sampling to a depth of at least 1 meter (3 feet) at regular intervals along transects. (It is preferable to georeference these inspection sites using GPS technology). Inspections are conducted every 400 metres (1/4 mile) around the perimeter of a section and every 200 metres (1/8 mile) along two transects at the 400 metres (1/4 mile) and 1200 metres (3/4 mile) points of the section, for a total of 30 sites (see Figure 2.5).
4. Classify soils in the field visually using standardized criteria for texture, colour, presence of carbonates, presence of mottles, type of parent material and landscape position. This information will assist in determining what soil horizons are present, which in turn will identify the soil series and phase present in each map unit.
5. Laboratory analyses for the following factors are conducted in order to verify field data for proper soil horizon classification: (Olson, 1984, p.22)
   - particle size (texture) - pipette method
   - bulk density
   - water retention
   - cation exchange capacity
   - base saturation
   - sodium adsorption ratio (SAR)
   - organic carbon
   - calcium carbonate, gypsum
   - N, P, K, S, Ca, Mg, Na, Fe, Al, NO_3^-, $CO_3^=$, HCO_3^-, Cl^-, $SO_4^=$ using atomic absorption and/or ion specific electrode analyses
   - electrical conductivity (EC) from the saturated paste method
   - pH *(in $CaCl_2$)*

Refer to *Methods of Soil Analysis*, Parts 1 and 2, and Carter (1993) for specific analyses of the above soil properties.

6. Refine map units and soil boundaries from field descriptions, laboratory data and variability observations.
7. Verify soil classifications by recording all pertinent data, reviewing field and laboratory data, re-examining stereo photographs and consulting with experienced pedologists.
8. Draw lines to indicate the soil boundaries and include soil symbols on the air photos or base map.
9. Write soil map unit descriptions.
10. Integrate all the information into a soil survey report for the area (based on Olson, 1984, pp10-11).

B. How to Use a Soil Survey Report

For more information on the legal land survey system, refer to "Understanding Western Canada's Land Survey System", by McKercher and Wolfe (1978).

1. Locate the area of interest in terms of the quarter section (NW, NE, SW or SE), section, township and range.

Figure 14.1. Section Number Layout on Township Map

31	32	33	34	35	36
30	29	28	27	26	25
19	20	21	22	23	24
18	17	16	15	14	13
7	8	9	10	11	12
6	5	4	3	2	1

2. Consult the index to map sheets in the soil survey report to locate the appropriate map sheet number.
3. Refer to the appropriate soil map and locate the area(s) of interest on the map and identify pertinent map unit symbols (eg. NBG, PGK). Arabic numerals placed as superscripts following map symbols indicate approximate proportions of each soil type within the map unit (eg. LOP^7-LLT^3 indicates 70% of the map unit is a Long Plain (LOP) series; the remaining 30% of the map unit is a Lelant (LLT) series).
4. Locate the desired map unit symbols in the map legend (in the appendix of the soil survey report). Symbols are listed alphabetically giving the soil name, surface texture, soil drainage, mode of origin, soil material and classification subgroup.
5. A good starting point is usually in the pull-out chart of the report, which categorizes each soil series according to its parent material, texture and drainage. Tables on agricultural capability, irrigation suitability and potential environmental impact ratings are provided. Individual series descriptions and additional suitability ratings are described and provided as well.
6. For further information, consult the appropriate sections in the soil report. Definitions, background information, general descriptions of individual soils and interpretive information are found in each soil survey report.
7. If additional information is required, contact a soils specialist with Manitoba Agriculture, Food and Rural Initiatives.

C. Other Sources of Land Information

Table 14.1. Sources of landbase information for remote sensing

Type of Map	Cost	Source	Phone #
Detailed and Reconnaissance Soil Survey Reports	~$10.00 ea	Statutory Publications 200 Vaughan St., Winnipeg, MB R3C 1T5 Or contact your local MAFRI office	(204) 945-3101 (204) 474-6112
Black & White Aerial Photos	~$8.50/section	Manitoba Surveys & Mapping Branch 1007 Century St. Winnipeg, MB Or visit Agri-Maps website: http://geoapp2.gov.mb.ca/website/mafri/index2.html	(204) 945-6666
Digital Orthophotos	$25-50/quarter section	Manitoba Agricultural Services Corporation 400-50-24th St. NW, Portage la Prairie, MB R1N 3V9	(204) 239-3246
Infrared Photos	$50-300/section	Prairie Agri-Photo Box 817, Carman, MB R0G 0J0	(204) 745-2479
Elevation Maps	N/A	Manitoba Industry, Trade & Mines Association of Manitoba Land Surveyors (for company listings)	945-6530 943-6972
Yield Maps	Combine yield monitor GPS equipment Computer software	Various agriculture machinery and precision farming dealers	
Satellite Imagery	$825-1300 for a full Landsat 7 image field level vegetation products field level vegetation products	Radarsat International Agri Imagis www.satshot.com Noetix Research Inc. 265 Carling Ave., Suite 403, Ottawa, ON K1S 2E1 www.noetix.on.ca	1-888-780-6444 (701) 438-2243 (613) 236-1555

D. Sources of dilute hydrochloric acid

Dilute (1 N) HCl for carbonate testing can be acquired for $12-35/L from the following suppliers:

- Anachemia Science (204) 661-6734
- Fisher Scientific 1-800-234-7437
- VWR International 1-800-932-5000

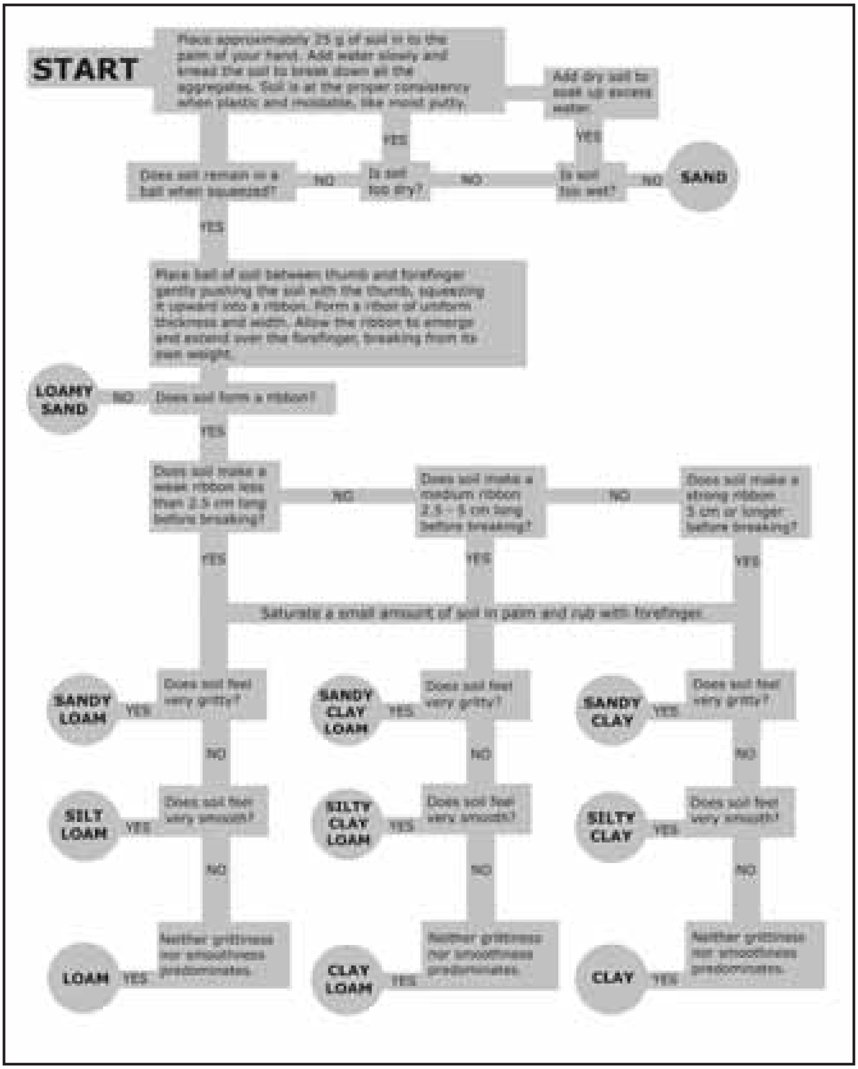
E. Drinking water quality guidelines for humans, livestock

Nitrate-nitrogen: 10 mg/L as N

Fecal Coliform Bacteria or E. coli: 0 CFU's/100 mL

Total Dissolved Solids: <500 mg/L (humans); <3000 mg/L (livestock)

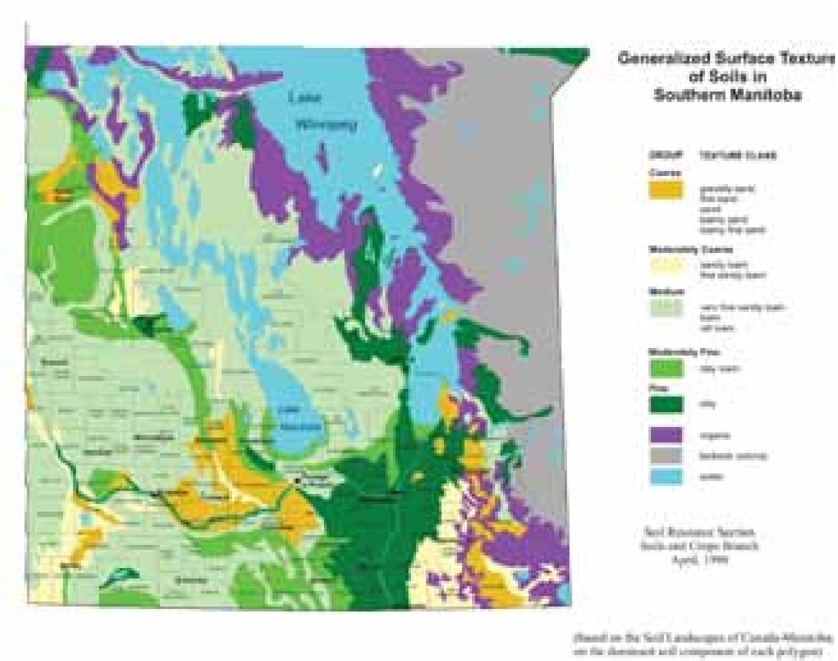
F. Determining Soil Texture By Feel



Soil texture is important as it determines such properties such as moisture holding capacity, drainage, erosion potential, and to some extent, the ability to hold and supply nutrients to the crop. Information on soil texture is available in soil survey reports, and detailed textural analysis can be requested from various soil testing laboratories.

An estimate of soil texture can be made in the field. The soil is rubbed between the fingers and thumb to estimate of the amount of sand, silt and clay particles. First, the soil needs to be wetted up to make it pliable and easily worked. Step by step instructions are given in the above flowchart.

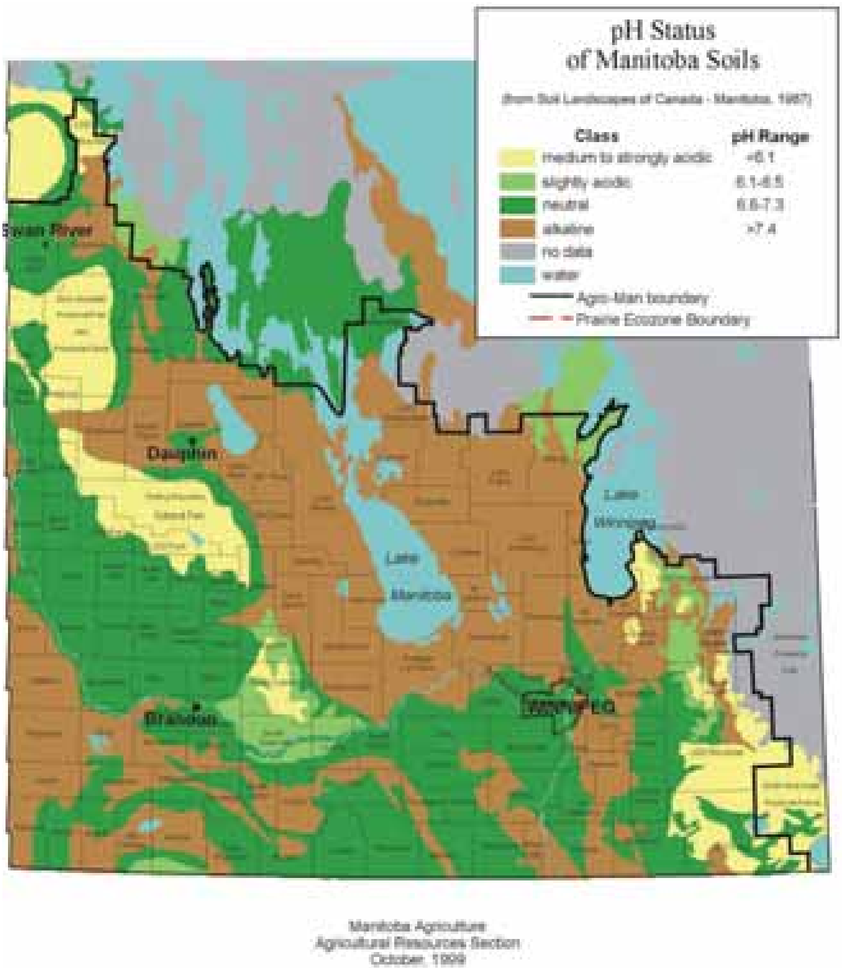
G. Generalized Surface Texture of Soils in Southern Manitoba



Soil texture strongly influences the soils ability to retain moisture (available water holding capacity), its general level of fertility and ease or difficulty of cultivation. Water moves easily through sandy soils therefore small amounts of moisture are retained and these soils dry out more quickly than clayey soils. Clayey soils transmit water very slowly; therefore these soils are susceptible to excess soil moisture conditions and to water erosion in undulating landscapes. Sandy soils do not retain plant nutrients as well as clayey soils and are lower in natural fertility; sandy soils often characterized by loose or single grained structure and are very susceptible to wind erosion. Medium-textured (loamy) soils are characterized by properties that fall between the extremes of coarse and fine-textured soils. They are generally fertile, able to retain sufficient moisture for plant use and are relatively easy to cultivate.

Mineral particles in soil are grouped according to size into sand (2-0.05 mm in diameter), silt (0.05- 0.002 mm) and clay (less than 0.002 mm). A soil containing nearly equal proportions of sand, silt and clay size particles is called a loam. The proportion of individual mineral particles present in a soil is referred to as texture. The presence of larger particles (diameter is greater than 2 mm) in soil is recognized as gravel, cobbles or stones.

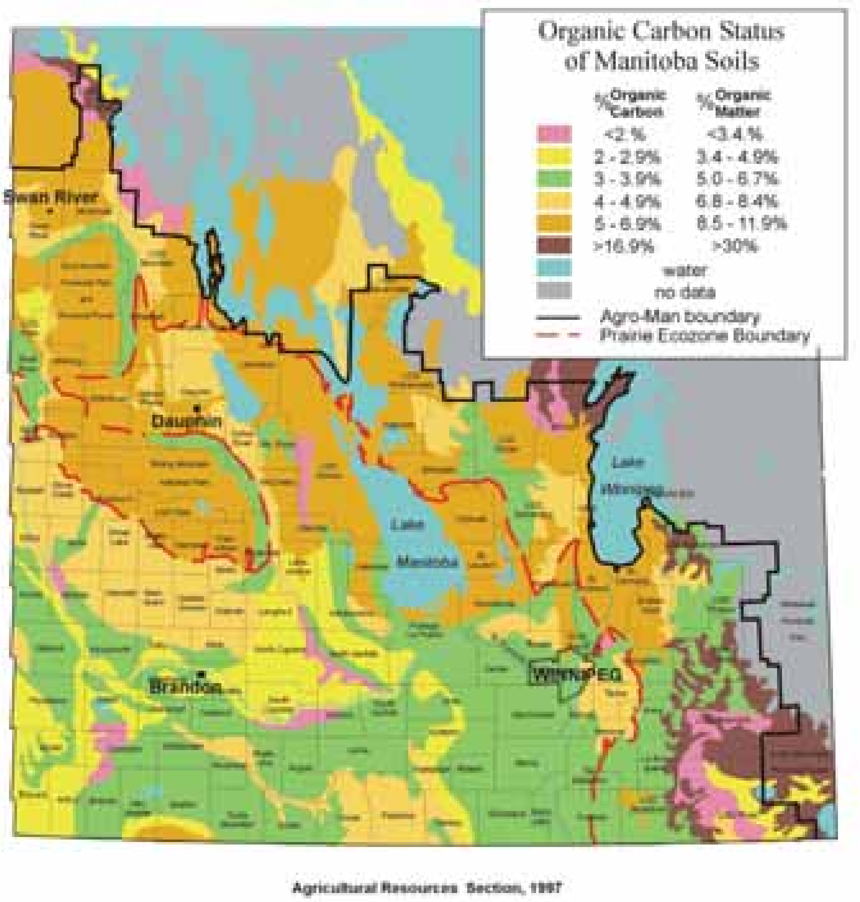
H. pH Status of Manitoba Soils



Soil pH (also referred to as soil reaction) refers to the degree of acidity or alkalinity. Soil pH is expressed by numbers from 1 to 14 on the pH scale. Most Manitoba soils range from 6.8 to 7.5.

Soil reaction influences the way minerals dissolve in soil water and thus the availability of many important nutrients for plants. It also affects the development and growth of such organisms as bacteria and fungi. At low soil pH (acid) some plant nutrients become so soluble that they leach out of the rooting zone. At high pH (alkaline), certain plant nutrients become tied up in the soil, so much so that they become deficient in the plant even when there are plenty of nutrients in the soil. Most crops prefer slightly acid to mildly alkaline conditions (pH 6.0 to 7.8).

I. Organic Carbon Status of Manitoba Soils

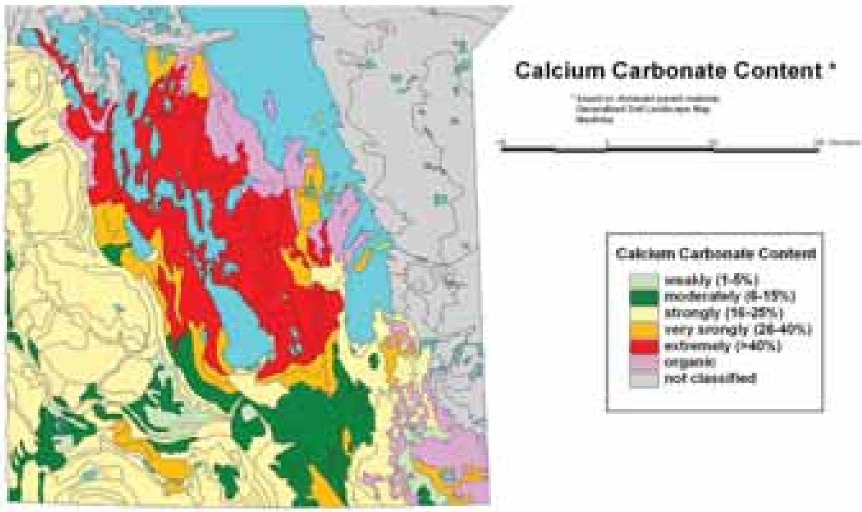


Soil carbon (organic matter) is a very important component of soil that stores and supplies plant nutrients (nitrogen, phosphorus and sulphur), and improves soil aggregation and tilth. It increases soil porosity and promotes water infiltration. Soil organic matter has a high cation-adsorption capacity and it also has an influence on the persistence, degradation, bioavailability and leachability of pesticides in soils.

The organic content of mineral soils generally ranges from 1% to 12% in the surface layers. In contrast, peat soils may contain as much as 98% organic matter. Climate and native vegetation determine the amount of organic matter in the soil. In south-western and southern Manitoba the native vegetation is mainly grass. This results in the addition of organic matter throughout the soil and the formation of dark coloured “A” horizons. North of these areas where soils have developed under forest vegetation, leaf fall, stem decay and decomposition of mosses results in most organic matter being added to the surface and only small amounts are incorporated into the soils.

Some variability in organic matter levels within similar textural groups may be due to factors such as soil drainage conditions, topography and degree of erosion.

J. Calcium Carbonate Content of Manitoba Soils



Calcium carbonates (and, to a lesser extent, magnesium carbonates) are common to most agricultural soils in Manitoba. They are derived mostly from fragments of limestone rocks. Over time, carbonates dissolve and move in the soil water.

The availability of plant nutrients is influenced by the amount of carbonates in the soil. This is a result of the effect that carbonates have on pH and of the direct effect that carbonates have on nutrient availability. Nitrogen fertilizers should be incorporated into calcareous soils to prevent nitrite accumulation or ammonium-N volatilization. Availability of phosphorous and molybdenum is reduced by high levels of calcium and magnesium which are associated with carbonates. In addition, iron, boron, zinc, and manganese deficiencies are common in soils that have a high calcium carbonate equivalent.

The calcium carbonate content of soils ranges from 0% in extremely leached soil profiles to over 40% in the high lime tills found in the Interlake region of Manitoba.

K. Unit Conversion Table

Length	Approximate Conversion Factor	
centimeter (cm)	x 0.39	inches (in)
metre (m)	x 3.28	feet (ft)
kilometer (km)	x 0.62	mile (mi)
Area		
square metre (m^2)	x 10.76	square feet (ft^2)
hectare (ha)	x 2.5	acres (ac)
hectare (ha)	x 10 000	square metres (m^2)
square kilometer (km^2)	x 0.3861	square mile (mi^2)
acre (ac)	x 43 560	square feet (ft^2)
Volume		
US gallon (US gal)	x 0.83	imperial gallon (imp. gal.)
litre (L)	x 0.035	cubic feet (ft^3)
litre (L)	x 0.22	imperial gallon (imp.gal.)
cubic metre (m^3)	x 35.31	cubic feet (ft^3)
cubic metre (m^3)	x 1.31	cubic yard (yd^3)
cubic metre (m^3)	x 220	imperial gallon (imp. gal.)
cubic metre (m^3)	x 1 000	litres (L)
cubic foot (ft^3)	x 6.24	imperial gallon (imp. gal.)
dekameter^3 (dam^3)	x 0.81	acre feet (ac-ft)
acre inch (ac-in)	x 22 615	imperial gallon (imp. gal.)
Weight		
kilogram (kg)	x 2.2	pound (lb)
tonne (t)	x 1 000	kilogram (kg)
short ton (ton)	x 0.91	tonne (t)
short ton (ton)	x 2 000	pound (lb)
Agricultural		
kilograms per hectare (kg/ha)	x 0.89	pounds per acre (lb/ac)
kilograms per tonne (kg/t)	x 2	pounds per ton (lb/ton)
kilograms per 1 000 litre (kg/1 000L)	x 10	pounds per 1 000 gallons (lb/1 000 gal.)
tonnes per hectare (t/ha)	x 0.45	tons per acre (tons/ac)
litres per hectare (L/ha)	x 0.089	imperial gallons per acre (imp. gal./ac)
litres per acre (L/ac)	x 0.22	imperial gallons per acre (imp. gal./ac)
Fertilizer		
Phosphorus (P)	x 2.3	P_2O_5
Potassium (K)	x 1.2	K_2O