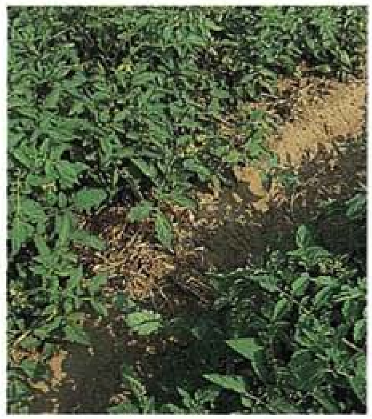
UNDERSTANDING THE BASICS

INTRODUCTION

Soil is the basis of most crop production. If you manage the soils on your farm with care, you'll be rewarded with:

- ▸ more consistent yields, even under adverse weather conditions
- ▸ lower input costs
- ▸ sustainable soils for years to come.

Well-managed soils can result in lower input costs and greater yields.



Well-managed soils also produce crops that have greater resistance to environmental stresses such as weather, and to many diseases such as root rot.

Soil is the basis of most crop production: manage it wisely.

The best management practices described in this booklet relate soil management to your entire crop production operation.

We'll look at how soil management benefits drainage, moisture storage, and crop yields. We'll also look at how good soil management helps reduce soil compaction, erosion, and runoff.

But first, it's back to the basics. This section provides an overview of the science that soil management is based on: what soil is, how it is developed, its physical, chemical, and biological properties, and how to find out more about the soils on your property.

A good understanding of the behaviour of soil and soil life will help you develop and use a soil management program that will serve you well in the long term.

Building on this knowledge base, the second half, "Putting It All Together", addresses in-field soil concerns and lays out best management practices for a variety of conditions.

Throughout the booklet, we'll be referring you to other booklets in the Best Management Practices Series. For the big picture, we urge you to read these too.

UNDERSTANDING THE BASICS

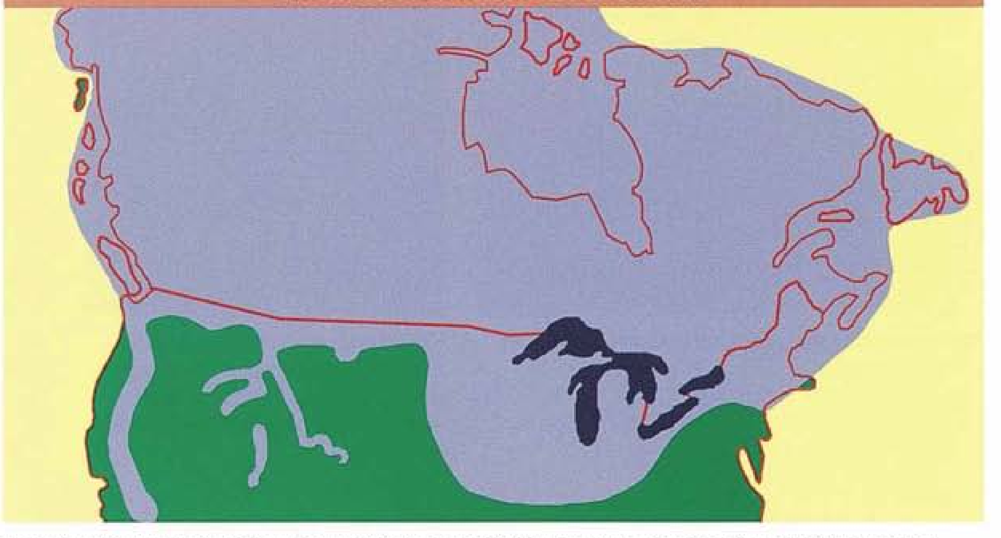
SOIL-FORMING FACTORS	
Climate	temperature, precipitation
Parent Material	source, size
Organisms	vegetation, animals, microorganisms
Topography	slope, position on slope
Time	start of soil formation, climatic change

The manner and speed in which a soil develops are determined by the interaction of five soil-forming factors.

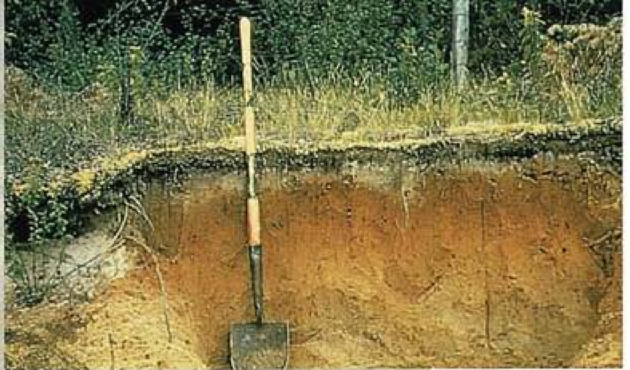
SOIL FORMATION

The properties of today's soils are closely related to landforms. These landforms were created by glacial ice, meltwaters, glacial lakes, and wind. Advancing glaciers ground rocks into fine particles, and mixed and moved existing soil. Retreating glaciers dropped soil materials from within the ice itself. Meltwater deposited sands and gravel as mixed layers. Lakes that formed by ponding meltwaters deposited flat beds of sand, silt, and clay. Strong winds across bare, level landscapes further distributed the soils. Today's soils developed on these deposits.

EXTENT OF GLACIAL ACTIVITY IN ONTARIO



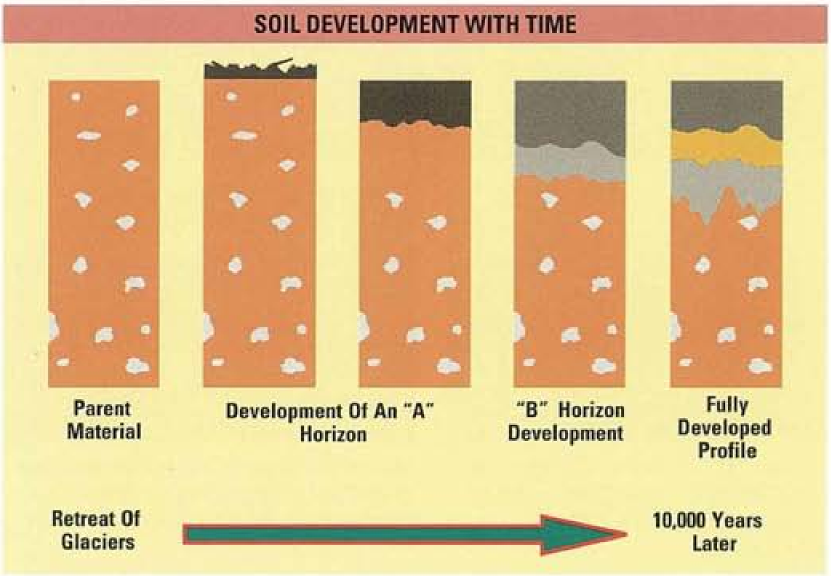
Today's soils are derived from the materials deposited by the retreating ice about 12,000 years ago. At that time, all of what we know as Ontario and most of Canada was covered with thick layers of ice called glaciers.



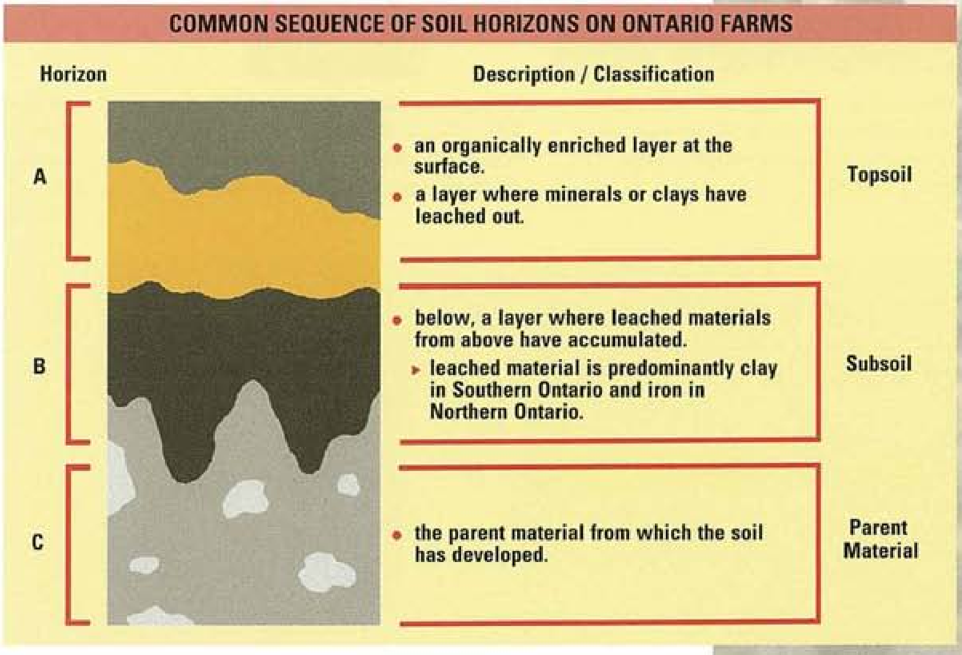
Thousands of years of coniferous forest have helped to form the distinct layers in this coarse-textured acid soil.

While soil formation has been an ongoing process for 12,000 years, the process can be easily disrupted by human activities. A host of physical, chemical, and biological processes combine to alter the original rock or rock debris.

UNDERSTANDING THE BASICS

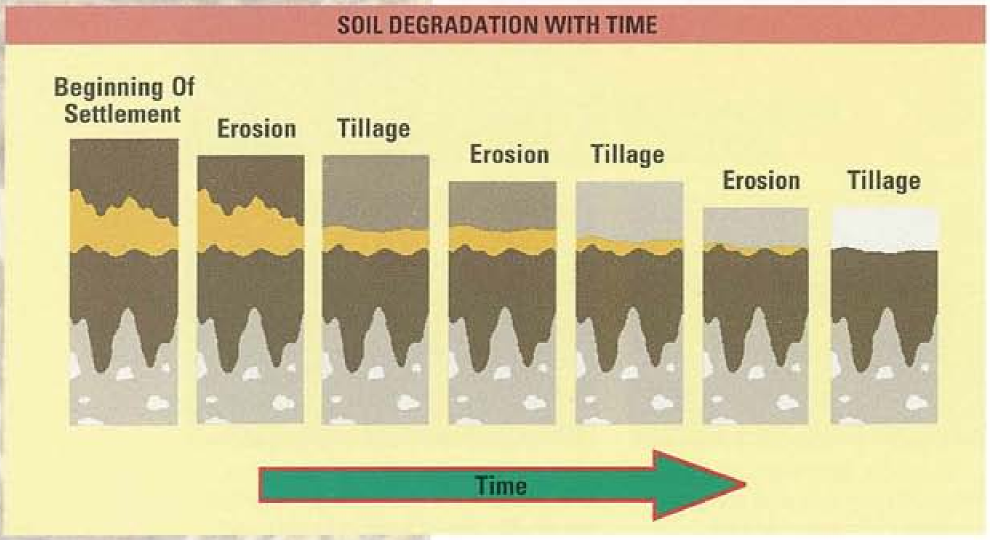


Soils develop over time. After glaciation, vegetation established itself on the unweathered parent materials. Gradually, roots and dead plant materials were added to the surface, and eventually incorporated into soil parent materials by soil organisms – forming topsoil. Acids released by roots and decaying organic matter helped lime and clay particles leach through the soil. This process created a leached layer below the topsoil and a clay-enriched layer below that. Today, the lime-rich parent materials are found at 60-120 centimetres (2-4 ft.) below the soil surface in uneroded fields.



The next two pages illustrate Ontario's most common landforms and the soils that have developed in each. Environmental and production limitations are also described.

UNDERSTANDING THE BASICS



This illustration shows the impact of cropping and tillage on our soils. Note the loss of organic matter (lighter soil colour) due to erosion and dilution of the topsoil with less fertile subsoil. If erosion continues unchecked, less suitable subsoil materials form the seedbed.

Eroded knolls, also known as whitecaps, indicate that the parent material is at the surface. Almost a metre of soil has been lost from these areas.

"Ontario soils are young and relatively shallow, often with a thin layer of topsoil over dense subsoil. These soils are fragile; therefore soil management is critical to long-term sustainability."

Dr. G.J. Wall, Agriculture and Agri-Food Canada

Humans have had, and continue to have, the most influence on soil development in recent years, largely through farming practices such as tillage and crop production.

Tillage can lead to:

- ▸ a breakdown of organic matter that had accumulated in the soil, and dilution by mixing with lower horizons
  - ▹ loss of organic matter and increased specialization and mechanization of agriculture have created soil structural problems such as compaction and soil crusting
- ▸ erosion
  - ▹ tillage of eroded areas dilutes the topsoil, as less fertile subsoil is brought up by the plow.

Each soil is unique, with characteristics developed over time that hinder or help manage a crop. All soils respond to proper management. Understanding your soil's limitations will help you design an effective management program.

Soil characteristics – such as soil physical properties, chemical properties, and biological properties – are related to soil formation and also influence ongoing soil management.

Soil properties that influence choices in crop production and environmental sustainability are considered in the next section.

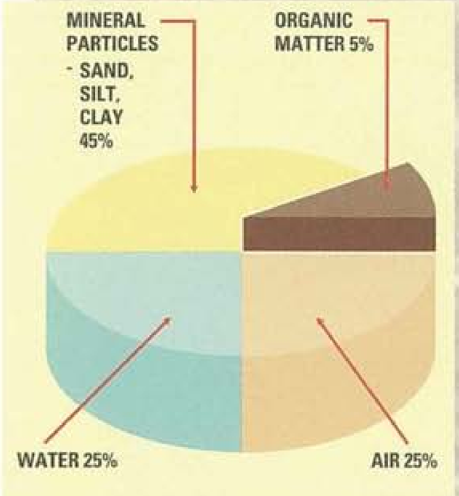
UNDERSTANDING THE BASICS

SOIL PHYSICAL PROPERTIES

The term **physical properties** includes:

- soil texture (sand, silt, clay)
- soil structure
  - structural form
  - structural stability and strength
  - porosity
  - bulk density
- organic matter
- water and air
- temperature.

A good understanding of what these components do and how they interact can help you better appreciate their considerable effect on crop production.



Shown here is an ideal loam topsoil, with the proper balance of air, water, organic matter, and mineral components. Note that the mineral fraction of the soil is almost 50%.

SOIL TEXTURE

Texture refers to:

- the mixture of different-sized mineral particles in a soil
  - soil particles range in size from gravel and stones to very fine clay particles
  - the percentage of sand, silt, and clay.

Sand has the largest particles; silt are smaller, and clay are the smallest. The texture of your soil influences all other soil physical properties, including drainage, water-holding capacity, soil temperature, aeration, and structure.

Soil texture can be considered an inherent soil property that you can't affect easily. However, you should know your soil texture and be aware of the limitations of that soil. (See the remainder of this book for more information on managing specific soil types.)

There are two ways to determine soil texture: a field method using your hands, and a laboratory method using a hydrometer.

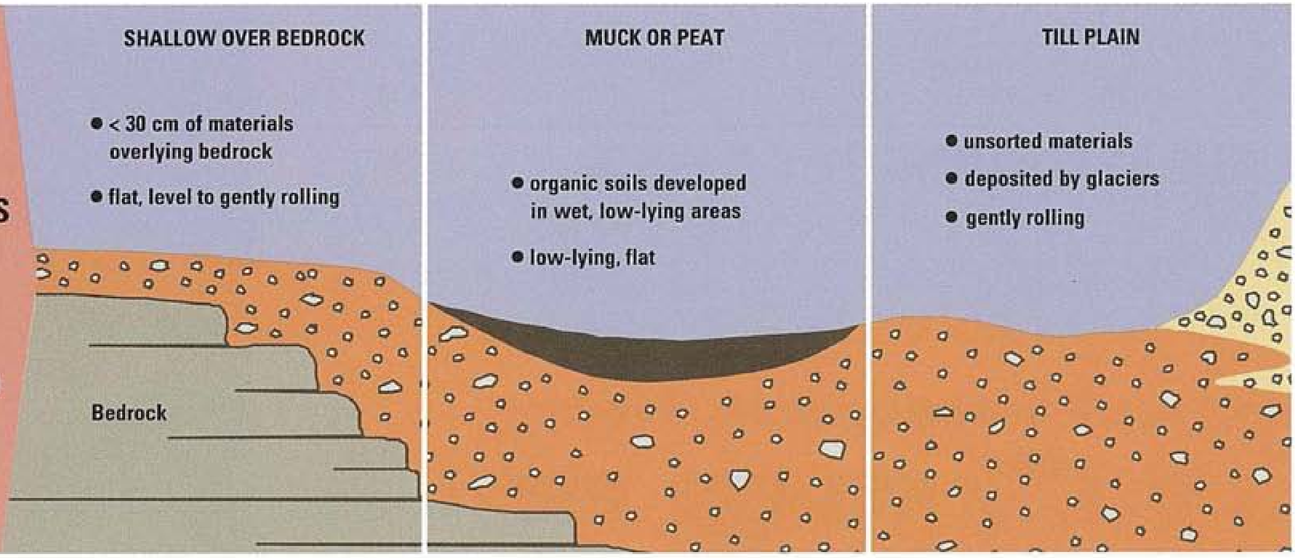
Hand texturing is used in the field to identify soil textures quickly. The first step is to determine the sand content. Rub a small amount of soil in the palm of your hand – is it under or over 50% sand?

If the sand content is less than 50%, add water to create a soil that is wet enough to roll.

Squeeze the soil roll between your thumb and forefinger to make the longest possible ribbon. A loam soil will form only a short ribbon.

Clay soils will form a much longer ribbon.

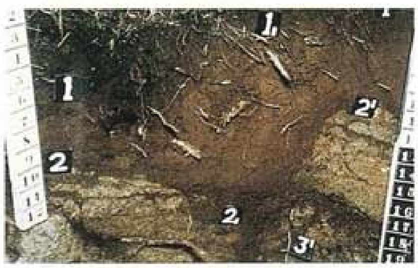
GLACIAL LANDFORMS AND THE COMMON SOIL TYPES OF ONTARIO



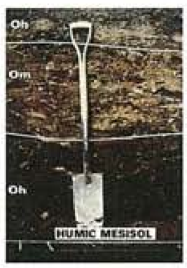
Shallow over bedrock lands are commonly used for extensive pasture and forest management in Eastern Ontario, and Bruce and Simcoe counties. ***(Farmington landscape from West Carleton)***

Muck soils, also known as organic soils, are used for intensive production of high-value vegetables. ***(Holland Marsh, Bradford area)***

Most of Southern Ontario's field cropland consists of gently rolling till plains. ***(Guelph loam, Wellington County)***



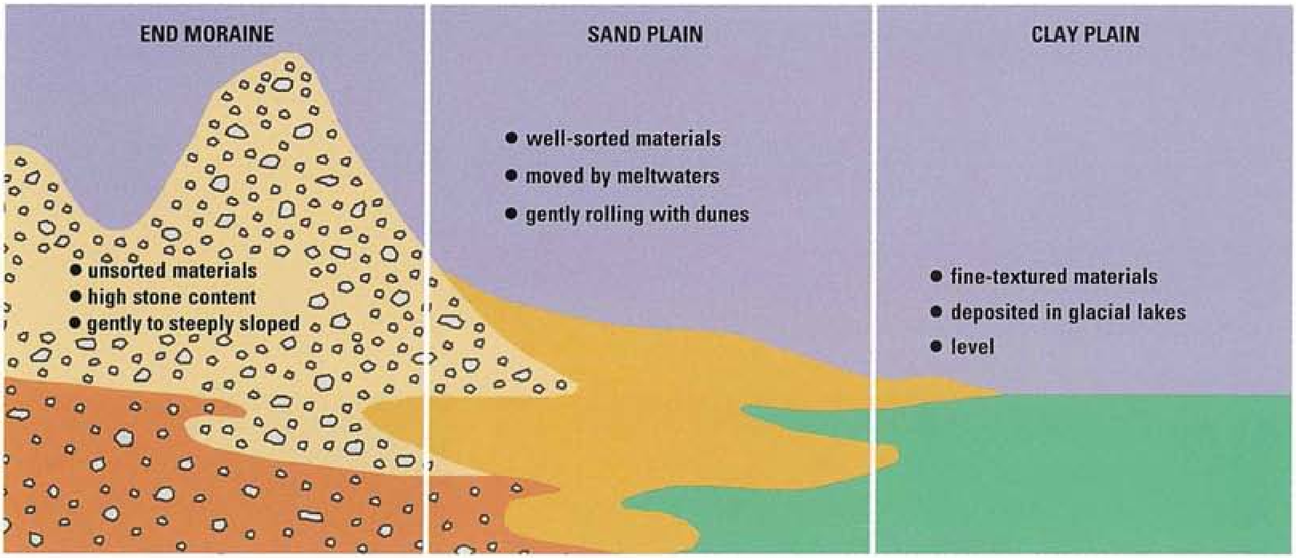
Most shallow over bedrock soils are too shallow for cultivation and for rooting of high-value crops. ***(Farmington loam, Lanark County)***



Muck soils have a naturally high water table. Tile drainage is essential for economic agricultural production. ***(Pelee Marsh, Leamington area)***

Till-plain soils are deep, loamy, and have good internal drainage. This makes them suitable for crop production, yet prone to erosion by water. ***(Guelph loam, Wellington County)***

	SHALLOW OVER BEDROCK	MUCK SOILS	TILL PLAINS
SOIL MATERIALS	sands to clays – mostly loams	poorly decomposed (fibric); highy decomposed (humic)	sandy loams to clay loams; some stone content
RISK OF: water erosion	high	moderate	high
wind erosion	moderate	high	moderate
compaction	moderate	low	moderate
ground water contamination	very high	high	moderate
surface runoff	high	moderate	moderate to high



The hilly terrain and stoniness of end moraines make them suitable for pasture-forage-small grain rotations or forest management. *(Pike Lake loam, Grey County)*

Fruits, vegetables, and other horticultural / specialty crops (e.g. tobacco) are grown on sand plains. *(Granby sand from Haldimand-Norfolk)*

With tile drainage, Ontario's stone-free clay plains are used for forages and field crops. *(Napanee clay from Lennox and Addington County)*

High stone content and shallow depths to unweathered, high-lime parent materials make end moraine soils too droughty and infertile for sustained crop production. *(Dummer loam, Peterborough County)*

Some of the soils in sand plains, like this one, have clay-enriched layers at depths of 50 to 100 cm. These layers are crucial for improving the available water for high-value crops. *(Fox sand, Brant County)*

The soils of clay plains have slow internal drainage and naturally high soil water tables – the grey colours and rust-coloured flecks are evidence of this. *(Brookston clay, Kent County)*

END MORAINES	SAND PLAINS	CLAY PLAINS
sandy loams and loams; very stony and gravelly	sands, loamy sands; stone-free	clays, clay loams, silt loams; stone-free
high	low to moderate	low to moderate
moderate	high to very high	low
low to moderate	low	high
high	high to very high	low
moderate to high	low	low to moderate

UNDERSTANDING THE BASICS

The laboratory method relies on the fact that heavier particles such as sand drop out of suspension more quickly. Here are some sample figures from a Soil Analysis Report:

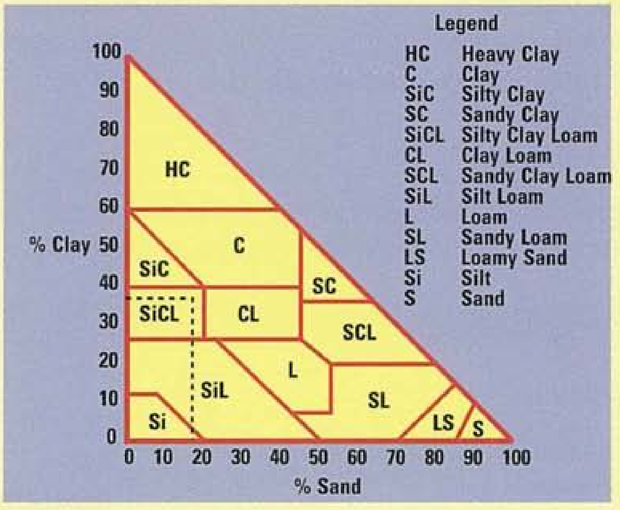
SAND 18.2% SILT 44.7% CLAY 38.0%

Results from the laboratory (i.e. percentage sand and clay) must be plotted on a textural triangle to determine soil class.

To use the triangle, start by finding one of the percent figures along that axis, then draw a line at right angles to the axis, e.g. clay 38.0%

Using the percent sand axis, find the percent figure e.g. sand 18.2%, again drawing a line at right angles to the axis.

The point where the lines cross is the soil textural class for that soil. Shown here is a silty clay loam.

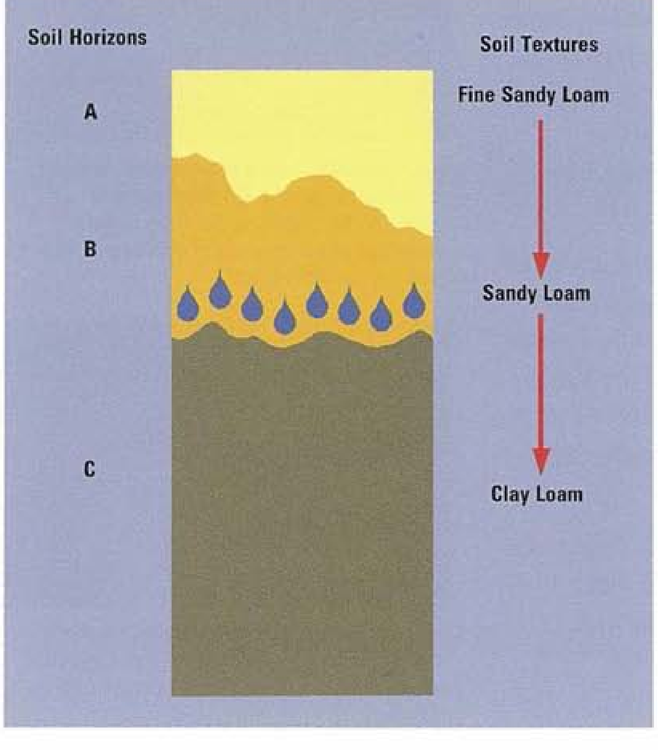


TEXTURAL LAYERS

Within some fields, the soil surface texture can be highly variable. This is also true of the subsoil. Because of the manner in which our soils were deposited and formed, layers of different textures are often present. This means that the subsoil can be an entirely different texture from the topsoil.

This can be seen easily during tile installation or along ditches. Refer to your county soil report.

INFLUENCE OF TEXTURAL LAYERS ON WATER MOVEMENT



Textural layers can play an important role in the drainage and water-holding abilities of a soil. Perched water tables are the result of textural layers – a layer of coarser-textured soil (e.g. sandy loam) over a finer one (clay loam in this example). Berrien sands and sand loams look somewhat like this.

UNDERSTANDING THE BASICS

SOIL STRUCTURE

Soil structure refers to how textural particles (sand, silt, and clay) are arranged into clumps or aggregates. The aggregates are bound together by clay and organic matter.

Soil structure can be considered in terms of form, stability, and strength.

The Brookston clay is one of the most common soil types (series) found in Southwestern Ontario. This particular sample is from a woodlot – note the fine, granular shape of the aggregates.

STRUCTURAL FORM

Structural form refers to:

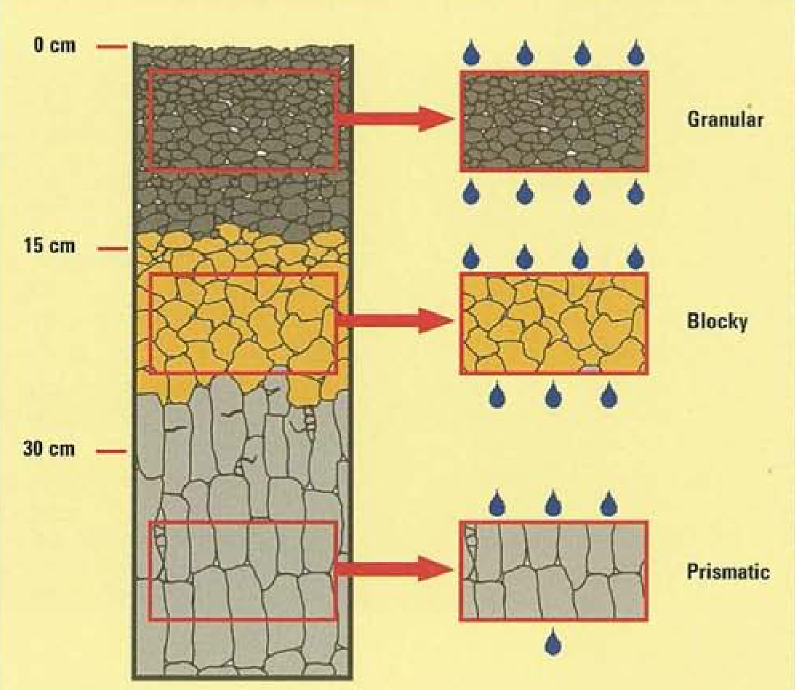
- the size and shape of the aggregates
- the network of pores or open spaces between and within the aggregates.

Many factors influence the size and shape of soil aggregates. These factors have the greatest influence in the topsoil layer, where there's usually a mixture of granular and blocky structures. The structure of the subsoil is more stable and the aggregates tend to be larger.

Structure affects:

- drainage
- infiltration
- aeration
- root growth
- germination.

STRUCTURAL FORMS — WITH DEPTH AND DRAINAGE



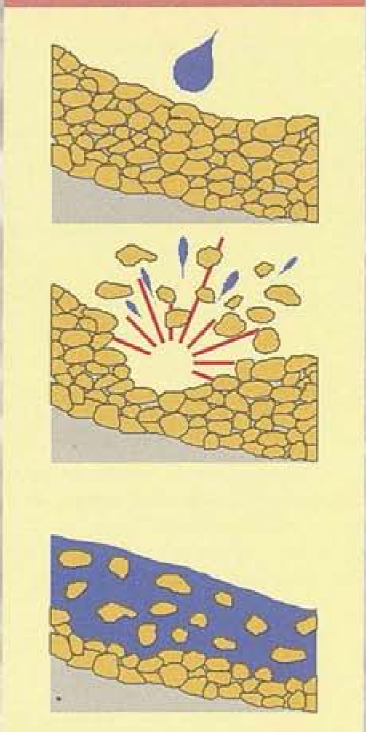
This diagram shows how structure can change with depth in a clay loam soil. The fine granular aggregates form a suitable seedbed and allow the free movement of air and water. Blocky aggregates are usually seen below the granular level and comprise the rest of the topsoil or A horizon.

Prismatic structures appear in the subsoil. This soil is usually more dense, hence water moves through this area more slowly.

In intensively managed soils, platy structures can also be seen (see disk pan, page 34). Platy structures slow the downward movement of water in soil.

UNDERSTANDING THE BASICS

RAINDROP IMPACT



Raindrops may feel gentle, but to a soil surface they can be like small bombs, breaking apart aggregates.

STRUCTURAL STABILITY AND STRENGTH

Structural stability refers to:

- the ability of the soil to maintain its structural form when subjected to stresses such as tillage, traffic, and climate.

CONTINUOUS CORN SOIL

WOODLOT SOIL

To illustrate soil stability, water was added to two petri dishes, with aggregates from a Brookston clay. One contained a soil sample from a woodlot (right); the other had soil from a field that had been continuously cropped to corn for 30 years. The continuous corn is unstable (i.e. it breaks apart), while the woodlot soil is strongly held together.

Here are the factors that affect soil aggregate formation and stability:

FACTOR	EFFECT
WETTING AND DRYING	• deep cracks that form during summer dry weather help to break down large clods and improve drainage and root penetration on heavy clay soils
FREEZING AND THAWING	• these encourage breakdown of large clods into smaller aggregates suitable for seedbed preparation
PLANT ROOT GROWTH	• roots penetrate weak areas in large aggregates and exert pressure to expand existing pores • roots and the substances they secrete help soil particles bind together
TILLAGE	• tillage reduces the size of soil aggregates
EARTHWORMS AND OTHER SOIL LIFE	• soil structural stability is improved when topsoil has passed through worm gut • fungae and other soil life help to stabilize soil aggregates

UNDERSTANDING THE BASICS

Soil scientists and farmers often talk about the **strength** of the soil. Soil strength refers to:

- the amount of energy that's required to break apart aggregrates or move implements through soil.

Soil strength is influenced by a number of factors:

FACTOR	EFFECT
SOIL WATER CONTENT	• as soils become drier, soil strength increases and more force is required to break down aggregrates
TEXTURE	• finer-textured, more dense soils (clays) stick together more than sands
STRUCTURE	• small, firm, granular aggregates are more easily tilled than large solid slabs.

You'll often find that a soil with poor structure is "tighter", which can interfere with root penetration and with tillage practices.

SOIL POROSITY

Soil porosity refers to the amount of pore space within the soil. **Soil pores** are the open spaces between and within aggregates, and are filled with air or water.

Soil pores play a vital role in the movement of air and water, as well as the growth of plant root systems.

Pores that are visible to the human eye permit water to pass and roots to move through, as long as the pores are continuous or connected.

There's also a network of smaller pores that can't be seen. They're important for the storage of plant-available water. Air and water move slowly through these micropores. For optimum plant growth, a mixture of large and small pores is necessary.

Note the roots and root hairs growing along the surface of this aggregate. Roots take the path of least resistance when soil strength is too great.

Penetrometers are used to estimate soil strength and to look at the different responses in experimental treatments. Penetrometers give a good estimate if used properly, although a flexible tile probe works just as well, particularly in farm fields. See "Detecting Compaction", page 36.

UNDERSTANDING THE BASICS

A plow layer in a no-till soil will usually have a bulk density that can be up to 20% higher than a moldboard plow layer.

The bulk density of the subsoil will be higher, depending on how it was deposited and the texture. For example, the subsoil density of a Guelph loam can be as high as 1.7 g/cm^3.

Ontario research suggests that the soil structural improvements generated by three years of a forage crop (e.g. hay) can be lost during one year of corn production with intensive tillage practices.

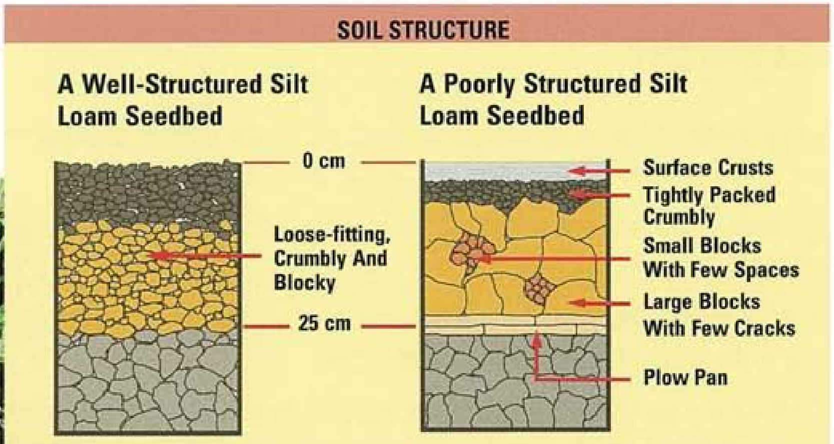
BULK DENSITY

An estimate of total porosity can be determined by measuring the bulk density of the soil. Bulk density is expressed as grams of soil per cubic centimetre.

A plow layer that has a density of 1.33 g/cm^3 will have a total porosity of 50%. This means that half the soil volume is available for occupation by water and air. As soils become more compacted, the bulk density will increase, meaning the porosity will decrease. The result is considerably less volume for water and air.

Soil is often tilled to loosen it or to create some structure in poorly structured soils. Tillage does "fluff" or increase the space between aggregates. However, excessive tillage also breaks down aggregates and increases the rate of organic matter loss.

Aggregates are altered by tillage. No-till and hay-pasture systems help to build stable aggregates, because they leave crop roots intact, increase biological activity, provide residue cover to protect the soil surface from weather, and leave undisturbed continuous pores such as worm holes and old root channels.



Poorly structured soils may have two common problems: compaction and crusting. Compare the "ideal" structure on the left with the crusted surface and compacted plow layer on the right. Note the changes in aggregate and pore sizes and arrangements.

Cropping and tillage practices affect soil structure. Note the granular structure of this sandy loam with grass hay (left), as opposed to the block structure of the same soil under edible beans (right).

UNDERSTANDING THE BASICS

SOIL ORGANIC MATTER

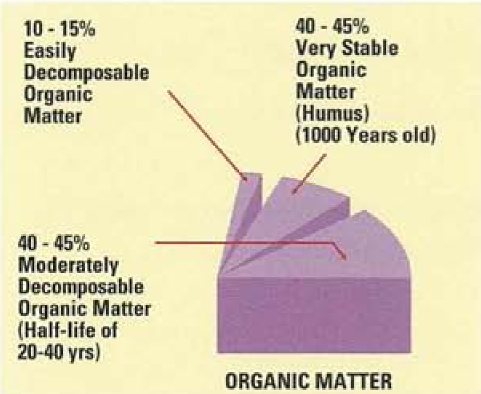
Of all the components that make up our soil, **organic matter** is the most important. Organic matter:

- ▸ plays a major role in moisture retention, helping crops withstand drought
- ▸ contributes to the chemical and biological properties of the soil
  - ▹ is a source of and exchange site for nutrients
  - ▹ affects the fate of applied pesticide
- ▸ contributes to the physical properties of the soil
  - ▹ organic matter provides glue-like substances that act to stick individual particles together to form stable aggregates and good soil structure.

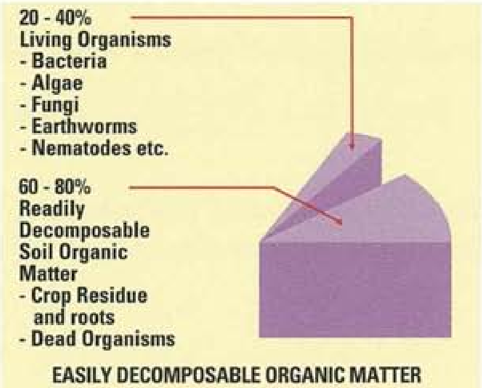
EFFECT OF SOIL ORGANIC MATTER ON SOIL TYPES AND STRUCTURAL PROBLEMS

SOIL TYPE	CRUSTING	INFILTRATION / DRAINAGE	COMPACTION	ERODIBILITY	WATER-HOLDING CAPACITY
SAND	🟥	🟩	🟥🟥	🟥🟥	🟩🟩🟩
MEDIUM (loam)	🟥🟥	🟩🟩	🟥🟥	🟥🟥🟥	🟩🟩
CLAY	🟥🟥🟥	🟩🟩🟩	🟥🟥	🟥🟥	🟩

🟥 decreases 🟩 increases



ORGANIC MATTER



EASILY DECOMPOSABLE ORGANIC MATTER

An understanding of organic matter and its forms within soil is helpful when considering soil management techniques. There are three pools of organic matter in soil:

- ▸ **40 to 45% is very stable and with an age in the thousands of years (Humus)**
- ▸ **40 to 45% is moderately stable with a half-life in the range of 20 to 40 years**
  - ▹ **this portion is protected or held within soil clods and on clay particles**
- ▸ **the remaining 10 to 15% is easily decomposable material, and is composed of living and dead organisms.**

Dense, fibrous root systems encourage the development of stable, granular aggregates. These help form the type of seedbed that's resistant to crusting. Try to include grasses and forages in your rotation.

UNDERSTANDING THE BASICS

Field corn cannot be matched for residue returned to the soil – or can it? Consider a recent study comparing the soil structure created under field corn and bromegrass.

Of the two crops, bromegrass produced a more stable soil structure. It produced 2 times more root exudates or organic compounds that bind soil particles and feed soil life.

The study also suggested that the material produced by the bromegrass was of higher quality and more attractive to various forms of soil life.

Soil aggregate stability and porosity are directly affected by soil organic matter content. This is then observed as less crusting, better water infiltration and drainage, reduced compaction and erodibility, and an improved water-holding capacity.

Crops and other plants vary in their ability to influence aggregate formation and stability:

- ▶ long-term crops with dense fibrous root systems help to form water-stable aggregates, e.g. forage grasses and legumes
- ▶ row crops such as corn, soybeans, or vegetables have relatively sparse root systems.

BUILDING ORGANIC MATTER (A CALCULATION)

Soil organic matter is measured in the top 15 centimetres or to plow depth. This "hectare/furrow slice" weighs about 2,000,000 kilograms. Thus, 1% organic matter equates to 20,000 kilograms.

	Crop Residue kg/ha
Corn Stover	5,400-7,200
Wheat Straw	1,800-3,600
Plowdown Clover	2,700-4,500
Soybean Residue	1,400-2,200

Common Cover Crops*	Dry Matter kg/ha
Oats	1,000-5,500
Rye	1,000-4,000
Oilseed Radish	2,000-7,500

* dry matter production depends on a number of factors related to plant growth.

In a best case scenario, only 20% of any residue returned to the soil will make it to the organic matter pool. The remaining 80% becomes part of living organisms, is released as gases during digestion, or has not become part of the organic matter flow.

It takes 5 kilograms of residue to make 1 kilogram of organic matter.

$$20{,}000 \text{ kg O.M.} \times \frac{5 \text{ kg residue}}{1 \text{ kg O.M.}} = 100{,}000 \text{ kg residue (1\% O.M. increase)}$$

Thus, it requires 100,000 kilograms of crop residue to raise the soil organic matter 1%. Assuming an average residue return of 5,000 kilograms from the above table:

$$\frac{100{,}000 \text{ kg residue}}{5{,}000 \text{ kg residue/y}} = 20 \text{ yrs}$$

UNDERSTANDING THE BASICS

It would take 20 years to build the organic matter by 1% (provided that the soil was never worked to speed up decomposition). But don't despair! It may be a slow process, but it's possible to improve over time. Cover crops and manure certainly help.

Work to either improve or at least maintain organic matter. If you do nothing and continue cropping, your organic matter levels will continue to drop.

Organic matter levels vary across fields in response to soil texture and slope position. For example:

	LOCATION	CULTIVATED ORGANIC MATTER	WOODED ORGANIC MATTER
Sand Middlesex Co.	Knoll Depression or low area	2.0% 5.8%	7.0% 20.0%

As you can see, erosion and tillage have taken their toll on organic matter. The depression (or deposition area) has retained much higher levels.

In contrast with the sand soil illustrated above, clay soils typically have higher organic matter levels, probably due to the greater aeration and organic matter loss in sand soils.

WOODLOT – 21% ORGANIC MATTER

CONTINUOUS CORN – 3.8% ORGANIC MATTER

PERMANENT SOD – 7.1% ORGANIC MATTER

Management and crop rotation directly influence soil organic matter levels. Crop rotations that involve a variety of crops, including forages and grasses, help to maintain and build organic matter levels.

A long-term experiment with clay soils illustrates this. Soil colour and structure indicate the soil organic matter level: woodlot, 21%; plowed, continuous corn, 3.8%; and permanent sod, 7.1%. (The apparent darker colour of the continuous corn soil is due to slightly higher soil moisture at time of photo.)

UNDERSTANDING THE BASICS

Earthworms are one of the first visible signs of soil improvement under no-till. Well-managed soils under conventional soils can also have large worm populations. However, under no-till systems the worm burrows are not disturbed. These continuous macropores help to improve water infiltration.

SOIL WATER AND AIR

Soil water and air play vital roles in plant growth, as we'll see in this section.

SOIL WATER

As soil moistens from rainfall or irrigation, the soil eventually reaches a point where it can't hold any more water, and any excess drains away freely. The soil moisture content after the excess water has drained is known as **field capacity.**

As more and more moisture is taken out of the soil by plant roots, eventually it becomes very difficult for the plant to remove any more water and the plant starts to wilt. The **permanent wilting point** is the soil mosture content at which plants will not recover from wilting.

The difference between field capacity and permanent wilting point is the **available water-holding capacity** or the moisture available for plant growth.

SOIL TYPE	mm OF WATER AVAILABILITY IN A METRE OF SOIL	
	AT FIELD CAPACITY	AVAILABLE TO PLANTS
SAND	100	75
SILT LOAM	267	167
LOAM	283	167
CLAY LOAM	317	167
CLAY	325	117

The available water in a soil varies, depending on texture, structure, and soil depth. These concepts are important in water management for irrigation and can help to explain some differences in field performance under identical conditions.

UNDERSTANDING THE BASICS

The **drainage** of water through the soil depends on the continuity of large pores and channels. Drainage can be influenced by structural layers as well as other layers of different permeability (texture, buried crop residues).

For more information on drainage, see the Best Management Practices booklet, *Water Management*. *Field Crop Production*, *Horticultural Crops* and *Irrigation Management* address crop and field management in greater detail.

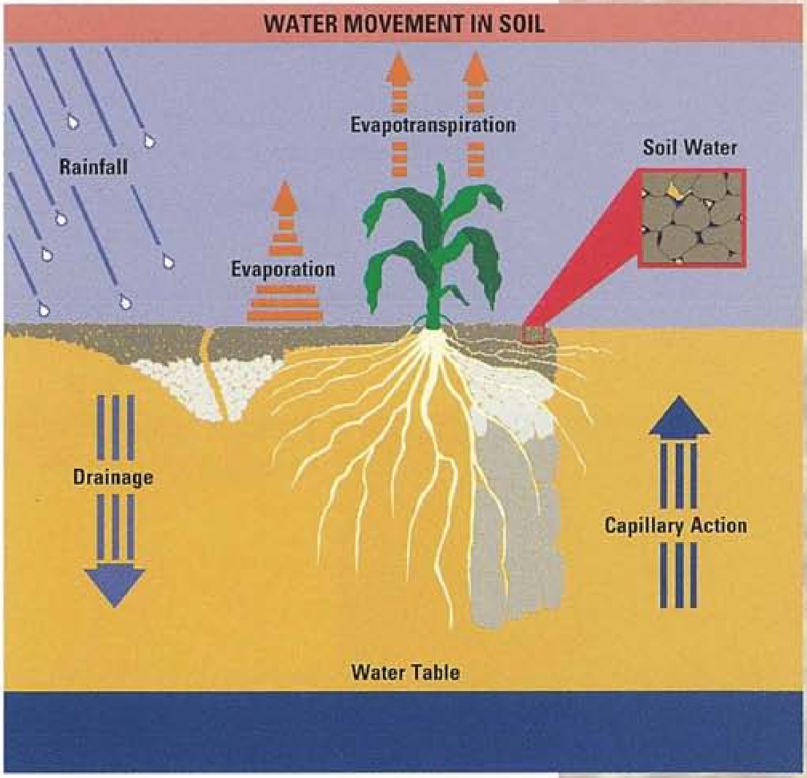
Once the water has drained, there's still some water movement called **capillary water movement**. This includes water drawn upward from the water table through very narrow cracks and pores. Capillary water can play an important role during dry weather in loams and clays.

Ontario has more **precipitation** during the cold months of late fall, winter, and early spring than there is moisture loss due to **evaporation** or **plant transpiration.** This net gain of moisture replaces the moisture used during the growing season, and replenishes ground water.

Sometimes there's a moisture deficit during the growing season, usually during the months of July and August. You can employ a number of cropping practices and soil management options to reduce the impact of the moisture deficit. See the "Droughty Soils" section on page 48 for more information.

Water can be lost from soil through evaporation from wet soil and from transpiration from plant leaves. Transpiration is the major source of water loss from soils.

There has been talk in recent years of using plants (particularly living cover crops) as a "bio-pump" to remove moisture from heavy soils for early planting. Transpiration is reduced in saturated soils, so it isn't effective when the soil is at its wettest. But it can dry a soil that is close to or at a workable moisture level. All the answers are not in: this is a recent innovation and requires further testing.



Water movement in soil occurs in a number of ways. Evaporation and evapotranspiration remove water, while rainfall replenishes soil water. Water drains through the soil; capillary water movement carries water upward.

UNDERSTANDING THE BASICS

SOIL AIR

Anaerobic conditions stop plant root growth and can kill plant roots and whole plants due to the toxic substances formed by anaerobic bacteria.

Soil air or **soil aeration** refers to:

- the amount and ease of air movement in the soil.

Roots and soil organisms need oxygen and also give off carbon dioxide as part of respiration. There needs to be a constant exchange of air and carbon dioxide in the soil, or else the oxygen will be depleted and the area will become anaerobic (no oxygen). Plant roots need air to be healthy.

Soil aeration decreases as the amount of water increases. As pores become filled with water, the air is forced out. Air moves primarily through the macropores.

Higher clay-content soils tend to have more pores that are smaller, and do not lend themselves to air movement.

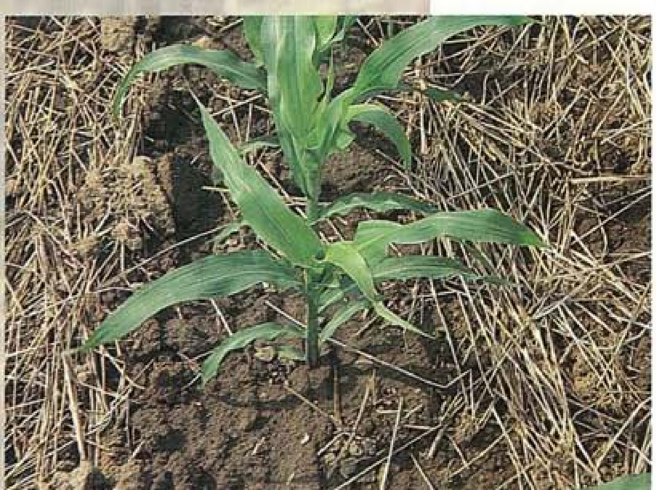
SOIL TEMPERATURE

The temperature of the soil follows the temperature of the air, but with a time lag. As you go deeper in the soil, air temperature has less effect on soil temperature.

Although air temperature has a great influence on soil temperature, there are other factors at play.

Water content affects the rate of temperature change. More heat is needed to warm a wet soil than a dry one. Evaporation is occurring simultaneously, absorbing heat and keeping the soil cool.

Sunshine also affects soil temperature. Any shading, i.e. clouds, weeds, or residue, will reduce the transfer of energy to and from soil.



Dark soils absorb more heat; light-coloured residues tend to reflect heat, causing soils to warm more slowly.

UNDERSTANDING THE BASICS

Frost occurs when the temperature at the soil surface drops below the freezing point. Most spring frosts are associated with rapid cooling of the soil under very clear, still conditions. The temperature at the soil surface can be 4-5° C cooler than the air 1.5 metres above. The amount of cooling at the surface under these conditions depends on how warm the soil is to start with, and how quickly heat can move out of the soil.

We often see crop damage from frost in fields that have been freshly cultivated, because cultivation creates an insulating zone of fluffy, dry soil at the soil surface. This zone blocks the movement of heat out of the soil, allowing temperatures to drop low enough to cause crop damage, while adjacent areas that weren't cultivated are not damaged.

Heavy crop residue can also increase crop damage from frost by insulating the soil and preventing the release of stored heat. Sunshine and soil water content play major roles in determining the amount of heat stored.

Frost heaving occurs when water freezes in the soil. This can wreak havoc with deep-rooted crops like alfalfa. However, frost heaving can help to build soil structure, and can break up shallow, compacted layers in soil.

Wet or poorly drained soils are often called "cold-bottomed" because the soil takes longer to warm up in the spring. Soils that drain quickly such as sands will warm quickly. But they also give off the heat more quickly and so can be more frost-prone.

UNDERSTANDING THE BASICS

SOIL CHEMICAL PROPERTIES

To understand soil management, you need to know a little about the chemical aspects of the soil, such as soil pH, cation exchange capacity, and chemical properties of soil organic matter.

For a more detailed discussion of soil chemical properties, see the Best Management Practices booklet, *Nutrient Management*.

SOIL PH

Soil **pH** refers to the level of acidity in a soil. The pH is a measure of the number of hydrogen (H^+) ions that are in the soil.

The pH is recorded on a logarithmic scale that goes from 0 to 14. A pH of 7.0 is considered to be neutral. The higher the number, the less acidic or more alkaline the soil; the lower the number, the more acidic the soil. With a logarithmic scale, a pH of 6.0 is 10 times more acidic than a pH of 7.0, while a pH of 5.0 is 100 times more acidic than a pH of 7.0.

Poor crop growth is common in soils with a low pH.

Soil pH influences how efficiently a crop grows in a soil by affecting:

- nutrient availability (and potential toxicity)
- microorganism activity
- disease organism activity
- potential crop damage by some herbicides.

Most crops in Ontario grow best in soils that have a pH ranging from 6.0 to 8.0. Agricultural practices tend to lower the pH of soils over time, making them more acidic. This is the result of a number of activities:

- crops and plants removing nutrients
- leaching or water flow through the soil, removing nutrients
- decomposition of organic materials
- fertilizer application, particularly banded ammonium fertilizers
- acid rain.

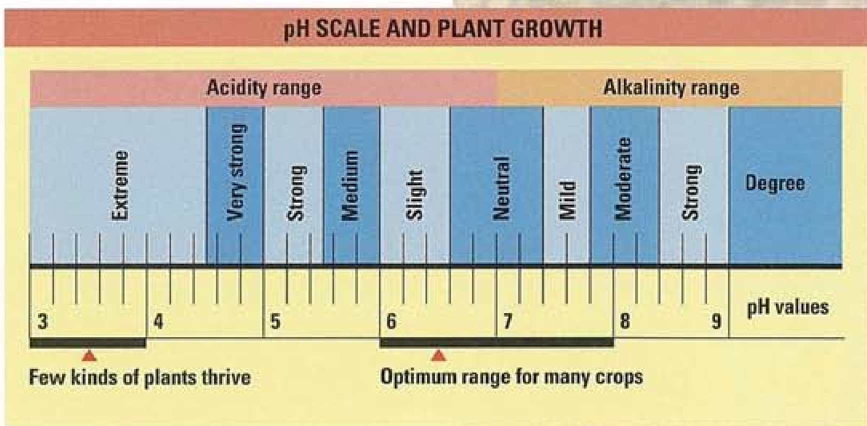
Eventually, the drop in pH will become great enough to affect crop growth and yield, and you'll have to take steps to raise the pH. Soil pH can be raised using agricultural lime. Ontario Ministry of Agriculture, Food and Rural Affairs *Publication 296, Field Crop Recommendations for Ontario* gives the current liming recommendations with some discussion of lime quality.

Not all soils become acidic. In areas with alkaline (calcareous) subsoils, tillage practices tend to raise the pH. This is due to dilution with subsoil as a result of tilling too deep, tillage erosion, and wind and water erosion.

UNDERSTANDING THE BASICS

Soil pH should be tested regularly, as part of your normal soil testing program. Regularly soil test fields to which large amounts of nitrogen are being applied to monitor changes in soil pH.

Some plants need highly acidic conditions to grow, such as blueberries, rhododendrons, and chestnuts. In some instances it may be necessary to lower the soil pH. For example, to grow blueberries effectively, a pH of 5.0 or less is required. You can lower soil pH through the application of elemental sulphur. However, if the soil pH is high (above 6.5), this can be extremely expensive.



CATION EXCHANGE CAPACITY

The **cation exchange capacity** is a measure of the capacity of the soil to hold some nutrients. It plays a role in soil fertility.

As soil minerals weather, **cations** are released into the soil water or solution. Cations are positively charged elements such as calcium, magnesium, hydrogen, and potassium (among others). These cations are attracted to the negatively charged surfaces of clay and organic matter particles. There's a constant exchange of cations between these surfaces and the soil water, called **cation exchange**. Cations aren't held tightly to these surfaces. Water can't remove them; however, they can be removed by changing places with cations discharged from plant roots.

The cations held on the organic matter and clay surfaces act as a reserve of nutrients, continually resupplying the soil solution with nutrients required by plants.

The size of the cation exchange capacity depends on the kind and amount of suitable surfaces for the cations to attach to. Organic matter supplies a much greater number of exchange sites for the cations than clay particles.

A high cation exchange capacity is desirable, because it indicates a fertile and resilient soil. However, the cation exchange capacity of a soil doesn't tell the whole fertility story – only the cation portion. That's why the Ontario system of fertility recommendation isn't based on cation exchange capacity.

High cation exchange capacities are associated with high clay contents and high organic matter levels. **For sandy and loamy soils, it's not easy to change clay content. However, organic matter levels can be maintained and improved to enhance cation exchange capacity. Follow the best management practices for soil structure and organic matter.**

UNDERSTANDING THE BASICS

Here are some examples of soil texture and cation exchange capacity:

SOIL TEXTURE	ORGANIC MATTER %	CLAY %	CATION EXCHANGE CAPACITY cmole (+) kg
SAND	1.7	7	6.3
SANDY LOAM	3.2	13.2	13.7
LOAM	4.9	16.8	20.2
SILT LOAM	5.4	18.4	24.0
CLAY LOAM	5.5	31.2	27.2
ORGANIC MATTER	100	—	100 - 300

NB: The cation exchange capacity of a soil is expressed in terms of centimoles of (+) charge per kilogram of soil. What's important here are the relative numbers as the clay and organic matter content increases.

SOIL ORGANIC MATTER

Soil organic matter acts like a bank for many essential plant nutrients, by:

- providing exchange sites for cations such as potassium and magnesium
- releasing nitrogen during breakdown
- providing virtually all of the manganese and boron that crops require throughout the growing season.

If you've ever taken out an old fencerow to make a larger field, you'll know that the fencerow produces tremendous crops during the first few years in production. This is attributable to organic matter, both in nutrient release and soil structure.

The benefits of organic matter to soil structure, coupled with increased nutrient release, explain the dramatic yields. Tillage promotes greater aeration of the soil, which increases the breakdown of organic matter and releases a large quantity of nutrients to support the following crop. In fact, this bank of nutrients is what many farmers relied upon to sustain crop production before the advent of commercial fertilizers.

Unfortunately, tillage also reduces the level of organic matter over time to the point that it may become difficult to maintain good soil structure, and increased additions of fertilizer are required.

UNDERSTANDING THE BASICS

SOIL BIOLOGICAL PROPERTIES

Soil structure is greatly affected by the animals and microbes in the soil. For example, the chemical and physical nature of the soil is changed as it passes through the intestines of worms. Soil animals and microbes can directly impact the availability of certain nutrients.

There are more organisms in a teaspoon of topsoil than there are people on Earth. Soil organisms are an intimate part of the organic fraction of soil, and contribute significantly to soil fertility and soil structure.

Plant residues have little value in the form we return them to the soil. The soil organisms, whether large (macro) or small (micro), feed on this residue and break it down in a continuous process.

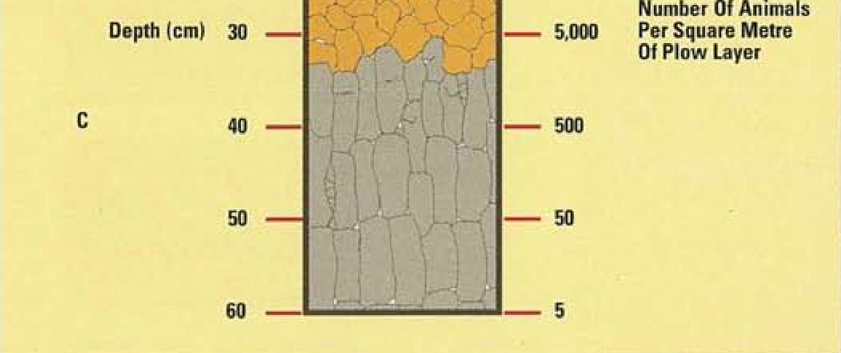
Virtually all topsoil has passed through the gut of soil animals. Although we might think of burrowing animals such as groundhogs, moles, and shrews as having a large impact on soil because they are relatively visible, they are far less important to soil processes than the much more numerous, tiny animals and microbes.

The living organisms of soils can be divided into two broad categories:

- ▶ microorganisms
  - ▷ includes fungi, bacteria, actinomycetes and algae
- ▶ macroorganisms
  - ▷ includes protozoa, nematodes, earthworms, arthropods (insects, spiders, etc.), and rodents.

There may be billions of protozoans (one-celled animals) and bacteria, tens of millions of nematodes, and hundreds of thousands of mites in a square metre of plow layer.

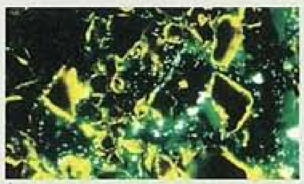
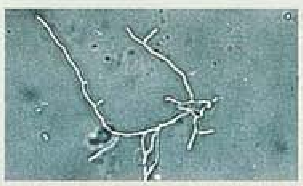
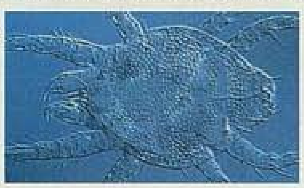
DISTRIBUTION OF SOIL LIFE



The animals and microbes are not evenly distributed throughout the soil. Their numbers shrink very rapidly as we move below a few centimetres deep in the topsoil, and most of them seem to gather around plant roots and earthworm burrows.

UNDERSTANDING THE BASICS

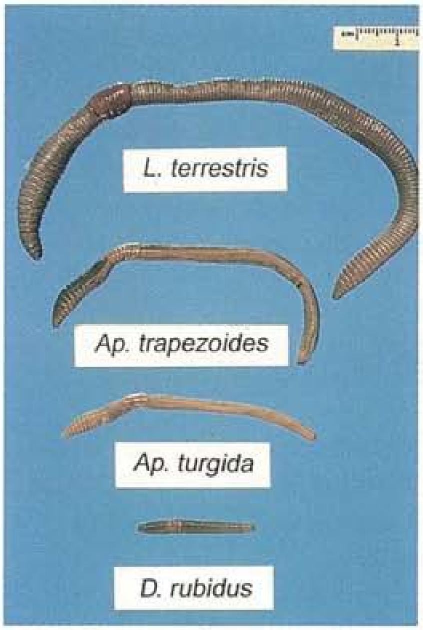
SOIL ORGANISMS

TYPE			IMPORTANCE
MICROORGANISMS	FUNGI		• after plant roots, they make up the largest amount of living material in the soil • help make soil nutrients available to plants • intolerant of intensive tillage • greatly involved in decomposition of organic matter
	BACTERIA		• important for good soil quality and fertility • N-fixing bacteria are particularly important and are associated with N-fixing plants such as soybeans, peas, clover, and alfalfa
	ACTINO-MYCETES		• decompose organic matter • abundant in low pH, droughty soils
	ALGAE		• decompose organic matter • commonly found in poorly drained soils
MACROORGANISMS	ARTHROPODS e.g. mite, spider, beetle		• graze on bacteria and fungi or decomposing plant materials • help to accelerate microbial decomposition
	EARTHWORMS		• burrow extensively, creating macropores and mixing soil • reduce bulk density • improve air and water infiltration • improve soil structure • increase nutrient pool
	RODENTS e.g. mice, groundhogs, muskrats, chipmunks		• pass organic materials through their gut when they burrow and feed in the soil • deposit fecal pellets rich in nutrients such as N, P, and K

Bacteria photo courtesy of H-J Altemuller FAL Braunschweig

UNDERSTANDING THE BASICS

EARTHWORMS AND ONTARIO SOILS



Smaller earthworms play an important role in organic matter cycling. They live within the top 4-8 centimetres, while the much larger dew worm can burrow 1-2 metres deep.

Earthworms are common in fine- and medium-textured soils (clays and loams), but rare in coarse-textured soils (sands). You can see this in a soil landscape where worms are rare on the sandy ridges, but abundant in depressional areas where fine soils, organic matter, and water accumulate.

One species, the **dew worm** or **Canadian Nightcrawler** (Lumbricus terrestris), is very abundant and widely recognized by most people. It's the species that's harvested from golfcourses, parks, and pastures. Hundreds of millions are annually exported to the USA for fishing bait.

Earthworm populations will dramatically increase in number:

- ▶ over two or three years when fields are converted to no-till or forages
- ▶ from regular manure applications
  - ▷ especially if conservation or no-till techniques are used.

WORMS AND GULLS

Studies have shown that gulls account for the death of only about 5% of the earthworms, while plowing can kill as many as 25% of the population. Many of the worms that gulls take are damaged by plowing and would die anyway. Gulls may also be feeding on soil insects.

EARTHWORMS

What are earthworms worth to you? Beyond the obvious soil benefits, earthworms are big business. Per thousand earthworms, pickers get \$15-\$20, wholesalers get \$40-\$50, and bait shops get \$1.70 to \$2 per dozen.

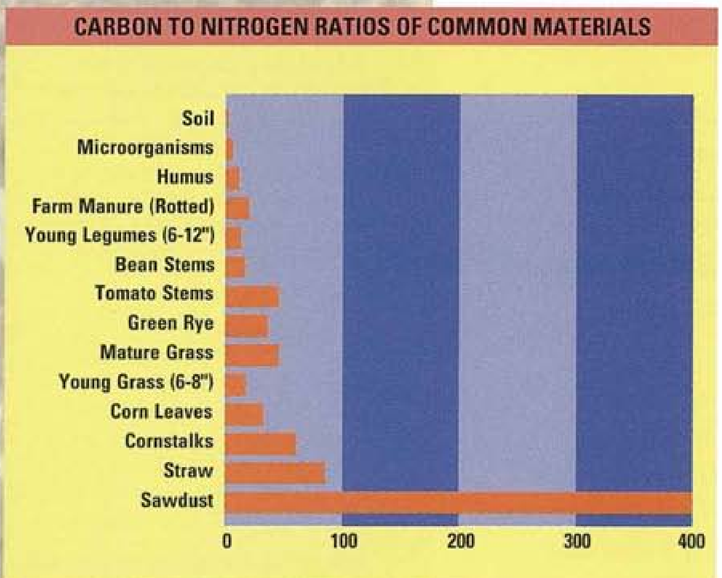
A field rich in earthworms can yield 100,000-150,000 worms/acre annually. Be aware of your worm population if negotiating with worm pickers. Don't be shortchanged!

THE CARBON AND NITROGEN CYCLES AND C:N RATIOS

Most soil organisms are involved in breaking down plant material (and other soil organisms) in different stages of decay to more readily available plant nutrients or more stable forms of organic matter.

We call this the **carbon cycle**. It's the single most important element cycle in soil. It converts some of the annual growth of plants (crop residues) into soil organic matter that can be recycled for more plant growth.

UNDERSTANDING THE BASICS



When materials with high C:N ratios are added to the soil, microorganisms will tie up nitrogen. This creates a risk that nitrogen may not be available when a crop needs it.

A measure of the interaction of carbon and nitrogen is the **C:N ratio**. This number gives an indication of the difficulty of breakdown or **decomposition.** Usually decomposition, like plant growth, is nitrogen-limited due to too much organic matter or not enough nitrogen.

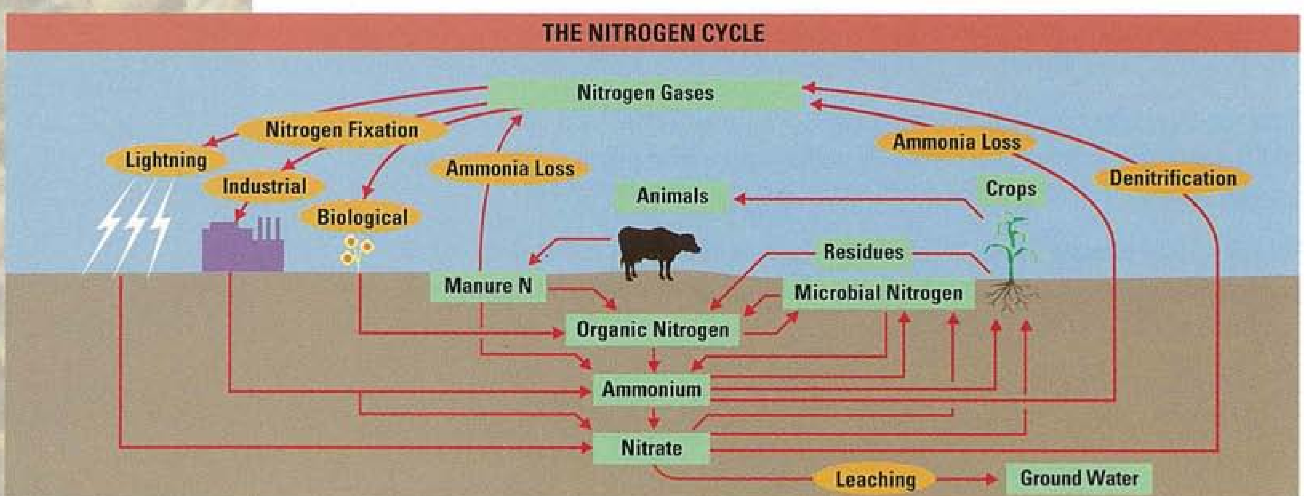
When the C:N ratio is very high (as is possible with added crop residues), nitrogen is used up by microorganisms, and the crop could become nitrogen-deficient. However, as the microorganisms die, nitrogen becomes available to either microorganisms or the crop.

SOIL ORGANISMS AND SOIL STRUCTURE

The effect of soil animals on soil structure is considerable. Topsoil is basically composed of animal feces of varying ages. Soil animals ingest organic matter and mineral components of soil, and mix them together before depositing the combined material as fecal pellets or casts.

Reduce tillage and add organic matter: this will increase soil organism populations and improve soil structure.

Highly specialized microbes, mostly bacteria, are involved in the transformation of nitrogen through the N cycle. Nitrogen is essential for plant growth and microbial activity. The rate of the decomposition is governed by the relative availability of a few key nutrients: carbon (C) and nitrogen (N). (The processes of this nutrient cycling are discussed more fully in the Best Management Practices booklet, *Nutrient Management.*)

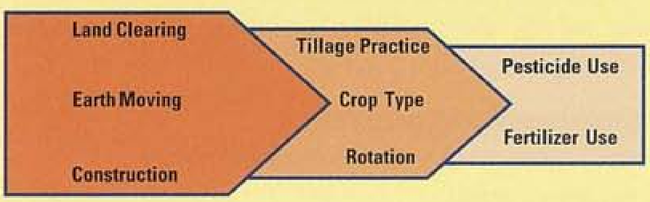


Nutrients are constantly cycling through soil, plants, and animals. The nitrogen cycle is an example of the nutrient cycling process.

UNDERSTANDING THE BASICS

IMPACT OF HUMAN ACTIVITIES ON SOIL ORGANISMS

HOW SOIL LIFE IS AFFECTED BY OUR ACTIVITIES

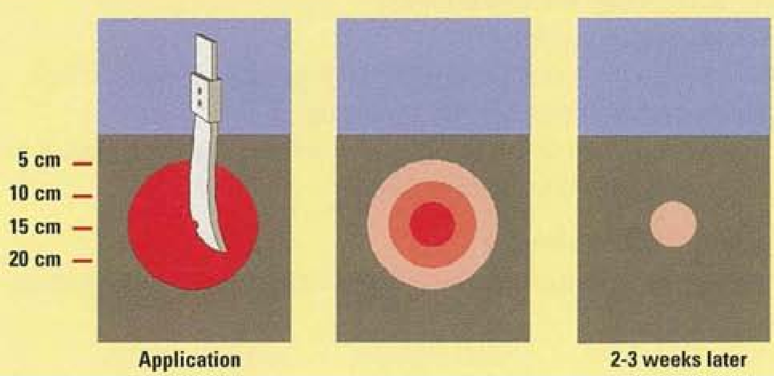


Tillage and earth moving have a much greater effect on the population of soil microorganisms and their diversity than pesticide use. Rotate crops and add organic materials such as manure when possible to increase biological activity and improve soil quality.

Pesticides have measurable but highly variable effects on soil organisms.

PESTICIDE TYPE	IMPACT
HERBICIDES	• can cause large reductions (usually temporary) of many soil organisms • less toxic than insecticides to soil animals
INSECTICIDES	• earthworms and other organisms can be very susceptible to rootworm insecticides, but the effect is limited to the zone of insecticide application
FUNGICIDES	• short-term reduction (2-3 weeks) in soil fungi populations. Benomyl fungicides are extremely toxic to earthworms and somewhat toxic to soil mites.

EFFECT OF ANHYDROUS AMMONIA ON SOIL LIFE



Anhydrous ammonia kills soil life in a small area around the applicator tooth. Soil animals move back into this zone over a period of several weeks.

FUNGAL MATS AND VAM FUNGI

The symbiotic relationship of bacteria and legume plants is well known. Researchers are just beginning to understand the role that fungi (VAM or vesicular arbusclar mycorhizzae) play.

VAM assist plant roots in obtaining nutrients from the soil by increasing the area exploited by the roots (up to 10 times the area). VAM play a significant role in low-fertility soils.

VAM in corn magnified 400 times.

Many microorganisms actually feed on pesticides: this is the primary means of pesticide breakdown.

UNDERSTANDING THE BASICS

Soil properties such as texture (surface and subsurface), organic matter, pH, etc. are intensely variable across a field. This variability is due to the original soil formation, erosion, and past and present management. Site-specific or precision management techniques are designed to measure and manage the differences across a field.

SOIL INFORMATION AND INTERPRETATIONS

Soil maps are available for most counties in Ontario. Soils are mapped based on their surface and subsoil texture, natural drainage (before tiling), stoniness, and other criteria. The amount of detail that can be included is limited, and your own experience of your farm's soils is important. Consider soil type and variability when making field management decisions about tillage, fertility, drainage, etc.

What is meant by "soil information and interpretations"?

- **soil information** refers to local (county or district) soil maps and reports
- soil maps show the extent of soil types (series)
- **soil interpretations** are suitability or risk ratings of soil types for various uses, e.g. agricultural capability and limitations for soil management, suitability for specialty crops, erosion risk, etc.

How can this information be useful for a soil management program?

- **soil maps** can help with farm planning by showing your soil types, their properties (materials, slopes, natural drainage class, stoniness), and the extent of these soils on your farm or area of concern
- **soil reports and interpretations** can help you learn more about the properties of your soils, the unseen areas of your soil (subsoil and geology), the implications for soil management, and potential environmental risks.

What are the limitations of this information?

- **scale** – most soil maps are mapped at a level of detail that is too general for intensive farm planning and development of a soil management program. Interpretations are based on experience and observation.

Soil properties within your farm can be quite variable. Often, only years of cropping a given parcel of land will reveal the extent of variability. Fortunately, soil maps give an excellent overview of the soils in your area, and are a good starting point for planning a soil management system.

How do you use the information on soil maps?

- **locate property** – use township, lots, concessions, and noticeable features like streams, woodlots, and buildings to locate property
- **list** – soil map unit symbols on property
- **soil map legend** – use legend to look up soil type and properties of interest (slope, texture, subsoil features, natural drainage), e.g. Brookston clay
- **soil report** – if you need further information about soil properties and interpretations of your soil type, look them up in the Soil Survey Report

How can you obtain soil information?

- **contact** your local office of the Ontario Ministry of Agriculture, Food and Rural Affairs.