Ontario Envirothon Study Guide

Ontario Envirothon

SOILS

This Study Guide is to be used to help Envirothon teams prepare for the Ontario Envirothon Program.

FORESTS ONTARIO

ONTARIO ENVIROTHON

Every year, more than 500,000 students, teachers and families across North America take part in the unique learning experience of Envirothon. The program engages high-school students in learning more about four main areas of the environment—soils, aquatics, wildlife and forests. Students learn in the classroom and through interactive workshops aimed at strengthening scientific knowledge of our natural ecosystems, they develop foundational skills needed to pursue studies and careers in the environmental sciences.

The program supports students in developing:

- A scientific understanding of natural ecosystems (soils, wildlife, forests, aquatics).
- Practical experience in resource management practices and technologies.
- The ability to apply scientific knowledge and creativity in developing innovative and sustainable solutions to major environmental challenges.
- Stronger communication, collaboration and problem solving skills.

North American Envirothon (NAE), a program of the National Conservation Foundation, partners with 56 provinces and states that coordinate events in which students receive training in essential resource management technologies and practices such as invasive species monitoring, habitat restoration, water and soil analysis, and forest management. Students are then tested on their ability to apply these practices.

Acknowledgements

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Contents

Learning Objectives

Overall Objectives

Students must be able to…

A. Understand and describe the physical properties of soil and the processes of soil formation
B. Understand and describe the chemical properties of soil and the chemical processes of soil formation
C. Understand and describe the biotic and abiotic characteristics and processes of soil ecosystems
D. Understand and describe practices involved in the conservation and management of healthy soil ecosystems and sustainable land use

Specific Objectives

Students must be able to…

A. Understand and describe the physical properties of soil and the processes of soil formation

1. Understand and describe soil structure in terms of three components: form, stability, and strength
2. Understand and describe how different amounts of organic matter affect and are affected by soil structure and texture
3. Identify and explain factors that influence soil temperature
4. Understand and describe the factors affecting soil formation: additions, losses, translocations and transformations

B. Understand and describe the chemical properties of soil and the chemical processes of soil formation

1. Understand and describe how soil pH affects plant growth
2. Understand and describe the cation exchange process and relate it to soil fertility
3. Identify and explain the benefits of soil organic matter to soil chemistry
4. Identify and explain the essential nutrient elements in soil and describe how they affect soil fertility

C. Understand and describe the biotic and abiotic characteristics and processes of soil ecosystems

1. Identify types of soil organisms and their functions within a soil ecosystem
2. Understand and describe the carbon cycle and the nitrogen cycle and their effects on soil chemistry and subsequent plant growth
3. Describe the effects of each type of erosion on the landscape and capability for various kinds of plant growth
4. Explain how soil composition and fertility can be altered in an ecosystem and identify the possible consequences of such changes
5. Know that plants must receive essential micronutrients and macronutrients from the soil in order to be healthy, and understand that soil fertility relates to the physical and chemical properties of the soil in addition to the quantity of nutrients

D. Understand and describe practices involved in the conservation and management of healthy soil ecosystems and sustainable land use

1. Identify the rights of Ontario's First Nations with regard to land use planning
2. Identify and describe best management practices for a variety of land uses, including agriculture and forestry, and explain why these management practices are used
3. Describe how invasive species can affect soil ecology
4. Understand and describe the effects that climate change has on soil ecology
5. Identify and describe erosion control methods (windbreaks, crop rotation, drainage, etc.)
6. Interpret a variety of laws, agreements, treaties, etc. that govern Ontario's soil ecology and land use management

7. Identify a variety of major stakeholders and agencies, including Federal, Provincial and Municipal government bodies, that provide oversight of land use and soil ecology in Ontario

Application/Analysis

Students must be able to:

1. Collect and interpret data using the following field equipment:
   - Soil triangle to determine soil class
   - Munsell soil colour chart or other colour charts
   - pH test kits or pH meters to measure soil pH
   - Soil test kits to determine preferred conditions for the growth of plants (i.e. nitrogen, phosphorus, potassium)
   - Use a soil probe and auger to extract soil samples
2. Describe and classify a soil profile using the Canadian System of Soil Classification and/or the Field Manual for Describing Soils in Ontario
3. Identify and measure soil horizons in a soil pit, photograph or sample
4. Name and map the soil orders of Canada and identify them on a map
5. Identify soil types according to textural characteristics
6. Classify soil structure according to aggregate characteristics (i.e. granular, blocky, columnar, platy, massive)
7. Relate stream velocity to sediment sorting

Evaluation/Synthesis

Students must be able to:

1. Understand how soil, water and air are interrelated
2. Use data and other observations of soils to explain prevalent vegetation in an area
3. Predict the types of soil organisms that would be found within a given soil type
4. Assess a site for evidence of erosion
5. Make recommendations on how to implement erosion control
6. Make on-site recommendations on how to improve soil quality

Tools and Apps

The following tools are recommended resources that can help you better prepare for the Envirothon program.

Envirothon Resources

Canadian Soil Classification http://www.ontarioenvirothon.on.ca/files/soil/Canadian_Soil_Classification.pdf

What Lies Beneath…Your Feet! http://www.forestsontario.ca/wp-content/uploads/2016/05/Canadian-Soil-Science-Society.pdf

Rocking in the Real Work: An Introduction to Aggregate Resources in Ontario http://www.forestsontario.ca/wp-content/uploads/2016/09/FO_AggregateResources_StudyGuide-FINAL-SM.pdf

Applications and Interactive Websites

SoilWeb: relevant only for the USDA-NRCS soil survey data. The application retrieves graphical summaries of soil classification and soil properties associated with any location in the United States.
http://websoilsurvey.sc.egov.usda.gov

Land information Ontario: make your own topographic map using Ontario data
http://www.ontario.ca/page/land-information-ontario

ArcGIS: great lesson plans and resources to introduce soils into your classroom
http://resources.arcgis.com/en/communities/soils/

Soil 4 Youth: Lesson plans and activities that challenge you to explore the world of soils
http://soilweb.landfood.ubc.ca/youth/

Canadian System of Soil Classification – in-depth information about the soils of Canada
http://sis.agr.gc.ca/cansis/taxa/cssc3/index.html

2.0 What is Soil?

2.1 The Significance of Soil

As you look around you may recognize that every object is directly, or indirectly, obtained from the soil. The clothes you are wearing may be derived from plants that once grew on soils. The road you travel on to get to school is constructed on the solid body of soil. The water you drink may be derived from clean groundwater that was filtered with the help of soils. All the agricultural, forestry, and wilderness areas in Canada would disappear entirely without the small accumulation of top soil that exists on this vast land. Clearly, soils provide for many of our basic needs.

2.1.1 Ecosystems

Different bodies of soils vary in their physical, chemical, and biological properties. Some soils are rich in **nutrients** and **organic matter**; others are thoroughly leached. Some have a high **water-holding capacity**; some allow rapid water **infiltration**. Soils also differ in age, depth, compaction, and temperature. The varying types and conditions of soils in a region are crucial in determining the species of plants and animals that can be supported in an ecosystem. Without diverse soils, the biodiversity that exists on earth would rapidly disappear.

Within the terrestrial ecosystem, all living organisms depend on soil. Trees and plants obtain water and nutrients from the soil and convert them into energy that is used by a variety of consumers, and soils serve as the structural **medium** supporting the roots of plants. Some living organisms such as bacteria, fungi, mites, earthworms, snails, and insects exist within the body of the soil. Other organisms such as turtles lay their eggs inside the soil. The interrelated web of plant and animal communities cannot exist without the soil.

2.1.2 Agriculture

Soils are often referred to as the medium of growth. Without soil, there would be no means of providing crops with the water and nutrients that are essential for growth. In Canada, only about 5% of the nearly 10 million square km of land is considered to be arable, that is, land that is or has the potential to be, cultivated for crop production. Nevertheless, Canada is one of the world's top suppliers of agricultural products, exporting products to the United States, Europe, and East Asia, with a substantial quantity of food left for domestic consumers.

Soils also provide the medium for growth of plant and animal materials for natural fabrics and cloths, including cotton, wool, silk, and leather. In many cases, soils also provide the natural dyes used to colour these fabrics. The use of soil for modern agriculture, just like in ancient civilizations, can cause complications which degrade the quality of soil and render agriculture impossible. The inappropriate use of heavy equipment for the purpose of tillage often causes soil compaction, preventing precipitation from penetrating the soil and resulting in runoff and erosion. Irrigation often leaves salts at the root zone of crops, preventing uptake of water. The addition of pesticides, insecticides, and fungicides destroys certain soil organisms and inhibits the natural function of the system.

2.1.3 Water Supplies

Soil also has the ability to acts as a natural purifying and filtering agent for the world's **groundwater** supplies. All rain and wastewater that percolates down to the groundwater storage is chemically and biologically treated to become drinkable once again. The sand and silt components of soil sieve out any solid components, while charged surfaces of clays absorb many hazardous contaminants that have been dissolved in the water. Meanwhile, billions of soil organisms act to eliminate pathogens, viruses, dissolved solids, and other colour and taste problems. Soil protozoa prey on pathogens as food. Bacteria and fungi produce antibiotics that destroy harmful pathogens. In addition, the new environment of the soil (temperature, pH, and nutrients) creates conditions that are intolerable for pathogens.

2.1.4 Engineering

Not only do soils provide an engineering medium for the foundation of roads, houses, and train tracks, they also provide the materials – wood, brick, sand, and gravel – used to build these facilities. The properties of soils place restrictions on the location suitable for building structures and influence their long-term stability. For example, the **permafrost** covering much of Canada's northern lands can be a strong and stable foundation for engineering when frozen. However, climate change and warming can cause the ground to thaw, resulting in soils becoming unsuitable for construction and prone to landslides and subsidence.

2.1.5 Recycling

Organic matter is cycled and recycled time and again as nutrients from mineral soil are converted to organic plant matter, consumed by animals to become flesh, and returned again to the soil to repeat the same cycle. Decomposers that live in the soil, including fungi, earthworms, snails, slugs, arthropods, lichens, and moss, break down dead organic matter to their mineral form to be taken up as nutrient by autotrophs.

3.0 The Process of Soil Formation

3.1 Introduction

As you look at the soils around you, do you ever wonder where they come from and why one soil is different than another? What natural forces act upon soils and what are the effects of these actions?

Pedology is the study of the formation and evolution of soil and the processes by which it is created. The formation of soils can be seen as a combination of the products of weathering, structural development of the soil, differentiation of that structure into horizons or layers, and finally, of its movement or translocation.

The journey of soil formation and evolution always begins from rocks. The rocks that form different soils are referred to as **parent material**. The chemical and physical properties of the parent rock are reflected in the characteristics of the soil. If the parent material is directly below the soil, it is the bedrock. However, the rock or parent materials that create different bodies of soils could have been transported great distances by forces of wind, water, or glaciers.

The formation of soil from rock can take thousands of years as natural forces such as physical and chemical weathering attempt to break down and modify the parent material. **Regolith** is the term used to describe the unconsolidated rock that has been physically and chemically modified. It is the transition stage from rock to soil. From this stage, the regolith is further evolved before mature soils are obtained.

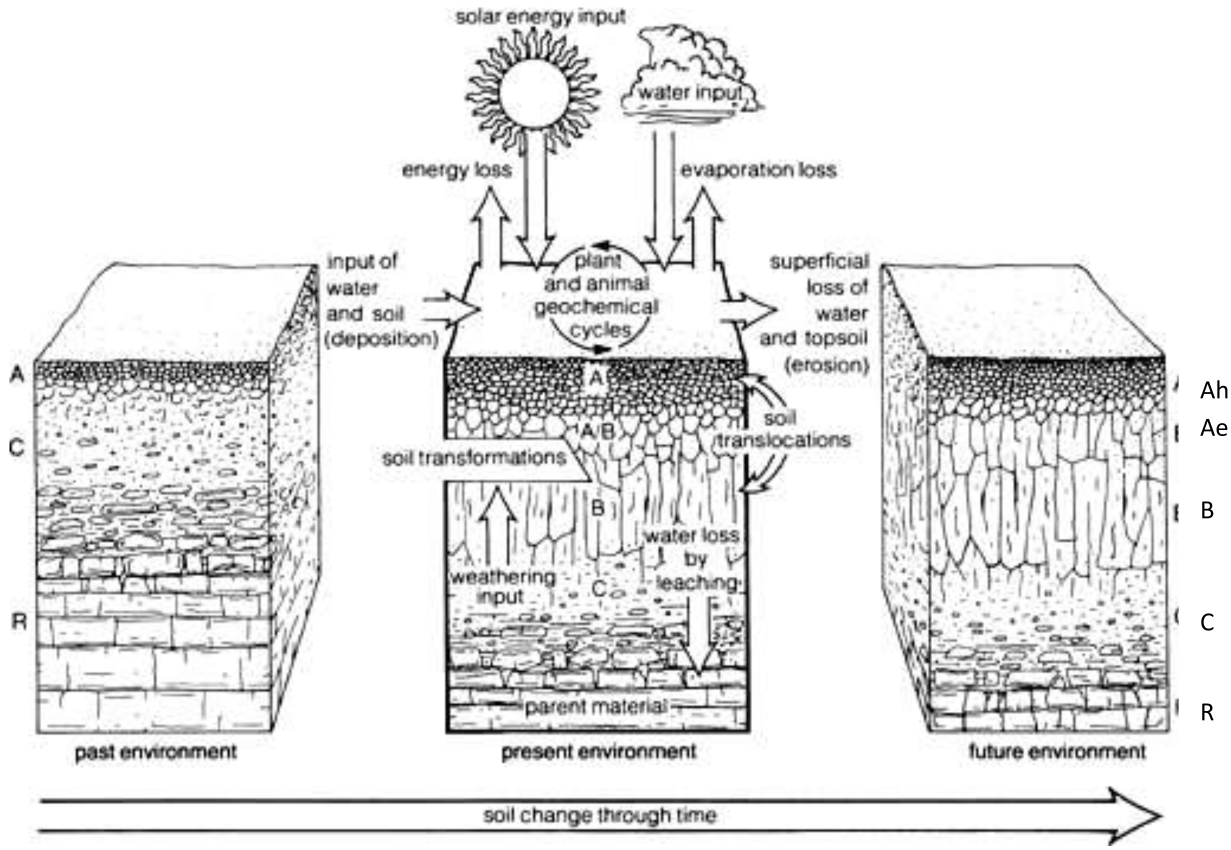


Figure 1: The evolution of soil from past to future (adapted from University of Arizona, 2007).

3.2 The Rock Cycle

If we examine the soil cycle carefully, we will realize that it is intimately connected with the rock cycle in a system that creates, destroys, and recreates rocks from soils, and soils from rocks.

Rocks are commonly classified as **igneous**, **sedimentary**, and **metamorphic**. The rock cycle does not necessarily start at any one of these three stages or proceed at any specific order. Rather, it can go from any one stage to any other and back. For example, any igneous rock can be transformed into a metamorphic rock, a sedimentary rock, or even into another igneous rock.

To understand how rocks form and transform, it is important to have a basic understanding of **plate tectonics**. Studies of the rock cycle have revealed that much of the driving force behind this process lies at the bottom of the oceans. Examining the ocean floor reveals diverging of the crust at mid-oceanic ridges; where constant volcanic eruption forms new crust and pushes the older crust outwards. The oceanic plate is forced away from the spreading ridge towards the continents. Where the oceanic and continental plates meet and collide, the older and heavier oceanic crust is forced beneath the lighter continent. This is called the **subduction zone**. Mountains are formed at the edge of the continent due to the intensity of colliding plates. The oceanic plate travels deeper and deeper beneath the ground, where high temperature and pressure cause melting of the crust. This is the basis for the formation of igneous rocks.

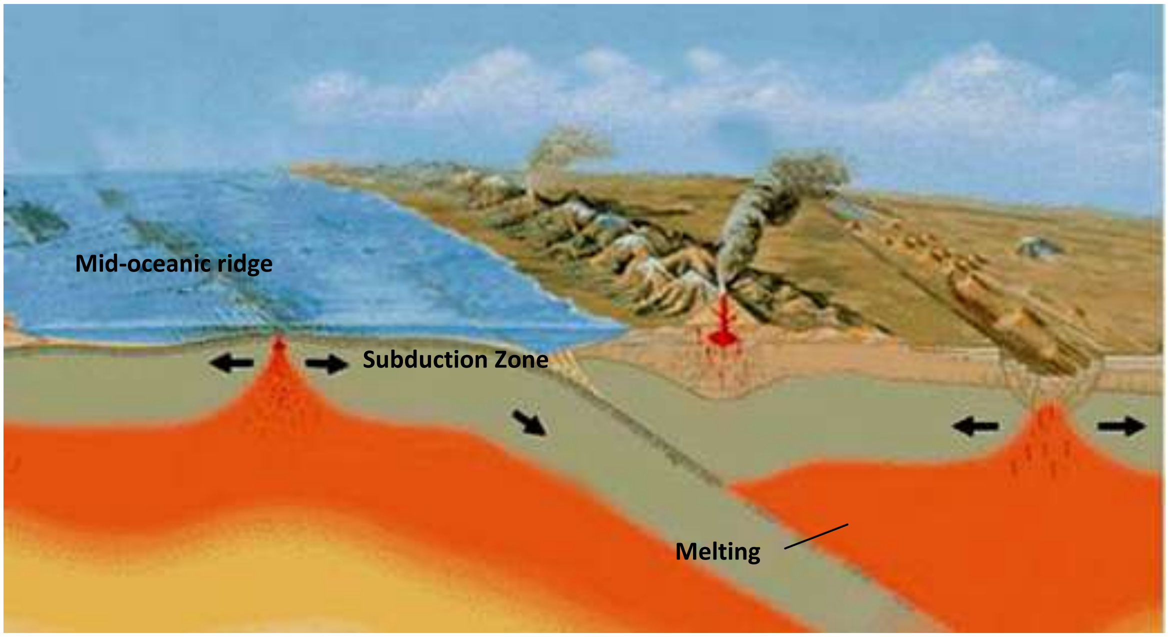


Figure 2: As new crust is produced at the mid-oceanic ridge, older crust is pushed outwards towards the continental crust. When oceanic and continental plates collide, the heavier ocean plates dive below at the subduction zone. High temperatures of the earth's interior cause melting of the subducting crust (Simon Fraser University, n.d.).

The word igneous means "born of fire". The name is apt considering that igneous rocks form from molten magma – that is rock which has been liquefied under the intense temperature and pressure of the Earth's internal conditions. Temperatures of molten rock inside the Earth's mantle can reach as high as 1600 °C! Intense heat causes liquid magma to rise within the volcanic chamber. As the magma rises towards the surface of the earth, it begins to cool and crystallize. Some magma cools and solidifies before it even reaches the surface, forming **intrusive** or **plutonic** igneous rocks. The remaining magma continues to rise until it penetrates through the surface of the earth. The pressure of rising magma causes it to erupt, often violently, at the volcano's mouth. The magma above the surface of the earth, called **lava**, solidifies rapidly as it comes in contact with much cooler air or water. The result is the formation of **extrusive** igneous rocks.

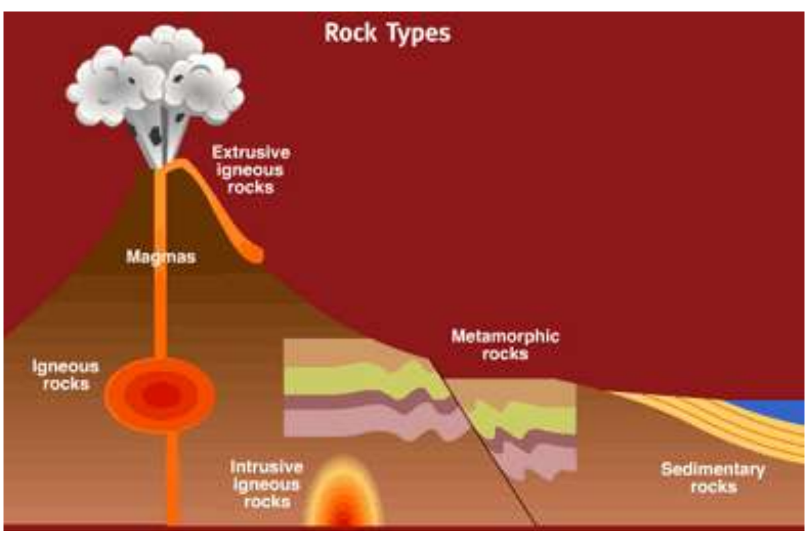


Figure 3: When magma cools beneath the surface of the Earth, intrusive or plutonic igneous rocks are formed. Extrusive igneous rocks form from the rapid cooling of lava above the surface of the Earth (Open Learn, 2006).

Exposed at the surface of the earth, these rocks are vulnerable to the processes of weathering and erosion. Weathering breaks the rocks down to smaller fragments and erosion (by wind, water or ice) carries fragments from their original location. The loose materials accumulate and are buried by more sediment. Eventually, the loose particles of clay, silt, sand, or gravel become fused together with a cementing agent and form sedimentary rocks. This process of compaction and cementation of unconsolidated sediments into sedimentary rocks is called **lithification**. **Clastic** sedimentary rocks form from the binding of small rock fragments. **Biogenic** sedimentary rocks occur when the remains of living organisms, such as broken bones and shells, become lithified. **Precipitate** sedimentary rocks occur as a result of the evaporation of seawater and formation of precipitated salt rocks.

When sedimentary or igneous rocks become buried deep below the Earth's surface, they experience changes in their temperature, pressure, and chemical conditions that cause them to metamorphose. In other words, over millions of years, the rocks experience changes in their physical and chemical characteristics without melting, this results in the formation of metamorphic rocks. Metamorphic rocks often occur in mountain belts where two continental plates collide, causing an extreme compression force. The pressure of collision acts on the existing rocks, leading to regional metamorphism. Another form of metamorphism occurs in close proximity to intrusive igneous rocks, where radiated heat causes recrystallization of the existing rock by means of contact metamorphism. Dynamic metamorphism occurs when two plates slide past each other. The heat generated by the frictional forces crushes and grinds the rock into metamorphic rock.

In time, igneous, sedimentary, and metamorphic rocks become exposed to the surface of the earth and experience new environment conditions which includes lower pressures, temperatures and the presence of vegetation. Unable to tolerate the new environmental conditions, different from those under which they were formed, rocks become unstable and begin to decompose into inorganic mineral matter that forms soil. This is when the process of soil formation comes into action.

3.3 From Rock to Soil

Bedrock begins to disintegrate into progressively smaller particles through a process called **weathering**. This is the first step towards soil formation. Chemical, physical, and biological actions help to facilitate the process of weathering.

Weathering is considered in terms of physical and chemical actions .In **physical weathering**, solid rock is broken into smaller constituents as a result of interaction with atmospheric conditions such as ice, water, heat, and pressure while maintaining the same chemistry. Physical weathering helps increase the exposed surface area of rock to accelerate further weathering processes and soil formation. **Chemical weathering** occurs when rock is broken down by chemical reactions such as carbonation, hydrolysis or oxidation.

3.4 The Principle Soil-Forming Factors

Following the accumulation of soil from chemical and physical weathering, the loose material continues to mature and stabilize. Five factors collectively bring about the natural transformation of lifeless mineral matter into the rich, life-sustaining substance we know as soil. The different kinds of soils that are formed can be attributed to the quantity and quality of these factors. Soil scientists call these the factors of soil formation.

Parent material, climate, relief, organisms, and time exert their influences to give soil profiles their distinctive characters. Understanding the five soil forming factors helps us better understand why soils differ from place to place, how they contribute to the existence of different global environments, and how they can best be managed to maximize productivity.

3.4.1 Climate

Variation in **climate** has a primary influence on soil formation and properties. Climate refers to the specific temperature and precipitation regime as well as humidity, sunshine, and wind velocity. Climate is significant to the process of soil formation because it provides the energy that drives physical, chemical, and biological reactions on parent material.

Perhaps the two most significant climate variables are temperature and moisture. Temperature and precipitation regimes directly impact the type and rate of physical and chemical weathering processes mentioned in the previous section. As temperature and precipitation increase, so does the rate of weathering, the frequency and magnitude of soil chemical reaction, and the rate of plant growth. Temperature controls the rate of biological activity by soil organisms, while moisture influences soil pH and the rate of decomposition of organic matter. Precipitation also affects horizon development or layering through leaching and the translocation of sediments within the soil profile.

3.4.2 Organisms

Soil organisms are responsible for aiding the process of organic matter accumulation and conversion of organic nutrients into mineral matter that can be taken up by plants. Soil organisms also help in profile differentiation and mixing.

Vegetation such as plants, shrubs, and trees, help protect the upper layer of soil against the harsh impacts of erosion by providing a protective cover that reduces the speed of wind and water. Vegetation can also help in slowing the rate of runoff and the wearing away of fertile soil. Plants accelerate the rate of physical and chemical weathering by pushing rocks apart with their roots and releasing organic exudates that decompose rocks and release nutrients necessary for growth. Vegetation can also prevent water from evaporating at the surface of the soil. Evaporation of water at the soil surface can sometimes lead to the accumulation of salts in the root zone of plants, which hinders water uptake. The moisture regime of the soil can impact the type of biotic environment that exists in different regions of the world.

When plants shed their leaves or die they leave behind organic matter that increases the structural stability of the soil aggregates and provides nutrients for the growth of other plants. Organic matter also increases moisture and cation-holding capacity.

Soil organisms also play a crucial role in soil formation. **Decomposers** within the soil help to recycle organic matter left by dead organisms into nutrient forms that are available to plants. Fungi, for example, consume leaf-litter and accelerate the process of decay. Bacteria capture nitrogen from the air and incorporates it into the soil to be used by plants. Earthworms and small mammals burrow, mix, and further incorporate organic matter into the soil. Overall, soil organisms add humus and nutrients to the soil, necessary for healthy soil functions including structure and fertility.

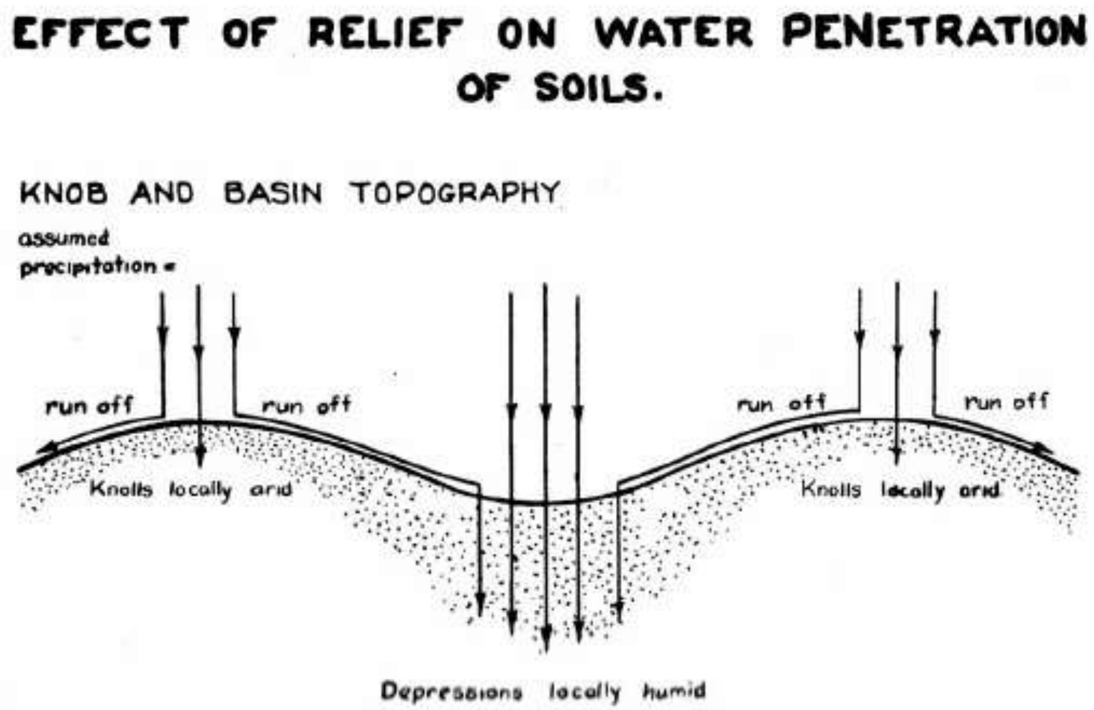


Figure 4: The impact of topography on microclimate can be seen when analyzing knolls and depressions. Hills maintain less moisture as rainfall and runoff collect in depressions (Pennock, 2006).

3.4.3Relief

Relief, or topography, refers to the configuration of land in terms of its altitude and slope degree. Topography can modify the microclimate and drainage ability of soil at a regional or local scale, and controls the type and rate of soil formation.

In the Northern Hemisphere, south-facing slopes receive greater exposure to sunlight and therefore experience warmer and drier microclimates than their north-facing counterparts. In the Southern Hemisphere, this is true for north-facing slopes. In comparing south and north-facing slopes, you will find major differences in the types of ecosystems that can be supported by each. Soil formation also differs on the two sides of a slope in terms of depth, texture, biological activity, and soil profile development.

Furthermore, the degree of a slope affects the rate of erosion and moisture accumulation. Steeper slopes are more prone to landslides and natural erosion due to gravity. Precipitation is much more likely to wash away topsoil on steeper lands such as mountains than on flat country such as prairies. Consequently, steeper topography inhibits the accumulation and development of soil due to continual removal of surface sediments.

In addition, the nature of soils found in valleys differs from that on uplands due to drainage. Depressions are locally humid and knolls are locally arid. During and after precipitation, water flows down the slope and gathers at the bottom of valleys. As a result, hill and mountaintops are much better drained than soils in depressions. Good drainage enhances the development of soil horizons through translocation of soil particles. Therefore, soils that are well drained are generally more mature.

Figure 5: The north-facing slope on the left receives less exposure to sunlight throughout the year and maintains a more moist and cool microclimate than the south-facing slope on the right. Weathering occurs at different rates on each side of the slope. (Wikipedia, 2015).

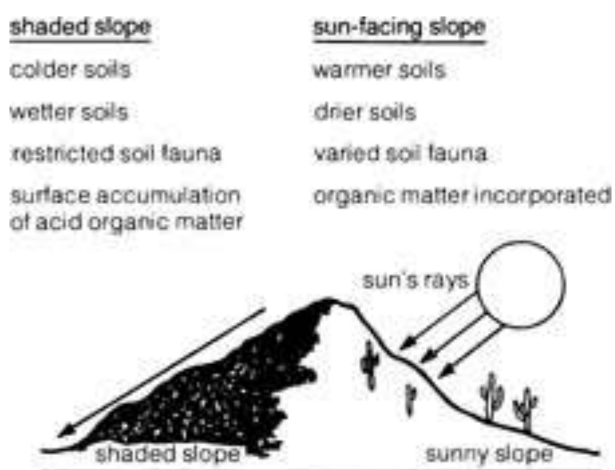


Figure 6: Effect of aspect on soils (University of Arizona, 2007).

3.4.5 Parent Material

Parent material refers to the unconsolidated material including igneous, metamorphic, or sedimentary rocks, in addition to other organic and mineral materials from which soils were developed. Parent material may be directly beneath the soil, in which case it is referred to as bedrock or it may have been transported to an area by erosive forces of wind, water, or glaciers.

The type of parent material influences the rate of soil formation, since some rocks breakdown much faster than others. The properties of parent material can also determine mineral composition as well as physical and chemical attributes of the soil. For example, soils formed from limestone are rich in minerals important to plant growth, while those derived from granite tend to be poor in essential nutrients required for a healthy plant lifecycle.

Texture, water-holding capacity, **acidity**, and **fertility** are also soil properties that are inherited from the parent material. Soil texture, a property of the parent material, affects the rate of downward water movement, thereby affecting translocation of nutrients and soil particles. The chemical makeup of parent material also affects **pH** and nutrient availability. For example, calcitic and dolomitic parent materials form alkaline soils that favour the availability of certain nutrients.

3.4.6 Time

The impacts of climate, organisms, relief, and parent materials are dynamic through time. A great length of time is needed for these factors to interact and produce soils from rock. It can take thousands of years for a few centimeters of soil to develop from parent rocks. Older soils are more mature and have better defined horizons than younger, immature soils. Younger soils may be less deep with a lower concentration of organic matter.

It is important to realize that the five factors of soil formation do not occur independently of one another. Rather, they are interrelated forces that collaborate to augment and further advance the impacts of the others. In the end, soils reflect the integrated work of the specific climate, biological activity, time range, parent material, and topography that helped form them.

3.5 Structural Differentiation

Over time, soils begin to differentiate vertically and display distinct horizons. A **horizon** is a specific layer in the soil that runs parallel to the ground surface and entails different properties from horizons above and below. Soil horizons vary in colour, texture, and structure. Though each soil has at least one horizon, the more mature soil is, the more differentiated its horizons are.

Soil horizons evolve through the addition, loss, **translocation**, and **transformation** of soil particles. Additions include organic matter, water, air, and energy from the sun. Soils losses include the evaporation of water, leaching of nutrients, or erosion. Translocation refers to the movement of soil-forming material up and down the **soil profile**. The soil profile consists of the combined sequence of all the horizons in a soil. Rainwater percolates down the soil profile due to gravity, transferring some materials from the upper part of the soil to lower portions. Burrowing animals further mix and move materials within the soil. The formation of arrangement of soil components into structural aggregates is called transformation.

Horizon formation is a function of the **biogeochemical** factors that influence soils over a long period of time (i.e. climate, organisms, parent material, topography, time). The type and sequence of the horizons that make up each body of soil are characteristics that help to classify them. In Canada, the horizons are identified with the capital letters: L, F, H, A, B and C.

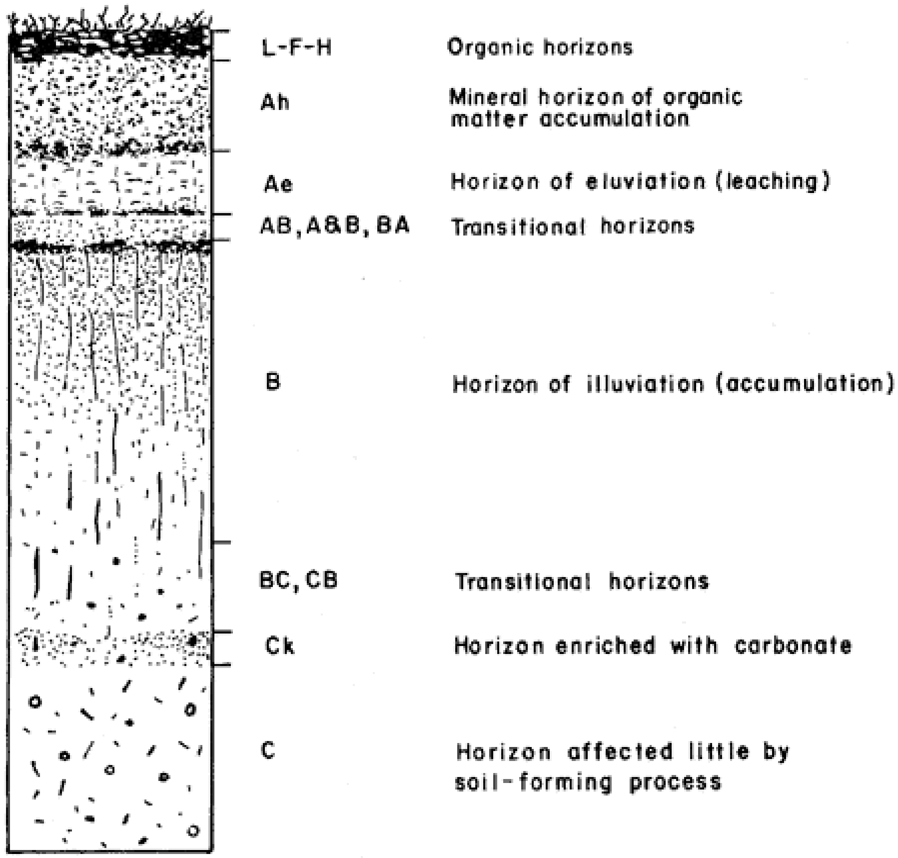


Figure 7: A simplified soil profile showing the designations used in Canada: L, F, and H, A, B and C horizons. Any given soil may have some or all of the seven horizons at varying depths (BC Ministry of Environment, 2015).

3.5.1 L, F and H Horizons

The organic horizon lies on the uppermost layer above the soil. Organic matter is generally distinguished by its dark colour. This horizon is nourished by the addition of dead vegetation and organisms that are at various stages of decay. Less decayed organic matter lies above the more decomposed organic humus.

In well aerated environments, leaves, needles, twigs and branches fall to the earth, accumulate and begin to decompose on top of the mineral soil. The level of decay is the criterion for distinguishing the three horizons L, F and H. The L horizon represents slightly decayed organic materials; F is intermediately decomposed; and H is the most decomposed layer that can no longer be attributed to the original material that made it. Not all soils are endowed with an organic horizon. It usually exists on soils that are permanently covered by vegetation. Those soils that do have an organic layer are subject to decreasing levels of organic matter down the soil profile. In poorly aerated environments (wet areas) the organic materials also accumulate but their character is different because of the saturated conditions. In these areas the horizons are designated O. O horizons are composed mainly of mosses, rushes and woody material.

3.5.2 A Horizons

The A horizon lies beneath the organic layer. In some soils the A horizon is higher in organic matter compared to the layers below due to the downward movement of organic material from the L, F and H horizons and is therefore darker in colour (Ah). In other soils this horizon experiences leaching or eluviation of organic matter, minerals and nutrients as a result of the downward movement of water; this is expressed by a lightening of the soil colour (Ae). The A horizon is also the zone where most biological activity occurs. Worms, nematodes, fungi, bacteria, and most plant roots are active in this horizon. Together, the A and L, F and H horizons constitute the topsoil. **Topsoil** is the portion of the soil that acts as a growth medium for vegetation, providing humans and other animals with food and habitat.

3.5.3 B Horizons

The B horizon is located between the A and C horizons. The B horizon is where the materials that are translocated accumulate from the upper portion of the soil profile. For example, organic matter, fine clay and mineral matter that were leached with water from the horizons above are deposited in the B horizon. This is also called the zone of illuviation. There is a close relationship between the A and B horizons. Translocations as well as many biological and chemical reactions take place between them.

3.5.4 C Horizons

The C horizon is often termed the parent material. Lying below the B horizon and above the hard bedrock is the zone of unconsolidated bedrock. This layer is the transition stage between bedrock and soil and is least affected by soil-forming processes. In very young soils that do not yet have defined horizons, the entire profile of the soil is called the C horizon. There is very little eorganic material found in this layer and plant roots do not generally penetrate into this layer.

Lowercase letters denote the predominant properties of the mineral soil horizons A, B and C. Thus h indicates a horizon enriched with organic matter and t indicates a horizon where clay has accumulated. The letters can be combined as well; for example, a horizon labeled Bhf indicates that it is a layer within the soil where organic matter, iron and aluminum have accumulated.

Not all soils contain all of the horizons mentioned. Soil horizons vary in terms of depth, composition, and structure. Newly formed soils are shallower and have less differentiated horizons, while the profile of mature soils may display the full set of horizons. The specific depth, chemical composition, and structure of soils and their horizons at a given time are a direct result of the factors that influenced their formation.

3.6 Soil Classification

Understanding the properties of horizons and the distinguishing characteristics of soil profiles has allowed scientists to classify soils into different categories. This is called soil **taxonomy**. The ability to classify soils allows scientists to recall knowledge systematically and communicate information in a consistent manner. Soil classification makes it simpler to understand the relationships among different soils and their environments and to implement appropriate management techniques.

The classification of soils is not an easy task. This is because unlike plants and animals, soils are not individual entities. Rather, soil is a continuous body that gradually transforms from one type of soil to another. There is no defined beginning and end to anybody of soil. Also, different countries have different systems for soil classification.

In Canada, the soil classification scheme is a comprehensive system based on the properties and arrangement of horizons which are products of the soil forming environment. These diagnostic properties are relatively stable and do not change significantly through time. Canadian soils have been categorised into five main hierarchal levels that divide and subdivide into more specific clusters. Soil orders are the highest level and of the most general grouping. There are ten main orders to Canadian soils, they are: luvisols, podzols, brunisols, regosols, cryosols, chernozems, gleysols, vertisols, organic, and solonetzic soils. Each order is further divided by great group, subgroup, family and series. Series are the most specific division.

Orders	Differentiated on the basis of characteristics of the soils that reflect the nature of the total soil environment and the effects of the dominant soil forming processes
Great Groups	Differentiated on the basis of characteristics that reflect the differences in the strengths of the dominant processes or a major contribution of an additional process
Subgroups	Differentiated on the basis of the kind and arrangement of horizons that reflect a conformity to the central concept of the Great Group, a gradation towards another soil Order, or the presence of a special horizon
Family	Differentiated on the basis of the parent geologic material characteristics such as texture, mineralogy, depth, and/or reaction and on differences in soil climatic factors
Series	Groupings of pedons with similar arrangements of horizons whose color, texture, structure, consistence, thickness, reaction, and composition fall within relatively narrow and well defined ranges

Table 1: Canadian Soil classification system; five levels are recognized in the hierarchical scheme used for the Canadian System of Soil Classification (Agriculture and Agri-Food Canada, 2013a).

The Ten Soil Orders of the Canadian System of Soil Classification

Source: FON and SWCS, 1995

Regosolic: Soils of the Regosolic Order are examples of azonal soils that are either in their early stages of development, or are developing under unstable environmental influences. They are found, for example, on disintegrating rock material, newly deposited sand or silt, severely eroded slopes, shifting sand dunes, or under dry cold conditions. Because of the characteristics of their soil-forming environments, regosolic profiles usually lack distinctive horizons.
General Locations: Weakly developed soils such as sand dunes or beaches under a wide range of climate and vegetation.

Chernozemic: Surface horizons of the Chernozemic Order are darkened by the accumulation of organic matter. The organic matter is derived from the decomposition of plants from grassland and grassland-forest communities such as those found in the Interior Plains of western Canada. Most Chernozems are frozen during some period each year and dry for some period in the summer.
General Locations: Grassland communities in the Interior Plains of western Canada.

Brunisolic: Brunisolis soils are found in a wide range of climatic and vegetative environments including forests, grassland and tundra. The dominant colour of their horizons is brown. As they are only minimally weathered they do not display distinct eluvial or illuvial layers.
General Locations: Deciduous or mixed forest in a wide range of climates.

Gleysolic: Gleysolic soils are typically found in low-lying areas, depressions, and fields with high water tables or poor underlying drainage. Their profiles show evidence of periodic or prolonged saturation by water. The visible results are dull colours, and discolouration such as brownish, rusty or bluish streaks, spots or mottles.
General Locations: Areas where soils are subjected to prolonged periods of intermittent or continuous saturation with water.

Lovisolic: Luvisolic soils have distinctly light-coloured eluvial horizons and dark, clay-rich B horizons. Typically these soils develop in well to imperfectly drained sites under forest vegetation in sandy loam to clay parent materials.
General Locations: Wide range of climates and vegetation from southern Ontario to permafrost and from Newfoundland to British Columbia. They predominate in the Interior Plains under deciduous, mixed, and coniferous forests.

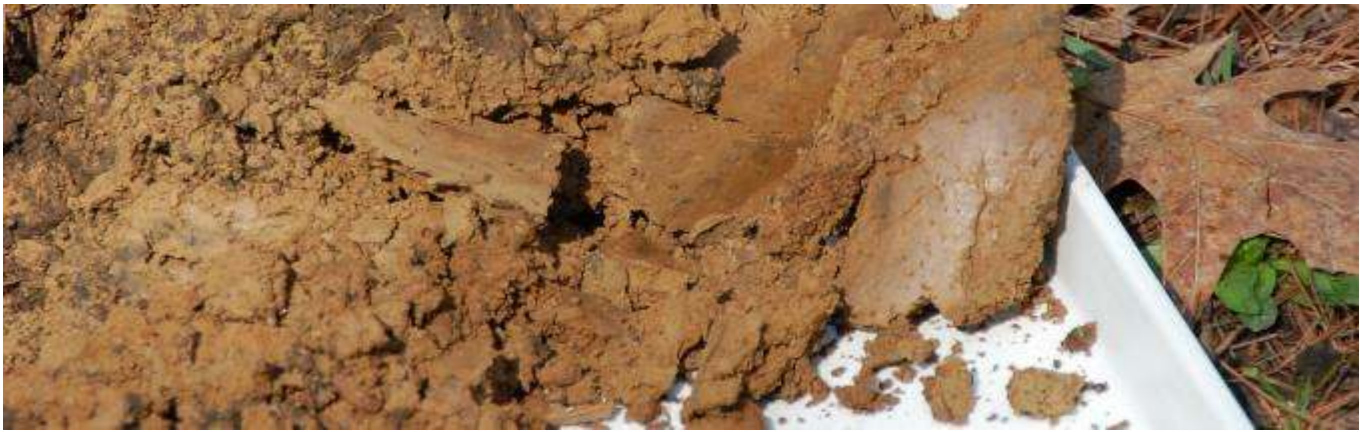
Solonetzic: Soils of the Solonetzic Order exhibit B horizons which are hard when dry but swell to a lowly permeable, sticky mass when wet. These B horizons usually have prismatic or columnar structure. Solonetzic soils develop on salty parent materials.

Podzolic: Podzolic soils are well-weathered soils that have developed under a forest where leaf litter has accumulated to form a rich organic layer. The products of decomposition in the organic layer (usually acidic) increase the leaching powers of water passing through the A horizon. Therefore, soils typically have light-coloured A horizons (elubial zones) and darker brown or rust coloured B horisons (illuvial zones) where minerals have accumulated from the leaching process above.
General Locations: Exist predominantly on coarse to medium-textured acidic parent materials under forest vegetation in cool to very cold climates.

Organic: Organic soils do not have defined horizons. They are formed from decomposing plant matter such as grasses, sedges or moss, and are generally neutral to acidic. To be considered organic in Canada's classification system, the soil must have 40% or more organic matter and be at least 30 cm in depth.
General Locations: Occur in poorly drained depressions, commonly known as peat, muck or bog soils.

Cryosolic: Cryosolic soils are formed in organic or mineral materials and have permafrost within one metre of the soil surface. Their annual temperature is below 0°C. Cryosols occupy much of the northern third of Canada.
General Locations: Found predominantly in Canada's north above the treeline where permafrost remains close to the surface.

Vertisolic: (A newly introduced soil Order). Clay soils that lack the degree of development necessary for other Orders and that have deep, wide cracks at some time during the year with high bulk density between the cracks. These soils have marked shrink-swell tendencies with changes in soil water content resulting in wedge-shaped aggregates and/or evidence of severe disruption of horizons in the solum.



4.0 The Physical Nature of Soils

The term 'fertile' usually describes a soil that is rich in essential nutrients that are necessary for plant growth. Though many people associate fertility with the ability to support growth, not all fertile soils are productive soils. There are a wide range of physical factors that contribute to the soil's ability to support vegetative growth. The physical nature of soil is among the key properties that determines the suitability of land for a particular practice.

Physical properties are those that can be quantified and described with measurements such as length, volume, mass, and temperature. Soils physical characteristics determine if it is strong enough to withstand the weight of traffic or if it will collapse under stress; if a soil can hold large amounts of water for plants to use or if it is easily leached. Agriculture and engineering depend heavily on soil's physical capabilities. The physical structure of any given soil has been determined by the impacts of vegetation, topography and climate on parent material over time. Any minor change in these five factors can create a soil with very different physical properties. This is why soil properties can vary widely from one location to another. Not all soils are appropriate for the same practices and applications, therefore it is important to have a thorough understanding of the physical properties of soils and their impact on soil functions.

4.1 Four Major Soil Components

Anybody of soil is comprised of four major constituents – mineral matter, organic matter, air and water in three different phases – the liquid phase, the solid phase, and the gas phase. Different bodies of soils vary in the proportion of these components. Ideally, the solid phase (organic & inorganic materials) contributes approximately 50% by volume to the soil. The remaining 50% of the soil volume is comprised of pore space (air & water). Air and water each contribute approximately 25% to the total volume but fluctuate according to soil wetting and drying cycles.

It is important to note that the composition of subsoil, which is located deeper beneath the surface of the earth, is slightly different from that of topsoil. Due to increased pressure, subsoils tend to be more compact and are thus lower in pore space. Pore space in the subsoil is generally smaller in size and is dominated by water, which seeps down the soil profile due to gravity. Also, subsoil contains less organic matter than its topsoil counterpart.

These four major soil components – mineral matter, organic matter, air, and water – interactively create the framework which determines the properties of soils as a natural system. The volume composition of soil is what determines its suitability for plant growth and activity of soil organisms.

4.1.1 Inorganic Mineral Matter

For the average mineral soil, 45% is composed of mineral matter. Mineral matter refers to the inorganic portion of soil that is derived from the physical and chemical weathering of the original parent rock into regolith (weathered parent material), and subsequently, into soil. Consequently, the mineral composition and properties of the mineral matter such as pH and texture are reflective of the parent rock from which it was derived. For example, the calcitic and dolomitic bedrock in much of southern Ontario has created the alkaline soils that often occur in the area.

The size and abundance of mineral particles in soil is extremely variable and contributes greatly to the properties of each soil. Mineral particles, divided by size, are categorized as **stone**, **cobble, gravel**, **sand**, **silt**, and **clay**. Stones, cobbles and gravel are classified as course fragments and are greater than 2mm in diameter.

Sands are 0.05 to 2 mm in diameter, easily seen by the naked eye, and give soil a loose, gritty texture. Soils that are dominated by sand generally have a large proportion of pore space and therefore drain faster than soils which are dominated by clay. Because of this property, sand particles are inefficient at attracting water and nutrients making them inhospitable to most plants. Water and nutrients are leached from the soil and enter the groundwater.

Silt particles are 0.002-0.05 mm in diameter and feel powdery when dry, and smooth but not sticky when wet. The smallest mineral particles are clays. Clays are less than 0.002 mm in diameter and are only seen with the aid of an electron microscope. Clay soils are very sticky when wet, and form hard aggregates when dry. Due to their large surface area and charge-carrying colloids, clays contribute vastly to the chemical properties of soils. Clays have a high electrochemical attraction for water and nutrients which prevents them from leaving the root zone of plants. However, plants must exert a greater force to take up water molecules, which are tightly held in the small pores of clay dominated soils. Uptake of water is much more difficult from smaller pores of clays than those of sands.

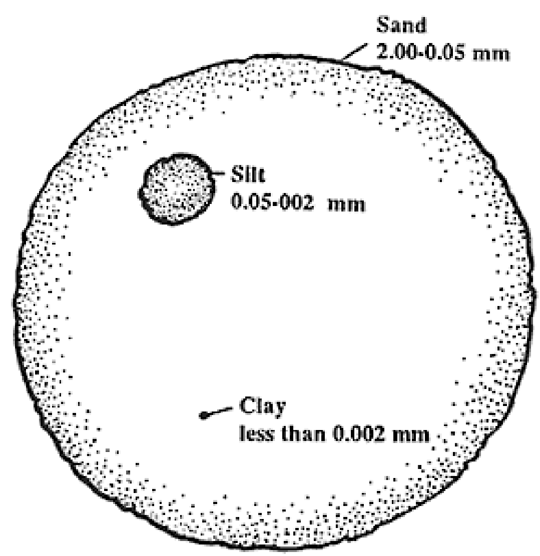


Figure 8: Relative size of sand, silt, and clay particles. (Outside Pride, 2015)

4.1.2 Organic Matter

Organic Matter is derived mainly from dead and decaying plant and animal material that have accumulated at or near the soil surface. Organic matter accumulates in the topsoil and decreases in concentration down the soil profile. For an average mineral soil, contents of organic matter typically range from 1-5% by volume. Soils high in organic matter can be identified by their darker colour.

The presence of organic matter is crucial to the health and productivity of soil. Organic matter assists in the binding of soil into aggregates, improves soil structure, allows roots to penetrate through soil, and helps to increase water-holding capacity. Furthermore, organic matter is a major source of essential nutrients such as nitrogen, potassium and sulphur (N, P, S), and provides energy for soil organisms. Humus, the decay-resistant portion of organic matter, exceeds clays in water and nutrient holding capacity.

4.1.3 Water

Water generally occupies one half of the soil's pore space, constituting up to 25% of total volume. The size distribution of soil pores determines the ease with which plants may take up water molecules. Water is held to the surface of solid matter with varying degrees of tension depending on the size of pores and the quantity of water content. Water in the largest pores (macropores) is effortlessly absorbed by plants. This is called *available* water.

As the water from the largest pores is taken up, it becomes increasingly difficult and more energy-intensive for plants to uptake water and dissolved nutrients. Water contained in tiny pores (micropores) and thin films is held tightly to the surface of soil particles and is not easily released for plant uptake. The *wilting* point is reached when the soil water can no longer be extracted for plant use, and at higher water content in clays compared to sands, due to the presence of a much larger proportion of smaller pores in clays.

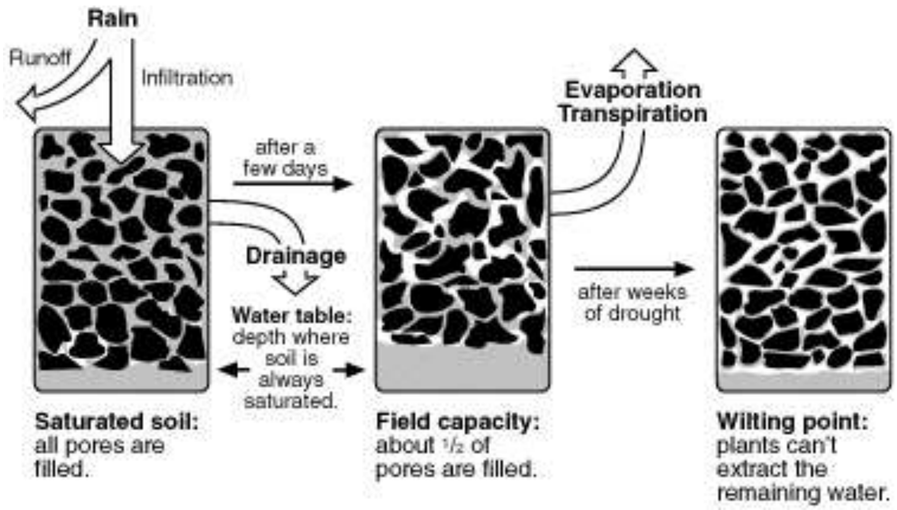


Figure 9: At wilting point, soil water is only contained in micropores and thin films around soil particles. This water is held so tightly that plants are unable to extract the water and therefore wilt (University of Minnesota, 2001).

Soil water is essential for the growth of plants as it provides not only the liquid to quench their thirst, but also the nutrient elements required for growth and reproduction. Soil water is the transport medium for essential nutrients. Nutrients are taken up by plants by three basic mechanisms: root interception, mass flow, and diffusion. Only a very small and insignificant portion of the plant's nutrient requirements are sustained through root interception. In this case, the nutrients are taken up directly from the soil solids. The second and most important mechanism of nutrient uptake is mass flow. Mass flow occurs when nutrients enter the roots zone of plants and are absorbed along with water. Nutrient uptake through mass flow is highly influenced by moisture availability and soil physical properties mentioned in the previous paragraph. Finally, diffusion is the mechanism by which nutrients move down the concentration gradient, from an area of higher concentration to an area of lower concentration. The solubility and availability of nutrient ions is heavily impacted by the pH of soil solution, which is yet another important aspect of soil water to consider.

4.1.4 Air

The gas component of soil serves the same purpose as the air in the atmosphere; it provides oxygen for living organisms to breath, and allows carbon dioxide from animal and root respiration to escape from the soil. Soil air differs from air in the atmosphere in that the composition of air in the atmosphere is much more uniform than soil air composition, which varies significantly in different air pockets. This is because soil air flow is greatly restricted by soil solids and liquids.

Furthermore, soil air has a significantly higher relative humidity (moisture content) that may reach up to 100% in ideal conditions. Soil air contains carbon dioxide concentrations that are several hundred times higher than that in the atmosphere, and oxygen concentrations that are much lower. Soil organisms take up oxygen from the air pockets, and release carbon dioxide from respiration. Since air flow between the atmosphere and the soil is very slow, the gaseous composition of soil and air are never the same. In soils with a large proportion of small pores, water usually dominates the pore spaces, preventing optimum aeration for plant growth and microbial activity. Carbon dioxide concentrations are generally high and oxygen levels are low, as water limits air flow and inhibits equilibrium between the atmosphere and the soil.

4.2 Soil Texture

The texture of soils is determined by the relative proportion of each of the three particle sizes (sand, silt, clay) that are found in a sample of soil. Soils that are dominated by clays are termed **fine-textured** soils while those dominated by sands are referred to as *coarse-textured* soils. Texture is a basic property of soil, in that it is static through time and is not easily subject to change.

Soil science professionals categorize soils into different soil textural classes based on similarities in particle size distribution. The range of each class is selected to represent textures with similar properties and is named to identify the dominant particle sizes. Soils with a moderate mix of the three particle sizes are called **loams**.

A soil **texture triangle** is used to visually display the different soil textural classes by the percentage of sand, silt, and clay. The different sides of the triangle represent the percentage of each soil particle size present in a sample of soil. The intersection of the three sizes inside the triangle represents the texture class, which is bounded by bolded lines. To read the percentage of clay, you use the axes that run horizontally; for sand, use the axes that run from lower right to upper left; and for silt, use the axes that run from upper right to lower left across the triangle.

Soil texture has a strong influence on the physical and chemical properties of soil. Permeability, water retention, aeration, fertility, bulk density, and structure are all affected by the soil texture. Furthermore, clays have a greater ability to absorb and store nutrient ions for use by plants. As a result, clay soils are more fertile than sandy soils.

Water-holding capacity –the amount of water a soil can hold – is a function of soil texture. Fine-textured soils, such as clays, have a greater surface-area to volume ratio than coarse-textured sands. The greater surface area of clays allows for greater adhesion between water and solid components. In comparison, sands have large macropores with less surface area to adhere to water molecules. Water drains easily from macropores of sand, leaving air to replace the pores. This is why sands have great **permeability** and higher **aeration** than clays and silts.

Soil textural class can be estimated fairly easily in the field using simple hand texturing tests that evaluate the relative proportions of each particle size in a soil sample. More accurate determinations of the percentages of sand, silt and clay are determined in the laboratory using the Bouyoucos method which utilizes a hydrometer to measure the density of a soil-water suspension at a reference depth over a period of time. The suspension density decreases with the passage of time as the larger particles settle.

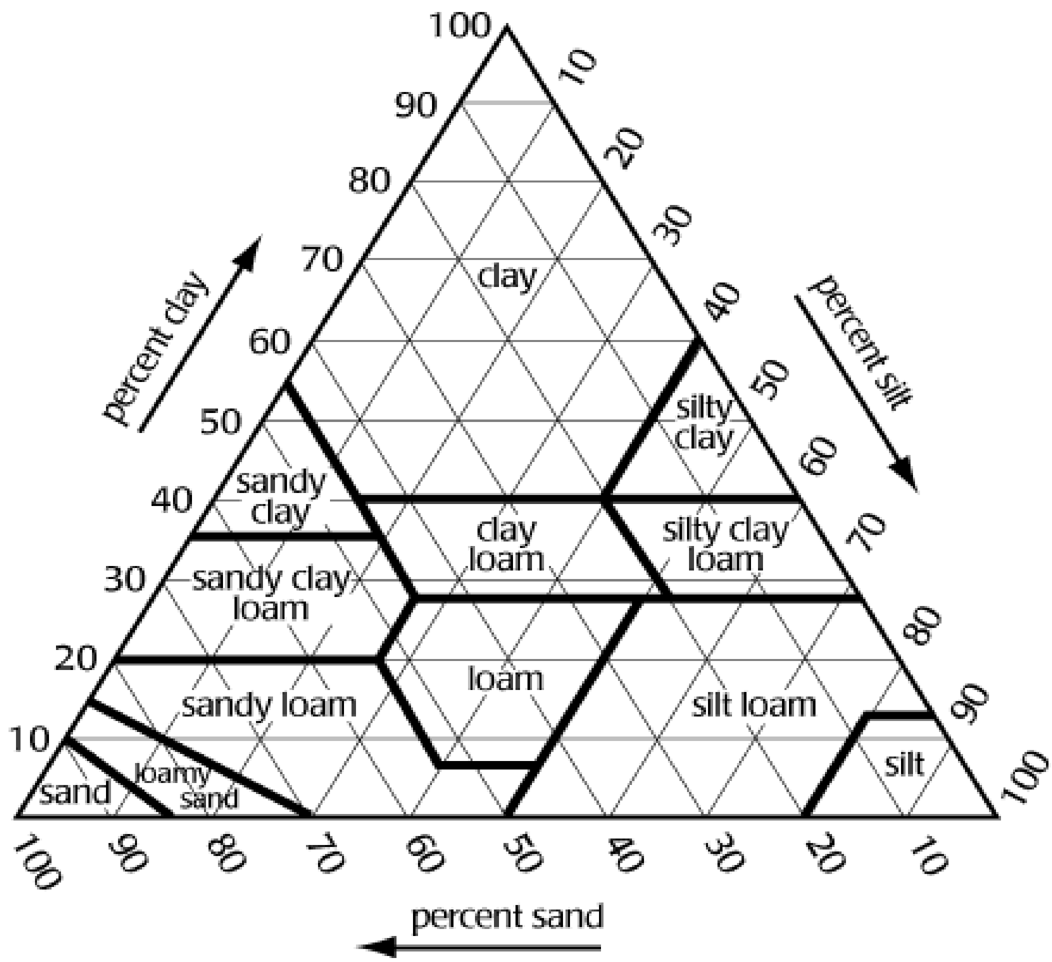


Figure 10: Soil Texture Triangle (Soil Genesis, n.d.).

4.3 Soil Structure

If you look closely at soils, you will notice the binding of individual granules into larger units that are called aggregates or peds. Soil structure refers to the nature of the arrangement of particles into these aggregate forms. Structure is very important because it affects the stability of soil and its resistance to degradation and collapse under pressure. The addition of organic matter can help to increase stability of aggregates, while physical disturbances by wind, water, traffic, and tillage can break apart and weaken the soil structure.

Good structure generally means the presence of large pores between aggregates that provide conduits for soil organisms and permit the penetration of plant roots, water, and air. This increases the rate of water infiltration, water retention, aeration, and plant growth. Soils with stable aggregates are also less prone to surface erosion both because the soil particles are less likely to be detached from one another, and because of improved drainage.

Poor soil structure often refers to a soil that is compact and weak. Weak soils are prone to collapse under pressure of overlying buildings and roads. Unstable soil aggregates are easily moved or eroded by wind and water and deposited elsewhere where they form hard crusts when they dry. Hard surface crusts prevent the emergence of seedlings, and encourage runoff, erosion, and reduce the availability of water. Dense or poor structure reduces the movement of air, water, nutrients, and soil biota.

The formation of aggregates is influenced by texture, composition, and the environment. Aggregation occurs when charged soil particles remain close together due to interactive forces such as hydrogen bonding, electrostatic, or van der waals forces. Aggregate formation is enhanced by biotic and abiotic factors that increase cementation. For example, organic matter can help cement aggregates to increase stability, and cycles of wetting/drying can decrease aggregation.

Aggregates are characterized by their size, shape, and strength. Some types of soil do not readily stick together to form stable and strong aggregates and are therefore structureless. You may have noticed this while attempting to build a sand castle on the beach. Sand particles easily fall apart into loose single grains. Some fine-textured clay soils are also structureless, forming dense and massive chunks that have no visible structure and are hard to break apart.

There are seven major classes of structure seen in soil. These are: single grain, massive, platy, prismatic, columnar, blocky, and granular.

Platy

Platy structured soils are made of flat, thin plates that are oriented horizontally. This type of structure is most commonly found in the subsurface of soils that have been compacted under pressure by animals and machinery. Platy structures usually hinder downward movement of water and penetration of plant roots through the soil.

Prismatic

Prismatic soil structures are characteristic of the subsoil and are formed when freezing/thawing or wetting/drying causes vertical cracks to develop in the soil. As the name indicates, prismatic structures have vertically extending surfaces with flat or round faces.

Columnar

Columnar structure is very similar to prismatic, with the distinction of each column having visible rounded tops with salt caps. Columnar structure is commonly found in arid climates. Growth of roots on columnar structured soils is rather slow and bound by the density of soil.

Blocky

As the name indicates, angular block-like or polyhedral units make up the blocky structure. This type of structure occurs commonly in soil with high clay content where swelling and shrinking of the clay causes cracks to develop.

Granular

The units of granular structure are composed of spherical or angular bodies that are comparable to cookie crumbs. This type of structure is commonly found in the surface-soil of areas with high organic matter content such as grasslands and highly amended gardens. Granular structures allow for good porosity and easy movement of air and water, and are very suitable for agriculture.

4.4 Bulk Density

Bulk density plays an important role in determining if soil has the necessary physical characteristics to support the foundation of buildings, plant growth or water infiltration. Bulk density is an indirect measure of pore space in the soil, which is primary impacted by soil texture and structure. It is calculated as the mass of dry soil solids divided by the total volume of soil (i.e. soil particles and pore space). It is measured in units of g/cm^3.

Soils that are porous, loose and well-aggregated have lower bulk density than compacted and non-aggregated soils. In general, bulk density increases with increases in sand content and decreases in organic matter content. While sandy soils have larger average pore sizes than clay soils they contain lower overall pore space and therefore have higher bulk densities. Organic matter content is light in weight and also promotes aggregation of soil into peds, which leads to increase in pore space and lower bulk density.

Figure 11: Shows a soil that has been compacted by heavy farming machinery. (OMAFRA, 2009)

The bulk density of soil is not an intrinsic property in that it is subject to change over time based on the management of the soil. Heavy traffic due to grazing or use of heavy machinery asserts high pressure on the soil and can increase the bulk density. With an increase in bulk density, the soil becomes more compact and less pore space is available to provide plants and soil organisms with air and water. More compact soils inhibit water movement and reduce infiltration down the soil profile. Low permeability causes water to remain on the surface and increases runoff and erosion.

There are several ways of measuring and calculating the bulk density of soil. Perhaps the most common method is the core sample method. Using this method, the soil science professional pushes or hammers a metal cylinder of known volume (with two open ends) through the soil to obtain a core sample. The sample inside core is extracted and oven dried to remove moisture. The weight of the oven-dried mass is divided by the volume of the cylinder to obtain the bulk density of the soil.

Figure 12: A metal core is used to collect soil core sample for bulk density measurements (University of Rhode Island, n.d).

4.5 Colour

The colour of soil can reveal important details about its properties and the processes operating in the soil profile. Colour variation is a simple and useful way of differentiating between various soil horizons and orders. Specifically, soil colour is indicative of three important facts: the state of aeration and drainage, the organic matter content, and the state of iron oxides.

Generally, moist soils and those with high organic matter appear darker in colour. This is why the rich organic topsoil appears darker than subsoil. Red and brown soils are usually well drained and aerated, allowing aerobic organisms in the soil to remain active. Also, in well aerated soils, iron is oxidized more readily and develops a 'rusty' colour. Gray and blue soils indicate an area of poor aeration due to poor drainage, prolonged saturation or waterlogging. The lack of oxygen means that the iron is in its reduced form, which can give soil a grey-blue colour. The table below summarizes some of the properties of soil that can be deduced from colour.

Condition	Dark (dark grey, brown to black)	Moderately Dark (brown to yellow brown)	Light (pale brown to yellow)
Organic matter	high	medium	low
Erosion factor	low	medium	high
Aeration	high	medium	low
Available Nitrogen	high	medium	low
Fertility	high	medium	low

Table 2. Properties of soil based on colours.

The colour of soil is described in a standardized fashion using notation from the Munsell Colour Chart which recognizes colour in terms of three dimensions: **hue**, **value**, and **chroma**. There are five principal hues: Red, Yellow, Green, Blue, and Purple, and five intermediate hues: Red-Yellow, Yellow-Green, Green-Blue, Blue-Purple, and

Purple-Red. Value indicates the lightness of a colour. The scale of value ranges from 0 for pure black to 10 for pure white. Finally, chroma describes the intensity of a colour. Colours of low chroma values are sometimes called weak or pastel, while those of high chroma are said to be highly saturated, strong, or vivid (fluorescent). The scale starts at 0 for neutral colours and extends to infinity (there is no upper limit).

The Munsell notation is written as follows: Hue Value/Chroma. An example would be 7.5R 7/2. 7.5R refers to the colour in the red hue, 7/ refers to the lightness, and /2 indicates the chroma.

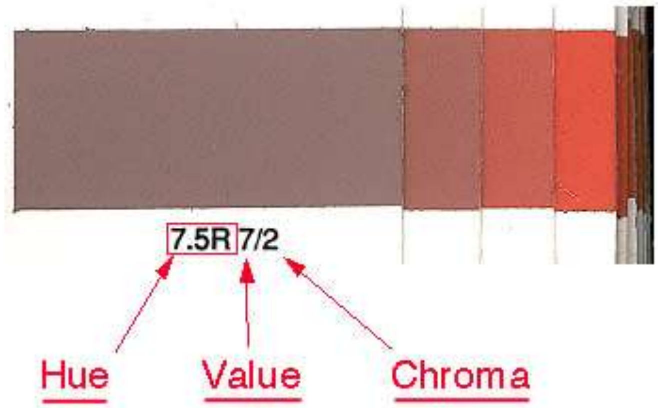


Figure 13: Musell notation (USGS, 2015)

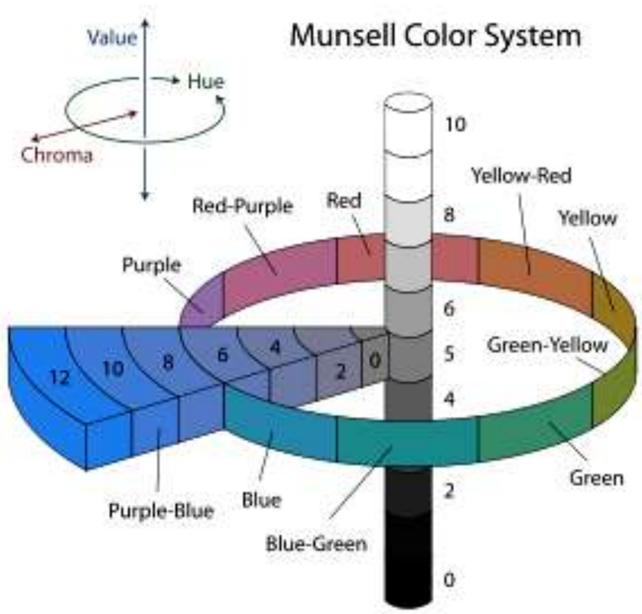


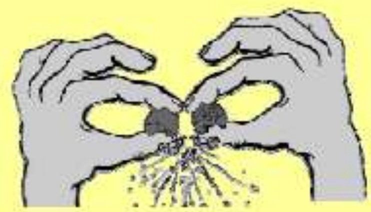
Figure 14: The Munsell system of colour classification recognizes colour in terms of three dimensions: *hue, value*, and *chroma* (Wikipedia, 2015b).

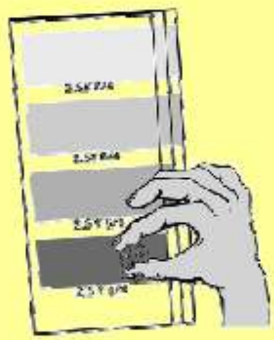
Measuring the colour of the soil using the Munsell Notation

Source: http://soil.gsfc.nasa.gov/pvg/color1.htm

1. Take a ped of soil from each horizon and note on the data sheet whether it is moist, dry or wet. If it is dry, moisten it slightly with water from your water bottle.

2. Break the ped.





3. Stand with the sun over your shoulder so that sunlight shines on the color chart and the soil sample you are examining.

4.6 Soil Temperature

The temperature of soil is an indicator of the energy needed to sustain normal activity of plants and soil organisms. It is a physical property of soil that is of great concern. All plants and microorganisms in the soil exhibit different preferences for temperature, which constitutes the upper and lower limits of the tolerance range. Within this range, plants and microorganisms can live and carry out a complete life cycle of birth, growth, and reproduction. The optimum temperature is a narrow range between the upper and lower tolerance limits that is most favorable and where plants and microorganisms perform best. Beyond the upper and lower limits of the optimum temperature range, growth and reproduction can slow down dramatically. The optimum temperature for different plants and organisms is widely variable.

The rate of physical, chemical, and biological processes is directly related to changes in soil temperature. Temperature can have a profound impact on the success of seed germination, root and shoot growth, nutrient uptake, and crop growth. In cold soils, the rate of biochemical reactions is slow. Decomposition and nutrient cycling can come to a complete stop as the activity of microorganisms decreases. For example, the activity of microbes that facilitate the oxidation of ammonium (NH_4^+) ions to nitrate ions (NO_3^-) occurs most readily at temperatures 27-32 ^oC and is severely slowed if the soil temperature is lowered to 10 ^oC. As a result, the availability of essential nutrients such as nitrogen, phosphorus, sulfur, and calcium is severely reduced, presenting adverse affects to higher plants. Temperature fluctuation can also provide benefits such as the control of pests and diseases. In addition, the effect of freezing and thawing can have profound influences on the physical structure of soil.

Figure 15: A soil temperature probe can be used to measure the temperature of the soil at various depths (http://www.ncusd203.org/madison/Links/teams/training.html)

Natural fluctuations in soil temperature occur regularly as the result of seasonal and diurnal changes in the amount of incident solar radiation or sunlight. Soil temperature change is also caused by variation in air temperature, moisture content, soil colour, slope of land and vegetation cover. Dark soils can absorb more heat than lighter soils that reflect sunlight, as a result, dark soils warm or thaw faster in the spring than light soils. It should be noted, however, that the evaporation of moisture from soil consumes heat, causing the soil to cool as the water evaporates at the surface. Since darker soils usually indicate higher moisture content, not all dark soils are warmer than light soils. Furthermore, soils that lie on south-facing slopes in the Northern Hemisphere receive more solar radiation throughout the year and are warmer in temperature. Vegetation also controls the amount of sunlight that can reach the ground surface. Bare soil cools and warms faster than vegetated soil that is insulated by vegetation.

Management practices can have significant effects on temperature of soil. Management of soil temperature involves placing controls on drainage, structure, organic matter content and proper mulching techniques.

5.0 The Chemical Nature of Soils

Soil is the primary source of nutrients for vegetation and crops. If soil lacks adequate quantities of nutrients, or if nutrients are locked in an unavailable form due to chemical properties of the soil, plants may become unhealthy and die. Soil chemistry is a branch of soil science that is concerned with chemical processes involving soil solids, soil solution, and soil air. Contemporary studies of the chemical nature of soil focus on chemical reactions in soil that affect plant growth and ecological health, such as the relationship between acidity, fertilization and crop yield. Since the 1960's studies in soil environmental chemistry and toxicology have emerged, which attempt to understand the fate, transport, and potential toxic impacts of contaminants that have been released into soil and their impact on ecosystem and human health. Environmental soil chemistry concentrates on reactions between soil and heavy metals, pesticides, industrial contaminants, acid rain and salts.

5.1 pH – Acidity and Alkalinity

pH is a measure of the concentration of hydrogen (H^+) ions in solution that is expressed as a negative logarithm (ie. $pH = -\log [H^+]$). In other words, pH is a measure of the acidity or alkalinity of a material. The pH scale runs from 0-14, where a pH of 7 represents an equal concentration of acids and bases and is called neutral. Any pH reading below 7 is considered acidic and any pH above 7 is called alkaline. As the concentration of hydrogen ions increases (i.e. solution becomes more acidic) the pH decreases. High pH values indicate low acidity.

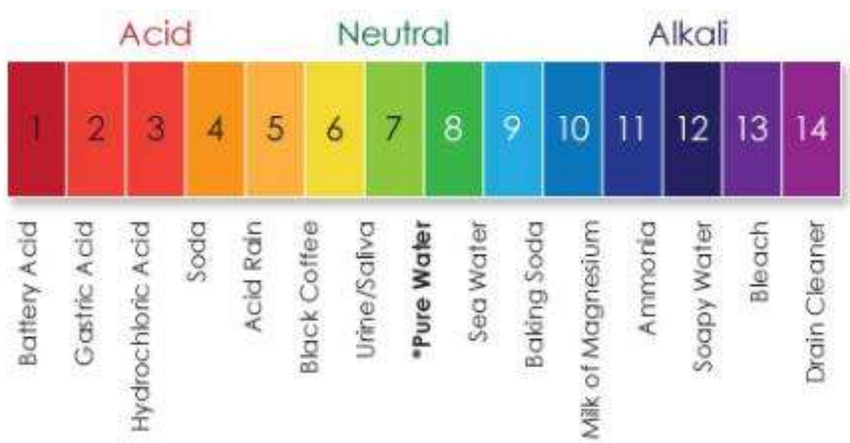


Figure 16: The pH Scale (Carmen's Science, n.d.).

Soil pH is one of the most informative properties of soil and has a profound influence on plant growth. One of the most important influences exerted by pH is the solubility and plant-availability of essential nutrients. Nutrients that are held on the surface of organic matter and clay particles must first be dissolved into the soil solution before they can be absorbed by plants. In some cases, excessive dissolution of elements into the soil solution can be toxic to plants. In other cases, dissolution of highly mobile elements causes them to be carried away by water, leaving the soil devoid of that nutrient. For example, herbicides, pesticides, and fungicides are absorbed by soil at certain pH values. Beyond these pH values these compounds can become mobile and be removed by leaching, causing runoff and pollution of water systems elsewhere. Soil pH also has an influence on the decomposition of agricultural and forestry residues, manure, sewage sludge and other organic materials.

All plants and soil organisms exhibit different preferences for acidity in their environment. Ideal conditions, or the optimum pH range, can vary widely from one organism to another. Specific levels of acidity are needed to grow, thrive, and fight off disease. Some plants, such as potatoes, strawberries, and blueberries are acid-loving and have a preference for acidic soils. Others enjoy slightly alkaline soils. Examples include the plants of the brassica family (e.g. cabbage and cauliflower).

It is extremely rare to find plants that prefer soils at either extreme of the pH scale. The majority of plants often prefer a neutral or slightly acidic soil between the range of 6.0 and 7.5. Below 6.0, essential elements such as nitrogen, phosphorus, and potassium become less available, and as the pH approaches 5.5 elements such as aluminum, zinc, iron, and manganese become soluble and available for uptake by plants in excessive quantities that are then harmful to plant growth. In acidic soils, plants are more likely to take up toxic metals and experience heavy metal poisoning which can cause injury or death. At any pH above 7.5, essential nutrients are less available and symptoms of deficiency may result. The result can be seen as slow and stunted growth, yellowing of leaves, and thin growth of stems.

Soil **acidification** occurs often in areas with high levels of precipitation, where rainfall causes the leaching of appreciable quantities of basic cations. Acidification also occurs through the addition of hydrogen through decomposition of organic matter, the addition of acid-forming fertilizers, and the exchange of basic cations for H^+ by the roots of plants. Soil alkalinity is caused by the addition of nitrogen fertilizers (e.g. nitrates, ammonium and urea), but could also be a reflection of basic parent materials such as limestone bedrock which is made up of calcium and magnesium carbonates.

Any excessive acidity or alkalinity which may cause stress or fatality in plants and organisms can be corrected. Lowering of soil pH due to high alkalinity can be achieved by incorporating elemental sulfur into the soil where the pH can be raised through the application of liming materials such as ground limestone or industrial by-products that contain calcium oxides or hydroxides.

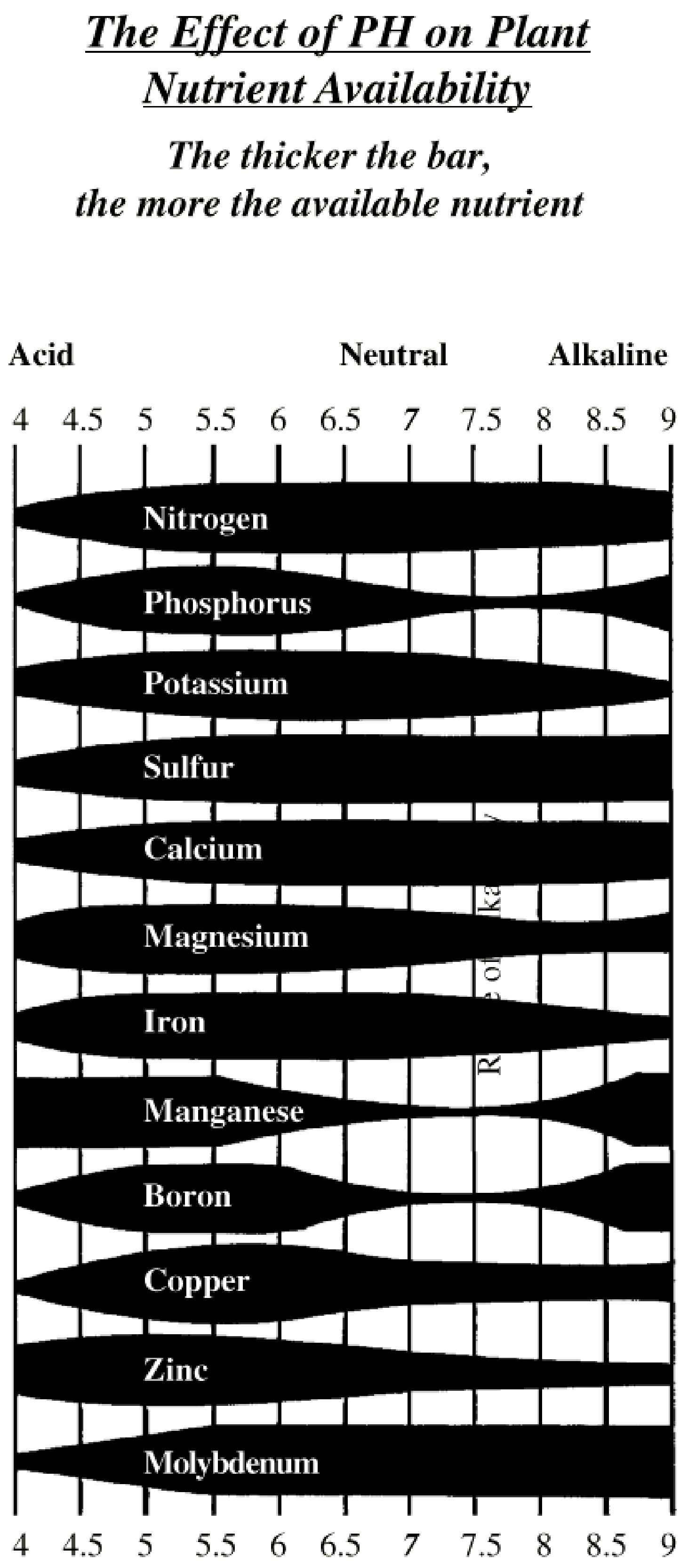


Figure 17: The change in availability of nutrients with changes in pH **(**University of Arizona, 1998).

5.2 Cation Exchange Capacity

Cation exchange capacity (CEC) refers to a soil's ability to maintain reserves of positively charged ions know as cations. Cation exchange occurs when cations are exchanged between soil particles and the soil solution. The six most abundant exchangeable cations in the soil are calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^{+}), sodium (Na^{2+}), aluminum (Al^{3+}) and hydrogen (H^{+}). CEC is influenced by the texture of the soil. CEC is higher in soils with high clay and organic matter contents as these are the most chemically active fractions of soil. In order to better understand this process, we must first investigate the properties of clay and organic matter that make them suitable for cation exchange.

The particles of fine clays and organic matter are called **colloids**. Two properties about colloids make them particularly suited for cation exchange. Colloids are extremely small in size, generally less than 1 µm (less than 0.001 mm) in diameter. The small size of colloidal particles means that they have extremely large surface area to volume ratios. In fact, the surface area of 1 g of colloidal clay is at least 1000 x that of sand. Second, colloids have negatively charged surfaces. Charges on the surface of clay colloids occur when an atom in the clay mineral r structure is substituted with an atom of similar radius but different charge. For example, Si^{4+} in a clay colloid can be replaced with Al^{3+} atoms. The balance is a negative charge. The negatively charged surfaces of the colloids serve to attract oppositely charged cations that are loosely held by electric forces. This loose attraction is referred to as **adsorption**.

Once adsorbed, mineral elements are stored on colloids preventing any losses from the soil. As a result, nutrient reserves are available to plant roots for uptake through exchange between colloids and soil solution. If cations are not held or adsorbed to colloids, such as in the case of a soil with low CEC, any added cations are susceptible to loss from the rooting zone of plants through leaching with percolating water. CEC is of particular importance in the application of pesticides and fertilizers. If the CEC of the soil is too low, the cations in these compounds are not adsorbed and will easily be leached away, possibly polluting underground or surface water resources elsewhere.

Not all cations are held with equal force by the soil colloids. As a general rule, atoms of increasing positive charge and smaller molecular radii are held with greater attraction. When cations are present in equal concentrations, the order of strength of attraction is summed as follows:

$$\mathbf{Al^{3+} > Ca^{2+} > Mg^{2+} > K^{+} = NH_4^{+} > Na^{+} > H^{+}}$$

In addition to the strength of adsorption, the relative concentration of cations in the soil solution also determines the degree of adsorption. The greater the concentration of a cation, the greater its adsorption.

Since not all cations are held equally tight and differ in relative concentration, they are subject to exchange with other cations of greater attraction. Once cations are exchanged and released into the soil solution, they can be taken up by roots and soil organisms.

A low CEC value means that the soil is unable to hold nutrients that are applied through fertilization and therefore there will be limited availability of these nutrients to plants and microorganisms. Low CEC is generally a reflection of low levels of clay and organic colloids in the soil. In such a case, addition of organic matter should assist in raising the CEC of the soil. Soil pH is also important for CEC because as pH increases, the number of negative charges on the colloids increase, thereby increasing the CEC. The pH of a soil with low CEC can be increased by addition of lime.

CEC is an important property of soil because it is a useful indicator of soil fertility, nutrient retention capacity, and the capacity to protect groundwater from contamination.

5.3 Essential Nutrients

One of the main reasons for the study of soil chemistry, soil pH and cation exchange capacity is to understand how nutrients are processed and made available to the plants and organisms that need them. Plants require a combination of adequate air, water, light and temperature to grow. In addition to these resources, plants also require a favourable concentration of 16 different elements or nutrients. These 16 nutrients are divided into two groups: *mineral* nutrients, and *non-mineral* nutrients. Non-mineral nutrients, namely hydrogen (H), oxygen (O), and carbon (C) are obtained from the air and water. In a process called photosynthesis, carbon dioxide from the air, water and soil are converted into starches and sugars. Non-mineral elements make up approximately 94% of plant tissues. The remaining 13 nutrients are mineral nutrients that are obtained in different quantities from the soil solution and absorbed through the plant's roots.

There are two main groups of mineral nutrients, each distinguished based on the quantity of the mineral that is required for healthy growth. Macronutrients are those nutrients that are required in relatively large quantities whereas micronutrients are required in comparatively small quantities.

The primary macronutrients are nitrogen (N), phosphorus (P), and potassium (K). Generally speaking, these are the first nutrients to be lacking in soil since they are used in the greatest quantity. The secondary group of macronutrients are calcium (Ca), magnesium (Mg), and sulphur (S). These are usually found in adequate quantities in soil. The trace elements or micronutrients are boron (B), zinc (Zn), chlorine (Cl), manganese (Mn), molybdenum (Mo), and iron (Fe) and are generally obtained by the recycling of organic matter. Nutrients are recycled within the soil environment to support plant needs. Plants grow normally until they run short of one or more nutrients. Growth and development become limited by the least available plant nutrient, regardless of how much of the other nutrients that are available to the plant. When one or more nutrients limit the plant's ability to perform normal tasks, we say that the plant is deficient in that particular nutrient(s). Deficiencies can cause discolouration or deformations of plant structures as well as declines in plant growth.

There are two types of deficiencies. Real deficiencies are those that result from the lack of a nutrient's presence in soil, whereas induced deficiencies are those that occur when high levels of one nutrient prevent the uptake of another. Real deficiencies occur when nutrients are removed from the system due to erosion, leaching and harvesting of plants, without subsequent addition of nutrients to the soil. Soils that are deficient in one or more nutrients must be replenished to maintain long-term fertility and plant productivity. This can be done through the addition of nutrient fertilizers or through soil conservation practices that recycle ecosystem nutrients.

Mineral/Element	Chemical symbol	Main requirement/use by the plant
Macronutrients		
Nitrogen	N	Plant growth; proteins; enzymes; hormones; photosynthesis
Sulfur	S	Amino acids and proteins; chlorophyll; disease resistance; seed production
Phosphorus	P	Energy compounds; root development; ripening; flowering
Potassium	K	Fruit quality; water balance; disease resistance
Calcium	Ca	Cell walls; root and leaf development; fruit ripening and quality
Magnesium	Mg	Chlorophyll (green colour); seed germination

Table 3: Role of soil macronutrients in plant lifecycle (University of Arizona, 2007).

Mineral/Element	Chemical symbol	Main requirement/use by the plant
Micronutrients		
Copper	Cu	Chlorophyll; protein formation
Zinc	Zn	Hormones/enzymes; plant height
Manganese	Mn	Photosynthesis; enzymes
Iron	Fe	Photosynthesis
Boron	B	Development/growth of new shoots and roots; flowering, fruit set and development
Molybdenum	Mo	Nitrogen metabolism
Chloride	Cl	Photosynthesis; gas exchange; water balance

Table 4: Role of soil micronutrients in plant lifecycle (University of Arizona, 2007).

6.0 The Biological Nature of Soils

Healthy soils consist of a complementary blend of minerals, rocks, water, air and organic matter. However, soil is so much more, containing in its body a concealed world of live and complex ecosystems, which include a variety of bacteria, fungi, protozoa and other living organisms. **Soil biota** are organisms that spend all or a portion of their lifecycle within the soil or on its immediate surface.

Soil communities are very diverse in size and number of species, which are defined by the chemical and physical nature of the soil body. The physical and chemical nature of soil in addition to factors such as vegetation, climate and nutrient content shape the environment for a myriad of flora and fauna that call the soil home. In one gram of any given body of soil, millions of individual soil organisms can be found carrying out their biological functions and executing the vital processes that make life on earth possible. In fact, soil is one of the most diverse and complex ecosystems on earth, providing shelter to thousands of different species of organisms.

The incredible diversity of life that inhabit soil, range in size from single-cellular submicroscopic organisms such as viruses to larger more complex organisms such as gophers and ground squirrels. Soil flora and fauna are categorized in terms of size as **macrobiota**, **mesobiota** and **microbiota**. Macrobiota refers to organisms that are visible to the naked eye which dig the soil for shelter and feed on, or in, the soil. Macrobiota include vertebrates such as mice, moles, and groundhogs and invertebrates such as ants, termites, earthworms and snails. Mesobiota are 0.1-2 mm in diameter and generally live within soil pores. These organisms, such as springtails, have little ability to burrow and generally feed on organic material and other soil organisms to survive. Microbiota which are comprised mostly of bacteria, fungi, algae and protozoa are the smallest organisms. They are extremely abundant and diverse and are able to decompose almost all existing residual organic matter.

The presence and functions of soil organisms is so vital that soil biodiversity is often used as an indication of the soil's quality and health. This is, of course, attributed to the fact that the routine activities of soil organisms moderate water flow, decompose and recycle organic matter, and make it possible to have clean water, clean air, and healthy, productive plants.

6.1 Soil Biodiversity

Soil biodiversity is defined as the variety of life found in soil, it includes numerous species of invertebrates and microorganisms, soil flora, plant roots, mammals, birds, reptiles and amphibians. Soil communities are among the most species-rich areas in terrestrial ecosystems. Most of the organisms inhabiting soil ecosystems are found within the top 10 cm of the soil profile.

There are several factors that can contribute to the biodiversity found within soil. These factors include soil texture and structure, abiotic conditions (sunlight, rainfall, wind) and interactions with other organisms. The amount of organic matter found in soil has a large impact on the surrounding biodiversity as it influences soil fertility and structure, workability and water-holding capacity. These factors influence the number and species of plants that are capable of growing in the soil, in turn impacting local wildlife. Soil structure is important because it affects the stability of soil and its resistance to degradation under pressure. Structure is strongly influenced by texture, organic matter, compaction and biological activities. Much like soil texture, soil structure can also impact the organisms living within the soil. Good structure generally means the presence of large pores between particles. Soils with good structure increase water-holding capacity, promote root growth, maintain aeration and drainage, provide a better habitat for organisms and reduce erosion risk.

As knowledge of soil biology increases, the threats to soil biodiversity also become evident. Indirect effects on biodiversity include structural decay, erosion and organic matter decline. These factors influence habitat for organisms within soil and contribute to biodiversity decline. Direct impacts on biodiversity include contamination of soils through salinization and pollutants. The impact of global change on biodiversity within soil ecosystems is not yet known, however, communities with high resiliency will not be impacted as greatly as communities with low resiliency. Climate change will have impacts on local communities as there is a strong connection between soil formation, soil structure and climate.

Soil ecosystems with higher levels of biodiversity result in more productive, sustainable communities. These communities are also more resistant to changes in surrounding biotic and abiotic conditions. Increased biodiversity leads to increased redundancy in an ecosystem. High redundancy allows one species to substitute for another, such that functions are continuously achieved, even with the loss of one species. With increased redundancy, soil ecosystems also have higher resistance to perturbations. More diverse systems are also more resilient following perturbations. Resilient ecosystems can withstand shocks and rebuild themselves when necessary. This is beneficial in changing environments.

The vast diversity of species found in soil communities impacts soil quality and functions by providing essential services to the abiotic components of the soil. Due to the extensive functions of soil biota, declining soil biodiversity will have dramatic negative impacts on ecosystem processes, ecosystem stability, community composition and community stability.

Function	**Comments**
Degradation of organic matter	The most obvious function carried out by soil biota. Up to 80% of the organic material fixed by primary producers flows to the detrital food chain.
Cycling of nutrients	As organic matter is processed, nutrients are released into the environment and become available for recycling back to primary producers.
Sequestration of carbon	Organic residues from decomposition become part of the stable structural carbon pools of terrestrial ecosystems.
Production and consumption of trace gases	As soil biota degrade organic material, recycle its nutrients, and sequester its carbon, they also carry out other functions that are important. Soil microbial activity leads to the production and consumption of a variety of trace gases (carbon dioxide, nitrous oxide, methane, carbon monoxide and sulfur gases), many of which are important greenhouse gases.
Degradation of water, air and soil pollutants	Soil and sediment biota processes (degrade, produce, alter) a variety of water, soil and air pollutants of anthropogenic origin, including pesticides and industrial compounds.
Development and maintenance of physical structure	Soil biota help to produce and maintain the physical structure of terrestrial ecosystems. Organisms are critical agents in soil formation. This role is expressed directly via the burrowing and tunneling activities of fauna and their production of sticky compounds, and indirectly via the production of structural organic matter.

Table 5: Soil biota functions that can be used to evaluate the links between diversity and ecosystem function.

6.2 Organisms of the Soil

Soil is a complex ecosystem with a community of diverse organisms that occupy a broad range of niches. Like other ecosystems of the earth, the soil flora and fauna are intimately related and interact through a complex network of energy and nutrient transfers known as a food web. The soil food web is the community of organisms that spend all, or a portion, of their lives in or around the soil.

The energy to fuel the food web is obtained from the sun by **primary producers** in fixing carbon dioxide from the atmosphere into sugars. Primary producers include plants, lichens, moss, photosynthetic bacteria, and algae.

Primary consumers of the soil ecosystem live off of photosynthesizing organisms or their by-products. **Detritivores** are organisms that consume dead and decaying plants, while **herbivores** consume living plants. The primary consumers are themselves sources of nutrition for higher tropic levels, such as **secondary consumers**, which are in turn food for **tertiary consumers**. When these organisms die and decompose, nutrients are once again returned to the soil and made available to plants and other soil organisms.

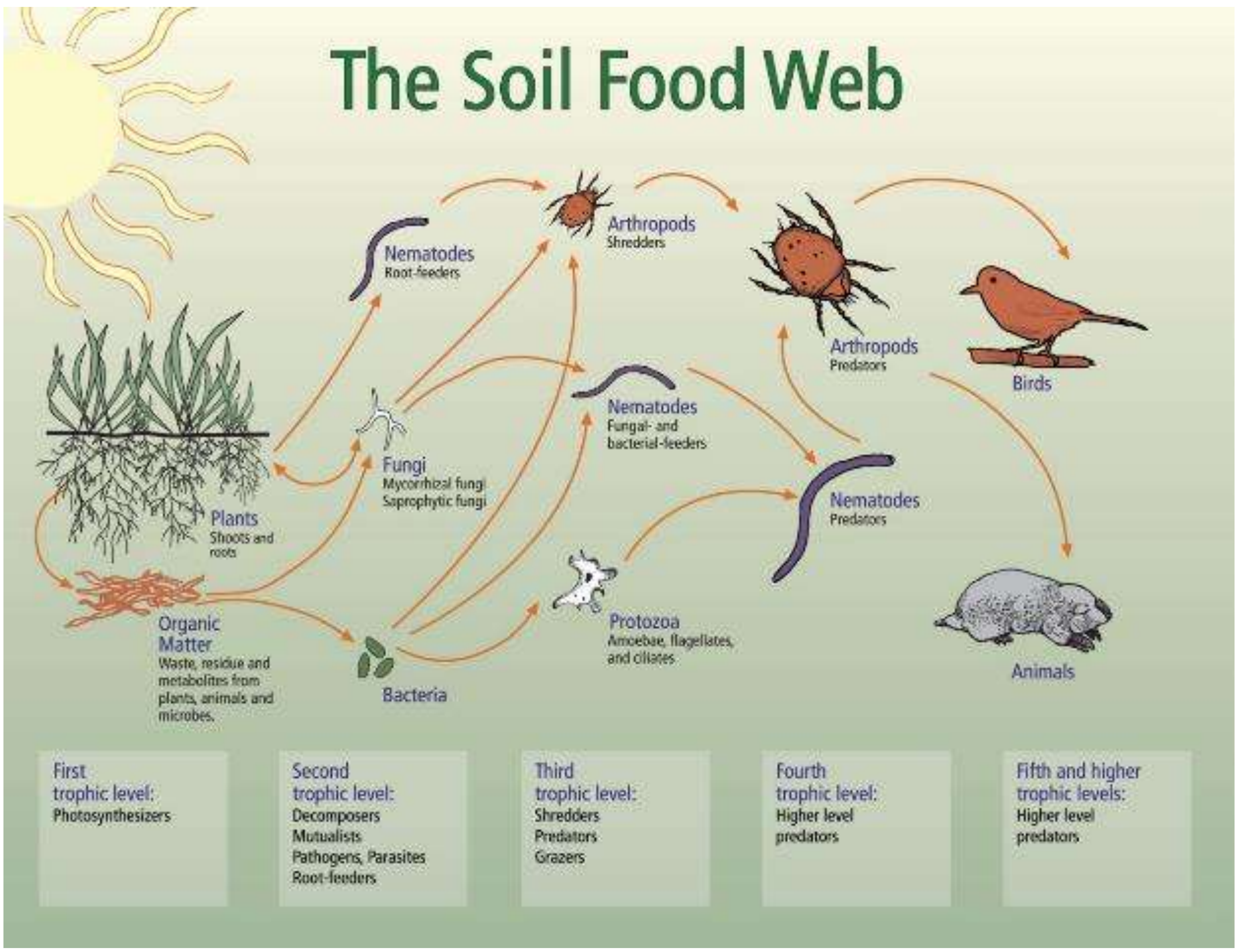


Figure 18: The food web of the soil (USDA, n.d.).

6.2.1 Soil Microbiota

Microorganisms are the smallest form of life that often exist in single-celled colonies. They are generally not visible to the naked eye. Microorganisms are most concentrated in the top-most horizons of the soil that are enriched in organic food sources; around roots, on humus and in dead and decaying litter. These organisms are the key decomposers of organic matter, however they carry out additional functions such as nitrogen fixation, aggregate formation, and production of antibiotics.

Algae

Algae are photosynthetic organisms that capture the energy of the sun to convert inorganic substances into organic matter. Algae need light to carry out their photosynthetic process, and therefore are found near the surface of the soil. Some algae are also able to capture nitrogen from the air as in nitrogen fixation, and provide nearby plants with this nutrient. Algae provide the important advantage of improved soil structure. They produce slimy (gelatinous) substances that glue soil particles into aggregates, helping to improve the strength and stability of the soil.

Fungi

Fungi come in many different species, sizes, and shapes in the soil, including threadlike colonies, single-celled yeasts, slime molds, and mushrooms. The most important soil fungi are molds, mushrooms, and mycorrhizae. Unlike algae, fungi are not photosynthetic, and must therefore obtain their energy from breaking down the organic matter found in soil. Fungi are the first organisms to attack fresh, organic residues before any other organisms join in the decomposition process. They tend to break down the more complex compounds and in the process, help release nutrients from organic matter into the soil. Fungi are also able to produce plant hormones and antibiotics that encourage growth and destroy diseases and pests. In addition, the network of fungal hyphae helps strengthen soil structure and stabilize aggregates by secreting a sticky gel that glues mineral and organic matter.

Mycorrhizae are a special group of fungi that live on or in plant roots and form symbiotic (mutually beneficial) relationships with the plants. Mycorrhizae infect the roots of plants and send out root-like structures called hyphae. The hyphae of fungi extend into the soil, and increase the contact of roots with soil. Hyphae absorb water and nutrient and provide them to the plant roots. Mycorrhizae also protect the plant roots against pest nematodes that cannot penetrate through the thick fungal network. In return, the fungi receive nutrients and carbohydrates from the root of the plants they live on.

Figure 19: Root heavily infected with micorrhizal fungi (Phys Org, n.d.).

Bacteria

Bacteria are the most numerous of the soil organisms with capacity to rapidly reproduction. In fact, every teaspoon of soil can carry billions of individual bacteria. Their wide range of tolerance allows them to exist in a wide range of habitats, including the guts of living organisms, oceans, freshwater, compost piles and soils.

Bacteria are one-celled organisms that are either autotrophic or heterotrophic. Autotrophic bacteria obtain their energy from the oxidation of inorganic substances such as ammonium, sulphur, and carbon dioxide. In the process, they increase the solubility of these nutrients for plants to absorb. Heterotrophic bacteria cannot make their own energy, and generally obtain it from the breakdown of organic matter in the soil. Unlike fungi, bacteria attack the more simple organic compounds. During this decomposition, bacteria help to release important elements for higher plants. Bacteria also make and release natural plant growth hormones to stimulate root growth. Some bacteria are also able to fix nitrogen from the air such as in the process of biological nitrogen fixation, both in association with, and independently of, legumes.

Actinomycetes

Actinomycetes are a type of bacteria that have fungi like characteristics including their thread-like structure. Actinomycetes break down lignin, a large and complex molecule found in the tissues of plant stems that is difficult for other organisms to break down. In addition, they produce antibiotics to fight diseases of roots. Actinomycetes develop in moist, well aerated soil, and are responsible for the rich organic scent of soil immediately following ploughing.

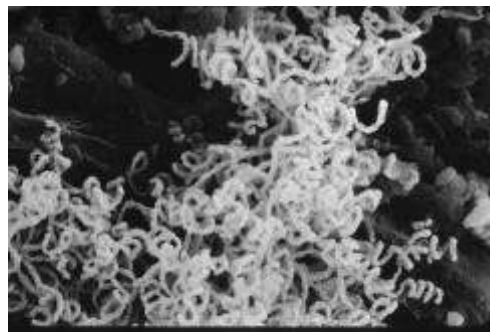


Figure 20: Actinomycetes, thread-like organisms. **(**USDA, n.d.).

Protozoa

Protozoa are single-celled organisms that are considered to be the most diverse and numerous of the soil microfauna. They thrive in moist, well-drained soils where they can crawl or swim in the water around soil particles. Protozoa prey on organic materials, bacteria, fungi, and other protozoa. They are considered to be secondary consumers of the soil, however they do not contribute significantly to decay and nutrient release.

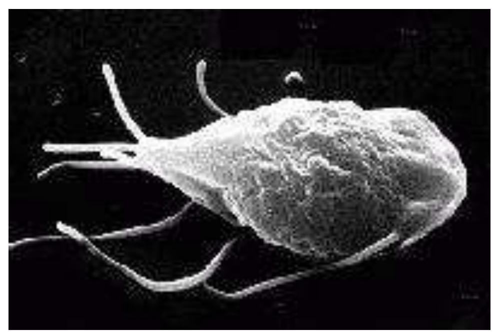


Figure 21: Protozoa (USDA, n.d.).

Nematodes

Nematodes, also called threadworms or eelworms are generally microscopic in scale and are found in abundance in almost all soils. Nematodes can be either beneficial or detrimental to the soil environment based on the particular species. Predatory nematodes consume plant litter, bacteria, fungi, algae, protozoa, and garden pests. Pest nematodes however, can attack the roots of practically all plant species, causing serious damage, especially to vegetable crops.

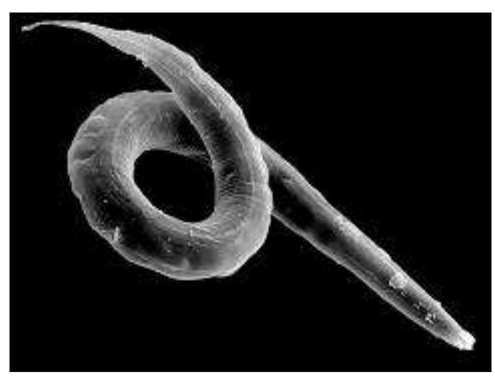


Figure 22: Nematode (USDA, n.d.).

6.2.2 Soil Mesobiota

Earthworms

Earthworms are a type of soil fauna with enormous favourable influences on soil and crop productivity. Earthworms burrow through the upper 15-35 cm of soil and ingest dead organic matter, minerals, and bacteria. This material is passed through the digestive system of the worms where it is mixed and is expelled as fecal casts. Casts are extremely rich in nutrient and organic content and contribute to the fertility as well as aggregation of soil. A good population of earthworms can process 20,000 pounds of topsoil per year!

Furthermore, the burrowing action of earthworms creates tunnels (biopores) which enhance aeration, allowing air to enter deeper into the soil and stimulate nutrient cycling and oxidative reactions. Burrowing also opens ways for water to infiltrate through soil, thereby reducing runoff and in turn enhancing groundwater recharge.

Comparisons between soils with and without earthworms have revealed reoccurring patterns of improved soil characteristics and productivity. These include lower bulk density, increased structural stability and increased CEC in addition to higher concentrations of calcium, potassium, phosphorus, and nitrogen.

Most earthworms prefer near-neutral soil pH and moist habitats with high organic matter content. In drier areas, earthworms tend to dry up and without organic matter there is no source of food. This is why earthworms thrive best in low to no-tillage environments. Tillage tends to dry the soil, bury organic plant residue deeper in the soil profile and render the soil more prone to freezing in cold winters. Tillage also destroys the burrows and kills the earthworms themselves.

As a rule, earthworm numbers can be increased by reducing or eliminating tillage, reducing organic matter particle size, through the addition of animal manures and minimizing pesticide use.

Termites

Termites are a significant force behind organic matter decomposition in or at the surface of soil. In some tropical climates they build mud nests or honeycombed mounds that can be as tall as 6m. Over 1 million termites can reside in each mound, where they lead very complex social lives.

Figure 23: Termite.(bioold, 1999).

Termites contribute heavily to the mixing of soil and organic material as they transport extensive amounts of soil from lower layers to the surface of the soil.

However, unlike earthworms, termites render soil more compact as they cement together soil particles for their mounds. In addition, termites differ from earthworms in that their deposits have much lower organic matter content than the surrounding soil. Crop production in soils where termite mounds existed is poor for these reasons. On the contrary, termites do offer the benefit of accelerated decay of dead trees and grasses.

Ants

The impact of ants on soil environments is much more negligible than that of earthworms and termites and is only locally notable. Ants build nests and mounds that differ substantially from conspicuous mounds to hidden underground nests. However, ants do bring about an extensive turnover in the soil when deeper subsoil is brought to the surface of the earth. In addition, some ants are quite efficient at breaking down woody debris.

Arthropods

Arthropods are a group of soil organisms with exoskeletons and jointed limbs that are still visible to the naked eye. Among them are sowbugs, millipedes, slugs, snails and springtails. These organisms are the primary decomposers in soil, eating and shredding large organic particles and mixing residue with the soil. The waste produced by arthropods is extremely rich in plant nutrients that are released after it is further worked on by bacteria and fungi.

6.2.3 Soil Macrobiota

Macrofauna

Large animals, including moles, rabbits, snakes, prairie dogs and badgers are all considered to be a part of the soil community. They burrow and spend a part of their lives below the soil, creating tunnels that decrease erosion. Some consume smaller soil organisms such as worms while others consume vegetation. Many soil macrofauna are considered to be a nuisance to agriculture since their underground tunnelling can be problematic to heavy farming machinery and live stock.

Macroflora

Roots of plants, trees and shrubs make up the macroflora of the soil. If soils physical and chemical conditions are unsuitable, plant roots do not grow properly and crops can fail. Plant roots impact the soil by influencing the formation of aggregates, as well as by releasing root exudates that nourish soil organisms.

6.3 Benefits of Soil Organisms

6.3.1 Organic Matter Decomposition and Nutrient Cycling

The matter that makes up the body of all humans, animal and plants was once a part of the body of soil that was transformed over time from plant matter to animal flesh and eventually returned back to the soil. This important cycle of life could not continue without the contribution of soil flora and fauna to decomposition. During decomposition, complex organic chemicals are broken down into physically smaller and chemically simpler compounds. In the process, carbon is either released to the atmosphere as CO_2, or it is **sequestered** within the body of soil organisms or stored in organic humus compounds.

Humus, the organic portion of topsoil, consists of dead plant and animal residue that has been decayed by soil biota. The process of decay occurs because soil organisms use organic carbon compounds from organic matter for energy and to make cell matter. Once decayed, nutrients that were trapped in the original organic matter – carbon, nitrogen, sulphur, and phosphorus – are returned to the soil, replenishing its fertility. This is the basis of nutrient cycling in all ecosystems around the world.

6.3.2 Soil Structure and Stability

When soil biota break decompose organic matter, they convert complex carbon compounds into simpler polysaccharides. Long and flexible polysaccharides act as a glue-like matter to hold soil particles together as aggregates. This binding of individual soil particles with adjacent particles is a significant feature that helps improve the stability of the soil. Aggregation also prevents or minimizes runoff and erosion, improves aeration, water drainage and the movement of plant nutrients.

6.3.3 Inorganic Transformations

The nitrogen, sulphur, and phosphorus contained in organic matter exist in an organic form, and are unavailable to higher plants. For the most part plants are only able to take up nutrients in their inorganic mineral forms. The organically-bound forms of the nutrients must be converted into plant-available forms first by microbial action. This process is called mineralization. Mineralization of organic material liberates carbon dioxide, ammonium (which is rapidly converted to nitrates), sulphate, and phosphate in addition to inorganic forms of other elements.

While doing this, some soil organisms take up nutrients to be used for their own means and sequester them within their body. The nutrients taken up by the soil organisms are immobilized and therefore unavailable to plants. It is not until these organisms die and decay that other soil organisms can make the nutrients tied up in their bodies available to higher plants.

In addition, soil biota can control the form of nutrients available in the soil. For example, the bacteria *Nitrosomonas* and *Nitrobacter* facilitate the oxidation of nitrogen in the form of ammonium (NH_4^+) to nitrite (NO_2^-) and nitrate (NO_3^-), respectively. In another case, the bacteria *Thiobacillus* facilitate the oxidation of elemental sulphur to sulphuric acid. The bacteria that facilitate oxidation of nitrogen, sulphur, and other compounds, use the energy released during oxidation to drive their own metabolisms.

6.3.4 Nitrogen Fixation

Biological Nitrogen Fixation is the process through which biological agents convert nitrogen from the air (N_2) into a form of nitrogen that is available to plants. This process is carried out for the most part by soil bacteria that exist in symbiotic relationship with plants. The most commonly recognized form of this relationship is between rhizobium and legume root-nodules. These bacteria thrive on the surface of roots of specific legumes and benefit from the supply of proteins and sugars that are released through exudates. In turn, the bacteria 'fix' large quantities of elemental atmospheric nitrogen into plant-available forms of nitrogen.

Many legumes are able to supply their own nitrogen through fixation. Nearly two thirds of the world's nitrogen supply is obtained from biological nitrogen fixation. The practice of green manuring is around the world to increase the nitrogen content of soil by planting legumes. In this practice, legumes are planted solely to improve the fertility of the soil without the use of synthetic agricultural fertilizers.

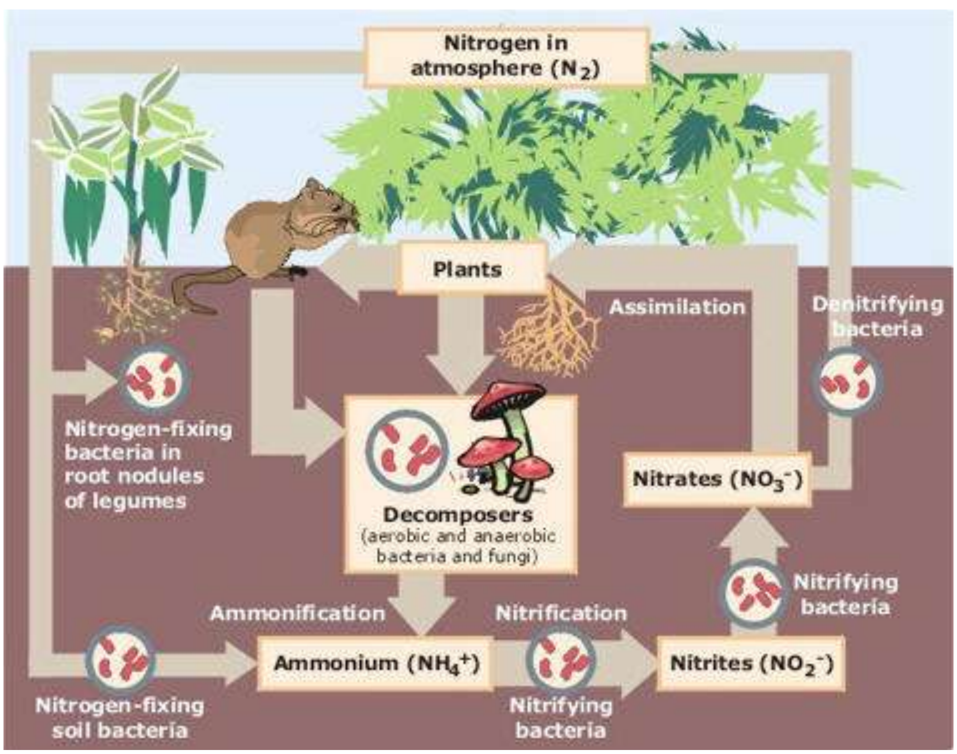


Figure 25: The nitrogen cycle (Wikipedia, 2013).

6.3.5 Degradation of Pollutants

Many soil microorganisms have the remarkable ability to break down, degrade or immobilize hazardous substances, including organic compounds, into less toxic or non-toxic substances. Examples of these materials include pesticides, herbicides, petroleum products and heavy metals. An important implication of pollutant degradation is purification of water and prevention of water pollution.

Soil science professionals have taken advantage of soil's ability to breakdown harmful substances to develop methods for remediation of contaminated soils using the soil's own organisms. This process is called **bioremediation**. Bioremediation is a method of cleaning contaminated soil using microorganisms such as bacteria to break down spilled pollutants within the soil. There are two ways of bioremediation a contaminated site.

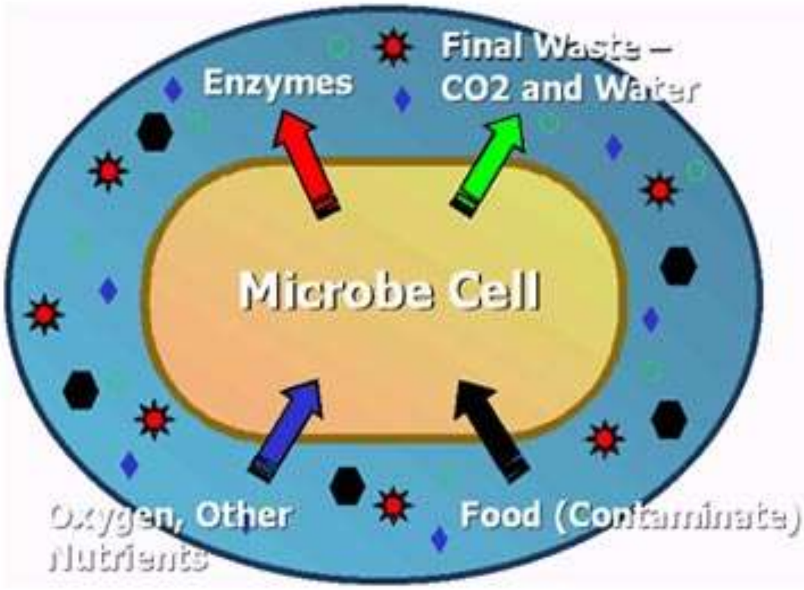


Figure 26: Bioremediation. Oxygen and nutrients are added to the soil to encourage multiplication of existing microbe cells (alternatively, new microbe populations are added to the soil). Soil microbes release enzymes that help them to consume contaminants as food. Harmless biological wastes such as carbon dioxide and water are released (Integra Environmental, n.d.).

One method, **biostimulation** modifies the environment of the soil so as to render it more favourable to the growth and development of soil organisms. Increased aeration and addition of fertilizing nutrients such as phosphorus, nitrogen, and potassium allow the rapid and persistent reproduction of already present microorganisms. The immense population of microbes, bacteria, and fungi in the soil naturally degrade and destroy any chemical pollutants in the soil. In contrast, **bioaugmentation** involves the introduction of non-indigenous microbial populations to speed up the degradation process.

7.0 Soil Degradation

Without a doubt humans and soils have evolved mutually throughout history; human survival has been linked to the health of the soil, and the health of the soil has been linked to the humans that use it. When human use of the land renders it less vigorous and healthy, we say that the land has been **degraded**. Soil degradation occurs as a result of both natural and human-induced processes that reduce its potential productivity. Changes in the physical, chemical and biological nature of soil that are brought about by inappropriate land-use practices and bad management reduce soil's ability to support plant and animal growth. The soil may decline in available moisture, nutrients, and biological activity.

During the past 50 years, inappropriate land use has degraded about 5 billion ha of the Earth's vegetated land. The figure amounts to approximately 23% of the world's previously usable land and is expanding at a rate of 9 million ha per year.

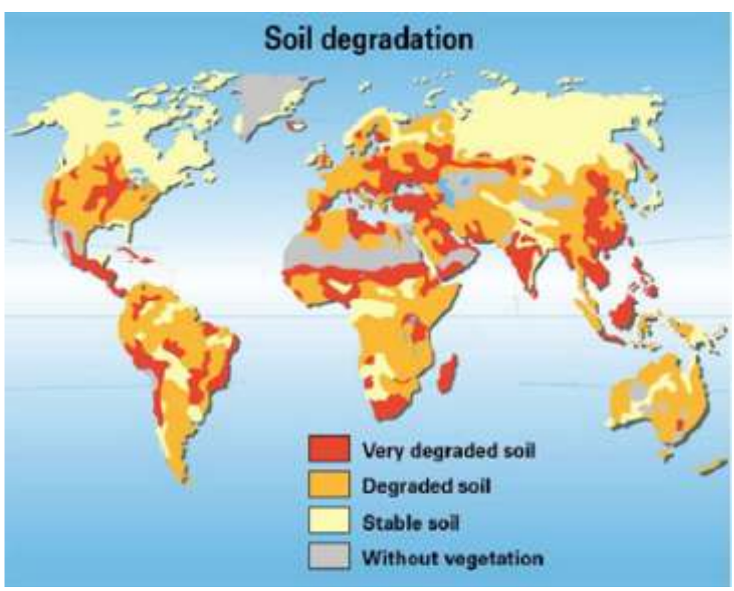


Figure 27: The state of soil degradation in the world in 1997 (Greenfieldgeography, n.d.).

Soil degradation is a result of economic, social and political pressures on the land. It occurs primarily due to overgrazing (35%), deforestation (30%), agricultural activities (27%), overexploitation of vegetation (7%) and industrial activities (1%). The results of these activities are generally manifested on the soil as loss of organic matter, salinization, desertification, acidification, compaction, contamination and erosion. While continued soil degradation will lead to loss of arable land and declines in food production, a 2015 report on the status of the world's soil resources by the United Nations states that degradation can be curtailed and reversed. Sustainable soil management practices and policies that require implementation of these practices are key to improving soil conditions.

7.1 Organic Matter Depletion

The total organic matter content retained by soil systems is a function of the organic matter gains and losses. The quantity of organic matter entering soil is determined by primary production of plants, litter and fine root inputs while the amount leaving is controlled by erosion and microorganism decay of organic matter. The organic matter content of soil depends on texture, drainage, vegetation and erosion. In general, coarse textured soils (sands) have less organic matter than fine textured soils (clays); well drained soils less than poorly drained ones; soils developed under trees less than those developed under grasses; and eroded soils less than those which have not been subject to past erosion.

The role of organic matter in soil is exceptionally important, as it influences all physical, chemical and biological properties of soil. Without organic matter as a cementing agent, soil particles would not be able to bind together to form aggregates that strengthen and stabilize the structure of soils. The soil would become weak and prone to erosion. Soil porosity and water-retention would also be reduced, meaning that any incident precipitation would be inhibited from entering the surface of the soil and result in runoff. Soil organic matter also contains a huge portion of the soil's essential nutrient reserves and accounts for more than half of soil's cation exchange capacity. Nutrients such as phosphorous, nitrogen, sulphur, and micronutrients are safely stored on the surface of organic colloids to be taken up by plants when needed. Organic matter is also one of the main resources that supply organisms with the energy needed for growth and reproduction.

The removal or depletion of organic matter can have harmful impacts on soil systems. Depletion occurs when the quantity of organic matter entering the soil is decreased while amount leaving increases. Example of activities that cause depletion include

- Removal or burning of crop residue – this prevents fresh organic material from entering the soil;
- Tilling - this increases the rate of organic matter break down by soil organisms;
- Physical removal of top soil – often by wind and/or water erosion, this dramatically reduces the organic matter content since the top soil contains the highest concentration of organic matter.

7.2 Salinization

Salinization occurs when water soluble salts – sodium, potassium, calcium, magnesium and chlorine – accumulate in concentrations in the root zone of plants to such an extent that they lead to degradation of soil and vegetation. When salinization is due mainly to the concentration of sodium, it is referred to as **sodicity**.

Soil salinization may occur naturally or due to conditions resulting from anthropogenic mismanagement of the land. Salinization occurs when conditions of low rainfall, high evaporation, high water table and the presence of soluble salts in the soil co-occur and work hand in hand to augment salt build-up.

In poorly drained soils, where the groundwater table is 3 m or less from the surface, water is unable to leach down and instead rises to the surface by **capillary action**. Capillary action is the natural upward movement of water between soil particles. In hot and dry regions, this water leaves the surface of the soil through evaporation. Since ground water contains naturally dissolved salts, the water evaporates leaving salts behind. This phenomenon repeats over time until salt concentrates reach a level in the root zone that is detrimental to plants.

7.3 Desertification, Causes and Implications

Desertification is arguably the world's most threatening form of soil degradation and affects over one billion people worldwide. Desertification is not necessarily the expansion of existing deserts; rather it is the degradation and deterioration of fertile arable land, caused chiefly by deforestation, overgrazing, over cultivation and poor irrigation.

Desertification occurs on all continents except Antarctica, but chiefly impacts the worlds drylands. These include arid, semi-arid and dry sub-humid regions where potential evapotranspiration often exceeds precipitation and vegetation cover is already sparse. With excessive the pressures of agriculture, deforestation and overgrazing, the natural vegetation cover can be reduced or completely eliminated, resulting in desert-like conditions. Desertification severely decreases the productive capacity of the land, which leads to a decline in agricultural productivity, food and water scarcity, malnutrition, poverty and ultimately mass migration out of degraded regions.

7.3.1 Natural Factors that reinforce Desertification

The soils of arid lands are naturally characterized by shallow depths, insignificant organic matter content, negligible leaching capacity, absence of structure, high salinity, and low fertility. In arid regions, a low precipitation regime means that the land can only support sparse vegetation cover. As a result, only a thin organic layer accumulates through the slow decomposition of plant remains. Soluble salts and sediments leach to shallow depths or remain at the surface due to the low precipitation regime. Violent dust storms and aggressive thunder storms cause intensive land erosion and carry away much of the top soil containing the nutrients and organic matter, leaving the soil even more infertile and unproductive.

7.3.2 Overgrazing

Over grazing is the single largest and most devastating cause of desertification in arid lands. Livestock are the main source of income and a way of life in many developing countries. Domestic stocks are widely diverse and consist of camels, donkeys, horses, cows, sheep and goats.

In many arid regions, the forage and overgrazing of livestock causes a chain of degradation, critically reducing vegetation cover and soil fertility, as well as increasing erosion and the chance of flooding. Domestic animals rapidly clear vegetation, placing stress on land that already has low vegetation cover. They also move in large groups and have sharp hooves that easily breakup the soil, leaving it susceptible to erosion. Erosion decreases the fertile organic matter content of the soil. The lack of organic matter can lead to desertification through reduced nutrient availability for plant growth.

Grazing and trampling causes soil compaction and degradation of soil structure. The result is decreased soil permeability and plugging of pores which reduces the ability of water to penetrate the soil by infiltration and percolation. Runoff occurs when rainfall intensity exceeds the infiltration capacity of the top-soil. Soil moisture is decreased due to a lack of soil organic matter and erosion is intensified because of livestock action. Water erosion may also carry sediments to streams, causing flooding and accumulation of salts.

7.3.3 Intense and Improper Agricultural Practices

When land is cleared and tilled, much of the natural vegetation is removed in anticipation of agriculture. The soil is suddenly bare and exposed to erosive forces such as intense wind and thunderstorms that occur frequently in arid regions. Substantial quantities of fertile topsoil and organic matter are removed. The outcome is a considerable decrease in fertility, water-holding capacity, and the loss of structural aggregation. With minimal moisture and nutrient content, the soil loses any ability to support vegetative growth. This ultimately leads to the creation of deserts.

7.3.4 Mismanagement of Irrigation

Proper irrigation is one of the biggest challenges in arid lands where a moisture deficiency makes it impossible for farming to occur without artificial irrigation. However, irrigation in arid lands can further enhance desertification through salinization and alkalinization.

Salinization occurs when irrigation water evaporates quickly, leaving natural salts (e.g. chlorides, sulphates and carbonates) at the surface of the soil. Over a prolonged period of time, excessive quantities of salts accumulate at, or near, the soil surface making it increasing difficult for plants to extract water from the soil.

Alkalinization is a similar process, where the accumulation of sodium ions causes the disintegration of soil aggregates, resulting in a weakened soil structure. Poor soil structure generally leads to decreased porosity and aeration, reduced infiltration, oxygen deficiency and an increase in runoff and erosion.

7.4 Acidification

Acidification is a major land degradation issue. It is a natural process that can be aggravated by poor agricultural and forestry practices. Soil acidification is a decrease in the pH of soil beyond those ranges tolerated by plants and soil organisms. When the pH of soil declines to levels far from ideal, plants may experience deficiencies in essential nutrients such as molybdenum, boron, calcium, magnesium and potassium, while toxic elements such as aluminum, manganese, and iron become abundant in higher concentrations.

By far the most common causes of soil acidification are attributed to high rainfall and the excessive use of ammonium-based fertilizers. While acid rain is one contributor to soil acidification, high quantities of rain fall also naturally cause the leaching of soluble basic cations such as calcium and magnesium and the irreplacement by acid cations such as aluminum and hydrogen. Nitrogen-based fertilizers also have a decalcifying and acidifying effect on soils. When agricultural crops or forests are harvested and removed from the land, basic elements are permanently removed. This is the means by which these practices exacerbate the rate of soil acidification.

When acidification occurs, the uptake of heavy metals increases and may cause toxicity in plants, whereas the concentration and availability of necessary nutrients decreases. The result is reduced crop yield and vegetation cover, leading to accelerated runoff and erosion. Soil microorganisms would also be negatively impacted by toxities, preventing the continued recycling of nutrients.

7.5 Compaction

Soil compaction is the increase in bulk density of the soil that occurs when soil particles are packed closer together, reducing the pore space between them. Compaction is a serious problem because it reduces the productive capacity of the land.

Soil compaction is induced in two ways:

1. Heavy agricultural machinery - soil is compressed under the pressure of the machine's weight, this is called mechanical compaction.
2. Livestock – compaction also occurs when grazing animals roam the in large herds, the weight of the livestock pushes the soil particles tighter together.

Soil compaction is more likely to occur when soils are wet and has several implications for soil health. When the porosity of the soil is reduced, infiltration rates decline, causing accelerated runoff and erosion. Also, when soils are compacted, root growth becomes restricted, causing a reduction in water and nutrient uptake, and eventually reducing growth and yield. This is bad news for farmers, who depend heavily on the economic capacity of the land. The population and diversity of micro and macroorganisms is also adversely affected by the lack of air and water circulation. Decreased soil microorganism activity leads to decreased organic matter decomposition, and diminishes the availability of nutrients.

7.6 Contamination

Soil pollution is associated with serious environmental impacts. Soil contamination results when hazardous chemicals are spilled or buried directly in soil, or when they migrate with air and water and are deposited in a new location. Common soil contaminants include pesticides and PCBs, oil, road salt and elements such as lead, nickel, or cadmium. Contaminants can be introduced though disintegration of underground storage tanks, addition of municipal sewage sludge, discharge of industrial waste, leaching of landfills, accidental spills or smelter emissions.

The wide spread use and disposal of harmful chemicals means there is the potential for these compounds to enter the food web and damage the health of plants and animals. Some pollutants in soil are taken up initially by plants and burrowing organisms, where they accumulate in the body without breaking down. When these plants and animals are consumed in large number by organisms higher in the food chain the pollutants build up in progressively higher concentrations. This process is called *bio-magnification*. Due to bio-magnification the impacts of soil toxins are most visible in organisms in higher trophic levels. In the long term, this accumulation of toxins can cause sickness, disease, reproductive failure, genetic defects and in extreme cases, death.

A common example of soil contamination stems from the use of sewage sludge as a fertilizer. Though sewage is a rich source of the essential nutrients including phosphorus and nitrogen, it can contain high concentrations of contaminants such as nickel, arsenic, zinc, and cadmium. Repeated applications of sewage sludge to soil can cause the buildup of these contaminants in the ecosystem with bio-magnification in humans and other animals high in the food web.

Another common source of soil contamination is road salt. Though essential for the removal of snow, salt concentrations can build up along roadways causing stress and even death in plants and other vegetation.

Most symptoms of soil contamination only become visible over the long term as pollutants steadily accumulate to toxic levels. However, some sources of pollution are extremely concentrated, immediately causing detrimental ecosystem effects. Oil leaks, for example, can occur when underground storage tanks deteriorate, releasing large volumes of chemicals into the soil. These chemicals can be carried vertically and laterally throughout the soil profile, contaminating underground and surface drinking water sources.

7.7 Erosion

Erosion is the loosening, transport and deposition of soil particles by wind, water, ice or gravity. Erosion is in reality a natural phenomenon that occurs in equilibrium with soil formation, so that the net impact of soil loss is actually zero. Unfortunately, anthropogenic influences such as mismanagement of agriculture, deforestation, overgrazing, and unmanaged construction activity have upset the balance between formation and removal, causing immense loss of fertile topsoil. The results can be devastating. Accelerated erosion depletes soils necessary for agriculture and forestry activities and damages downstream lands, habitats, roads, dams and waterways.

Erosion is one of most wide spread forms of soil degradation. It occurs on almost all land surfaces, and impacts the biological, physical, and chemical properties of soil.

7.7.1 Water Erosion

Water erosion is the detachment and transport of soil particles either directly by the impact of raindrops or indirectly by rapidly running water on the surface of soil. Snowmelt and rainfall are the primary driving forces behind water erosion.

Detachment occurs when the impact of rain drops causes soil particles to loosen and become dislodged from their original aggregates. The force of impact is determined by a combination of the weight of the rain droplet and its velocity. The energy of impact may create a forceful splash that will pick up and transport the soil an appreciable distance from its original location. Under conditions of heavy rain, the energy of impact is sufficient enough to displace soil particles by as much as 1-2 meters horizontally. However, rain splash usually only displaces particles by a few centimeters, this is called splash erosion.

Figure 28: The impact of a water droplet hitting the ground causes particles of soil to detach from the granule and be translocated (Plant and Soil Science eLibrary, 2015).

Compacted soils with poor water infiltration are at an increased risk of water erosion, because the soils become rapidly saturated and any additional water becomes surface runoff. Surface runoff exacerbates the effect of erosion. Bare soils are most vulnerable to water erosion since they lack the protection offered by vegetation. Plants, trees and shrubs can absorb the impact of raindrops and prevent particle detachment. Soils on slopes also frequently experience water erosion, since runoff gradually gains speed and energy as it moves down the slope.

The agent responsible for most translocation of soil particles is running water or runoff that flows at great velocity parallel to the surface of the soil, because of its velocity it easily sweeps away valuable topsoil. Moving water can have enough force to pick up and transport particles by floating, rolling, dragging or splashing. Sheet, rill and gully erosion are the most common types of water erosion. Mass erosion, through slips and slumps, occurs less often but can have catastrophic impacts.

Sheet Erosion

Sheet erosion occurs when water flows across the surface of the earth in thin unconfined sheets rather than in deined channels. Sheet erosion is caused by the flow of precipitation that is unable to penetrate through the ground, and instead flows above the soil as runoff. Sheet erosion does not carry sufficient volume or velocity to dislodge soil particles on its own; however, it can carry large quantities of particles that have been detached from their aggregates by splash erosion.

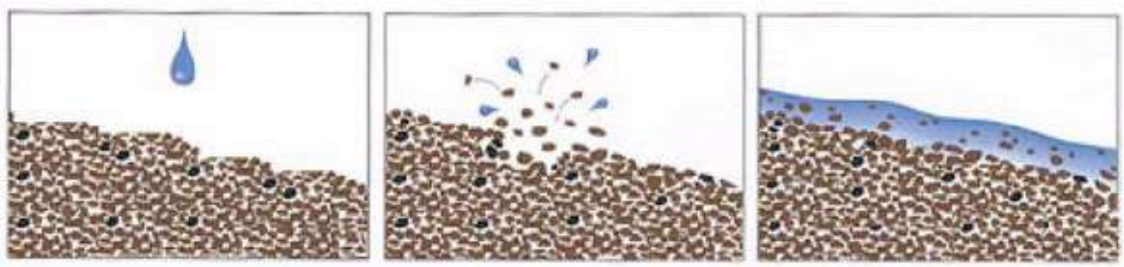


Figure 29: Detached soil particles are transported by runoff in the form of sheet erosion (Plant and Soil Sciences eLibrary, 2015).

Rill Erosion

Sheet erosion is difficult to detect until it evolves into rill erosion. Rill erosion occurs when sheet flow becomes concentrated and confined to a small streamlet. Water flows in narrow channels, on gently sloping lands, with enough strength to detach and carry away particles of soil from the bottom and sides of the channel. Contrary to sheet erosion, the concentration flow of rill erosion creates land features that are distinct and visible. Rill channels can be as deep as 30 cm and lead to the loss of the most productive part of the land.

Gully Erosion

Gully erosion is the advanced stage of rill erosion when the channels enlarge into deep ditches that are capable of eroding vast amounts of soil in a short period of time. Gullies usually occur near the bottom of slopes. They eat into the land, remove organic matter, and expose the subsoil beneath.

Figure 30: Gully erosion.
(Plant and Soil Science eLibrary,2015).

Slumps and Slips

Gullies expand by undercutting or slumping .Slumps and slips are both a form of mass erosion. Slumps are down-slope movement of land where as slips occur when the soil becomes so saturated with water that it can no longer stay intact. When a portion of the soil slides downhill, we say that a failure has occurred. Slips and slumps leave soils very susceptible to more gully erosion, and cause soil loss on a large scale.

Figure 31: Slump erosion.
(Plant and Soil Science eLibrary, 2015)

The rate and magnitude of water erosion is influenced by several factors. The intensity of precipitation is directly proportional to the rate of erosion. More intense precipitation carries more kinetic energy that is able to displace more soil. More runoff also occurs in the spring when large quantities of meltwater enter an already saturated system. Because water cannot seep through the soil, it flows above the soil, creating massive losses. The permeability of the soil affects its ability to absorb water, and soils with high permeability have less runoff. Texture is another factor that controls erosion. Soil textures that allow greater infiltration, have larger particle sizes and are well aggregated and more resistant to erosion. Sands are generally heavier particles with higher porosity, and therefore are less prone to erosion. Soils high in clay and organic matter form strong aggregates and resist erosion. The most erodible soil textures are silt and very fine sand. Soil erosion by water also increases with slope length and steepness. Vegetation cover is perhaps the most important factor in minimizing water erosion. Vegetation can intercept falling raindrops and prevent the impact with soil. Vegetation also slows down surface runoff and allows excess water to infiltrate the soil. Knowing about the factors that influence erosion has helped scientists create means of conserving soil by minimizing erosion.

7.7.2 Wind Erosion

Aeolian or wind erosion is most prominent in the world's drylands, particularly in areas with unconsolidated sediments, sparse vegetation cover and turbulent winds. Wind erosion is the process by which soil particles are dislodged from the soil surface and carried a distance away from their original location by the kinetic energy of wind. Wind erosion is a normal agent in the formation of many of the world's landscapes. However, the magnitude of damage caused by wind erosion can be immense and cause serious destruction in many regions of the world. Globally, areas most affected by wind erosion include North Africa, Near East, the Siberian Plains, Australia, Northern China, North America, and Southern South America.

Soils exposed to wind erosion lose much of their fertile topsoil and denude the roots of crops and plants. In addition, the airborne soil particles can also obscure visibility and pollute the air, causing health and safety issues. Similar to water erosion, there are numerous means by which soil particles can be eroded by wind.

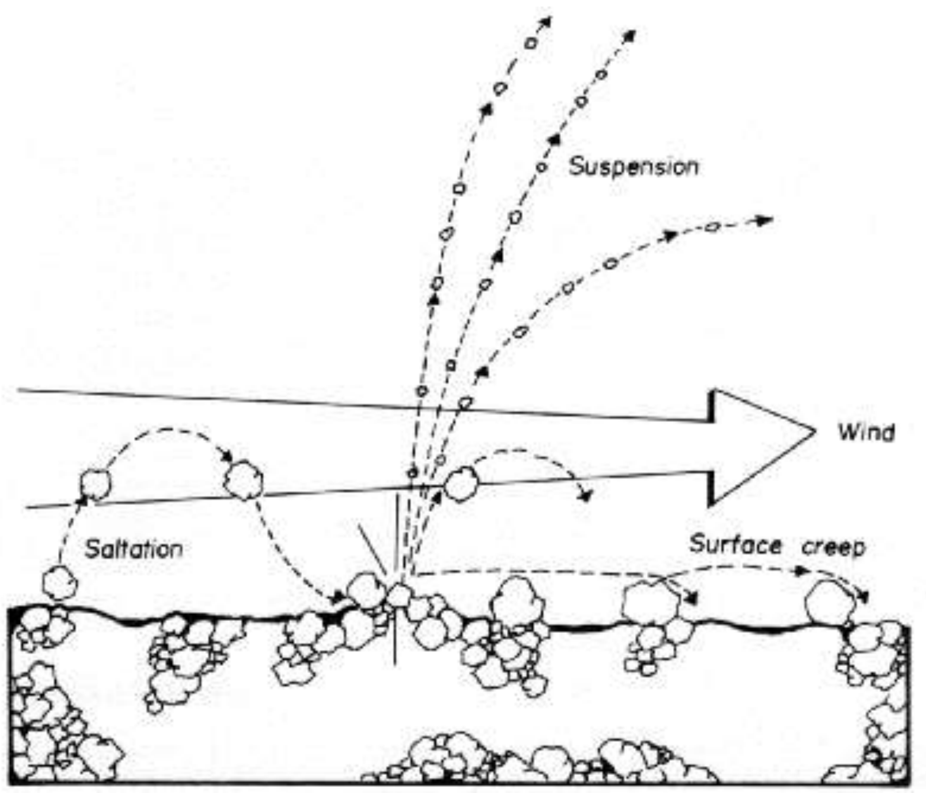


Figure 32: Types of wind erosion: saltation, surface creep, and suspension (Agronomy Guide, n.d.).

Creep

When wind travelling parallel to the surface of the ground strikes the surface, it causes soil granules to detach from the rest of the aggregates. The wind turbulence and velocity push particles forward. If the particles are too large to be picked up by wind, they roll along the surface of the ground, this is called creep. Creeping particles collide with other particles on the surface and set them into motion as well.

Saltation

Some soil particles are light enough to be picked up by wind turbulence, but not small enough to be carried large distances. These particles bounce up and down, moving short distances forward. When the particles drop back to the ground, they collide with and dislodge other particles, giving them kinetic energy to move forward as well. This bouncing action is called saltation.

Suspension

If soil particles are extremely fine and light they can become suspended in the air and may travel far distances, as much as hundreds of km, and cross continental distances in the upper atmosphere. Fine dust from the Sahara Desert in Northern Africa has been shown to travel to as far as South and Central America by suspension. The airborne particles are eventually deposited to the ground with precipitation.

Figure 33: June 17, 1999. NASA's TOMS Satellite shows dust coming off regional land sources in Africa and travelling across the Atlantic Ocean. (Greenbelt, 2003).

The rate and magnitude of wind erosion is controlled by several factors, with climate being the predominant variable. Windy regions with dry soil moisture regimes are most prone to erosion. The inherent erodibility of the soil refers to the ease with which particles can be detached and transported. Coarse soil particles such as sands are heavier and less prone to erosion. Very fine particles are highly cohesive and not easy to erode as well. Fine and medium sized particles, however, can be lifted and deposited relatively easily. Surface roughness influences wind erosion in that rough surfaces provide barriers against moving particles. Vegetation cover offers a similar protection barrier. Finally, the quantity of soil that is eroded depends on the length of exposed area. In large exposed areas the wind gains speed as it travels due to lack of obstacles. The rate and magnitude of erosion is enhanced as a result.

7.7.3 Economic Impacts

Erosion carries away organically rich topsoil, depletes nutrients, damages soil structure and exposes more erodible subsoil. This is unfortunate considering that it can take over two centuries to form just one inch of organic topsoil. Soil erosion presents a global threat that threatens food security and sustainable agriculture and forestry.

The economic impacts of soil erosion can be seen in terrestrial and aquatic ecosystems and occur on and off the site of erosion. On-site costs of erosion are costs associated directly where erosion has occurred. The removal of nutrients, organic matter and soil from land decreases the value of property as well as the potential income from the land. Decreased yield due to the removal of topsoil creates a need for the application of expensive fertilizers.

Soil erosion also creates indirect costs on land and aquatic ecosystems far from the original site of erosion. Off-site costs are generally a result of dust and air pollution, examples include clogged drainage ditches, sedimentation and pollution of water systems and damage to fish spawning sites. When large quantities of nutrient-rich sediments are washed away and enter surface waterways, they can increase nutrient concentrations which in turn increases algae growth, this process is called eutrophication. When large algal blooms die, bacteria at the bottom of water bodies use up large quantities of dissolved oxygen as they decompose. This lack of oxygen is called hypoxia or anoxia and can destroy aquatic habitates and kill fish. Th eoff-site impacts oferosion can include declining fish stocks and decreased recreational value of waterways. The consequences of erosion include increased costs to remove sediment from waterways to improve habitat or clean drinking water. Off-site costs of soil eroision can often excced the costs or on-site eroision. In Ontario alone, approximately $91.2 million is spent annuallyto correct adverse off-site effects of soil erosion (FON andSWCS, 1995).

8.0 Soil Management and Conservation

8.1 Management Techniques

Soil conservation practices are diverse and target different types of soil problems such as erosion, saltation, acidification and desertification. The first step to designing proper conservation techniques is to have a thorough understanding of soil properties and the problems affecting the land. There are many reasons to practice soil conservation, the Federation of Ontario Naturalists and the Soil and Water Conservation Society list the following reasons:

Ten Reasons to Practise Soil Conservation

1. **To maintain adequate amounts of organic matter and biological life in the soil.** These two components account for 90-95% of the total soil productivity.
2. **To ensure a secure food supply at reasonable prices.** It has been proven that soil conservation increases crop yields over the long term because it keeps topsoil in its place and preserves the productivity of the soil.
3. **To grow enough food.** Not only for ourselves but also for people in other countries, especially where there are food shortages.
4. **To save farmers money.** Erosion costs farmers millions of dollars each year in lost income as the loss of nutrients from the soil results in lower crop yields.
5. **To save citizens money.** Soil erosion costs taxpayers millions of dollars each year, especially related to off-site costs.
6. **To improve water quality and conserve water.** All forms of life require clean water to survive. Soil erosion is a major source of sedimentation and contamination of water supplies.
7. **To improve and conserve wildlife habitat.** Soil conservation practices such as the provision of buffer strips and windbreaks greatly enhance the quality of environment for wildlife of all kinds.
8. **To preserve natural beauty of the scenery.**
9. **To create or maintain an environment free of pollution where all life can live safely.**
10. **To ensure that our children will have sufficient healthy soils to support life into the future.** It has been said that the land has not so much been given to us by our forebears as borrowed from our children.

8.1.1Conservation Tillage and Cover Crops

Conservation tillage refers to a series of agricultural practices that attempt to prevent soil degradation by reducing (reduced tillage) or eliminating (no-tillage) the ploughing of soil before sowing. Tillage can cause soil compaction, loss of organic matter, degradation of soil aggregates, death or disruption of soil organisms and exacerbates erosion. In addition to changes in cultivation, conservation tillage also requires that plant residue is deliberately left on the ground rather than burning or incorporating it through ploughing. At least 30% of the ground must be covered by residue. Plant residue offers numerous benefits to soil ecosystems. First, it absorbs the impact of falling raindrops and slows running water, thereby reducing water erosion. Since the surface of the soil is covered and protected, wind erosion is less likely too occurring on conservation tilled soils. In addition, plant residues also help to conserve nutrients, add organic matter, improve water absorption and infiltration, slow the rate of moisture evaporation, and conserve biodiversity.

Cover crops offer similar benefits as the use of plant residue in conservation tillage. Cover crops are vegetation that is planted on bare soils during seasons when no crops are grown in order to reduce wind and water erosion. Some cover crops such as 'green manures' add nitrogen to the soil and help improve productivity and fertility. Cover crops also serve to protect soils against wind and water, add organic matter to the soil and increase absorption of water.

Figure 34: a) Conservation tillage, b) Cover crops (Wikipedia, 2015).

8.1.2 Crop Rotation

Crop rotation is the practice of planting different crops on the same piece of land during consecutive growing seasons. Crop rotation offers many benefits to the health and quality of soil. On a farm where the same crop has been planted year after year, the population of diseases and pests that may be hosted by a specific crop is allowed to grow and develop. Consequently, a much greater quantity of pesticides are required to control the constantly growing population of pests that can gradually develop tolerances to chemical pesticides. The rotation of crops prevents the build-up of harmful pests and lowers the requirement for pesticide use. In addition, planting the same crops year over year tends to deplete the reserves of certain nutrients. Crop rotation of plants that require different quantities of macro- and micro-nutrients helps to avoid decreased soil fertility.

Figure 35: Crop rotation is a system of farming in which a regular succession of different crops is planted on the same area, as opposed to growing the same crop time after time (Wikipedia, 2015).

8.8.3 Integrated Pest Management

Integrated Pest Management (IPM) is the management of pest through a combination of cultural, biological and chemical methods. Using IPM best practices (e.g., surveillance of insect populations and understanding their life cycles as to when the populations are at their most sensitive to pesticide treatment) allows the farmer to reduce the number of pesticide treatments required. Crop rotation is another means by which the population of pests can be reduced or eliminated. Other methods include the uses of pest-resistant crops and biological controls such as the release of pest predators.

8.8.4 Vegetation Barriers: Conservation Buffers and Agroforestry

Conservation buffers are small strips of vegetation that are designed to manage environmental degradation. Examples of conservation buffers include windbreaks, riparian buffers and grassed waterways. Windbreaks refer to trees or other forms of vegetation that are generally planted on the border of a farm. Riparian buffer strips are planted along rivers and water courses in order to prevent pollutants and sediments from entering water systems with runoff. Riparian strips also hold the soil to prevent slump erosion and create cooler habitats that are suitable for aquatic organisms including fish. Grassed waterways are permanently vegetated channels that are commonly used to prevent gully and rill formation by directing runoff through land, to stable outlets such as streams. In contrast, **agroforestry** refers to a system of farming in which trees are planted in rows directly on the farm. The crops are integrated in rows or alleys between trees.

Figure 36: a) Conservation buffer, b) Agroforestry (Wikimedia, 2007; Village Agroforestry, 2006).

8.8.5 Sediment control

Sediment control is important in areas that are prone to water and wind erosion. Two methods are used to control transport of sediments in these conditions. One method is **Silt fences** which are used to slow the rate of both wind and water erosion. These fences help to reduce the velocity of wind and are similar to vegetation barriers. They are also able to filter out sediments that are transported with runoff, by allowing running water to pass through, but trapping sediments behind. The other method is sediment ponds which are ditches or depressions that hold large quantities of running water in one place, and prevent them from flowing away in channels. Over time, the sediments are able to settle to the bottom as the water evaporates. Use of this method prevents large quantities of fertile topsoil from leaving the ecosystem.

8.8.6 Acidification Control

Soils that are acidified to the point where production and yield are adversely affected can be corrected by the application of lime and other alkaline fertilizers. Though costly, these methods can help reclaim acidic soils.

8.8.7 Salinization Control

Though it is difficult to reverse soil acidity, there are ways to manage soils that have been affected by salinity and sodicity. Here are some recommendations made by the Federation of Ontario Naturalists and Soil and Water Conservation Society:

- Summer fallowing of land should be decreased
- Deep-rooted crops that require high moisture levels should be grown in the groundwater recharge area
- Salt-tolerant plants should be planted in the salt-affected area
- Growing crops continually uses more water than summer fallowing
- When the amount of water entering the groundwater recharge area is decreased, the water table drops and there is less water available for soil salinization processes
- If salinization is caused by water from irrigation, till drainage will remove the excess water and slow the salinization process. Irrigation canals should also be lined to prevent water seepage.

8.8.8 Combating Desertification

Combating desertification is best done through prevention rather than rehabilitation and involves collaboration between governments, policy makers, scientists and local residents. With a diversity of stakeholders and opinions reaching agreements can be a complex process.

Effective prevention of desertification requires active land and water management strategies that protect against erosion, salinization, and other forms of soil degradation. Grazing of animals should be kept at a harmonious level with the carrying capacity of the land. Vegetation that protects the soil against wind/water erosion should not be harvested excessively for means such as fuel wood, grazing or cultivation. Irrigation of soil in drylands should be kept to a minimum and done during the cooler periods of the day/night (see section on salinization control).

8.8.9 Sustainable Forest Management

Sustainable forest management is a way of using and caring for forests so as to maintain their environmental, social and economic values and benefits over time. Forest management planning is used to ensure that forests are managed sustainably and includes legislated forestry practices designed to protect soil and other ecosystem services that are linked to healthy soil (e.g., water quality, erosion protection, and biodiversity).

Sustainable forestry practices pertaining to soil protection include guidelines on proper logging road construction (road locations, stream crossings, maintenance), harvesting operations (protected areas and areas of concern, timing of operations, harvesting system, slash management, renewal strategy), and hazardous materials (fuel handling, waste disposal). Guidelines for sustainable forest management are science-based and therefore best practices are regularly revised as new knowledge becomes available.

9.0 Soils and Land-Use in Ontario

9.1 Distribution of Canada and Ontario's Soil Orders

Soils are constantly changing as they are weathered and eroded, deposited elsewhere and covered by fresh organic debris. Understanding the distribution of soil orders across Canada and Ontario helps scientists and policy makers to better understand the suitability of soils for various purposes.

The maps below show the geographical distribution of soils (with the exception of Vertisols). Of the ten soil orders identified under Canada's Soil Classification System, seven are present in Ontario. These are brunisols, podzols, luvisols, regosols, gleysols, cryosols and organic soils. Organic and cryosol orders are most prevalent in the northern part of the province; brunisols in the northwest part of the precambrian shield and south of the precambrian shield; podzols over much of the central and southern precambrian shield; luvisols in the clay belt region of northeastern Ontario and over much of southern Ontario; gleysols in the clay belt region and regosols only occur in a thin band along the southwest shore of Hudson Bay.

All maps below are from Agriculture and Agri-Food Canada (2007)

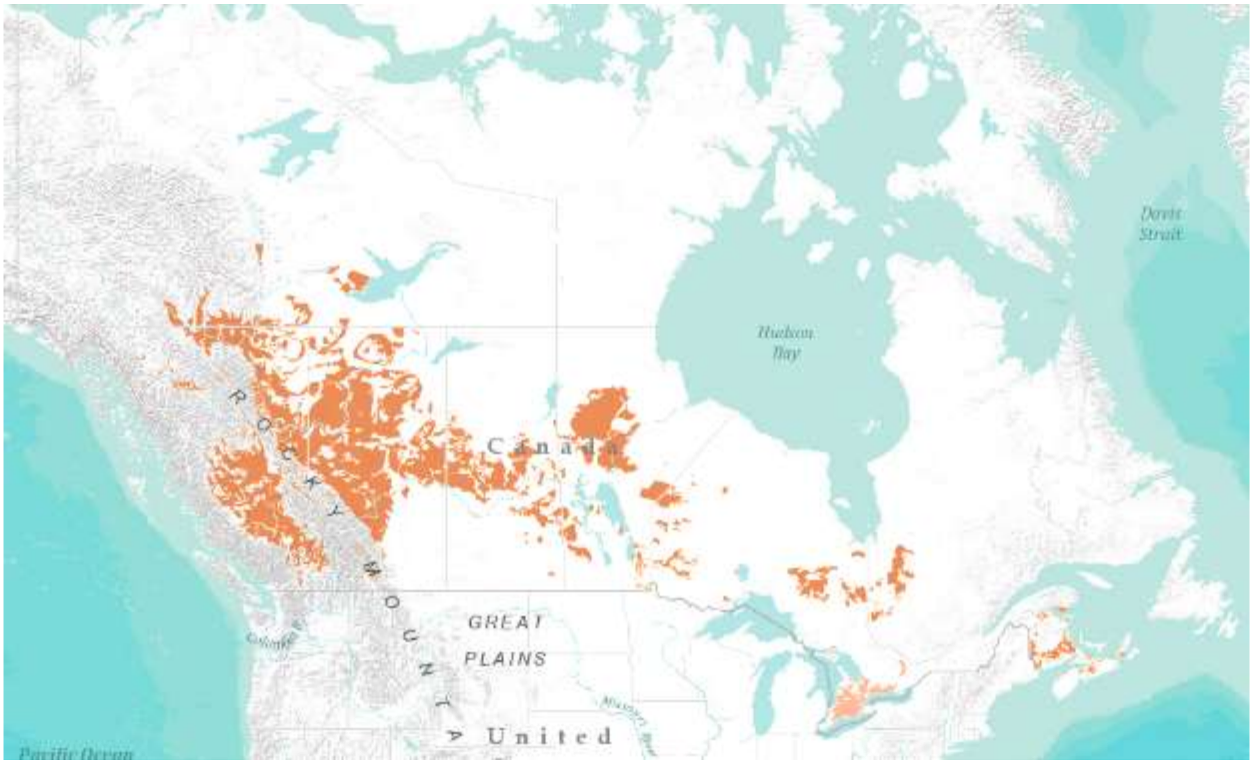


Figure 37: Geographic distribution of the Luvisolic soil order in Canada

Figure 38: Geographic distribution of the Podzolic soil order in Canada

Figure 39: Geographic distribution of the Gleysolic soil order in Canada

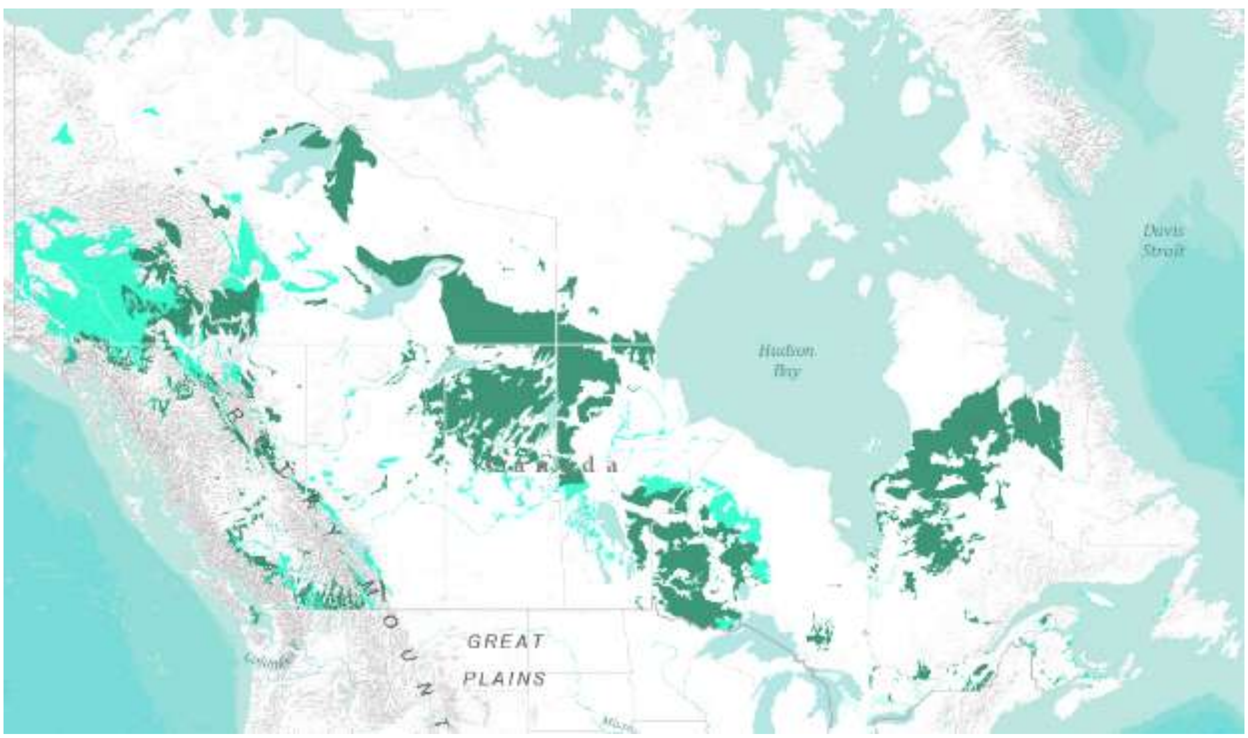


Figure 40: Geographic distribution of the Brunisolic soil order in Canada

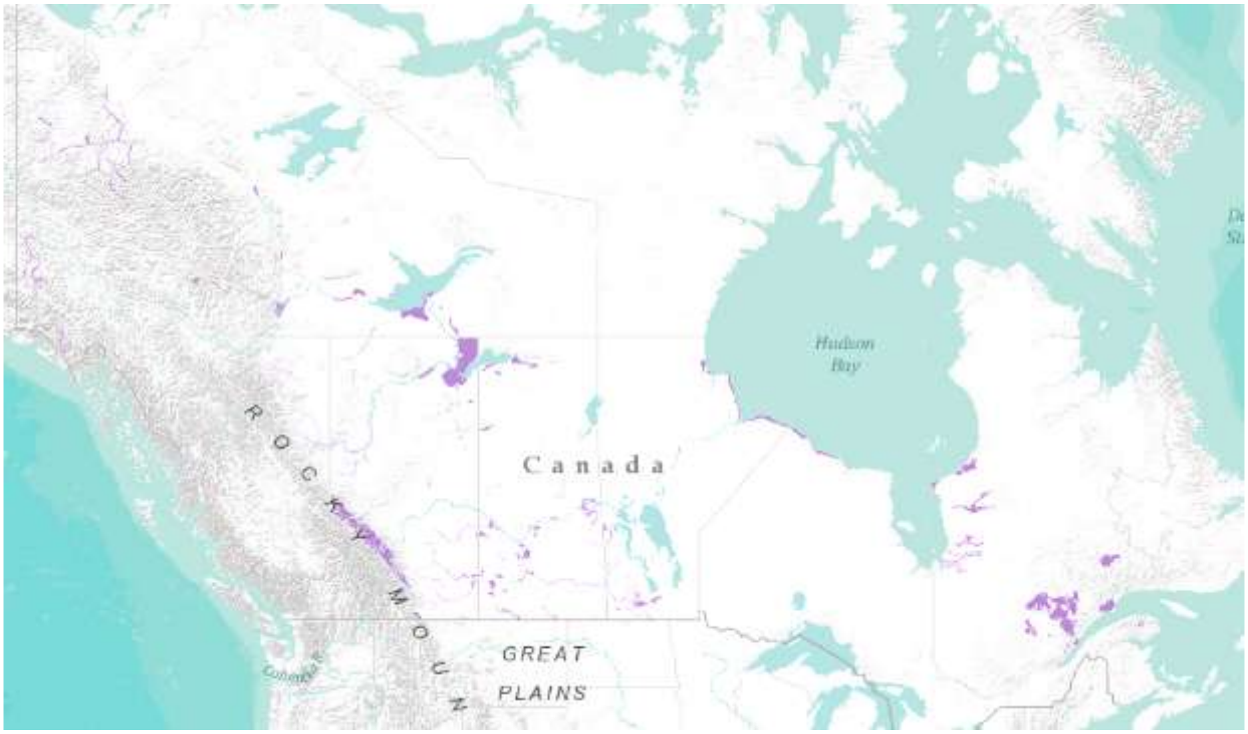


Figure 41: Geographic distribution of the Regosolic soil order in Canada

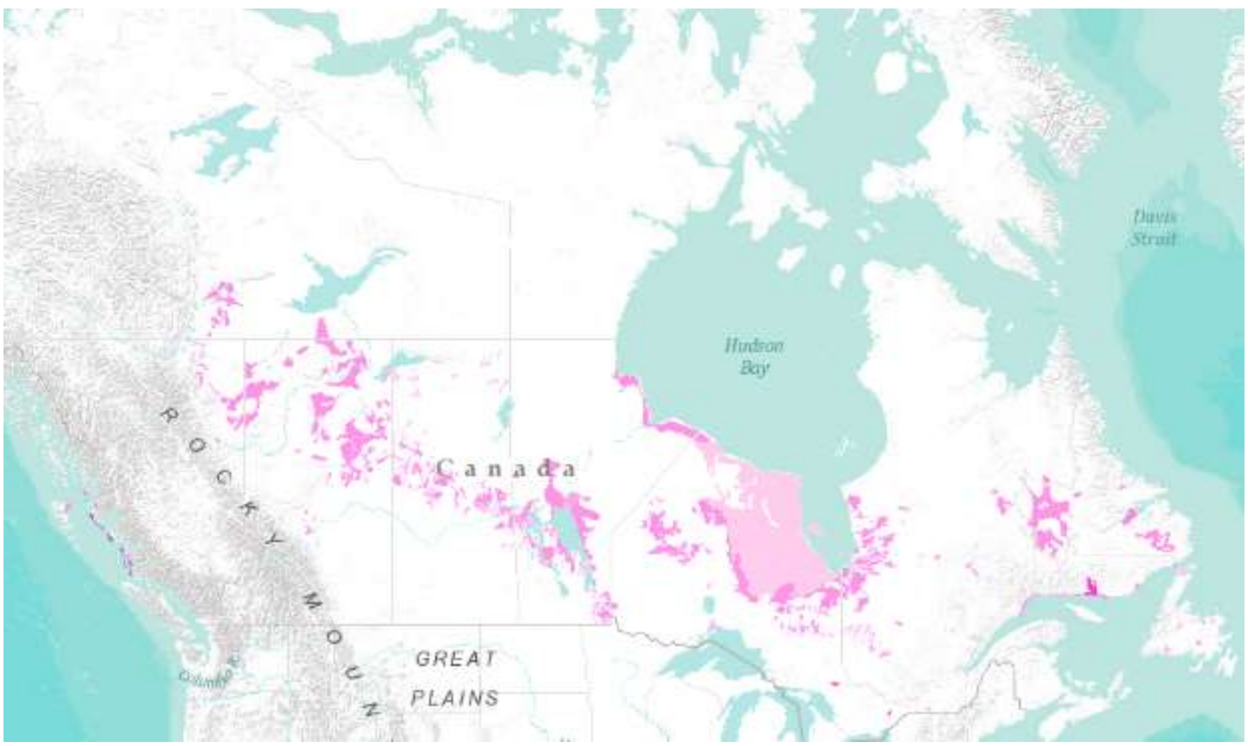


Figure 42: Geographic distribution of the Organic soil order in Canada

Figure 43: Geographic distribution of the Chernozemic soil order in Canada

Figure 44: Geographic distribution of Solonetzic soil order in Canada

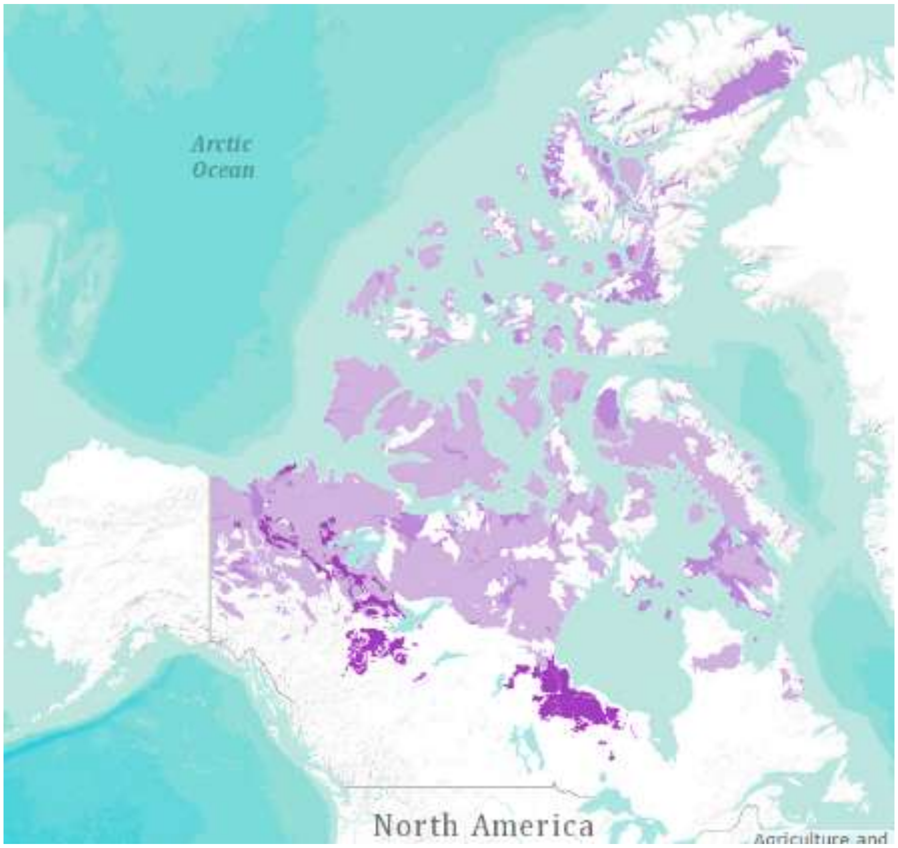


Figure 45: Geographic distribution of the Cryosolic soil order in Canada.

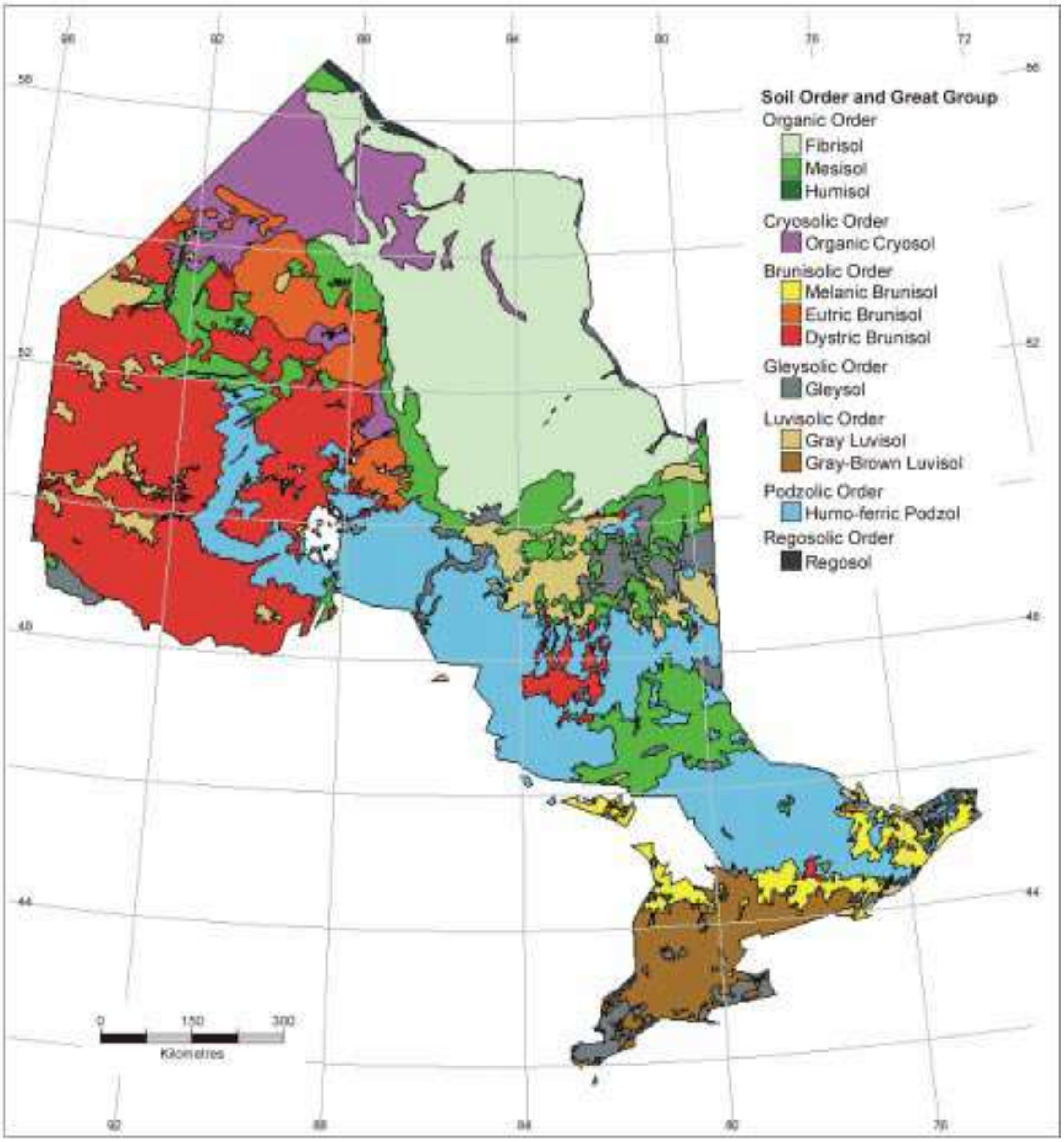


Figure 46: Geographical distribution of Ontario's soil orders (Baldwin et al., 2007).

9.2 Land-Use Trends in Canada and Ontario

Canada is the second largest country in the world by area and the largest country on the continent of North America. The country is endowed with copious amounts of both land and water; a landmass of nearly 10,000,000 km^2 and an estimated one seventh of the world's freshwater reserves (Canadian Geography, 2007).

Despite its grand expanse which spans from the Atlantic Ocean on the east coast to the Pacific Ocean on the west coast, the multitude of demands far outweigh the supply of good quality soil and land. The problem is in part due to the fact that over 90% of Canadians live in a narrow band along the southern Canadian border that conveniently coincides with much of the most fertile land in the country (Urban Consumption of Agricultural Land, 2001). Most of the land in the northern part of the nation consists of permafrost that is frozen for much of the year. The remaining usable land is therefore, in high demand for competing uses such as agriculture, urban areas, forest land, recreational areas and wildlife reserves. All such demands place tremendous pressure on soils that are not uniformly endowed with the same productive properties.

From 1963-1995, a combined effort between the federal and provincial governments to evaluate the capability of Canada's lands to sustain agriculture, forestry, recreation and wildlife resulted in the production of the *Canada Land Inventory* (Canada Land Inventory 2000; Canada Land Inventory: Land-Use Capability, 2005). The Canada Land Inventory is a comprehensive document consisting of air photos, surveys, and maps that rank the suitability of land for different purposes on a scale of 1-7, where Class 1 soils are of prime suitability for crop production, and Class 7 soils have no capacity for agriculture. In Canada, 7% of the overall landmass (673,000 km^2) is utilized for agriculture (Canada Land Inventory, 1978).

Class	Description
1	Soils in this class have no significant limitations in use for crops.
2	Soils in this class have moderate limitations that restrict the range of crops or require moderate conservation practices.
3	Soils in this class have moderately severe limitations that restrict the range of crops or require special conservation practices.
4	Soils in this class have severe limitations that restrict the range of crops or require special conservation practices.
5	Soils in this class have very severe limitations that restrict their capability in producing perennial forage crops, and improvement practices are feasible.
6	Soils in this class are capable only of producing perennial forage crops, and improvement practices are not feasible.
7	Soils in this class have no capacity for arable culture or permanent pasture.

Table 6: Agricultural land classes in Canada (Agriculture and Agri-Food Canada, 2013b).

Despite Canada's immense size, prime Class 1 agricultural land is actually quite a scarce resource, covering a mere 0.5% of the country (Agriculture and Agri-Food Canada, n.d). Soils of Classes 1, 2, and 3 that are free from severe constraints and can support economically viable agricultural production are referred to as dependable agricultural land. Dependable agricultural land constitutes only about 5% of Canada's total land area due to limitations in climate and soil quality (Stats Canada, 2005). However, not all of Canada's agricultural land is high-quality soil. In reality, many marginal or poor quality lands are used for agricultural activity.

Urban expansion is a threat to maintaining agricultural land. Over the past several decades, rapid growth in population, together with increased average size of urban houses have led to the expansion of urban areas that consumed a large amount of dependable agricultural land. This is a concern due to the limited quantity of this non-renewable resource. Between 1971 and 1996, the city-dwelling population in Canada grew by 37% from 16.4 to 22.5 million persons (Stats Canada, 2001a).

From 1971-1996, urban growth in Ontario permanently claimed 18% of Class 1 farmland, particularly in the southern part of the province (Stats Canada, 2001) that. This is unfortunate, since the province has 56% of Canada's Class 1 farmlands (Stats Canada, 2005).

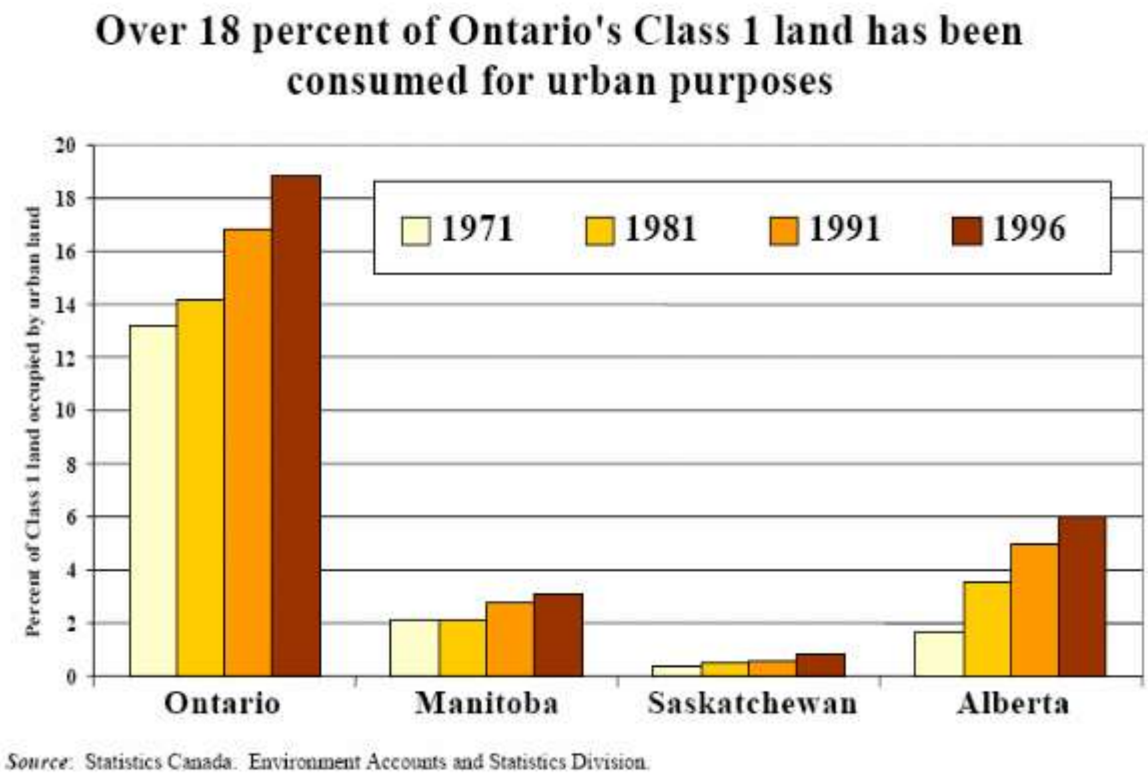


Figure 47: Urban sprawl has claimed much of Ontario's most productive agricultural land (Stats Canada, 2001).

With so many competing uses over Ontario's lands, many attempts have been made to regulate the designation of land towards different uses. As of 2008, 9.7 million hectares of land, or 9% of the province's area were designated as protected areas. These protected areas consist of five National Parks covering 207,100 hectares as well as 316 provincial parks and 249 conservation areas (Propsectors & Developers Association of Canada, 2008). Mineral exploration, mining and urban development are prohibited in protected areas. Eighty seven percent of the land in Ontario is Crown land or publicly owned, and the remaining 13% is private land (Prospectors & Developers Association of Canada, 2008).

In 2005, the Ontario government passed the Greenbelt plan. The Greenbelt is a permanently protected area of green space, farmland, forests, wetlands, and watersheds in southern Ontario that encompasses ecologically sensitive features such as the Niagara Escarpment, the Oak Ridges Moraine and Rouge Park. The aim is to prevent urban sprawl from consuming southern Ontario's first grade land, particularly farmland that is rapidly being lost in favour of development. The Greenbelt plan has been met with much controversy, particularly by farmers who insist on the right to sell their land to whomever they wish. The Greenbelt Plan is currently under its planned 10-year review.

10.0 Glossary

Acidification: a decrease in the pH of the soil beyond those ranges tolerable by plants and soil organisms

Acidity: the level of acid in substances such as water or soil

Aeration: is the process by which air is circulated through, mixed with or dissolved in a liquid or substance

Agroforestry: a system of farming in which trees are planted in rows directly on the farm

Alkalinization: an accumulation of excessive quantities of sodium at or near the soil surface due to evaporation

Bioaugmentation: the addition of living bacterial cultures required to speed up the rate of degradation of a contaminant

Biogenic: produced or brought about by living organisms

Biogeochemical: relating to or denoting the cycle in which chemical elements and simple substances are transferred between living systems and the environment

Biological Nitrogen Fixation: the process through which organisms convert nitrogen from the air (N_2) into a form of nitrogen that is available to plants

Bioremediation: use of biological agents, such as bacteria or plants, to remove or neutralize contaminants, as in polluted soil or water

Biostimulation: the modification of the environment to stimulate existing bacteria capable of bioremediation. This can be done by addition of various forms of rate limiting nutrients for example

Capillary action: the tendency of a liquid in a capillary tube or absorbent material to rise or fall as a result of surface tension

Cation Exchange Capacity (CEC): a measure of the number of sites on soil surfaces that can retain positively charged ions (cations) by electrostatic forces

Chemical weathering: the breakdown of rock by chemical forces

Chroma: purity or intensity of colour

Clastic: denoting rocks composed of broken pieces of older rocks

Clay: mineral soil particles <0.002mm in diameter

Climate: the weather conditions prevailing in an area

Cobble: a coarse fragment found in soil 8- 25 cm in diameter

Colloid: fine particles of organic matter and clay that have a large surface area to volume ratio

Conservation buffers: small strips of vegetation that are designed to manage environmental degradation

Cover crop: a crop planted between periods of regular cop production to prevent soil erosion and provide humus or nitrogen

Crop rotation: the system of varying successive crops in a definite order on the same land, to avoid depleting the soil fertility and to control weeds, diseases and pests

Decomposer: an organism that decomposes organic material

Degrade: to lower in quality or value; make inferior or less valuable; in terms of geology it is to wear away by erosion or weathering

Erosion: the gradual wearing a way of something by natural forces such as water, wind or ice

Detritivore: an organism, such as a bacterium, fungus, or insect, that feeds on dead plant or animal matter

Desertification: the process by which fertile land becomes desert

Extrusive: relating to or denoting rock that has been extruded at the earth's surface as lava or other volcanic deposits

Fertility: soil that is rich in essential nutrients

Fine-textured: soils with a large percentage of small mineral particles (clays)

Gravel: a coarse fragment found in soil <8 cm in diameter

Groundwater: water held underground in the soil or in pores and crevices in rock

Herbivore: an animal that feeds only on plants

Horizon: a layer of soil or rock with particular characteristics

Hue: a colour or shade

Humus: organic portion of topsoil

Igneous: having solidified from lava or magma

Infiltration: process by which water on the ground surface enters the soil

Intrusive (intrusion): the action or process of forcing a body of igneous rock between or through existing formations, without reaching the surface

Lava: hot molten or semifluid rock erupted from a volcano or fissure or solid rock resulting from cooling of this

Lithification: is the process in which sediments compact under pressure, expel connate fluids and gradually become solid rock

Loam: a textural class with a moderate mix of sand, silt and clay

Macrobiota: the series of organisms visible to the naked eye that dig the soil for shelter and feed on or in the soil

Medium: the substance in which an organism lives

Mesobiota: include vertebrates such as mice, moles, and groundhogs and invertebrates such as ants, termites, earthworms and snails

Metamorphic: rock that has undergone transformation by heat, pressure, or other natural agencies

Microbiota: soil organisms 0.1-2 mm in diameter that generally live within the soil pores

Mycorrhizae: special group of fungi that live on or in plant roots and form symbiotic relationships with the plants

Nutrients: an element that provides nourishment essential for growth and the maintenance of life

Organic matter: matter composed of organic compounds that has come from the remains of organisms

Permafrost: a layer of soil that remains frozen throughout the year

Pedology: soil science

Parent material: the underlying geological material in which soil horizons form

Permeability: the state or quality of a material or membrane that causes it to allow liquids or gases to pass through it

Physical weathering: the breakdown of rock by physical forces (i.e. ice, water and wind)

pH: a measure of the concentration of hydrogen ions in the soil

Plate tectonics: a theory explaining the structure of the earth's crust and many associated phenomena as resulting from the interaction of rigid lithospheric plates that move slowly over the underlying mantle

Plutonic: relating to or denoting igneous rock formed by solidification at considerable depth beneath the Earth's surface

Precipitate: a solid material that emerges from a liquid solution

Primary consumer: an organism that that feeds on plants or other autotrophic organisms, also called a herbivore

Primary producer: photosynthetically active organisms that produce biomass from inorganic compounds

Regolith: the layer of unconsolidated rocky material covering bedrock

Relief: the configuration of land in terms of its altitude and slope

Sand: mineral soil particles 0.05-2mm in diameter

Salinization: occurs when water soluble salts – sodium, potassium, calcium, magnesium and chlorine – accumulate in excess concentrations in the root zone of plants to such an extent that leads to the degradation of soil and vegetation

Secondary consumer: an organism that feeds on primary consumers in a food chain

Sedimentary: rock that has formed from sediment deposited by water or air

Sequester: to remove or withdraw; to trap (a chemical in the atmosphere or environment) and isolate it in a natural or artificial storage area

Silt: mineral soil particles 0.002-0.05mm in diameter

Silt fences: temporary sediment control used to protect water quality from sediment in stormwater runoff

Sodicity: when salinization is mainly due to the concentration of excess sodium

Soil biota: organisms that spend all or a portion of their lifecycle within the soil or on its immediate surface

Soil profile: consists of the combined sequence of all the horizons in a soil

Stone: a coarse fragment found in soil > 25 cm in diameter

Subduction zone: sites of high rates of volcanism, earthquakes and mountain building

Taxonomy: the classification of something

Tertiary consumer: an organism that largely feeds on secondary and primary consumers

Texture: the percentages of sand, silt and clay in a particular soil sample. Can be estimated by the feel, appearance, or consistency of the soil sample

Texture triangle: a tool used to identify a soil textural class associated with various combinations of sand, silt and clay

Topsoil: the portion of the soil that acts as a growth medium for vegetation, providing humans and other animals with food and a wild habitat

Translocation: the movement of soil-forming materials up and down the soil profile

Transformation: the formation of soil components into structural aggregates

Value: lightness or darkness of a colour

Water-holding capacity: the amount of water a soil can hold

Weathering: the breakdown of rock by physical and chemical forces

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