2025 SOILS AND LAND USE

STUDY RESOURCES

2025 NCF-ENVIROTHON ALBERTA

2025

Soils and Land Use

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NCF-Envirothon 2025 Alberta
Soils and Land Use Study Resources

Key Topic #1: General Physical Properties of Soil and Soil Formation in Alberta

1. Define the five soil-forming factors and describe their influence on a particular soil.
2. Identify different types of parent material in Alberta and how they are formed (such as residual material, eolian deposits, alluvial deposits, colluvial deposits, glacial deposits and organic deposits).
3. Explain the importance of pore space, types of pores (macropores and micropores), and pore connectivity in relation to soil health and vegetation growth.
4. Describe the importance of organic matter in various forms (humus, litter, et cetera) to soil health, structure, and fertility.
5. Describe what factors influence soil structure and explain the impact of soil structure on soil properties.

Study Resources

Resource Title	Source	Located on Page
Soils of Canada: Factors	*Canadian Society of Soil Science, 2020*	4
Soil Structure and Macropores	*Soil Quality for Environmental Health, 2011*	5
Soil Organic Matter	*Canadian Society of Soil Science, 2021*	10

Hans Jenny suggested a slightly different way of considering the factors of soil formation and their effects, in his 1941 book "Factors of Soil Formation". Jenny's model (idea) is consistent with others in that it indicates five factors of soil formation: (1) climate (cl); (2) organisms (o); (3) topography (r); (4) parent material (p); and (5) time (t). Because the factors define the state and the history of soil systems, they are referred to as state factors, and the whole idea is called the state factor approach. Jenny considered that soil systems could be described mathematically by the following expression:

$$S = f\ (cl, o, r, p, t....)$$

where the....(dots) are additional unspecified factors that may be unique to a particular soil, S= a measurable soil property, and f means "is a factor of".

Later, Jenny suggests that the model is best used in a conceptual way to understand and study soil formation by considering changes in the soil system that are the result of regular variations in one factor, with all other factors more or less constant. For example, the effect of topography can be evaluated by studying related groups of soils where topography varies, as in a hillslope, and the other variables (parent material, organisms, climate and time) are similar.

Climate as a soil-forming factor

- Water is the solvent, reaction environment, and transport medium for nearly all reactions/processes in soil.
- Temperature determines the rate of chemical reactions and the intensity of biological activity. Also freeze-thaw processes.
- Wind influences soil directly (erosion or deposition) and by influencing the effectiveness of precipitation.

Organisms/vegetation as a soil-forming factor

- Vegetation helps to hold parent material in place, allowing time for soil formation to occur. Plant roots bind soil particles together and increase the entry of water (infiltration) into the soils, reducing runoff and erosion.
- Plant roots growing in cracks and fissures break apart rocks, speeding up soil formation. Similarly, lichen on rock surfaces increases weathering.
- Plants produce weathering agents that increase rates of chemical weathering of soil minerals by releasing acidic components such as organic acids and carbon dioxide. The result is faster breakdown of the minerals and release of nutrients required by the plants and other biota.

- Vegetation is the initial source of the carbon fixed by photosynthesis that becomes organic matter in the soil. Plants that fix atmospheric nitrogen in symbiotic association with Rhizobacter bacteria are an important means by which nitrogen is added to the soil system.
- Vegetation modifies microclimates by: slowing wind speeds, shading the soil surface, and retaining snow, resulting in cooler and more moist soil environments, as well as less variation in soil-forming environments with topography.

Topography (relief) as a soil-forming factor

- The shape of the land surface influences the redistribution of the water received as precipitation. As a general rule land surfaces that are higher in landscapes, particularly sloping or convex surfaces lose water by runoff: and lower surfaces, particularly those that are concave or depressional receive extra water. The net result, is drier, less developed soils on the convex and sloping surfaces, and deeper, more strongly developed soil profiles in the more moist lower areas. Poorly drained or Gleysolic soils often occur where the amount of water received results in water ponded on the soil surface for a significant period of time.
- The climate becomes cooler, and more moist with increase in elevation, which coupled with related changes in vegetation results in regular changes in the soil. This is a good example of the interrelations among factors.
- In the northern hemisphere, slopes with south-facing aspects receive more solar radiation (insolation) than north-facing slopes, so south-facing slopes are warmer and less moist. The differences in soil temperature and soil moisture are not great (perhaps about 2 degrees cooler on average, and just a bit more soil moisture) but the net result over time is deeper, more strongly leached, more acidic soils on the north slopes, and drier, shallower and less well-developed profiles on the south-facing slope.

Parent material as a soil-forming factor

The initial stage of soil formation is the accumulation of the parent materials - the sediments or rocks in which the soils will form. The vast majority of the Canadian land mass was glaciated during the last glacial episode, and hence the majority of parent materials in Canada are of glacial origin and (by the standards of geological time) are relatively young. The nature and properties of the parent materials exert a very strong subsequent control on the pathways of soil genesis. The categories of major parent materials in Canada are shown in the table below. The initial stage of soil formation is the accumulation of the parent materials - the sediments or rocks in which the soils will form. The vast majority of the Canadian land mass was glaciated during the last glacial episode, and hence the majority of parent materials in Canada are of glacial origin and (by the standards of geological time) are relatively young. The nature and

properties of the parent materials exert a very strong subsequent control on the pathways of soil genesis. The categories of major parent materials in Canada are shown in the table below.

Parent Material	Brief Description
Residual	Bedrock weathered in place; common in non-glaciated areas; soils reflect characteristics of parent rocks Lacustrine Sediments which have been deposited in still, fresh-water lakes; commonly well sorted sands, silts, and clays; deposits associated with glacial episodes called glacio-lacustrine
Fluvial	Sediments deposited in flowing water environments (rivers); commonly well sorted sands and gravels; deposits associated with glacial episodes called glacio-fluvial
Glacial Till	Sediments deposited directly beneath, within, or on top of glacial ice; commonly poorly sorted mixture of gravel, sand, silt, and clay
Eolian	Sediments moved and deposited by the wind; commonly consist of well-sorted sand and silt (loess)
Colluvial	Sediments moved and deposited by unchannelized flow on slopes. Properties reflect sediments from where it was derived
Marine	Sediments originally deposited on the ocean floor and then exposed due to rebound of the land surface
Lacustrine	Parent materials deposited in lakes. Most lacustrine parent materials in Canada were deposited in lakes that existed during the glacial periods and are called glacio-lacustrine sediments. Lacustrine sediments are typically well- sorted sands, silts, and clays. Well-sorted means that one particle size (e.g. clay) is dominant in the texture.

Parent material influences:

- Soil texture, which influences the entry of water (infiltration) into the soil and its transmission in the soil are related to texture. The depth of leaching is related to the average depth to which water penetrates the soil. Other factors being equal, clayey soils take in water more slowly and, because the moisture storage capacity for a given depth is greater, are less leached, resulting in shallower soil profiles, whereas sandy soils are leached to greater depth
    - Clay content also affects the soil's ability to retain cations, or the cation exchange capacity (CEC) and organic matter content generally increases with clay content - due to the higher plant production on the more clayey soils, and

the formation of clay humus complexes that stabilize humus and slow its decomposition.

- Soil mineralogy: minerals vary in their resistance to weathering, and therefore the degree to which elements are made soluble and soils change during soil formation. Some minerals are important stores of nutrients (such as phosphorus, potassium and calcium), which are released slowly as soils weather. Some minerals are characteristic of an Order (for example, the smectite content in Vertisolic soils).
- Buffering capacity, which is the ability of a soil to resist changes in pH. The content of calcium carbonate is important to buffering, in that CaCO3 is able to neutralize soil acidity. Clay and organic matter contents are also important to buffering capacity.

Soil Structure and Macropores

Soil Quality for Environmental Health

What it is: Sand, silt and clay particles are the primary mineral building blocks of soil. Soil structure is the combination or arrangement of primary soil particles into aggregates. Using aggregate size, shape and distinctness as the basis for classes, types and grades, respectively, soil structure describes the manner in which soil particles are aggregated. Soil structure affects water and air movement through soil, greatly influencing soil's ability to sustain life and perform other vital soil functions.

Soil pores exist between and within aggregates and are occupied by water and air. Macropores are large soil pores, usually between aggregates, that are generally greater than 0.08 mm in diameter. Macropores drain freely by gravity and allow easy movement of water and air. They provide habitat for soil organisms and plant roots can grow into them. With diameters less than 0.08 mm, micropores are small soil pores usually found within structural aggregates. Suction is required to remove water from micropores.

Photo: Crumbly structure of surface soil is associated with adequate organic matter content.

Why it is important: Important soil functions related to soil structure are:

- sustaining biological productivity
- regulating and partitioning water and solute flow
- cycling and storing nutrients.

Soil structure and macropores are vital to each of these functions based on their influence on water and air exchange, plant root exploration and habitat for soil organisms. Granular structure is typically associated with surface soils, particularly those with high organic matter. Granular structure is characterized by loosely packed, crumbly soil aggregates and an interconnected network of macropores that allow rapid infiltration and promote biological productivity. Structure and pore space of subsurface layers affects drainage, aeration, and root penetration. Platy structure is often indicative of compaction.

Specific problems that might be caused by poor function: Clay soils with poor structure and reduced infiltration may experience runoff, erosion, and surface crusting. On-site impacts include erosion-induced nutrient and soil loss and poor germination and seedling emergence due to crusted soil. Off-site impacts include reduced quality of receiving waters due to turbidity, sedimentation and nutrient enrichment. Water entry into a sandy soil can be rapid, but subsurface drainage of sandy soils with poor structure can also be rapid such that the soil cannot hold water needed for plant growth or biological habitat.

Practices that lead to poor soil structure include:

- Disturbance that exposes soil to the adverse effects of higher than normal soil drying, raindrop and rill erosion, and wind erosion
- Conventional tillage and soil disturbance that accelerates organic matter decomposition
- Residue harvest, burning or other removal methods that prevent accumulation of soil organic matter
- Overgrazing that weakens range and forage plants and leads to declining root systems, poor growth and bare soil
- Equipment or livestock traffic on wet soils
- Production and irrigation methods that lead to salt or sodium accumulation in surface soils

What you can do: Practices that provide soil cover, protect or result in accumulation of organic matter, maintain healthy plants, and avoid compaction improve soil structure and increase macropores.

Practices resulting in improved soil structure and greater occurrence of macropores favorable to soil function include:

- Cover Crop
- Conservation Crop Rotation
- Irrigation Water Management
- Prescribed Grazing
- Residue and Tillage Management
- Salinity and Sodic Soil Management

Photo: High residue and cover crops contribute organic matter to soil, while no-till management helps protect organic matter and allow accumulation. Organic matter provides food for earthworms and other soil biota. All play a role in developing or protecting soil structure and macropores to help soil function at a high level. Inset shows relationship of macro- and micropores to soil aggregates.

SOIL ORGANIC MATTER

Sylvie Quideau; Myrna Simpson; and Adam Gillespie

INTRODUCTION

Soil organic matter has been increasingly in the news lately, in part because the vast majority of terrestrial carbon is contained in soils. As such, soils play an important role in the global carbon cycle. In addition to serving as a key carbon store, soil organic matter is one of the central attributes of soils. Organic matter influences virtually all of soil properties and overall health, including its physical structure, nutrient status, and biodiversity. Soil organic matter is composed of plant and animal residues at various stages of decomposition, microbial biomass, and products of microbial synthesis. Organic matter accumulation in soils reflects the balance between plant litter inputs and losses through microbial respiration, erosion, and leaching. Carbon stocks may vary widely among soils and across the landscape as a function of parent geological material, climate, vegetation, and topography.

WHAT IS SOIL ORGANIC MATTER?

Soil organic matter is comprised of both living and non-living components. The living component includes soil macro- and micro-fauna, and soil microbial communities, which may be active or dormant. The non-living portion of soil organic matter is derived from dead plant and faunal inputs into the soil (Figure 3.1). These inputs undergo various biogeochemical processes and are either lost, preserved or transformed in soil. The non-living component of soil organic matter is currently hypothesized to be a complex mixture of different biologically-derived molecules that are at various stages of oxidation and preservation (Schmidt et al., 2011). The chemical structure of soil organic matter has been under debate for many decades and it was previously believed that the non-living component of soil organic matter was made of recognizable plant- or animal-derived biomolecules and humic substances, large by-products that resulted from both biological and chemical decay of organic inputs to soil (Schmidt et al., 2011; Lehmann and Kleber, 2015; Can You Dig It Box 1). A more current paradigm recognizes the key contribution of microbial communities in the formation of soil organic matter (Simpson et al., 2007). As organic inputs are decomposed and processed by microorganisms, the majority of the carbon is respired as CO2, but some is incorporated into microbial biomass, can interact with clay minerals or is partially degraded and remains in the soil. Consequently, soil organic matter consists of a complex mixture of plant, animal or microbial-derived residues at various stages of decomposition, and of new molecules synthesized by microbes. Soil organic matter can also interact with soil minerals to form organic matter – mineral complexes that contribute to soil aggregation and may increase the stability of organic matter in soil by hindering microbes from physically accessing organic matter substrates that are protected through these organic matter – mineral interactions (Oades, 1988; Baldock and Skjemstad, 2000).

Major Sources of Soil Organic Matter

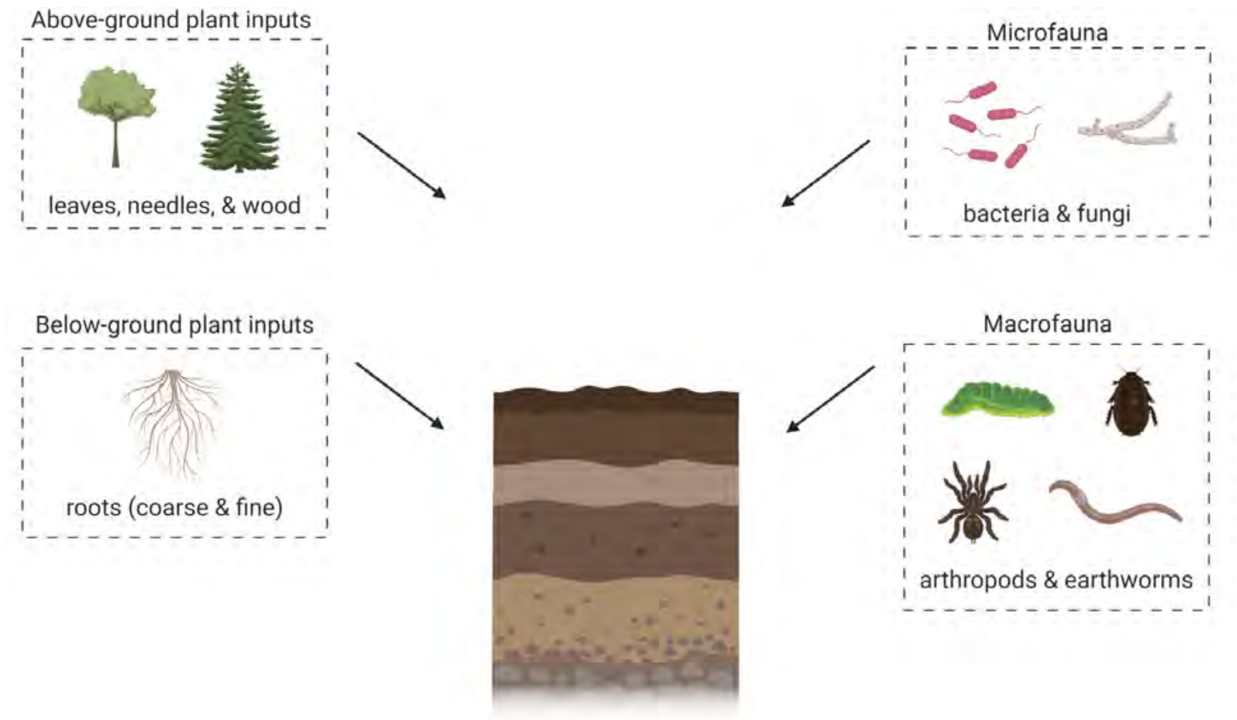

Figure 3.1. Major sources of inputs that form soil organic matter. The types and quantities of inputs vary with different ecosystems and land management practices. © Myrna Simpson. Figure created with BioRender (www.biorender.com). © Myrna Simpson; licensed under a CC BY (Attribution) license.

Organic matter plays several key roles in soil properties and soil processes. The presence of organic matter improves soil stability by promoting aggregation which reduces the potential for soil erosion. Soil organic matter also improves water in soil and has a high cation exchange capacity (from 100 to 500 cmol kg-1) which contributes to the total cation exchange capacity of the soil, depending on the amount of soil organic matter present. This improves the soil's ability to retain important cations (Ca2+, Mg2+, K+ , and Na+), that can enhance the buffering capacity of the soil. Soil organic matter is also the most biogeochemically active and dynamic portion of the soil and it is important for regulating many processes related to the global cycling of elements such as carbon. Soil organic matter acts as a storehouse and a slow release fertilizer for many plant nutrients, including nitrogen, phosphorus and sulfur. Finally, organic matter supports a large and varied faunal and microbial community.

WHY IS SOIL ORGANIC MATTER IMPORTANT?

Soil organic matter is intimately linked to numerous key physical, chemical, and biological soil properties. It is so important for soil function that it is almost impossible to find a soil property that is not influenced by soil organic matter in some way. We can see that the properties of soil organic matter allow it to mitigate plant growth limiting conditions and accentuate important plant growth promoting processes in soils.

Soil Water: Soil organic matter has the ability to buffer water supply in soil. High organic matter increases water infiltration during intense rain events, limiting ponding, soil saturation and anoxic conditions which limit plant growth. Soil organic matter also has the ability to retain water in times of drought and water deficit. Together, these two phenomena act to stabilize the hydrodynamics of plant water supply. Sandy soils benefit hydrologically from increased organic matter because they are intrinsically droughty as a result of large inter-particle pore spaces that do not hold water tightly.

Soil Structure and Compaction: Soil aggregation is a strong indicator of healthy soil structure because it reduces stress on root growth and allows for better water infiltration. Indeed, granular structure tends to be encouraged in soils with higher organic matter, whereas soils exhibiting management-induced blocky structure also tend to have shown soil organic matter depletion. Compaction, which is always a risk in heavily managed soils, can be mitigated in soils with higher organic matter levels, particularly in the particulate, or 'light' organic matter fraction (see Soil Organic Matter Composition section). Finally, clay soils can be more easily managed when organic matter is high because it reduces the inter-particle cohesion and plasticity.

Soil nutrient status: Organic matter contains a wide range of functional groups that can increase cation exchange capacity. Indeed, soil organic matter may contain between 50 to 90% of the cation-adsorbing ability of a soil. Also macronutrients of nitrogen, phosphorus and sulphur have very important storage pools in soil organic matter, becoming available to plants through microbial mineralization.

Soil cation exchange capacity: Soil organic matter contributes to the total cation exchange capacity of soil. Soil organic matter cation exchange capacity ranges from 100 to 500 cmol kg-1 and is considerably higher than most minerals found in soil. Soil organic matter has a pH-dependent cation exchange capacity due to the dissociation of its functional groups with increasing pH of the soil solution. Cation exchange capacity is important for the ability of a soil to retain important nutrients, which include the major cations Ca2+, Mg2+, K+ , and Na+ that also contribute to the buffering capacity of the soil.

Soil biology and energy storage: Chemical bonds in soil organic matter contain energy, and this energy is consumed by microbes for growth and metabolism. It is this stored energy that drives microbial nutrient cycling and all the other plant beneficial associations that soil biology maintains with plants.

FORMATION OF SOIL STRUCTURE

The structure of the soil plays a very important role in formation of pores that consequently impact air, gas, and water movement in the soil as well as the ability of roots to penetrate into the soil to extract water and nutrients. The initial structure of a soil is inherited from the parent sediments but many of the soil-forming processes discussed above lead to distinctive arrangements (called aggregates or peds) of mineral and organic materials and soil pores (Figure 2.26).

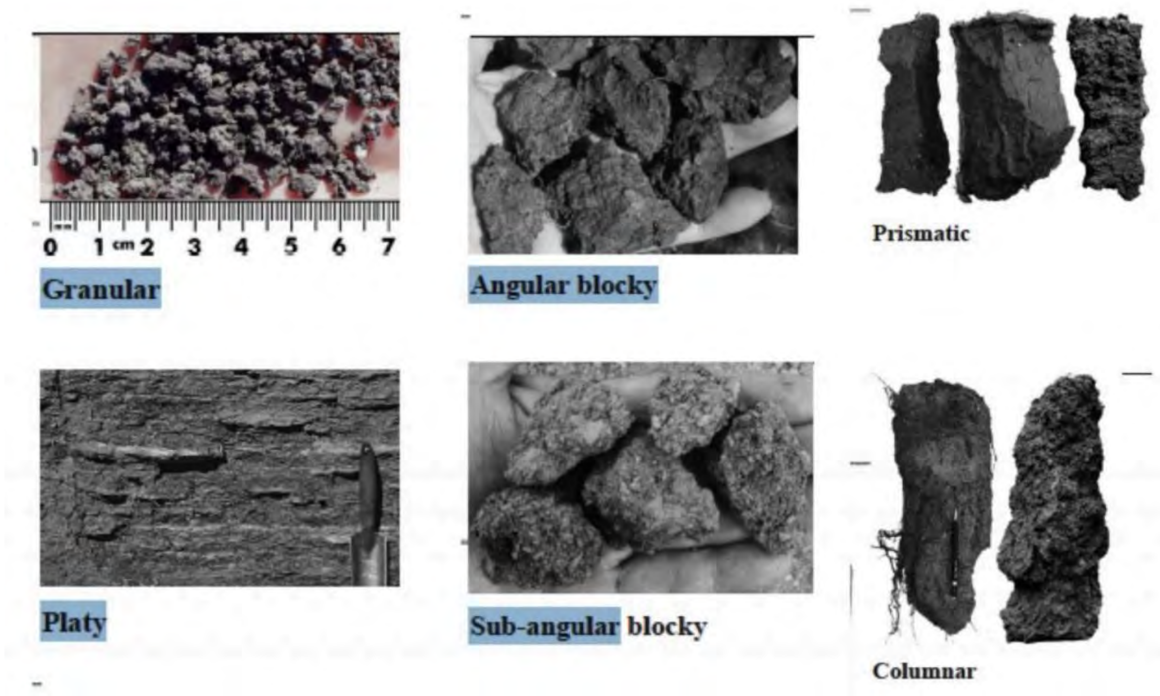

Figure 2.26. Main types of soil structural units or aggregates. From Watson and Pennock (2016). Reproduced with permission; licensed under a CC BY-NC (Attribution NonCommercial) license.

The key property of the parent sediment that influences the types of aggregates formed is the clay content. Clay particles are reactive (due to their small size and presence of charges on their surfaces) and can bond together into large and stable structural units. Soils dominated by sand-sized particles are largely non-reactive; hence, sandy soils have weakly developed and readily disrupted aggregates (if they are present at all).

Two sets of soil-forming processes modify the initial, sediment-derived structure. The first is the addition, transformation, and mixing of OM that occurs in grassland soils, tundra soils (due to small mammals), and in forest soils where earthworms have invaded the forests (such as in southern Ontario and Quebec). The dense root network of grasses acts as netting to bind solid soil material together and the larger soil organisms such as earthworms create soil aggregation by ingesting and excreting the soil material. The result of these agents is formation of relatively loose granular aggregates (Figure 2.26), and such soil structure is well suited to root penetration and growth.

The second bundle of processes are the physical processes, especially those associated with freezing and thawing of soil water and swelling and shrinking of clay minerals. In some cases freezing and thawing in the bleached eluvial horizon in forest soils creates a horizontally layered platy structure (Figure 2.26). In loamy or clay-dominated soils the physical processes create a range of sizes and shapes of aggregates (Figure 2.26). In some cases (such as the high Na+ soils of grasslands), the structural units become so dense that they prevent root penetration and limit plant growth (clay-rich layer in Figure 2.25). Another example of growth-limiting structural units occurs in forested landscapes where deposition of iron-organic compounds and clay can clog soil pores and solidify into a near-solid mass. Depending on the type of cementing agent these features are called duric horizon or placic horizons.

Apparent structural units caused by human activity, such as cultivation, are referred to as clods, which do not cohere in the same manner as structural units that are naturally formed.

HUMAN ACTIVITY AS A SOIL FORMING FACTOR

So far in this chapter we have only considered soil formation under natural conditions but in many parts of Canada soils have also been transformed by human use. The impact of humans on soil formation has been most pronounced since settlement by Europeans began. Initially this impact was largely through conversion of land to agriculture and exploitation of forests but in the 19th and 20th Centuries the impact of mining and petroleum exploitation also became important. In the 20th Century the great expansion of urban areas has also profoundly affected the soil landscape. The conversion of grassland and forested landscapes to agricultural production affects almost all of the processes that occur in soil. In terms of soil genesis the almost universal impact of agricultural conversion is a loss of SOM due to the combined effects of the breakup of aggregates and exposure of SOM to microbial decomposition and accelerated microbial decomposition and soil erosion (discussed below). Globally studies have shown that on average about 30% of the original soil organic carbon is lost when conversion from forest or grassland to cropland occurs (FAO, 2019). In forested sites with leaf litter lying on the surface, the clearance of trees and ploughing incorporates part of the leaf litter layer into the soil, resulting in an organically enriched mineral surface horizon. Clearing of the land surface also leads to increases in soil erosion by water, wind, and tillage. Soil erosion is the detachment and transport of soil from one position and its deposition elsewhere (FAO, 2019). Water erosion involves soil detachment and transport by water. Soil can be detached by both raindrop impact and by flowing water, and transport is by water flowing on the surface. Where water concentrates on the soil surface, channels can be incised into the surface, creating shallow rills (Figure 2.27A) or deeper gullies (Figure 2.27B). The eroded soil may be deposited within the field or at the field edge but in some cases it is carried directly to stream systems, where it causes many environmental problems.

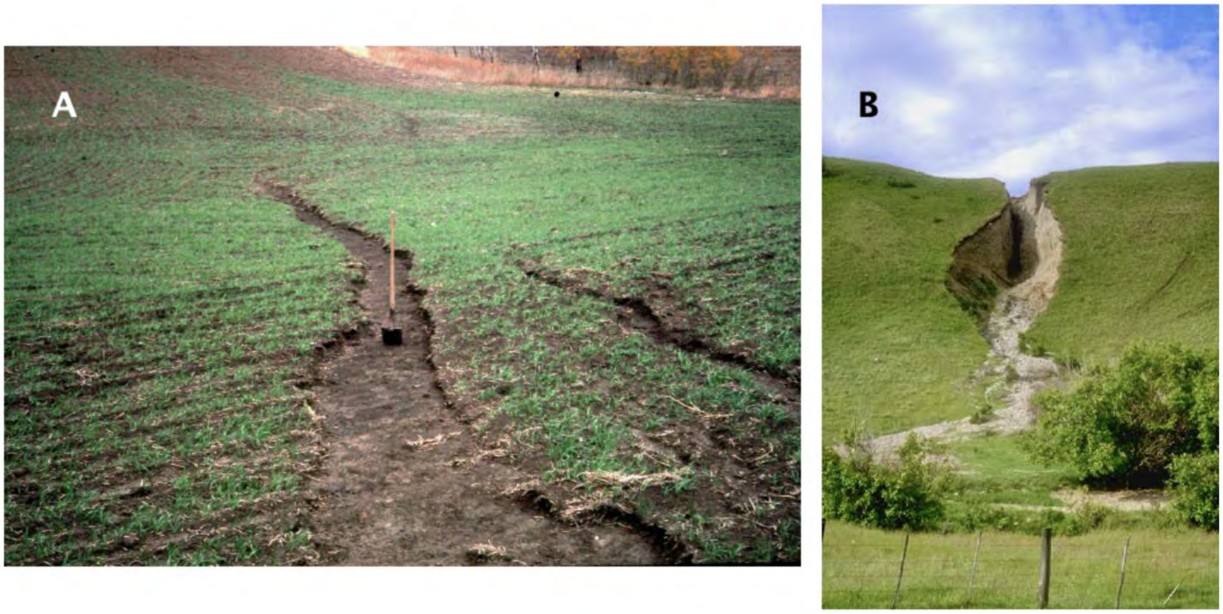

Figure 2.27. Water erosion in Saskatchewan (left) and British Columbia (right). (A) Rill erosion in which flowing water has incised through the loose, organically enriched topsoil and then widened its channel (or rill) when it encountered a denser soil layer. These rills will be filled in with soil the next time it is tilled. Image courtesy of Dan Pennock, Univ. of Saskatchewan (Saskatchewan Center of Soil Research). (B) Gully erosion in which water channelled across unprotected land washes away the soil along the drainage lines. Image courtesy of Maja Krzic, Univ. of British Columbia. Both images licensed under a CC BY (Attribution) license.

In wind erosion the wind itself detaches and transports soil particles. Wind erosion can occur anywhere where the soil is dry and bare and the land surface is flat. The worst episodes of wind erosion in Canada occurred in the southern part of the Prairie ecozone in the 1930s (hence, the Dirty Thirties) and lead to widespread land abandonment and depopulation. Tillage erosion is a more insidious type of erosion. Tillage operations by farm implements inexorably remove soil from upper slopes and deposits it in lower slope positions during farm operations, yet the effects of any one operation are almost undetectable (FAO, 2019). In terms of soil formation the main effect of soil erosion is to remove part of the organically enriched surface soil. In tillage erosion the amount of soil removed in a year may be very small (0.5 to 1 mm) but the cumulative effect year-after-year can be substantial. In water erosion rills and gullies can remove part or all of the organically enriched layer, as can wind erosion during very severe events. This loss (or truncation) of the surface layer leads to a loss of the most fertile part of the soil for plant production. It may also bring a growth-limiting lower soil layer (for example, with high sodium levels) closer to the surface, further reducing plant growth. Where deposition of eroded soil occurs in lower slope positions, the upper soil layer becomes unnaturally over-thickened. These are termed cumulic soils (Figure 2.28).

Figure 2.28. Cumulic soil formed by deposition of water-eroded soil at the base of a slope. The original topsoil from upslope has been buried under less fertile subsoil. The aluminum stick is 1 m long. © Dan Pennock, Univ. of Saskatchewan (Saskatchewan Center of Soil Research); licensed under a CC BY (Attribution) license.

Resource extraction and transport activities such as mining for minerals or for bitumen or pipeline development also fundamentally alter the soil, in some cases by completely excavating the soil and underlying sediment. Currently, regulations are placed to require some level of reconstruction of a soil but inevitably the constructed soil will differ from the original soil profile. Soils resulting with major disruption from human activities are termed anthropogenic (i.e., formed by humans). A final (in every sense of the word) impact of humans on soil genesis is the complete stripping and/or burial of soils that occurs where infrastructure such as houses, roads, and shopping centers is constructed. This irrevocable loss of soil is termed soil sealing and globally is one of the major threats to soil. In Europe, for example, soil sealing was judged in 2015 (Montanarella et al., 2016) to be the major threat to the soil in that region. In Canada, the largest areas of urban development also correspond to our most productive soils and hence this human-induced destruction of soil is a significant concern here as well (Montanarella et al., 2016).

HOW CAN WE MANAGE SOIL ORGANIC MATTER?

Environmental Factors

Soil carbon storage results from the balance between carbon inputs and outputs. Carbon sequestration occurs when aboveground and belowground (i.e., leaf and root-derived) inputs exceed outputs, which are usually dominated by CO2 fluxes from the soil surface, but may also include in some instances important contributions from methane (CH4) and leaching of dissolved organic carbon (DOC). Plant residues are the major substrate for soil organic matter formation. When microbial communities decompose plant litter, the majority of carbon contained in these residues is eventually evolved as CO2. However, a small portion remains in the soil as soil organic matter, sometimes for centuries or even millennia. Figure 3.5 shows the distribution of soil carbon (related to soil organic matter) of the soils of Canada. The intricate balance of these inputs and outputs, as well as organic matter stabilization to clay minerals, is what determines soil organic matter persistence.

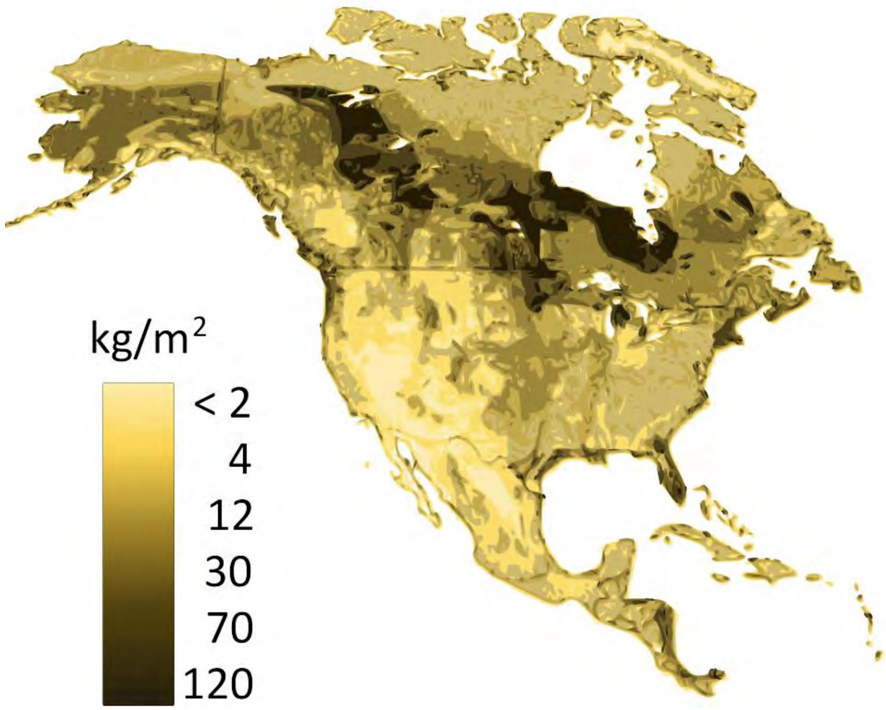

Figure 3.5. Soil carbon distribution from soils in North America. Adapted and generalized from USDA sources © Adam Gillespie. CC-BY. © USDA adapted by Adam Gillespie is licensed under a CC BY (Attribution) license.

The rate of carbon accumulation varies greatly among soils, which reflects the influence of environmental factors; i.e., soil forming factors (climate, organisms, parent geological material, relief and time) on pedogenic processes. Climate directly affects soil carbon stocks by controlling the balance between litter inputs and decomposition outputs. Increasing precipitation increases plant growth and litter production, and decreasing temperature decreases decomposition losses. At the global scale, carbon accumulation in soils is more influenced by temperature than precipitation and tends to increase in high-latitude soils where low temperatures limit decomposition. The largest stocks of carbon are found in the northern permafrost region, where both Organic soils and Cryosols are present. In arid environments, water availability may limit plant growth and plant residue inputs to soils, and consequently lead to lower soil carbon stocks.

Across Canada, soil carbon stocks also vary as a function of precipitation, where high local precipitation along both the Atlantic and Pacific coasts allows for the establishment of dense forest vegetation and consequently, large surficial litter inputs. In addition, placement of the vegetation inputs directly affects the distribution of carbon within the soil profile as well as total soil carbon stocks. In grassland soils where belowground (root) inputs can be plentiful, carbon stocks can be greater and not decrease as sharply with depth as they do under forest vegetation. Lastly, while vegetation may be the main factor controlling surface organic carbon, the soil parent geology may also be a key factor for carbon sequestration in the mineral soil profile.

Soil carbon and clay content are positively correlated, both because of the formation of organic matter-mineral complexes resistant to decomposition losses, and because of the indirect effects of clay that promotes greater fertility and plant growth, hence increasing carbon returns to the soil.

At the landscape level, organic carbon accumulation is favoured in lower slope positions where soil conditions are wetter and tend to inhibit decomposition losses. Similarly, in the northern hemisphere, soil carbon stocks tend to be greater on northfacing slopes compared to south-facing slopes, where lower temperature and lower evaporation increase soil moisture and decrease decomposition.

Average carbon stocks in the different mineral soil orders found in Canada vary from around 11-12 g m-2 for Regosols, Brunisols, Luvisols, Chernozems and Solonetzs to 16-20 g m-2 for Podzols and Gleysols. In forest soils, carbon stocks increase from well-drained Luvisolic and Brunisolic soils to poorly drained Gleysolic and Organic soils (Figure 3.6). Carbon stocks in Organic soils may be an order of magnitude higher than in other soil types and average 134 g m-2. Within mineral soil orders, Cryosols contain the highest stocks averaged at 41 g m-2. Cryosols also occupy the largest area in Canada, as they constitute more than one third of Canadian soils. Cryosols and Organic soils contain roughly the same amount of carbon, which is by far the largest amount compared to other soil orders. Taken together, these two soil orders hold about 80% of the total carbon stocks contained in Canadian soils. Podzols and Brunisols contain 5-10%, and the remaining orders < 5%.

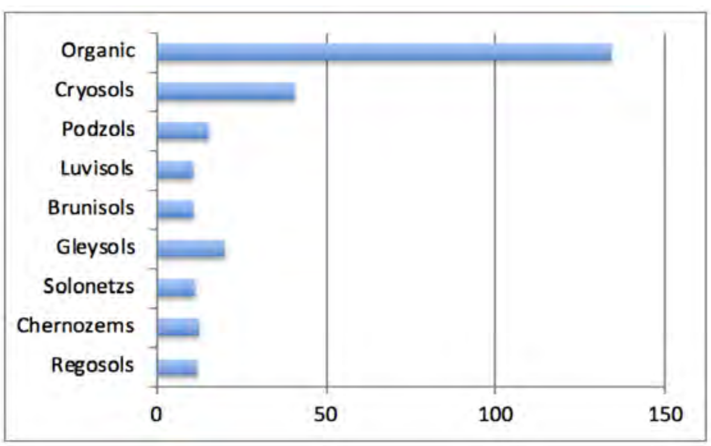

Figure 3.6. Carbon stocks (kg m-2) in different Canadian soil orders (adapted from Shaw et al. 2008; Tarnocai 2008). Adapted by Sylvie Quideau and licensed under a CC BY (Attribution) license.

Pedogenic processes (i.e., the processes of soil formation) can directly affect carbon stocks and carbon stability in soils. In turn, soil carbon content and soil classification are directly related for many soil types. The most obvious example may be the case of Organic soils, where organic matter accumulation is at the core of their formation and classification. Paludization, the accumulation of thick organic layers on the mineral soil surface, creates the fibric (Of), mesic (Om), and humic (Oh) horizons representative of Organic soils. In upland forests, littering, the thinner, surficial accumulation of fresh plant residues, is responsible for forest floor accumulation, which can be separated into three distinct horizons (LFH) based on the degree of decomposition.

Humification, the formation of humic substances from plant residues, and melanization, the darkening of a soil color due to carbon addition, are both responsible for the accumulation of carbon within the top mineral soil layers, in particular in Chernozemic horizons. The formation of these horizons is favoured by the extensive network of grass roots that contributes large exudate and residue inputs. Bioturbation by earthworms and stabilization of organic matter by calcium are two common processes contributing to carbon accumulation in Canadian Chernozems. The extent of darkening is used to differentiate between great groups of Chernozems and Solonetzs, with in increasing amount of carbon: Brown, Dark Brown and Black great groups. The absence or presence of a carbon-rich Ah horizon is also used to differentiate great groups of Brunisols, Luvisols, Gleysols, and Regosols; i.e., Melanic and Sombric Brunisols, Gray Brown Luvisols, Humic Gleysols and Humic Regosols. Lastly, carbon content is used to separate subgroups of several additional mineral soil orders. For instance as opposed to the processes just mentioned, podzolization results in carbon accumulation at depth. Mostly, during podzolization, carbon is added from soluble organics leached from the soil surface. The other carbon input at depth would result from root exudates or root turnover. Podzolic great groups are partially differentiated based on their carbon content, with the Ferro-Humic Podzols containing more carbon in their subsoils than the Humo-Ferric Podzols.

Lastly, processes that are not directly linked to humification may nonetheless increase soil carbon. **Gleization**, which results in anaerobic conditions, may lead to the accumulation of carbon in Gleysols. Extreme cold, which also inhibits decomposition, can result in thick surficial carbon accumulation characteristic of Organic Cryosols, and, in the case, of Turbic Cryosols, in carbon accumulation in the mineral horizons, which can also be found at depth due to cryoturbation, the process of soil mixing due to freezing and thawing.

Land Management

In Canada, conversion of native land to arable agriculture resulted in a loss of about 25% of the carbon present in the soil surface layers (0-30 cm) prior to the onset of cultivation. In other words, carbon lost over the 19th century from Canadian cultivated grassland soils would have resulted in an emission of about 1 Pg (Janzen et al. 2018).

Carbon losses may be attributed to removal of crop residues, as well as to increased erosion and decomposition. In some cases, fire was used to clear land, which resulted in increased losses. Increased decomposition, rather than erosion is typically he main culprit following cultivation, and results from the physical disruption of soil aggregates by tillage, which exposes previously inaccessible organic matter to the degradative actions of soil microorganisms. The majority of carbon lost upon cultivation consists of the light fraction, which is composed of still "young", only partially decomposed plant residues. Most of the loss occurs rapidly, i.e., during the first twenty years of soil conversion to arable agriculture.

Because of past losses of carbon from agricultural soils, these have significant capacity to store more carbon. Several management practices can promote soil carbon gains. Specifically, some can decrease soil carbon losses including: reduction in tillage intensity and reduction in summer fallow. Some measures contribute by increasing carbon inputs to soils, either by adding carbon from other sources (e.g. manure, biochar), or by promoting greater plant inputs to soils (e.g., by growing cover crops, improving residue retention, increasing use of perennials, and optimizing fertilization). Chemical fertilization (i.e., addition of inorganic fertilizers), by promoting plant growth, typically results in carbon accumulation in soils. The annual carbon storage rate for soils receiving inorganic fertilizers has been estimated at 23 ± 13 g C m^{-2} yr^{-1} (VandenBygaart et al., 2004). Application of organic amendments such as animal manure or biosolids (human waste) also leads to an increase in soil carbon, especially when applied regularly over many years or even decades. However, this may also increase the generation of greenhouse gases, in particular nitrous oxide. An upper limit in soil carbon sequestration may be reached, which corresponds to the fact that the soil matrix may become saturated with carbon as it has reached its full storage capacity. Fine-textured soils have a higher ability to store carbon than coarse-textured soils.

Conservation tillage, including reduced and no tillage, can promote soil carbon accumulation, although recent studies have shown that the increase is likely confined to the upper layer of soil (0-10 cm), and that tillage has no effect on carbon stocks integrated over the full 0-130 cm depth interval (Mary et al., 2020).

Soil organic matter can also be impacted by other anthropogenic activities. It is well documented that conversion of native lands for use in farming can lower soil organic matter content, especially with tillage. The incorporation of crop residues, as well as conservation tillage practices, is being used to preserve soil organic matter in agricultural lands. Crop residues are applied to the soil surface after harvest and are reincorporated into the soil organic matter pool. The application of charred residues (biochar or through slash and burn agriculture) improves both the organic matter content and cation exchange capacity of the soil and alters the soil pH, all of which benefits both plants and soil microbes. Char can be long-lived in soil, and though the benefits of its application vary with time as the composition of the char can change, the addition of char does contribute to the overall soil organic matter continuum found in managed soils.

While deforestation typically results in a loss of soil carbon, afforestation may, at least in part, restore the original soil carbon levels. Reforestation in the boreal zone results in smaller rates of soil carbon increase compared to other climates, likely because tree growth rates are slower there (Laganière et al., 2010). Previous land use and the type of disturbance is also an important factor controlling the rate of soil carbon increases following afforestation. Afforestation of agricultural lands yields to greater increases in soil carbon stocks compared to pastures or grasslands (Mayer et al., 2020). Afforestation of soils disturbed by industrial activities, such as surface mining, can also lead to a significant increase in soil carbon levels (Prescott et al., 2019). If suited to the site conditions, deciduous trees help to increase soil carbon stocks faster than conifers do; in the long run, deciduous trees also contribute to higher carbon stocks in the mineral soils compared to the forest floors.

NCF-Envirothon 2025 Alberta
Soils and Land Use Study Resources

Key Topic #2: Soil Ecology and Soil Health

6. Describe the ecosystem services provided by soil, such as water filtration, carbon sequestration, nutrient cycling, and growing medium.
7. Describe the roles and services of soil organisms (including fungi, microorganisms, microorganisms, and fossorial animals) in the overall health and functioning of the soil.
8. Explain how plants take in nutrients and water, and what soil conditions and characteristics influence this uptake.
9. Describe how soils and their associated ecosystems can be impacted by pollution.

Study Resources

Resource Title	Source	Located on Page
Why is Soil Important?	*Soil Science Society of America, 2013*	24
The soil provides “services” to me?	*Mary Stromberger and Nick Comerford; Soil Matters, Get the Scoop, 2016*	26
Critical Ground - Why Soil is Essential to Canada's Economic, Environmental, Human, and Social Health, Chapter 1	*Report of the Standing Senate Committee on Agriculture and Forestry, Canadian Senate, 2024 Pages 23-27*	28
Critical Ground - Why Soil is Essential to Canada's Economic, Environmental, Human, and Social Health, Chapter 2	*Report of the Standing Senate Committee on Agriculture and Forestry, Canadian Senate, 2024 Pages 95-101*	31
The Living Soil: How Unseen Microbes Affect the Food We Eat - *VIDEO*	*Morehead Planetarium and Science Center, YouTube, 2017*	36
What Are Mycos? - *VIDEO*	*Down To Earth Fertilizers, YouTube, 2018*	37
Water Uptake and Transport in Vascular Plants	*McElrone (U.S. Department of Agriculture, Agricultural Research Service, University of California, Davis), et al, 2013 Nature Education*	38
Polluting our soils is polluting our future	*Food and Agriculture Organization of the United Nations, 2018*	47
Critical Ground - Why Soil is Essential to Canada's Economic, Environmental, Human, and Social Health, Chapter 5	*Report of the Standing Senate Committee on Agriculture and Forestry, Canadian Senate, 2024 Pages 115-121*	50

Soil Science Society of America

Soil Science Society of America

Helping to Create Solutions from the Ground Up

Why is Soil Important?

Soil provides ecosystem services critical for life: soil acts as a water filter and a growing medium; provides habitat for billions of organisms, contributing to biodiversity; and supplies most of the antibiotics used to fight diseases. Humans use soil as a holding facility for solid waste, filter for wastewater, and foundation for our cities and towns. Finally, soil is the basis of our nation's agroecosystems which provide us with feed, fiber, food and fuel.

SSSA Members & Professionals

SSSA members are researchers, educators, extension agents, consultants and industry advisers. Our members, along with practicing Certified Professional Soil Scientists (CPSSc) and Certified Professional Soil Classifiers (CPSC), advise land managers in decisions that meet our nation's modern agricultural, water quality, land management, and environmental challenges. SSSA members educate, train, and mentor the future workforce of scientists, science educators, and extension agents to ensure the availability of expertise in soil science for sustainable agricultural production, natural resource management, and environmental protection.

Ecosystems Services

Advances in watershed, natural resource, and environmental sciences have shown that soil is the foundation of basic ecosystem function. Soil filters our water, provides essential nutrients to our forests and crops, and helps regulate the Earth's temperature as well as many of the important greenhouse gases. As our awareness of the value of natural and managed ecosystems services grows, new biodiversity, carbon, and water markets are emerging, such as the Chicago Climate Exchange, and the nutrient trading programs under the new Executive Order on the Protection and Restoration of the Chesapeake Bay. These markets place an economic value on management practices which increase those ecosystem services, producing goods that enhance human and environmental health.

Environmental & Human Health

Industrial, household, and non-point source pollution jeopardizes the health of the environment and humans. Over the past several decades, soil scientists have identified new practices which limit the mobility of contaminants and rehabilitate polluted land. As a result, land managers now have access to new, innovative soil management strategies that can mitigate soil, water, and air pollution, while also enhancing ecosystem performance.

Food Security

We must develop new technologies and techniques to produce more feed, fiber, food and fuel with less— less land, less water, less energy, and fewer nutrient inputs. Achieving this will require improved crops and novel soil management strategies that can only be accomplished through investment in interdisciplinary research and development.

"To Forget how to Tend the Soils is to Forget Ourselves"
- Mahatma Gandhi

Climate Change

Almost 35% of all greenhouse gases (GHG) released into the atmosphere due to anthropogenic activities since 1850 are linked to land use changes. Crop, grazing, and forest lands, as well as wetlands, all have the potential to contribute to or, through sound management strategies, mitigate GHG emissions through soil carbon sequestration, while also enhancing ecosystem services. Soil stores carbon dioxide (CO_2) and other GHGs in soil organic matter. Soil organic matter offers several added benefits: it filters and cleans water, enhances water retention and storage, mitigates the impacts of extreme weather events, improves soil structure, reduces soil erosion, provides microbial habitats, and serves as a source of long-term, slow-release nutrients.

Science & Education Workforce Development

Funding for science education and workforce development must, in addition to other important disciplines, include soil science. Research, education and training provided through the U.S. Department of Agriculture's National Institute of Food and Agriculture (NIFA) and Land-Grant University System (LGU), as well as the U.S. Environmental Protection Agency (EPA), National Science Foundation (NSF), U.S. Department of Energy (DOE), and U.S. Geological Survey (USGS), are essential to prepare the next generation of interdisciplinary soil scientists. Only with adequate investment in soil science will the nation have the workforce (educators, researchers, and land managers) necessary to safeguard this irreplaceable resource and ensure ecosystem health as well as the continued sustainable production of feed, fiber, food and fuel.






Soils Sustain Life

Soil Science Society of America

Soil Science Society of America

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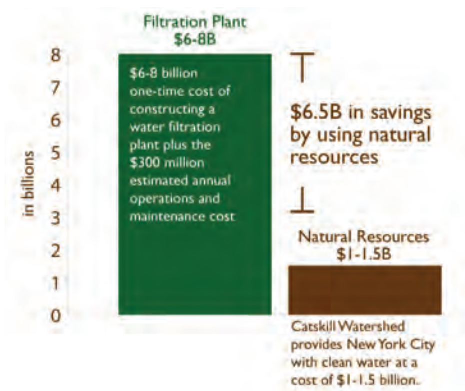
Soil science integrates scientific principles from physics, biology, and chemistry to elucidate how soils provide these essential services. Soil science provides an understanding of how soil properties relate to and can be managed for optimal agricultural production, forest, range, and wetland management, urban land use, waste disposal and management, and reclamation of drastically disturbed sites, such as mines. Soil science addresses nutrient management, sustainable agriculture, global biogeochemical cycles and climate change, ecosystem structure and function, or nuclear waste disposal and management, among many others.

Soil scientists research soil biogeochemical and physical processes, map soil characteristics, and teach aspiring scientists about soil processes. Soil scientists perform soil surveys, develop land use plans, conduct site evaluations for septic systems or storm water facilities, examine soil function and health, identify optimal food production methods, develop climate change mitigation strategies, and develop new approaches for clean water and resource management at many spatial scales.

Important Facts about Soil

- Wetlands deliver a wide range of ecosystem services that contribute to human well-being, such as fish and fiber, water supply, water purification, climate regulation, flood regulation, coastal protection, recreational opportunities, and, increasingly, tourism. Despite these important benefits, the degradation and loss of wetlands is more rapid than that of other ecosystems.
- Through natural processes, such as soil adsorption, chemical filtration and nutrient cycling, the Catskill Watershed provides New York City with clean water at a cost of $1-1.5 billion, much less than the $6-8 billion one-time cost of constructing a water filtration plant plus the $300 million estimated annual operations and maintenance cost.



- U.S. agriculture produces about 500 million tons of crop residue annually, most of which contributes to maintaining soil organic matter. Plans to use crop residues for bioenergy production could deprive agroecosystems of important inputs for future soil productivity, potentially upsetting existing agroecosystem balances.
- Arsenic from smelter emissions and pesticide residues binds strongly to soil and will likely remain near the surface for hundreds of years as a long-term source of exposure.
- Archaeologists have determined that the demise of many sophisticated civilizations, such as the Mayans of Central America and the Harappan of India, resulted directly from the mismanagement of their soils.
- Covering just 6% of Earth's land surface, wetlands (including marshes, peat bogs, swamps, river deltas, mangroves, tundra, lagoons and river floodplains) currently store up to 20% (850 billion tons) of terrestrial carbon, a CO_2 equivalent comparable to the carbon content of today's atmosphere.

Soil Trivia

- Did you know that there are more living individual organisms in a tablespoon of soil than there are people on the earth?
- Did you know that almost all of the antibiotics we take to help us fight infections were obtained from soil microorganisms?
- Did you know that agriculture is the only essential industry on earth?
- Did you know that soil is a non-renewable natural resource?
- Did you know that the best china dishes are made from soil?
- Did you know that about 70% of the weight of a text book or glossy paged magazine is soil?
- Did you know that putting clay on your face in the form of a "mud mask" is done to cleanse the pores in the skin?

The soil provides "services" to me?

These "gifts from nature" come all year, not just at Christmas!

Just like water and air, soil provides "services" to all life on earth, year round. It's a gift from the soil to humanity. Soil scientists have broken down these services into four categories, known as "soil ecosystem services." In this blog post, we'll explain the services, and try to give you an idea of what your life might be like if soil didn't work so hard for you.

Soil is a gift that keeps giving year-long. Read more about how soil gives to civilization, and subscribe to Soils Matter! Art: P Scullion

Supporting Soil Ecosystem Services

These services are your "basics." Without them, soil could not perform any of its other functions. Soil is a home – or habitat – to the world's largest biodiversity. Fungi, bacteria, and fauna do many of their own jobs, but without their home – the soil – they would not survive. Soil also holds the nutrients plants need to survive, and provides the physical structure for the roots and stems that helps hold plants up.

How would you thrive without your home or basic nutrition?

Regulating Soil Ecosystem Services

These are services that regulate the quality of our air, water, and other resources, and therefore provide controls on climate, flooding, and even disease. An example of a regulating soil ecosystem service could be the ability of soil to clean water by acting as a spongy filter! When it rains hard, puddles of muddy water can sometimes form on soil surfaces, or dirty water can runoff from roads onto soil. But slowly, that water sinks through the soil, and into the water table below. As that water moves down through the soil, it gets cleaned.

Soil also plays a role in cleaning the air we breathe, and the quality of our climate. In the United States, most of us have access to clean, drinkable water. How thirsty would you need to get before you might drink muddy water?

Provisioning Soil Ecosystem Services

Soils provide many items for us – things we can use. Food for our hungry bellies (from our farms that grow the food!). Clothes to keep us warm (think cotton, linen and hemp clothing!). Lumber for our homes. Around the world, 80% of homes are made from soils.

Did you know that the major antibiotic, Streptomycin, was first isolated from soil? That's because the bacterial group that makes it, *Streptomyces*, calls soil its home! From this first discovery, hundreds of antibiotics have been developed that save lives all over the world.

Provisioning soil ecosystems are made possible by adding together qualities of the supporting and regulating roles soils play.

We think the answer to "What would you do without provisioning services from soils" is pretty clear!

Cultural Soil Ecosystem Services

For millennia, cultures have had a strong link to the soils. Egyptians used soils for paint, as did Native Americans. Other cultures used soils as dyes for their cloth.

Songs and books have been written about soils, and many famous paintings include soils in their landscapes, adding to the non-material benefits that society gets from soil.

Do you read books, wear make up, use porcelain china…or any of the other cultural and societal items made with or about soil?

Soils are the source and foundation of many ecosystem services. Without soils, there would be no life. That's why the Soil Science Society of America's tag line is *Soils Sustain Life!*

Answered by Mary Stromberger and Nick Comerford, editors of the SSSA publication ***Soil Ecosystem Services and Natural Capital***

Critical Ground - Why Soil is Essential to Canada's Economic, Environmental, Human, and Social Health

Chapter 1: The Current State of Agricultural and Forest Soils in Canada

Soil mixed with leaves from the soil lab at the Canada Agriculture and Food Museum.

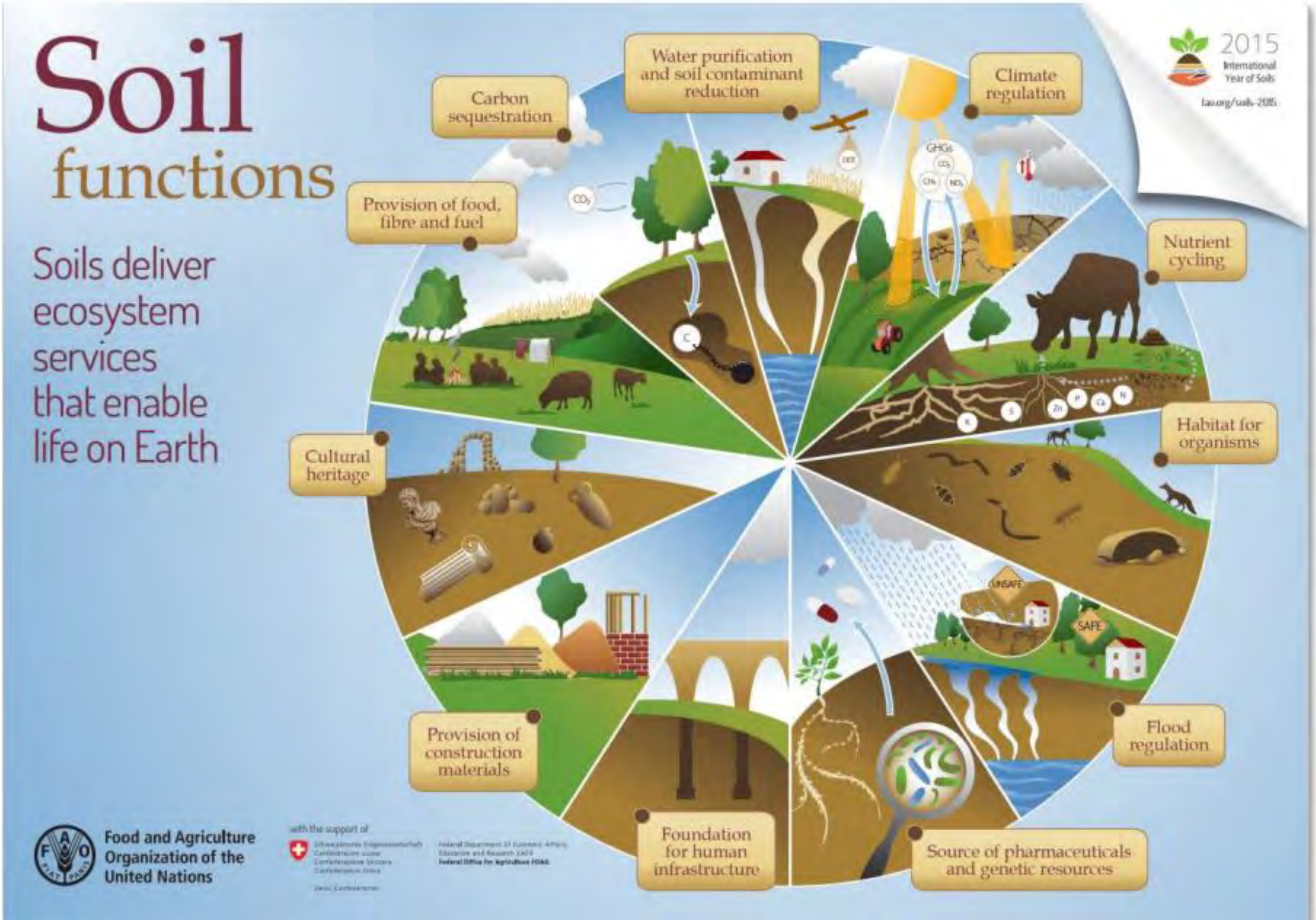
What is healthy soil?

There are more living organisms in a tablespoon of soil than there are people on Earth. One cubic metre of healthy soil can retain over 250 litres of water. Ninety-five percent of our food comes from soils, yet the FAO estimates that 33% of the earth's soils are already degraded and over 90% could become degraded by 2050.[11]

Soils deliver a variety of ecosystem services that enable all—plant, animal, human—life on Earth, including carbon sequestration, nutrient and energy (carbon and organic matter) cycling, water storage and cycling, climate regulation, habitat for organisms, among others as shown in Figure 1.

Soil is the foundation of a living ecosystem with dynamic interactions between physical, chemical, and biological properties. The committee learned that soil health is an evolving concept whose definition varies in each sector and requires different management strategies.[12] In agriculture, a healthy soil produces food for people, feed for animals, and fiber and fuel for national and global consumption.[13] The concept, however, does not apply equally to forest soils because ecosystem services do not always work in concert. [14] For example, large areas of peat soils in Northern Canada have high organic matter content, but are not productive in terms of timber yield.[15] The topic of forest soil health is not often heard of, yet 35% of Canada is covered by forest, representing 9% of the world's forest area.[16] Soil degradation prevents all soils from providing ecosystem services. It negatively affects the livelihoods of millions of people and poses a serious threat to food security. Figure 2 presents the main drivers, types, and consequences of soil degradation, as well as sustainable soil care and management solutions.

Figure 1 – Soil Functions and Ecosystem Services



Source: Food and Agriculture Organization of the United Nations, "Soil Infographics," Global Soil Partnership, 2015.

Laura L. Van Eerd, Professor, Sustainable Soil Management, University of Guelph, told the committee the first approach to protect and enhance soil health is to minimize threats to degradation; the second is to adopt practices that build or maintain soil health. Degradation threats must be identified and mitigated and are farm- and field-specific.[17]
Throughout Canada, beneficial soil management, or soil care, practices such as soil compaction reduction, crop and animal diversity, conservation tillage, using compost and amendments, and continuous living plants and cover crops can help build or maintain soil health. However, witnesses told the committee there is no "one-size-fits-all-approach" to soil care practices as soils and climates vary throughout the country.

Section 95 of the Constitution Act, 1867 establishes agriculture as a concurrent or shared jurisdiction between the federal government and the provinces. Provinces may enact laws relating to agriculture if they do not contravene federal legislation in the area. In practice, the federal, provincial, and territorial governments negotiate five-year funding agreements—the recent $3.5 billion, five-year Sustainable Canadian Agricultural Partnership (Sustainable CAP)—for cost-shared agricultural initiatives such as business risk management programs for farmers. Collaboration is required to make the agriculture and agri-food sector stronger, more powerful, and more responsive to the environmental and economic challenges that farmers, ranchers, growers, and all Canadians face. In its hearings, the committee heard from witnesses representing every province and territory in Canada. Witnesses described:

- the soil conditions and main threats to soil degradation in their regions;
- the valuable work they are doing to improve and protect soils through beneficial soil management practices; and,
- the barriers they face to entry, financing, accessing programs, soils data collection, and technology.

11 Food and Agriculture Organization of the United Nations, Global Symposium on Soil Erosion, 2019.
12 AGFO, Evidence, 7 December 2023 (Derek MacKenzie, Associate Professor, Department of Renewable Resources, University of Alberta, As an individual).
13 AGFO, Evidence, 27 September 2022 (Laura L. Van Eerd, Professor, Sustainable Soil Management, University of Guelph, As an individual).
14 AGFO, Evidence, 25 October 2022 (Sean Thomas, Research Professor, University of Toronto, As an individual).
15 Ibid.
16 AGFO, Evidence, 14 February 2023 (Dominic St-Pierre, Director General, Laurentian Forestry Centre, Natural Resources Canada).
17 AGFO, Evidence, 27 September 2022 (Laura L. Van Eerd, Professor, Sustainable Soil Management, University of Guelph, As an individual).

Early Adopters

Many witnesses told the committee that the early adopters - the farmers, ranchers, and growers who first implemented regenerative and beneficial soil management practices - must be compensated fairly and recognized for their practices.

> *"These producers did the heavy lifting and on-farm experimentation required to develop many of the best management practices that contributed to the increased soil carbon sequestration from 1981 to 2016. While offsets may not acknowledge these early adopters, we do need to acknowledge and support early adopters when creating future programs to identify further best management practices. We must also celebrate these trailblazers to showcase where early adoption of best practices provided meaningful, long-term benefits — not only environmentally, but also as sound business decisions."*
>
> *Mary Robinson*[167]

Marco Valicenti, Director General, Innovation Programs Directorate, AAFC, told the committee that the On-Farm Climate Action Fund (OFCAF) allows early adopters to participate as long as it is on new land or a new piece of their property.[168]

Several witnesses disagreed with this criterion and said that incentive programs, such as OFCAF, leave farmers, ranchers and growers feeling left behind. Brodie Berrigan, Director of Government Relations and Farm Policy, Canadian Federation of Agriculture, emphasized the importance of and need for incentives by asking: "What incentive are you putting in place when you're not recognizing the efforts of those early adopters?" [169]

> *"Manitoba farmers have embraced innovative agricultural practices to reduce emissions and enhance soil health, such as 4R uptake and the uptake in the On-Farm Climate Action Fund, or OFCAF, programs.*
>
> *However, factors such as crop inputs, debt, market conditions and profitability may influence the decision-making around adopting these practices, so it is key to have an incentive-based model to increase adoption. At the end of the day, you can't be in the green if you're in the red."*
>
> *Jake Ayre*[170]

167 AGFO, Evidence, 16 February 2023 (Mary Robinson, Past President, Canadian Federation of Agriculture).

168 AGFO, Evidence, 14 February 2023 (Marco Valicenti, Director General, Innovation Programs Directorate, Agriculture and Agri-Food Canada).

169 AGFO, Evidence, 16 February 2023 (Brodie Berrigan, Director of Government Relations and Farm Policy, Canadian Federation of Agriculture).

170 AGFO, Evidence, 4 May 2023 (Jake Ayre, Vice President, Keystone Agricultural Producers of Manitoba).

Some witnesses urged the federal government to set the record straight on when the additionality principle starts, that is from what date should the early adopters be recognized and compensated for their regenerative and sustainable practices?' For example, Marty Seymour, Chief Executive Officer, CarbonRX, recommended that day zero should start at the Paris Agreement in December 2015: "All practices beyond 2015 and the signing of that accord would, for me, be the baseline for net zero."[171] Rachel Hor, Chief Operating Officer, CarbonTerra, agreed with this date, but also suggested that the federal government go as far back as 2010.[172]

With respect to baselines and additionality, Kristjan Hebert, President, Hebert Group, from Saskatchewan, urged the federal government to incentivize the leaders to lead:

> *"Yes, they might have adopted zero-till 20 years ago, but they're still seeing incremental changes and they're adopting incremental practices that continue to improve. Let's incentivize the rest of the group with practice incentives to get to the point where the leaders are. You can't disincentivize the leaders to quit leading. We're trying to grow leaders in this country."*
>
> *Kristjan Hebert*[173]

Some witnesses recommended the creation of a regenerative agriculture commission:

> *"By utilizing innovative practices on our farm, we have managed to achieve the following: healthier soils, crops, and livestock; supplied beef and pork to our local communities; lowered our synthetic fertilizer up to 75% and lowered our CO_2 equivalent footprint. Yet, farmers still struggle to get paid fairly for our stewardship efforts."*
>
> *Colby Hansen*[174]

Crop Insurance

Furthermore, several witnesses told the committee that traditional crop insurance must be restructured to incentivize people for regenerative and sustainable practices rather than the current program that incentivizes people to, for example, plant canola on marginal land and then harvest the insurance.

Cedric MacLeod, Executive Director, Canadian Forage and Grassland Association, pointed out that: "[…] if we don't require some of that cross-compliance to access crop insurance, there is actually a reverse incentive toward conservation. Because if you can get crop insurance on Class 4 or Class 5 land to grow canola or potatoes when it should actually be in permanent cover grassland, that has a very negative impact on the landscape as a whole."[175]

171 *AGFO, Evidence, 1 May 2023 (Marty Seymour, Chief Executive Officer, CarbonRX).*

172 *AGFO, Evidence, 18 May 2023 (Rachel Hor, Chief Operating Officer, CarbonTerra).*

173 *AGFO, Evidence, 9 March 2023 (Kristjan Hebert, President, Hebert Group).*

174 *AGFO, Evidence, 14 December 2023 (Colby Hansen, Owner/Operator, Hansen Beef).*

175 *AGFO, Evidence, 22 September 2022 (Cedric Macleod, Executive Director, Canadian Forage and Grassland Association).*

Stuart Chutter, Senior Policy Analyst, Agriculture Financial Services Corporation, and livestock producer from Saskatchewan, explained that crop insurance is a business risk management program with goals of food security and economic risk management for producers.[176] Chutter said that with risk management at the farm level and soil organic carbon as a metric, there is alignment in those incentives, so there is opportunity, without compromising the goal of primary financial risk management for the producer.[177]

For instance, in a soil analysis for crop insurance, Chutter used an aggregated data set of soil organic carbon across Alberta that was made available through funding by the Sustainable CAP, which then funded Food Water and Wellness in Calgary, to map soil organic carbon at the field level for the entire province of Alberta. Soil mapping was key for Chutter's analysis:

> *"My message today is that a key role for federal policy is funding that sort of soil mapping and data aggregation so we can run our analyses and make good data-driven decisions. We are dependent upon those sorts of data sets to complete our analyses."*
>
> *Stuart Chutter*[178]

How would a lending institution look at an insurance program that bases insurance risk on soil health? Justine Hendricks, President and Chief Executive Officer, Farm Credit Canada (FCC), responded that FCC has been approaching it through the incentive to continue these best practices:

> *"[…] whether you're a livestock or crop producer and considering exactly what your unique requirements are to contribute to the best output, we customize those incentive programs to make sure that we can respect the level of every subsector. As a result, we'll give back a percentage against interest paid on their working capital facilities, which rewards the good behaviour."*
>
> *Justine Hendricks*[179]

Todd Klink, Executive Vice-President and Chief Marketing Officer, Farm Credit Canada, added that FCC has tried to look for industry best practices, and where industry sees the opportunities within their subsector, whether that be crops, beef, or other commodities: "Then the question is how we work with those groups to partner and work with their growers who grow those crops to move forward this discussion that ultimately ends with best management practices and improving soil health."[180]

176 *AGFO, Evidence, 9 November 2023 (Stuart Chutter, Senior Policy Analyst, Agriculture Financial Services Corporation).*

177 *Ibid.*

178 *AGFO, Evidence, 9 November 2023 (Stuart Chutter, Senior Policy Analyst, Agriculture Financial Services Corporation).*

179 *AGFO, Evidence, 9 November 2023 (Justine Hendricks, President and Chief Executive, Farm Credit Canada).*

180 *AGFO, Evidence, 9 November 2023 (Todd Klink, Executive Vice-President and Chief Marketing Officer, Farm Credit Canada).*

Creating A Viable Soil-Based Carbon Marketplace For Agriculture

While the 1984 report of the committee considered the economics of soil conservation, the idea that soil health is a commodity was not on the horizon in the 1980s as it is now.[181]

Canada has a regulated/compliance and voluntary/non-compliance carbon marketplace. The ISO 14064 is the main standard, which is used by Alberta and ECCC when designing protocols.

Graham Gilchrist, Chief Executive Officer, Biological Carbon Canada, told the committee that soil health must be treated as a commodity and that “Canada needs a carbon regulator for the buying and selling of certificates, and a market regulator to keep Canada on pace with the people in our competition—the United States and our other trading partners around the world.”[182] The United States, for example, recently earmarked US$300 million of new money on carbon measurement and verification in agriculture. “Soil-based Canadian carbon is already in our marketplace, […], but it is a[n unregulated] commodity. Canada’s carbon marketplace deserves to have the legislation it needs to grow and thrive.”[183]

Marty Seymour, Chief Executive Officer, CarbonRX, suggested that the federal government step in to facilitate the growth of the voluntary carbon credit market in Canada:

> *“It might be counterintuitive that the government might help to support the voluntary market, but it allows private-sector money to flow into the Canadian food system. It’s a great vehicle to help finance and move producers along that change curve. The federal and provincial government carbon schemes actually create market confusion. Global buyers want nature-based carbon credits, which Canada is rich in, and agriculture and forestry offer this great opportunity for carbon removal.”*
>
> *Marty Seymour*[184]

Furthermore, Seymour recommended the creation of “an industry-owned and industry-driven carbon economy—and I don’t mean Canadian-industry-owned; I’m talking about international partners and members as well.”[185]

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181 *AGFO, Evidence, 23 November 2023 (Graham Gilchrist, Chief Executive Officer, Biological Carbon Canada).*

182 *Ibid.*

183 *Ibid.*

184 *AGFO, Evidence, 18 May 2023 (Marty Seymour, Chief Executive Officer, CarbonRX).*

185 *Ibid.*

Similarly, witnesses from CarbonTerra expressed their interest in developing a voluntary or compliance carbon credit market that could be endorsed by the federal government, where a carbon credit has value, even if it starts to trade in Canada and is then adopted globally:

> *"We need the federal government to work with the provinces instead of this mishmash of one province wants to do this, and the feds want to do something else. We need a coherent system that we can almost bank on, where we can say that now we have a path, let's build something. Right now we're guessing. We're trying to steer it, but we're just a small company. We need the government to step in and take some leadership."*
>
> *Jason Mann*[186]

Marty Seymour added: "If we've been zero-tilling in Saskatchewan for 20 years, and we agree we will not convert that land to tilled land, there may be a carbon conversation in that. It's a nuance in the recipe. We've been so focused on rewarding for the practice. Maybe we're missing an obvious one to say, "Wait a minute, if we don't convert and release 20 tonnes of carbon, that's carbon credit by definition."[187] Similarly, Jocelyn Velustuk said: "If there is a value to carbon and farmers know that, farmers will keep adding to that."[188]

Witnesses pointed out additional barriers to widespread adoption of this type of market. For example, Robin Woodward, Director, Carbon Asset Solutions, mentioned the inability to measure anything, and to get to a place in a market where you can have confidence globally that what is being delivered to market has value.[189]

Martin Caron, President and CEO of the Union des producteurs agricoles du Québec, suggested a compliance declaration, a practice that exists in Quebec, but that could be used at the federal level: "The producer declares how long he has been carrying out sequestration activities or other work that has been beneficial. Then the advisers can validate the farm's work. There are ways of simplifying things and recognizing those pioneers who have really contributed. I think of the organic producers, who have done a lot of work on this."[190] Caron believes that monetizing soil carbon sequestration as a tool to mitigate global climate change could be implemented at a relatively low cost per tonne of CO_2 equivalent with co-benefits such as increased fertility, cleaner water and greater farm product profitability and productivity.[191]

186 AGFO, Evidence, 18 May 2023 (Jason Mann, Chief Executive Officer, CarbonTerra).

187 AGFO, Evidence, 18 May 2023 (Marty Seymour, Chief Executive Officer, CarbonRX).

188 AGFO, Evidence, 9 March, 2023 (Jocelyn Velestuk, Farmer, Grain Growers of Canada).

189 AGFO, Evidence, 23 November 2023 (Robin Woodward, Director, Carbon Asset Solutions).

190 AGFO, Evidence, 16 February 2023 (Martin Caron, President and CEO, Union des producteurs agricoles).

191 Ibid.

Video – The Living Soil

https://youtu.be/-dhdUoK7s2s?si=q3-WImg9qCFFbJF8

Video – What Are Mycos?

https://youtu.be/0oyqPZJj-2w?si=JrUCUrQM5jn_Wilo

Water Uptake and Transport in Vascular Plants

By: Andrew J. McElrone (U.S. Department of Agriculture, Agricultural Research Service, University of California, Davis), Brendan Choat (University of Western Sydney), Greg A. Gambetta (University of California, Davis) & Craig R. Brodersen (University of Florida) © 2013 Nature Education

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How does water move through plants to get to the top of tall trees? Here we describe the pathways and mechanisms driving water uptake and transport through plants, and causes of flow disruption.

Why Do Plants Need So Much Water?

Water is the most limiting abiotic (non-living) factor to plant growth and productivity, and a principal determinant of vegetation distributions worldwide. Since antiquity, humans have recognized plants' thirst for water as evidenced by the existence of irrigation systems at the beginning of recorded history. Water's importance to plants stems from its central role in growth and photosynthesis, and the distribution of organic and inorganic molecules. Despite this dependence, plants retain less than 5% of the water absorbed by roots for cell expansion and plant growth. The remainder passes through plants directly into the atmosphere, a process referred to as transpiration. The amount of water lost via transpiration can be incredibly high; a single irrigated corn plant growing in Kansas can use 200 L of water during a typical summer, while some large rainforest trees can use nearly 1200 L of water in a single day!

If water is so important to plant growth and survival, then why would plants waste so much of it? The answer to this question lies in another process vital to plants — photosynthesis. To make sugars, plants must absorb carbon dioxide (CO2) from the atmosphere through small pores in their leaves called stomata (Figure 1). However, when stomata open, water is lost to the atmosphere at a prolific rate relative to the small amount of CO2 absorbed; across plant species an average of 400 water molecules are lost for each CO2 molecule gained. The balance between transpiration and photosynthesis forms an essential compromise in the existence of plants; stomata must remain open to build sugars but risk dehydration in the process.

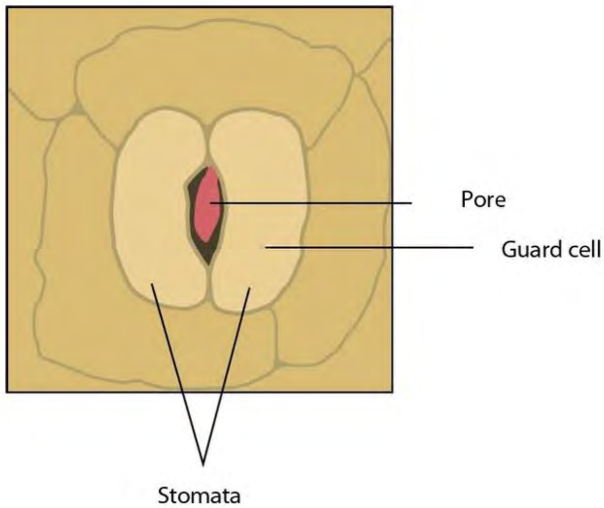

Figure 1: Rendering of an open stoma on the surface of a tobacco leaf.
Stomata are pores found on the leaf surface that regulate the exchange of gases between the leaf's interior and the atmosphere. Stomatal closure is a natural response to darkness or drought as a means of conserving water.

From the Soil into the Plant

Essentially all of the water used by land plants is absorbed from the soil by roots. A root system consists of a complex network of individual roots that vary in age along their length. Roots grow from their tips and initially produce thin and non-woody fine roots. Fine roots are the most permeable portion of a root system, and are thought to have the greatest ability to absorb water, particularly in herbaceous (i.e., non-woody) plants (McCully 1999). Fine roots can be covered by root hairs that significantly increase the absorptive surface area and improve contact between roots and the soil (Figure 2). Some plants also improve water uptake by establishing symbiotic relationships with mycorrhizal fungi, which functionally increase the total absorptive surface area of the root system.

Figure 2: Root hairs often form on fine roots and improve water absorption by increasing root surface area and by improving contact with the soil.

Roots of woody plants form bark as they age, much like the trunks of large trees. While bark formation decreases the permeability of older roots they can still absorb considerable amounts of water (MacFall et al. 1990, Chung & Kramer 1975). This is important for trees and shrubs since woody roots can constitute ~99% of the root surface in some forests (Kramer & Bullock 1966).

Roots have the amazing ability to grow away from dry sites toward wetter patches in the soil — a phenomenon called hydrotropism. Positive hydrotropism occurs when cell elongation is inhibited on the humid side of a root, while elongation on the dry side is unaffected or slightly stimulated resulting in a curvature of the root and growth toward a moist patch (Takahashi 1994). The root cap is most likely the site of hydrosensing; while the exact mechanism of hydrotropism is not known, recent work with the plant model Arabidopsis has shed some light on the mechanism at the molecular level (see Eapen et al. 2005 for more details).

Roots of many woody species have the ability to grow extensively to explore large volumes of soil. Deep roots (>5 m) are found in most environments (Canadell et al. 1996, Schenk & Jackson 2002) allowing plants to access water from permanent water sources at substantial depth (Figure 3). Roots from the Shepard's tree (Boscia albitrunca) have been found growing at depths 68 m in the central Kalahari, while those of other woody species can spread laterally up to 50 m on one side of the plant (Schenk & Jackson 2002). Surprisingly, most arid-land plants have very shallow root systems, and the deepest roots consistently occur in climates with strong seasonal precipitation (i.e., Mediterranean and monsoonal climates).

Figure 4: Tree roots at significant depths accessed via caves.
Plant scientists examine: deep roots of Juniperus asheii growing at 7m depth in a cave in Austin, TX USA (left); an extensive fine root network attached to a single ~1cm diameter tap root accessing a perennial underground stream at 20m depth in a cave in central TX, USA; and twisty roots in a cave located in southwest Western Australia below a forest dominated by Eucalyptus diversicolor — roots in this cave system are commonly found from 20-60m depth.

Through the Plant into the Atmosphere

Water flows more efficiently through some parts of the plant than others. For example, water absorbed by roots must cross several cell layers before entering the specialized water transport tissue (referred to as xylem) (Figure 4). These cell layers act as a filtration system in the root and have a much greater resistance to water flow than the xylem, where transport occurs in open tubes. Imagine the difference between pushing water through numerous coffee filters versus a garden hose. The relative ease with which water moves through a part of the plant is expressed quantitatively using the following equation:

$$\text{Flow} = \Delta\psi / R,$$

which is analogous to electron flow in an electrical circuit described by Ohm's law equation:

$$i = V / R,$$

where R is the resistance, i is the current or flow of electrons, and V is the voltage. In the plant system, V is equivalent to the water potential difference driving flow ($\Delta\psi$) and i is equivalent to the flow of water through/across a plant segment. Using these plant equivalents, the Ohm's law analogy can be used to quantify the hydraulic conductance (i.e., the inverse of hydraulic R) of individual segments (i.e., roots, stems, leaves) or the whole plant (from soil to atmosphere). Upon absorption by the root, water first crosses the epidermis and then makes its way toward the center of the root crossing the cortex and endodermis before arriving at the xylem (Figure 4). Along the way, water travels in cell walls (apoplastic pathway) and/or through the inside of cells (cell to cell pathway, C-C) (Steudle 2001). At the endodermis, the apoplastic pathway is blocked by a gasket-like band of suberin — a waterproof substance that seals off the route of water in the apoplast forcing water to cross via the C-C pathway. Because water must cross cell membranes (e.g., in the cortex and at apoplastic barriers), transport efficiency of the C-C pathway is affected by the activity, density, and location of water-specific protein channels embedded in cell membranes (i.e., aquaporins). Much work over the last two decades has demonstrated how aquaporins alter root hydraulic resistance and respond to abiotic stress, but their exact role in bulk water transport is yet unresolved.

Once in the xylem tissue, water moves easily over long distances in these open tubes (Figure 5). There are two kinds of conducting elements (i.e., transport tubes) found in the xylem: 1) tracheids and 2) vessels (Figure 6). Tracheids are smaller than vessels in both diameter and length, and taper at each end. Vessels consist of individual cells, or "vessel elements", stacked end-to-end to form continuous open tubes, which are also called xylem conduits. Vessels have diameters approximately that of a human hair and lengths typically measuring about 5 cm although some plant species contain vessels as long as 10 m. Xylem conduits begin as a series of living cells but as they mature the cells commit suicide (referred to as programmed cell death), undergoing an ordered deconstruction where they lose their cellular contents and form hollow tubes. Along with the water conducting tubes, xylem tissue contains fibers which provide structural support, and living metabolically-active parenchyma cells that are important for storage of carbohydrates, maintenance of flow within a conduit (see details about embolism repair below), and radial transport of water and solutes.

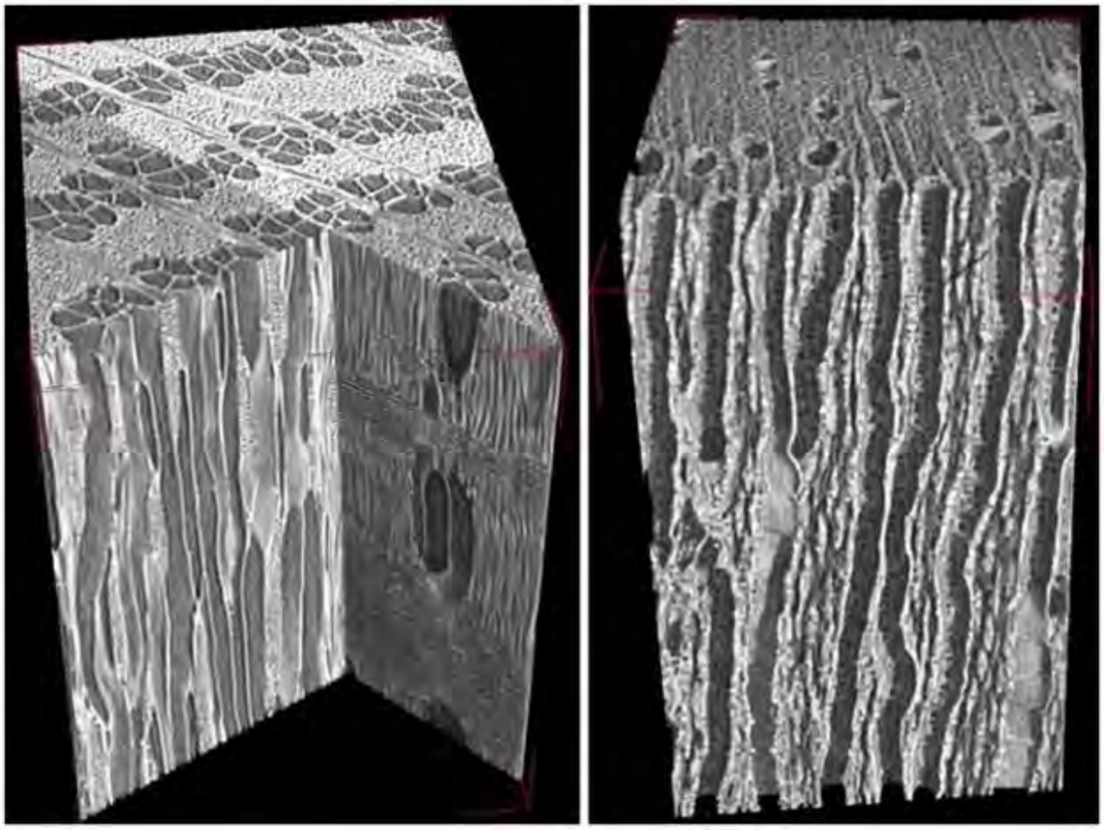

Figure 5: Three dimensional reconstructions of xylem imaged at the Ghent microCT facility. Differences in xylem structure and conduit distributions can be seen between Ulmus americana (left) and Fraxinus americana (right) xylem. © 2013 Nature Education Images from S. Jansen, Ulm University. All rights reserved.

When water reaches the end of a conduit or passes laterally to an adjacent one, it must cross through pits in the conduit cell walls (Figure 6). Bordered pits are cavities in the thick secondary cell walls of both vessels and tracheids that are essential components in the water-transport system of higher plants. The pit membrane, consisting of a modified primary cell wall and middle lamella, lies at the center of each pit, and allows water to pass between xylem conduits while limiting the spread of air bubbles (i.e., embolism) and xylem-dwelling pathogens. Thus, pit membranes function as safety valves in the plant water transport system. Averaged across a wide range of species, pits account for >50% of total xylem hydraulic resistance. The structure of pits varies dramatically across species, with large differences evident in the amount of conduit wall area covered by pits, and in the porosity and thickness of pit membranes (Figure 6).

After traveling from the roots to stems through the xylem, water enters leaves via petiole (i.e., the leaf stalk) xylem that branches off from that in the stem. Petiole xylem leads into the mid-rib (the main thick vein in leaves), which then branch into progressively smaller veins that contain tracheids (Figure 7) and are embedded in the leaf mesophyll. In dicots, minor veins account for the vast majority of total vein length, and the bulk of transpired water is drawn out of minor veins (Sack & Holbrook 2006, Sack & Tyree 2005). Vein arrangement, density, and redundancy are important for distributing water evenly across a leaf, and may buffer the delivery system against damage (i.e., disease lesions, herbivory, air bubble spread). Once water leaves the xylem, it moves across the bundle sheath cells surrounding the veins. It is still unclear the exact path water follows once it passes out of the xylem through the bundle sheath cells and into the mesophyll cells, but is likely dominated by the apoplastic pathway during transpiration (Sack & Holbrook 2005).

Mechanism Driving Water Movement in Plants

Unlike animals, plants lack a metabolically active pump like the heart to move fluid in their vascular system. Instead, water movement is passively driven by pressure and chemical potential gradients. The bulk of water absorbed and transported through plants is moved by negative pressure generated by the evaporation of water from the leaves (i.e., transpiration) — this process is commonly referred to as the Cohesion-Tension (C-T) mechanism. This system is able to function because water is "cohesive" — it sticks to itself through forces generated by hydrogen bonding. These hydrogen bonds allow water columns in the plant to sustain substantial tension (up to 30 MPa when water is contained in the minute capillaries found in plants), and helps explain how water can be transported to tree canopies 100 m above the soil surface. The tension part of the C-T mechanism is generated by transpiration. Evaporation inside the leaves occurs predominantly from damp cell wall surfaces surrounded by a network of air spaces. Menisci form at this air-water interface (Figure 4), where apoplastic water contained in the cell wall capillaries is exposed to the air of the sub-stomatal cavity. Driven by the sun's energy to break the hydrogen bonds between molecules, water evaporates from menisci, and the surface tension at this interface pulls water molecules to replace those lost to evaporation. This force is transmitted along the continuous water columns down to the roots, where it causes an influx of water from the soil. Scientists call the continuous water transport pathway the Soil Plant Atmosphere Continuum (SPAC).

Stephen Hales was the first to suggest that water flow in plants is governed by the C-T mechanism; in his 1727 book Hales states "for without perspiration the [water] must stagnate, notwithstanding the sap-vessels are so curiously adapted by their exceeding fineness, to raise [water] to great heights, in a reciprocal proportion to their very minute diameters." More recently, an evaporative flow system based on negative pressure has been reproduced in the lab for the first time by a ‘synthetic tree' (Wheeler & Stroock 2008).

When solute movement is restricted relative to the movement of water (i.e., across semipermeable cell membranes) water moves according to its chemical potential (i.e., the energy state of water) by osmosis — the diffusion of water. Osmosis plays a central role in the movement of water between cells and various compartments within plants. In the absence of transpiration, osmotic forces dominate the movement of water into roots. This manifests as root pressure and guttation — a process commonly seen in lawn grass, where water droplets form at leaf margins in the morning after conditions of low evaporation. Root pressure results when solutes accumulate to a greater concentration in root xylem than other root tissues. The resultant chemical potential gradient drives water influx across the root and into the xylem. No root pressure exists in rapidly transpiring plants, but it has been suggested that in some species root pressure can play a central role in the refilling of non-functional xylem conduits particularly after winter (see an alternative method of refilling described below).

Disruption of Water Movement

Water transport can be disrupted at many points along the SPAC resulting from both biotic and abiotic factors (Figure 8). Root pathogens (both bacteria and fungi) can destroy the absorptive surface area in the soil, and similarly foliar pathogens can eliminate evaporative leaf surfaces, alter stomatal function, or disrupt the integrity of the cuticle. Other organisms (i.e., insects and nematodes) can cause similar disruption of above and below ground plant parts involved in water transport. Biotic factors responsible for ceasing flow in xylem conduits include: pathogenic organisms and their by-products that plug conduits (Figure 8); plant-derived gels and gums produced in response to pathogen invasion; and tyloses, which are outgrowths produced by living plant cells surrounding a vessel to seal it off after wounding or pathogen invasion (Figure 8).

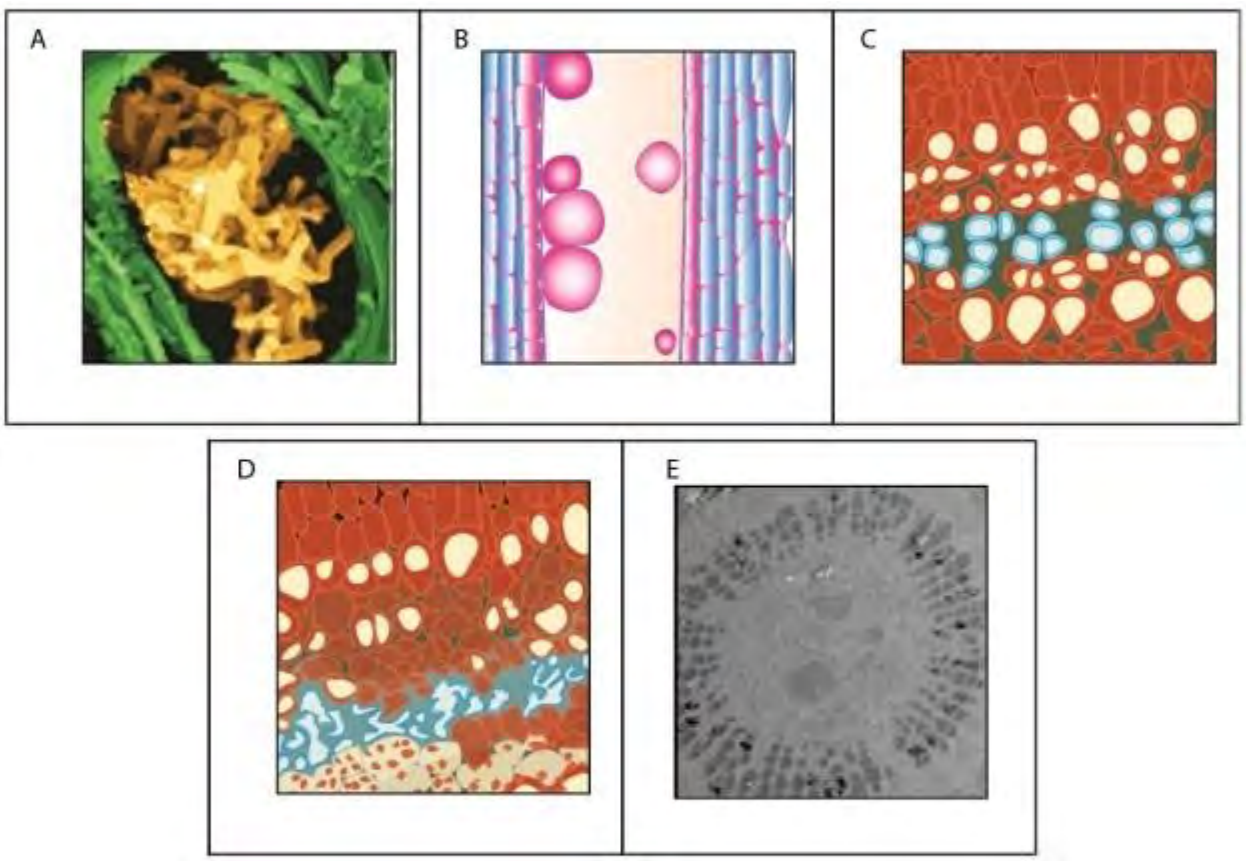

Figure 8: Sources of dysfunction in the xylem.

Left to right: (A) xylem-dwelling pathogens like Xylella fastidiosa bacteria; (B) tyloses (plant-derived); (C and D) conduit (in blue) implosion (Brodribb and Holbrook 2005, Pine needle tracheids); and (E) embolized conduits among *water filled ones in a frozen plant samples (Choat unpublished figure, Cryo SEM). © 2013 Nature Education All rights reserved.*

Abiotic factors can be equally disruptive to flow at various points along the water transport pathway. During drought, roots shrink and lose contact with water adhering to soil particles — a process that can also be beneficial by limiting water loss by roots to drying soils (i.e., water can flow in reverse and leak out of roots being pulled by drying soil). Under severe plant dehydration, some pine needle conduits can actually collapse as the xylem tensions increase (Figure 8).

Water moving through plants is considered meta-stable because at a certain point the water column breaks when tension becomes excessive — a phenomenon referred to as cavitation. After cavitation occurs, a gas bubble (i.e., embolism) can form and fill the conduit, effectively blocking water movement. Both sub-zero temperatures and drought can cause embolisms. Freezing can induce embolism because air is forced out of solution when liquid water turns to ice. Drought also induces embolism because as plants become drier tension in the water column increases. There is a critical point where the tension exceeds the pressure required to pull air from an empty conduit to a filled conduit across a pit membrane — this aspiration is known as air seeding (Figure 9). An air seed creates a void in the water, and the tension causes the void to expand and break the continuous column. Air seeding thresholds are set by the maximum pore diameter found in the pit membranes of a given conduit.

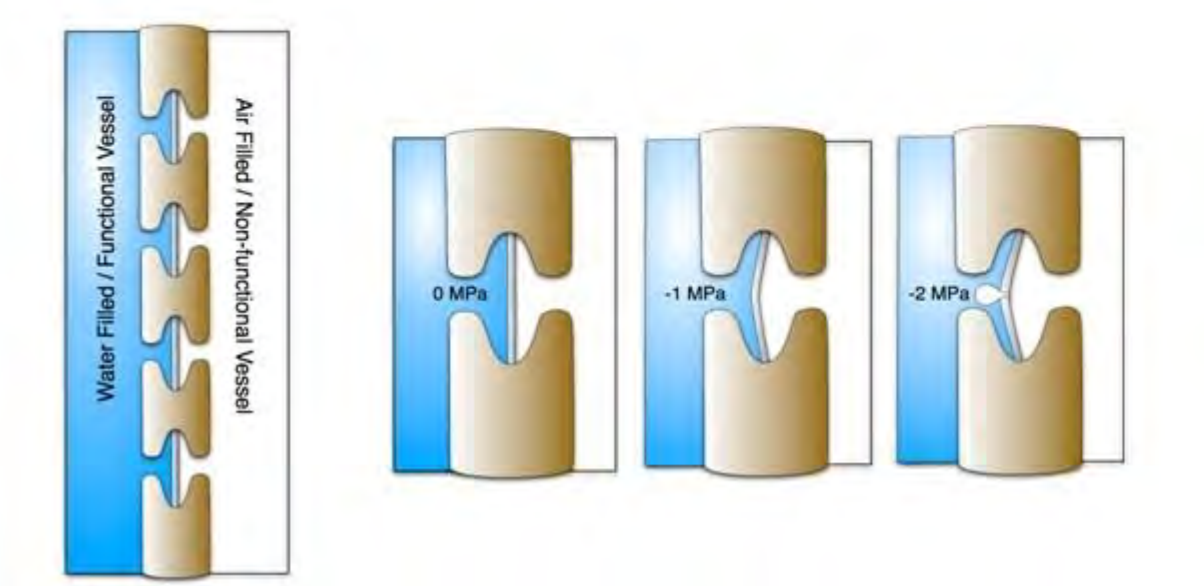

Figure 9: Air seeding mechanism.
Demonstrates how increasing tension in a functional water filled vessel eventually reaches a threshold where an air seed is pulled across a pit membrane from an embolized conduit. Air is seeded into the functional conduit only after the threshold pressure is reached. © 2013 Nature Education Adapted from Tyree & Zimmermann 2002. All rights reserved.

Fixing the Problem

Failure to re-establish flow in embolized conduits reduces hydraulic capacity, limits photosynthesis, and results in plant death in extreme cases. Plants can cope with emboli by diverting water around blockages via pits connecting adjacent functional conduits, and by growing new xylem to replace lost hydraulic capacity. Some plants possess the ability to repair breaks in the water columns, but the details of this process in xylem under tension have remained unclear for decades. Brodersen et al. (2010) recently visualized and quantified the refilling process in live grapevines (Vitis vinifera L.) using high resolution x-ray computed tomography (a type of CAT scan) (Figure 10). Successful vessel refilling was dependent on water influx from living cells surrounding the xylem conduits, where individual water droplets expanded over time, filled vessels, and forced the dissolution of entrapped gas. The capacity of different plants to repair compromised xylem vessels and the mechanisms controlling these repairs are currently being investigated.

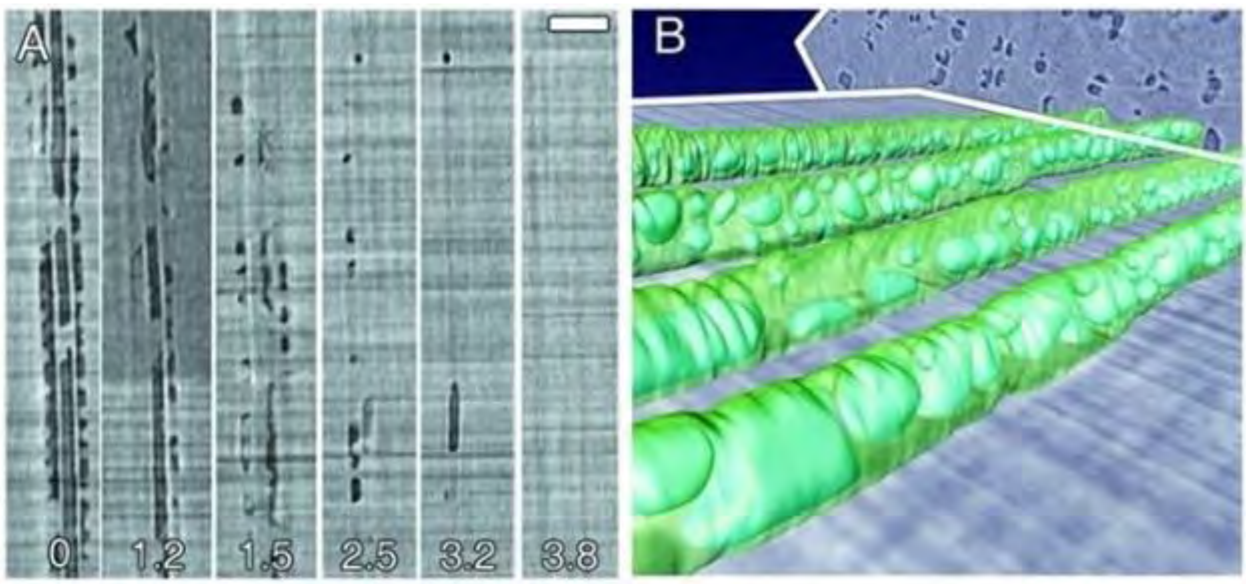

Figure 10: Embolism repair documented in grapevines (Vitis vinifera L.) with X-ray micro-CT at the ALS facility at Lawrence Berkeley National Lab CA, USA.
(A) Longitudinal section showing a time series of cavitated vessels refilling in less than 4 hrs; (B) 3D reconstruction of four vessel lumen with water droplets forming on the vessel walls and growing over time to completely fill the embolized conduit.

Polluting our soils is polluting our future

02/05/2018

#StopSoilPollution: 6 reasons why soil pollution should not go unnoticed

Soil is a finite resource, meaning its loss and degradation is not recoverable within a human lifespan. Soils affect the food we eat, the water we drink, the air we breathe, our health and the health of all organisms on the planet. Without healthy soils we wouldn't be able to grow our food. In fact, it is estimated that 95 percent of our food is directly or indirectly produced on our soils.

Healthy soils are the key to food security and our sustainable future. They help sustain food production, mitigate and adapt to climate change, filter water, improve resilience to floods and droughts and so much more. Yet, an invisible threat is putting soils and all that they offer at risk.

Soil pollution causes a chain reaction. It alters soils' biodiversity, reduces soil organic matter and soils' capacity to act as a filter. It also contaminates the water stored in the soil and groundwater, and causes an imbalance of soil nutrients. Among the most common soil pollutants are heavy metals, persistent organic pollutants and emerging pollutants – like pharmaceutical and personal care products.

Soil pollution is devastating to the environment and has consequences for all forms of life that encounter it. Unsustainable agricultural practices that reduce soil organic matter can facilitate the transfer of pollutants into the food chain. For example: polluted soil can release contaminants into the groundwater, which goes on to accumulate in plant tissue, and is then passed to grazing animals, birds, and finally to the humans that eat the plants and animals. Pollutants in soil, groundwater and in the food chain can cause a variety of diseases and excess mortality in humans, from short-term acute effects, such as intoxications or diarrhea to long-term chronic effects, like cancer.

Beyond the impact on the environment, soil pollution also has high economic costs due to the reduction of crop yields and quality. The prevention of soil pollution should be a top priority worldwide. The fact that the vast majority of pollutants are a result of human action means that we are directly responsible for making the necessary changes to ensure a less polluted, more secure future.

Soils need to be recognized and valued for their productive capacities as well as their contribution to food security and the maintenance of key ecosystem services. Here are just a few reasons why soil pollution can't be underestimated:

> **1.** Soil pollution affects everything. The food we eat, the water we drink, the air we breathe – our health and the health of all the organisms on the planet is dependent on

healthy soil. The nutrient content of a plant's tissues is directly related to the nutrient content of the soil and its ability to exchange nutrients and water with the plant's roots.

2. Soil pollution is invisible. Today, one third of our soils are moderately or highly degraded due to erosion, loss of soil organic carbon, salinization, compaction, acidification and chemical pollution. It takes about 1 000 years to form 1 cm of top soil, meaning that we won't be able to produce more soil within our lifetime. What we see is all there is. Yet, soils are facing even more pressure from soil pollution. The current rate of soil degradation threatens the capacity of future generations to meet their most basic needs.

3. Soil pollution affects soils' capacity to filter. Soils act as a filter and buffer for contaminants. The potential of soil to cope with the strain of pollutants is finite. If soil's capacity to protect us is exceeded, contaminants will (and do) seep into other parts of the environment – like our food chain.

4. Soil pollution affects food security by reducing crop yields and quality. Safe, nutritious and good quality food can only be produced if our soils are healthy. Without healthy soils, we won't be able to produce enough food to achieve #ZeroHunger.

5. Soil pollution can be a result of poor agricultural practices. Unsustainable agricultural practices reduce soil organic matter, compromising soils' capacity to degrade organic pollutants. This increases the risk of the pollutants being released into the environment. In many countries, intensive crop production has depleted the soil, jeopardizing our ability to maintain production in these areas in the future. Sustainable agricultural production practices have therefore become imperative for reversing the trend of soil degradation and ensuring current and future global food security.

6. Soil pollution can put our health at risk. A significant proportion of antibiotics, used widely in agriculture and human healthcare, are released into the environment after being excreted from the organism to which they were administered. These antibiotics can seep into our soils and spread throughout the environment. This creates antimicrobial resistant bacteria, which decreases the effectiveness of antibiotics. Each year around 700 000 deaths are attributable to antimicrobial resistant bacteria. By 2050, if not tackled, it will kill more people than cancer, and cost, globally, more than the size of the current global economy.

With a global population that is projected to exceed 9 billion by 2050, our current and future food security hinges on our ability to increase yields and food quality using the soils that we already have available today. Soil pollution negatively impacts us all, and has been identified as one of the main threats to soil functions worldwide.

We need to be aware of the causes of soil pollution so that we can create and implement solutions. Soil protection and conservation starts with us. Making sustainable food choices, properly recycling dangerous materials like batteries, composting at home to reduce the amount of waste that enters landfills or managing antibiotic waste more responsibly, are just a few examples of how we can be part of the solution. On a larger scale, we need to promote sustainable agricultural practices in our communities.

Healthy soil is a precious, non-renewable commodity that is increasingly threatened by destructive human behaviours. We are responsible for the soils that provide us with food, water and air, and we need to take action today to ensure that we have healthy soils for a sustainable and food secure future. Be the solution to soil pollution!

Chapter 5: Soil Pollution and Contamination

Introduction

The committee learned that soil pollution affects the food we eat, the water we drink and the air we breathe, and that most people do not understand how significant a problem soil pollution is.

> *"There are 20 million contaminated sites across the world. On average, there are 1.72 contaminated sites per 100,000 inhabitants. [...] In Canada, there are approximately 20,000 normal industrial sites and about 250,000 sites that arise out of abandoned oil and gas wells. Whether or not you consider those true contaminated sites is another issue."*
>
> *Steven D. Siciliano*[215]

Ravi Naidu, Chief Executive Officer and Managing Director, *crcCARE*, explained to the committee that healthy soils act as a natural buffer against the spread of pollutants and disease.[216] Biodiverse soils form a resilient barrier against pathogens, preventing their transmission to plants, animals and humans. Healthy soils are also more resilient and able to retain and immobilize agrochemical pollutants entering the ecosystem.

As Figure 30 illustrates, soils act as a sponge by holding and filtering water, directly influencing the quality of water resources, and protecting communities from waterborne diseases and pollution. Any pollutants entering the soil system impact soil health, and ultimately the environment, food, and human health.

Naidu told the committee that while Canadian soils are generally well maintained with minimal tillage, challenges remain, including cadmium and diffused pesticide contamination.[217]

Steve Siciliano, University of Saskatchewan, added that human activities impact ecosystems andthese ecosystems, in turn, impact human health primarily through the release of direct pollutants such as hydrocarbons or excess fertilizer, and through compaction and sealing off the surfaces.[218]

Figure 30 – The Effects of Soil Contamination on the Environment, Food and Human Health

Source: Food and Agriculture Organization of the United Nations, "Communication material," *Global Soil Partnership*.

Federal Initiatives

The committee learned that, over the last 30 years, the federal government has undertaken some strong initiatives regarding soil pollution. For example, the soil health group at ECCC is a world- leading institute for the development of soil ecotoxicity testing species and the frameworks for it. Health Canada's contaminated soils advisory group provides expert support in human health assessment arising from soil pollutants. However, Steven D. Siciliano, Professor, Department of Soil Science, University of Saskatchewan, also said some emerging policy gaps are challenging Canada's existing policy framework, one of which has to do with contaminated sites. Siciliano explained that contaminated soils are a provincial jurisdiction, unless they are on federal lands or other territories, or they impact waterways. The policies and frameworks that were developed never envisioned situations where contaminated soils would be impacting the atmosphere.[219]

Siciliano said: "Over the last 20 years, a scientific consensus has emerged about the importance of contaminated systems in methane and nitrous oxide release and mitigation. This is currently living in a policy no-man's-land. Nobody knows who should be managing that."[220]

Siciliano suggested that the federal government take the following steps to benefit the health of Canadians from contaminated soils:

- paving roads throughout Canada;
- updating the guidelines for polycyclic aromatic hydrocarbons (PAHs) such as pyrene and phenanthrene, so that owners of contaminated sites can manage the ecosystem to better restore it (earthworms, etcetera); and,
- re-envision the current chemical criteria to restore and enhance ecosystem health.[221]

Mining and Oil/Gas Industries

An overhead view of Meadowbank Mine in Nunavut.

Witnesses told the committee about problems stemming from the mining and oil/gas industries. For instance, decommissioned gas stations, lead paint and lead in gasoline can pollute soil and, because they are persistent pollutants, they still cause issues even when they have been banned. Remediation technology is available; however, Subhasis Ghoshal, Professor, Civil Engineering and Director, Trottier Institute for Sustainability in Engineering and Design, McGill University, said there is a lack of awareness and a lack of data on where contaminated sites are located.[222] Overall, there is no data on, nor a uniform definition of, contaminated soils.

On the reclamation of contaminated agricultural sites in Alberta from oil and gas leaching, the committee learned that disrupting the site can bring on other contagions or pathogens. Trevor Wallace, Provincial Nutrient Management Specialist, Natural Resource Management Branch, Alberta Agriculture and Irrigation, Government of Alberta said: "There are a lot of other issues other than soil health that we have to deal with on a regular, annual basis — things like weeds and invasives, et cetera, and moving them off sites. There's also the movement of pathogens like clubroot, which is a soil-borne pathogen that can move off-site. Those are the activities that we need to work more on, and on a regular, everyday basis,

too."[223]
Francis Zvomuya, Professor, Department of Soil Science, Faculty of Agricultural and Food Sciences, University of Manitoba, told the committee that high levels of lead have been found in the urban soils that Canadians use for their vegetable gardens. Lead pollution comes from the legacy source of leaded gas: "For most root crops like carrots or potatoes, it's stuck on the outside or the skin of the carrot. It's always good practice to peel carrots and potatoes before you consume them. For green vegetables, a lot of it is not coming from the ground through the roots. It's coming from the dust that's contaminated with lead. Making sure that you wash those green vegetables thoroughly will also help reduce the risk of lead poisoning."[224]

Agriculture

In agriculture, the committee heard that pesticides, nutrients, chemicals, and antibiotics are well regulated by the Pest Management Regulatory Agency. Daniel Alessi, Professor and Encana Chair in Water Resources, Department of Earth and Atmospheric Sciences, University of Alberta, said that support for education for farmers on the application of herbicides, pesticides, natural amendments, as well as proper management of fertilizer use, is a worthy endeavour to explore and expand.[225]

Gordon Price, Professor, Department of Engineering, Faculty of Agriculture, Dalhousie University, added: "We put a lot of responsibility on farmers to be environmental stewards, and that's not a mantle they necessarily started with. They are business people and are generational families that are practising the production of food. We put a lot of responsibility on their shoulders."[226]

Two significant sources of materials with potential benefits to soil health originate from the management of urban organic wastes, specifically food wastes and biosolids. Price stated that, many organic residues entering soils originate from outside of agriculture. As a result, these residues carry "the footprint of Canadians' daily activities, and can have a direct effect on the health of soils, good and bad, and ultimately on human health." [227]

Zvomuya told the committee about emerging contaminants such as antibiotics: "Some of the research we did in Alberta was looking at the antibiotics that are fed to animals. Then, we apply the manure on agricultural land as a good source of nutrients — what happens to those antibiotics in light of the superbugs or the development of antibiotic resistance?"[228]

Witnesses advocated for more research on and awareness of:

- nano fertilizers, which have less adverse effects on soil;
- the overall risks caused by microplastics on human health;
- the origins of microplastics from domestic wastes;
- the overuse of plastic mulch in fruit and vegetable production, and how banning plastic bags would decrease microplastic pollution;
- alternatives to conventional pesticides such as biochar, a carbon-negative soil amendment, which has been shown to improve soil health and fertility;
- the proper management of waste, sewage, and water; and,

- the impacts of pharmaceutical product pollution and per- and polyfluorinated substance compounds on soil.

Ghosal said that there is lack of federal guidance on how to clean up agricultural soils, especially with emerging contaminants such as pharmaceuticals and the per- and polyfluoroalkyl substance compounds.[229]

Daniel Alessi, Professor and Encana Chair in Water Resources, Department of Earth and Atmospheric Sciences, University of Alberta, described the opportunities, such as resource recovery pathways, that exist in the face of challenges related to soil contamination:

> *"For example, legacy sources of soil contamination such as produced water from oil and gas wells, or fly ash piles from coal combustion to generate electricity contain critical minerals. Researchers in government, industry and academia are developing methods to extract these metals, turning what was a liability to soil and water health into a resource."*
>
> *Daniel Alessi*[230]

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215 AGFO, Evidence, 7 December 2023 (Steven D. Siciliano, Professor, Department of Soil Science, University of Saskatchewan, As an individual).

216 AGFO, Evidence, 6 February 2024 (Ravi Naidu, Chief Executive Officer and Managing Director, crcCARE).

217 AGFO, Evidence, 6 February 2024 (Ravi Naidu, Chief Executive Officer and Managing Director, crcCARE).

218 AGFO, Evidence, 7 December 2023 (Steven D. Siciliano, Professor, Department of Soil Science, University of Saskatchewan, As an individual).

219 Ibid.

220 Ibid.

221 Ibid.

222 AGFO, Evidence, 15 February 2024 (Subhasis Ghoshal, Professor, Civil Engineering and Director, Trottier Institute for Sustainability in Engineering and Design, McGill University, As an individual)

223 AGFO, Evidence, 20 April 2023 (Trevor Wallace, Provincial Nutrient Management Specialist, Natural Resource Management Branch, Alberta Agriculture and Irrigation, Government of Alberta).

224 AGFO, Evidence, 15 February 2024 (Francis Zvomuya, Professor, Department of Soil Science, Faculty of Agricultural and Food Sciences, University of Manitoba, As an individual).

225 AGFO, Evidence, 15 February 2024 (Daniel Alessi, Professor and Encana Chair in Water Resources, Department of Earth and Atmospheric Sciences, University of Alberta, As an individual).

226 AGFO, Evidence, 15 February 2024 (Gordon Price, Professor, Department of Engineering, Faculty of Agriculture, Dalhousie University, As an individual).

227 Ibid.

228 AGFO, Evidence, 15 February 2024 (Francis Zvomuya, Professor, Department of Soil Science, Faculty of Agricultural and Food Sciences, University of Manitoba, As an individual).

229 AGFO, Evidence, 15 February 2024 (Subhasis Ghoshal, Professor, Civil Engineering and Director, Trottier Institute for Sustainability in Engineering and Design, McGill University, As an individual).

230 AGFO, Evidence, 15 February 2024 (Daniel Alessi, Professor and Encana Chair in Water Resources, Department of Earth and Atmospheric Sciences, University of Alberta, As an individual).

NCF-Envirothon 2025 Alberta
Soils and Land Use Study Resources

Key Topic #3: Alberta Soils and Land Use

10. Describe the characteristics of the major Alberta soil orders (Chernozemic, Luvisolic, Brunisolic, Regosolic, Gleysolic, Solonetzic, and Organic).
11. Explain how certain types of soil are better suited than others for specific human uses such as mining, farming, forestry, septic tanks, and urban development.
12. Relate soil conservation concepts to Alberta agriculture, land development/construction, and everyday life.

Study Resources

Resource Title	Source	Located on Page
Digging Into Canadian Soils, Major Soils of the Prairie Provinces, chapter 10 (p 385)	*Daniel J. Pennock, Canadian Society of Soil Science, 2021*	56
Overview Of Classification Methodology for Determining Land Capability For Agriculture	*Government of Canada, Canada Land Inventory, 2013*	71
Soil Fertility	*Government of Alberta*	73
Critical Ground - Why Soil is Essential to Canada's Economic, Environmental, Human, and Social Health, Chapter 1, pages 46-59	*Report of the Standing Senate Committee on Agriculture and Forestry, Canadian Senate, 2024*	74
Critical Ground - Why Soil is Essential to Canada's Economic, Environmental, Human, and Social Health, Chapter 4	*Report of the Standing Senate Committee on Agriculture and Forestry, Canadian Senate, 2024 Pages 107-114*	86

Digging Into Canadian Soils

MAJOR SOILS OF THE PRAIRIE PROVINCES

At the broadest scale, the sedimentary rock region has multiple zones of soils that radiate out from SW Saskatchewan and SE Alberta. The dominant soil order in the southern part of this region is the Chernozemic order, which formed in the grasslands that were found in this area prior to European settlement. Throughout most of the region, the Chernozemic soils are bounded by soils of the Luvisolic order, which are associated with the mixed deciduous-coniferous forest characteristic of the northern part of this region.

Brunisolic soils are the dominant soil order on the Canadian Shield and consist of acidic forest soils develop on the sand and gravelly parent materials characteristic of this area. In north-central Manitoba a large area of glacio-lacustrine silts and clays were deposited (Figure 10.3) and Luvisolic soils have formed in these parent materials.

Closer to Hudson Bay, the rebound of the land surface after glaciation has created a poorly drained region of near-level beach ridges and former shorelines with saturated soils. The cold temperatures and permanent water saturation has led to the development of thick layers of peat and formation of permanently frozen layers within the peats. These soils are classified as Organic Cryosols in the CSSC.

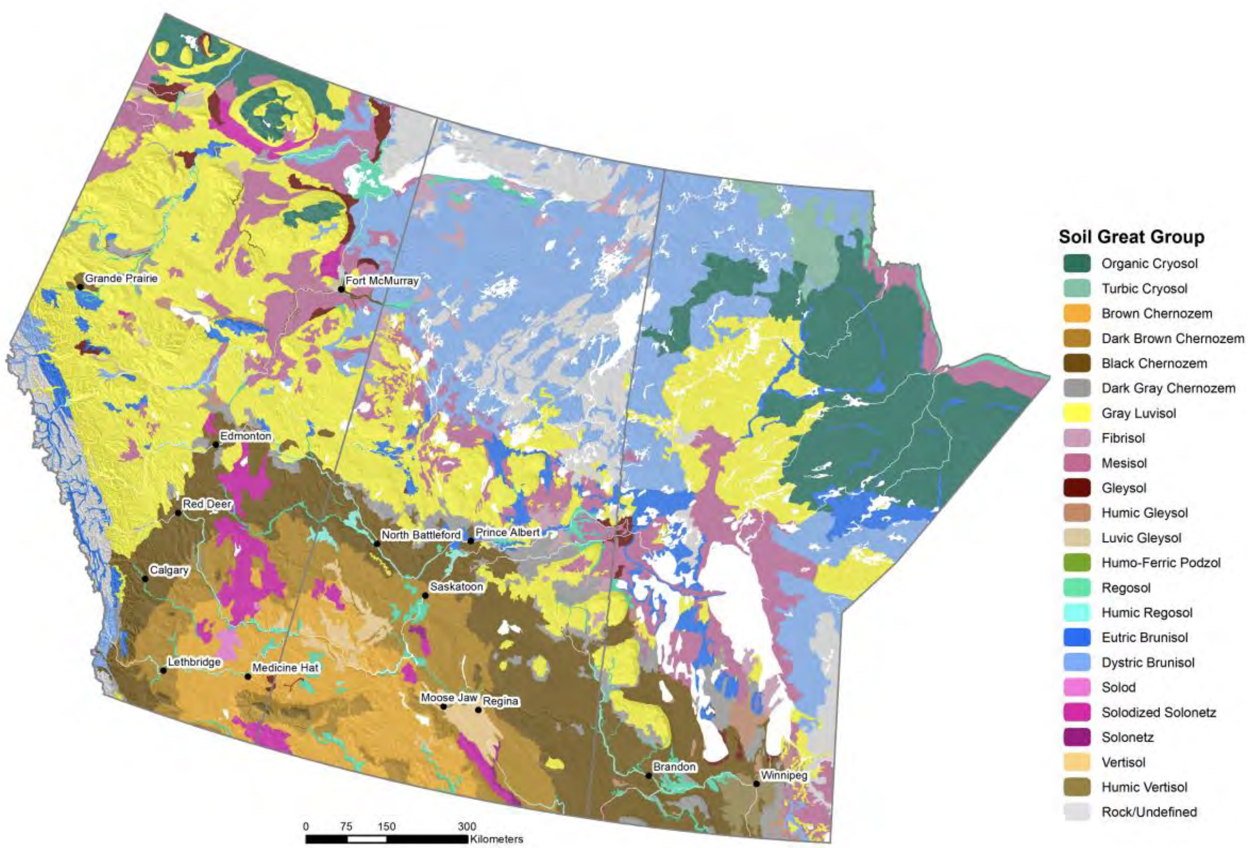


Figure 10.1. Map of soil great groups (according to the Canadian System of Soil Classification) for the Prairie Provinces. Map is a reproduction of an official work published by the Government of Canada and is based on the 1:1,000,000 Soil Landscapes of Canada map. Map courtesy of Darrel Cerkowniak, Agriculture and Agri-Food Canada. © Darrel Cerkowniak, Agriculture and Agri-Food Canada, is licensed under a CC BY (Attribution) license.

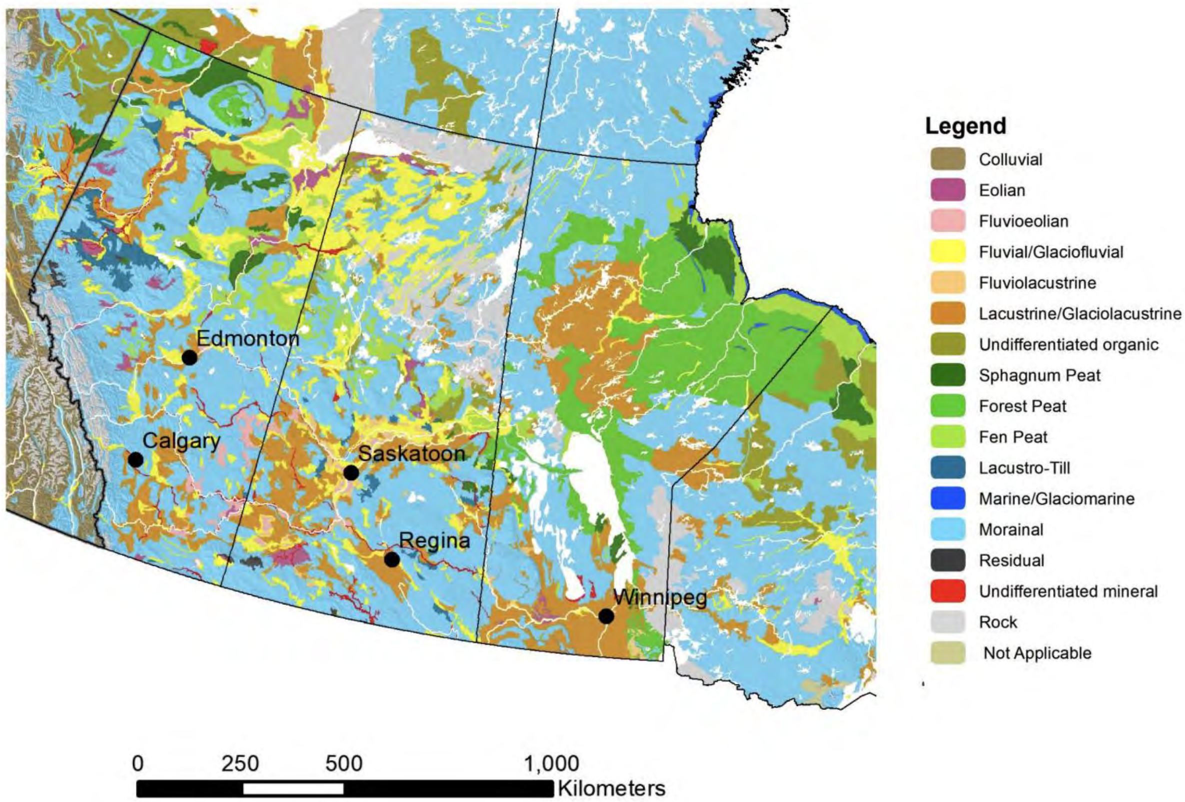


Figure 10.3. Major soil parent materials found in the Prairie Provinces. Map is a reproduction of an official work published by the Government of Canada and is based on the 1:1,000,000 Soil Landscapes of Canada map. © Darrel Cerkowniak, Agriculture and Agri-Food Canada, is licensed under a CC BY (Attribution) license.

The complex pattern of soils in northern and north-eastern Alberta departs from the overall zonation of soils. In this area there are several major uplands (such as the Caribou Mountains) that are elevated plateaus occupied by Gray Luvisols and Organic Cryosols. The uplands are separated by wide valleys occupied by the Athabasca, Hay and Peace Rivers. The relatively level valleys have a complex mixture of sandy Brunisolic, loamy Luvisolic and Fibrisol Organic soils. The extensive area of oil sand extraction near Fort McMurray devastates these soil landscapes, and reclamation of the landscapes (and remediation of the spoil from oil sands operations) is a major activity for soil scientists in this region.

Finally, the Cordilleran region at the Alberta-British Columbia border has a complex mixture of forested soils and exposed rock faces. The regional map shows areas of exposed rock and both

Dystric and Eutric Brunisolic soils, but areas of Gray Luvisolic soils also are found as well as Cryosolic alpine tundra soils at higher elevations.

GRASSLAND AND PARKLAND SOILS

The zonal pattern of great groups of the Chernozemic order reflects the different types of grasslands that once occupied the area (and the regional climates responsible for the zonation of grasses) (Fuller, 2010; Pennock et al., 2011). These grasses were responsible for organic carbon inputs into the soil, and the colour of the diagnostic Ah horizons reflects differences in the amount of organic carbon additions from the various grass communities. The great groups of the Chernozemic order are based on the colour differences of the A horizons.

The major climate attribute that varies across the region is the mean annual water deficit (Pennock et al., 2011, Table 10.2). The driest portions of the region have annual water deficits of approximately 200 mm and the native grasses of this region were low grasses with limited above- and below-ground biomass. The lower organic carbon inputs lead to the development of soils of the Brown Chernozemic great group (Figure 10.4). The water deficit decreases west and north of this dry region, and greater organic carbon inputs lead to formation of Dark Brown Chernozemic soils and Black Chernozemic soils. The highest organic carbon levels occur in southern Manitoba where the annual water deficit is only approximately 70 mm.

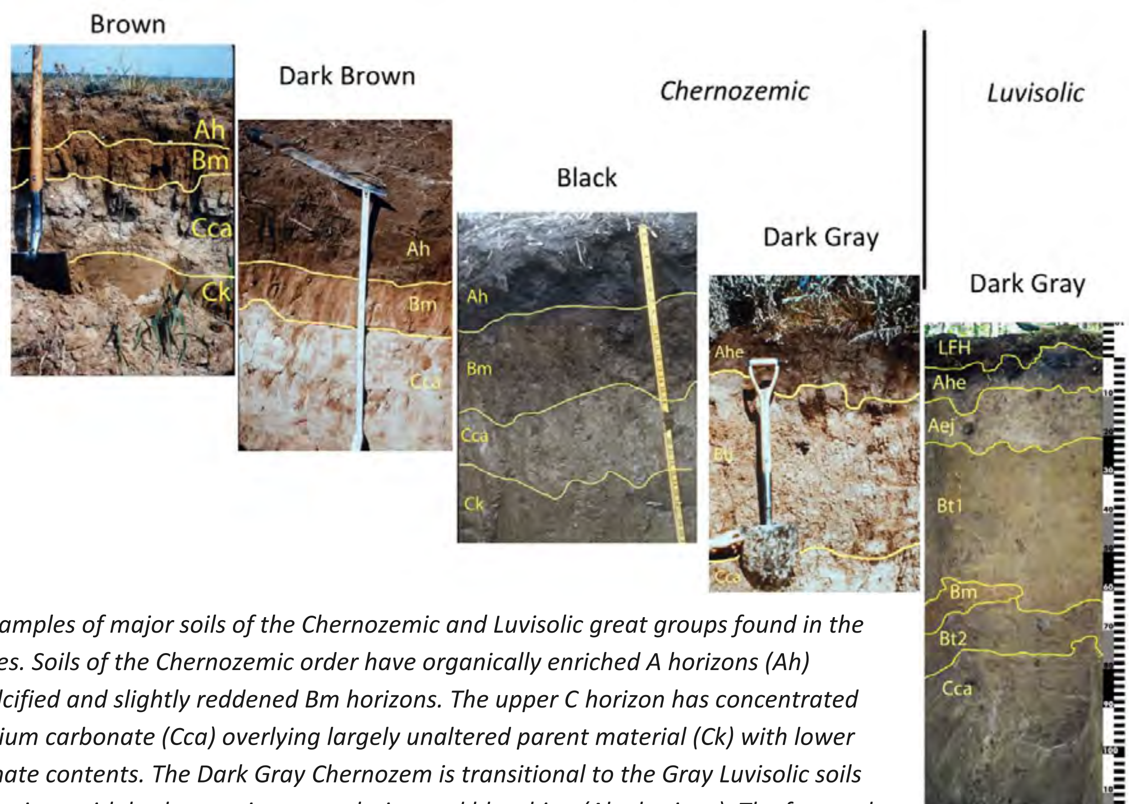


Figure 10.4. Examples of major soils of the Chernozemic and Luvisolic great groups found in the Prairie Provinces. Soils of the Chernozemic order have organically enriched A horizons (Ah) overlying decalcified and slightly reddened Bm horizons. The upper C horizon has concentrated secondary calcium carbonate (Cca) overlying largely unaltered parent material (Ck) with lower calcium carbonate contents. The Dark Gray Chernozem is transitional to the Gray Luvisolic soils and has an A horizon with both organic accumulation and bleaching (Ahe horizon). The forested Gray Luvisols have a leaf litter layer (LFH) on top of the mineral soil horizons. The uppermost bleached Ae horizon overlies a B horizon with higher clay levels than the Ae (Bt horizon). © "Brown, Dark Brown, Dark Gray Chernozem: Saskatchewan Center of Soil Research; Black Chernozem: Roly St. Arnaud (Saskatchewan Center of Soil Research); Dark Gray Luvisol: Kent Watson (Saskatchewan Center of Soil Research)" is licensed under a CC BY (Attribution) license.

Within these broad soil zones there are many pockets of other soil classes in the former grassland areas. During melting of the ice sheets glacio-lacustrine silts and clays were deposited in vast glacial lakes throughout the region, with large areas of deposition in west-central Saskatchewan, southern Manitoba, and north-central Manitoba (Figure 10.3). In the former, grassland region the high-clay soils of the Vertisolic order form in these glacio-lacustrine deposits (Anderson, 2010a; Brierly et al., 2011). The great groups of the Vertisolic order (Figure 10.5) reflect the differences in organic carbon inputs discussed for the Chernozems above: Vertisols in southern Saskatchewan are classified into the Vertisol great group, whereas the higher organic inputs that occur in the region south of Winnipeg result in Humic Vertisols.

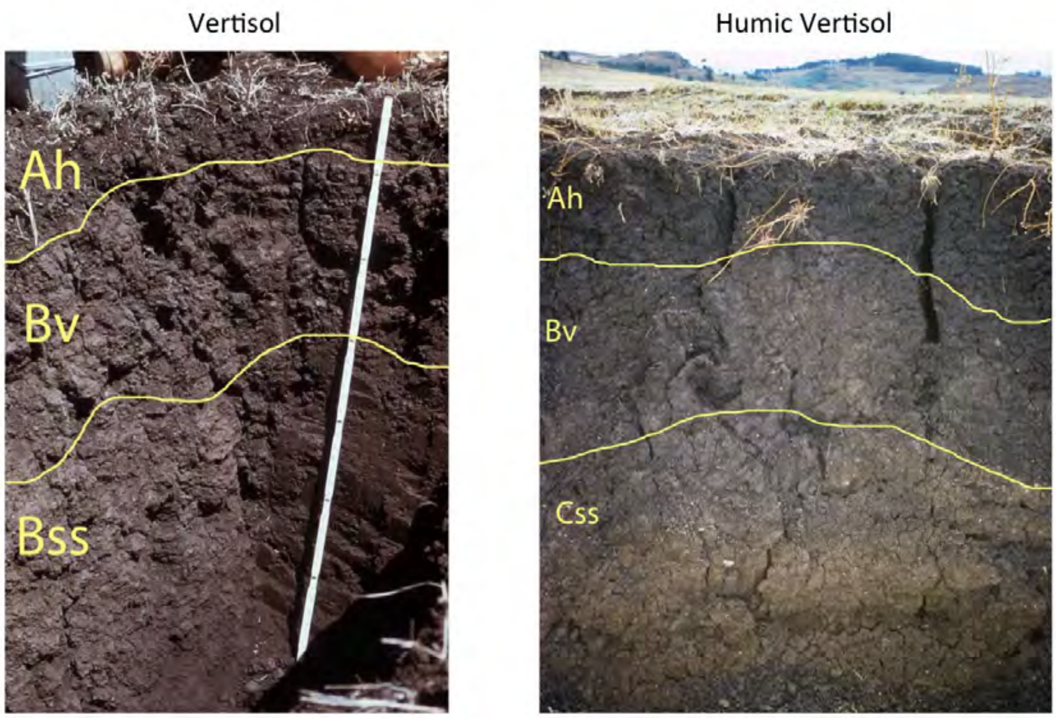


Figure 10.5. Great groups of the Vertisolic order. Mixing of soil by shrinking and swelling of clays prevents visually distinct horizons from forming. The mixed horizons are assigned a 'v' suffix, and in lower horizons polished surfaces (slickensides, assigned a 'ss' suffix) form on the face of fractures in the soil. The Humic great groups have higher organic matter inputs and a more distinct Ah horizon that the Vertisol great group. © "Vertisol: Roly St. Arnaud (Saskatchewan Center of Soil Research); Humic Vertsol: Darwin Anderson (Saskatchewan Center of Soil Research)" is licensed under a CC BY (Attribution) license.

The distribution of Solonetzic soils is largely controlled by the presence of sodium-rich bedrock within a few meters of the soil surface rather than a particular type of glacial sediment (Anderson, 2010b; Miller and Brierley, 2011). In both Alberta and Saskatchewan, the marine shales of the Cretaceous-aged Bearpaw formation are the main bedrock type associated with Solonetzic soils. Movement of soil water and groundwater circulates sodium through the soil profile, which can lead to vertical movement of clay from the surficial Ah horizon soil to the B horizon and formation of a bleached, eluvial Ae horizon overlying the B horizon. The B overlies a saline and carbonate-rich C horizon (Csk).

The great groups of the Solonetzic order reflect the degree of development of the Ae horizon and the AB horizon, which forms through weathering of the upper B horizon. In the Alkaline Solonetz great group the Ae is very thin or absent, and the B horizon is high in sodium (Bn) but often without higher clay levels than the Ah (Figure 10.6). The Solodized Solonetz great group has an Ae greater or equal to 2 cm thick and an intact Bnt or Bn horizon with well-developed columnar structure. In the Solod great group the top of the Bnt has disintegrated through weathering and this weathered layer forms a transitional AB horizon between the Ae and the Bnt horizons. The Solodized Solonetz great group is the most common in the landscape (Figure 10.1).

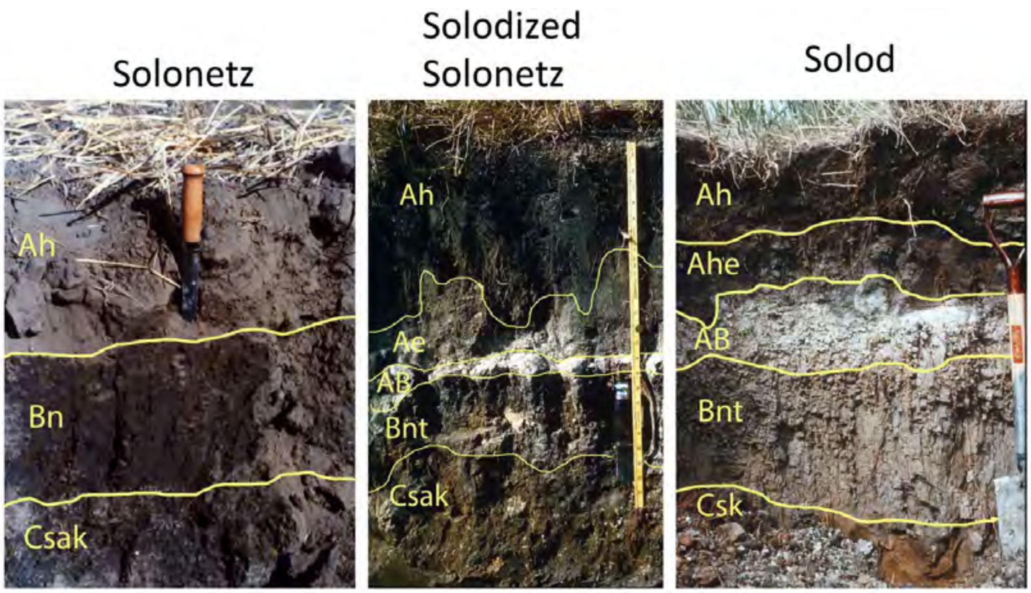


Figure 10.6. Great groups of the Solonetzic order. The great groups of the Solonetzic order reflect the progressive disintegration of the upper part of the Bnt horizon (a horizon enriched in both sodium and clay) to form a transitional AB horizon. The AB horizon begins to form in the Solodized Solonetz great group and reaches maximum thickness in the Solod great group. © "Solonetz: Darwin Anderson (Saskatchewan Center of Soil Research); Solodized Solonetz: Roly St. Arnaud (Saskatchewan Center of Soil Research); Solod: Saskatchewan Center of Soil Research" is licensed under a CC BY (Attribution) license.

Small areas dominated by Regosolic soils (VandenBygaart, 2011) are also found throughout the region. Regosolic soils are associated with unstable land surfaces (such as river floodplain or sand dunes) where soil development is limited to development of an Ah horizon either directly overlying the C horizon or with a thin (<5 cm) Bm between the A and C horizons (Figure 10.7). The Regosol-dominated areas in the Prairie Provinces are associated with sandy fluvial or glaciofluvial deposits along river valleys or areas of active or recently stabilized sand dunes such as the Great Sand Hills of Saskatchewan. As well, the knolls in many cultivated landscapes in the Prairie Provinces have experienced considerable soil loss due to tillage erosion, and thin Ap (p for ploughed) horizons directly overlay Cca horizons on these hill crests.

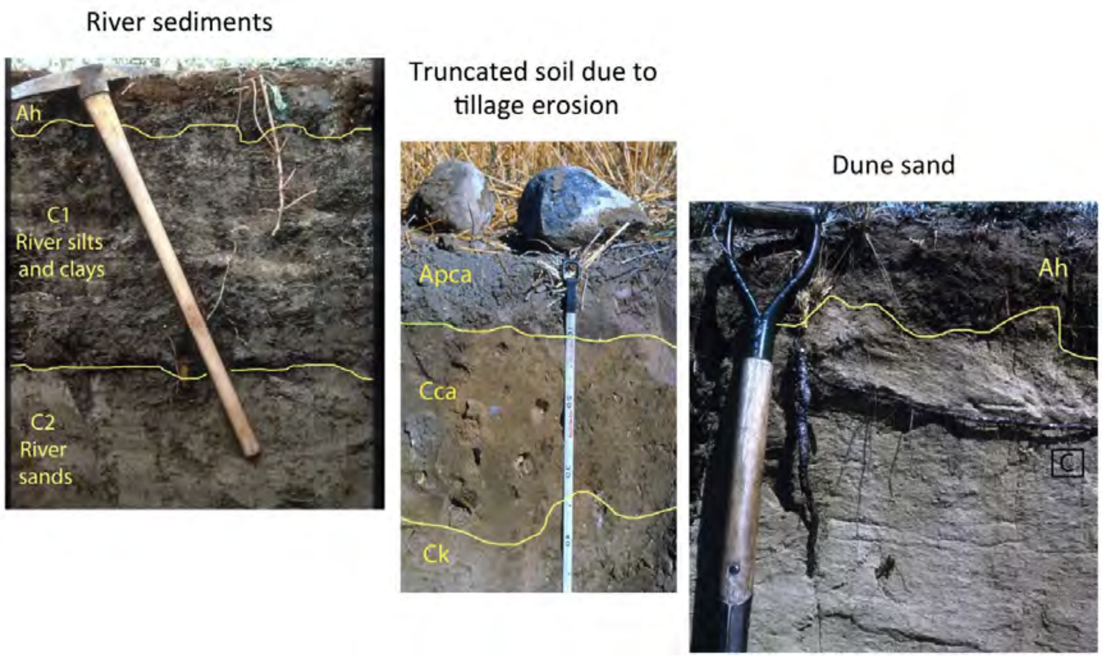


Figure 10.7. Regosolic soils. Regosolic soils occur in very young sediments (such as on active floodplains or in active sand dune areas) or due to erosion of surface soils in cultivated fields. In all cases, B horizon formation is either absent or less than 5 cm thick. © "River sediments: Darwin Anderson (Saskatchewan Center of Soil Research); Truncated soil: Dan Pennock (Saskatchewan Center of Soil Research); Dune Sand: Roly St. Arnaud (Saskatchewan Center of Soil Research)" is licensed under a CC BY (Attribution) license.

Many of the glacial landforms in the area are associated with melting in-place of stagnant ice masses, and the resulting land surface is a very complex assemblage of small knolls and depressions. This land surface is labelled as hummocky or knob and kettle on soil maps. Wetlands on these surfaces are often occupied by Gleysolic soils, whose Bg and Cg horizons have dull gray colours and, in some cases, patches of reddish oxidized iron within the dominantly gray material (Figure 10.8) (BedardHaughn, 2010, 2011). Texture-contrast horizons are also common in these soils, with a Btg horizons underlying a mottled Aeg horizon. Soils with a Btg horizon are classified into the Luvic Gleysol great group.

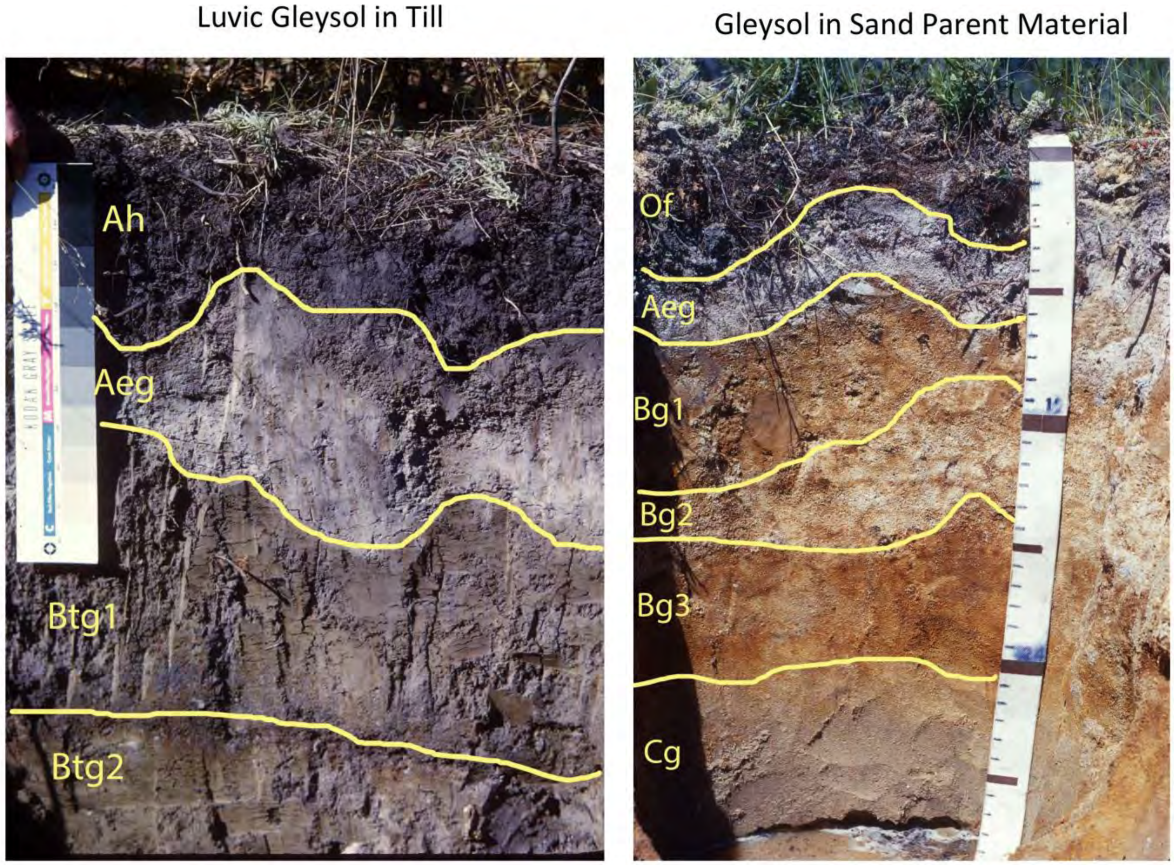


Figure 10.8. Gleysolic soils. The Luvic Gleysol great group soil developed in clay loam till has dull, grayish colours throughout and small reddish mottles in the Aeg horizon. The Gleysol great groups soil developed in sandy glaciofluvial parent materials has much brighter coloured mottles throughout with maximum expression of oxidized iron in the Bg3 horizon. © Both slides: Darwin Anderson (Saskatchewan Center of Soil Research) is licensed under a CC BY (Attribution) license.

A final soil class that is largely unmapped are saline soils. The Canadian System of Soil Classification (CSSC) does a poor job of identifying saline soils. This is in part due to the very dynamic nature of soil salinity, which fluctuates considerably due changes to soil water and groundwater flow patterns. Salinity can only be recognized in profile descriptions through the use of the suffixes s and sa in horizon labels (e.g., Csa, Cs, Bsa, Ahsa, etc.). Agriculture and AgriFood Canada has mapped soil salinization risk for several decades as part of its Agri-Environmental Indicators program and the main areas that are vulnerable to salinization (i.e., areas mapped as moderate, high, and very high risk) are widespread throughout the Prairie region. The largest areas are the region stretching NE from Calgary to almost Saskatoon, SW Alberta, in SE Saskatchewan near Estevan, and in areas of Manitoba south of Brandon and of Winnipeg. The AAFC maps show that the risk of salinization has decreased since the 1980s due to adoption of no-till cultivation practices and the near-elimination of tillage summer fallow throughout this region.

FOREST AND WETLAND SOILS

At the northern boundary of the Chernozemic soils the grasslands become increasingly interspersed with clumps of trees and shrubs and ultimately the forest forms an almost continuous cover over the soil. The transitional grassland-forest zone is referred to as the Parkland zone, and the continuous forest cover as the Mixedwood forest, reflecting the forest cover of deciduous and coniferous species.

In the Parkland, the inputs of organic carbon from grasses decrease and leaf litter from trees builds up on the soil surface as a LFH layer. The colour of the Ah horizon grows lighter, and bleaching of the horizon also begins to occur, forming a surface A horizon with both humus inputs (given an 'h' suffix) and bleaching (an 'e' suffix) – the Ahe horizon. These soils are classified into the Dark Gray Chernozemic great group.

North of the forest-grassland transition zone, organic inputs form a discrete layer laying on top of the mineral soil (the LFH layer) and the soils have a well-developed bleached layer (Ae horizon) overlying a B horizon with higher clay levels (Bt horizon). The Bt horizon is underlain by a C horizon with secondary (Cca) or primary (Ck) carbonates. These soils are classified into the Gray Luvisolic great group (Figure 10.9), which dominates the forested landscapes underlain by neutral-alkaline tills (Pettapiece et al., 2010; Lavkulich and Arocena, 2011). Gray Luvisols also occur in the large area of glacio-lacustrine parent materials in north-central Manitoba.

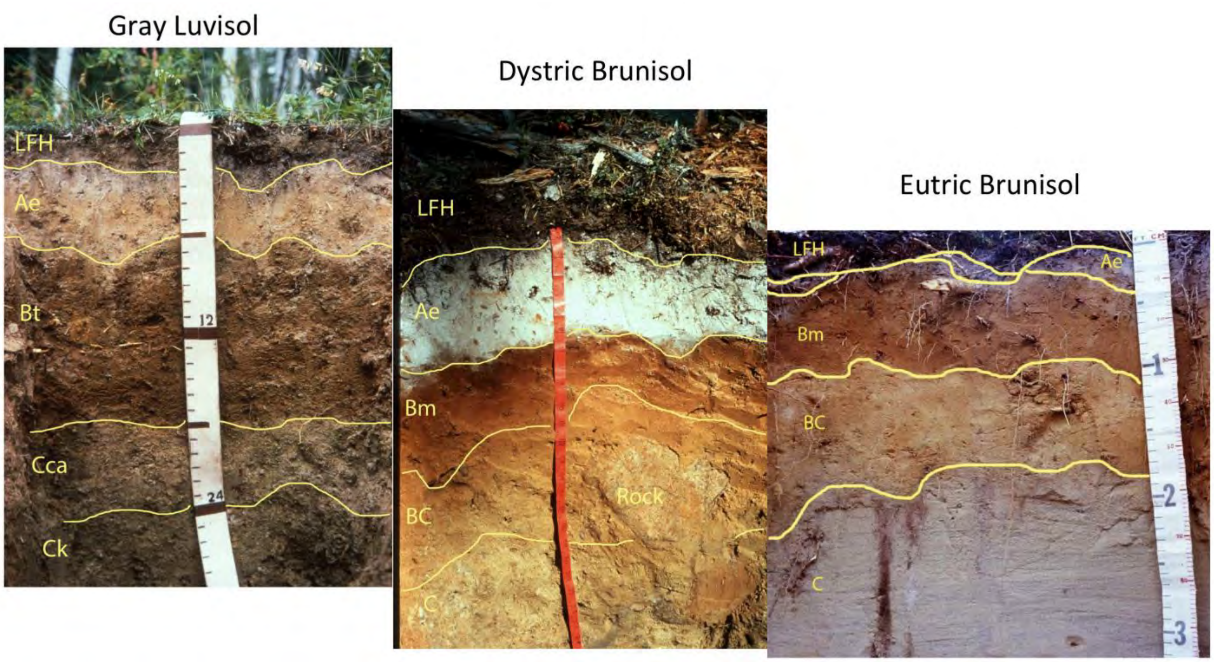


Figure 10.9. Luvisolic and Brunisolic soils. Soils of the Gray Luvisol great group have well developed texture contrast (Ae and Bt) horizons overlying the C horizons with primary (Ck) and secondary (Cca) calcium carbonate. Both of the great groups of the Brunisolic order develop primarily in sandy parent materials and have the diagnostic Bm horizon. The great groups differ on the acidity of the parent materials: Dystric Brunisols develop in acidic parent materials, and Eutric Brunsiols develop in neutral pH

parent materials. © "Luvisol: Darwin Anderson (Saskatchewan Center of Soil Research); D. Brunisol and Eut. Brunisol: Saskatchewan Center of Soil Research" is licensed under a CC BY (Attribution) license.

At the boundary between the sedimentary rocks of the Interior Plains and the Canadian Shield a complex assemblage of forest and wetland soils occurs. The forested soils form in parent materials that include sandy sediments from the Canadian Shield and pulverized sedimentary rocks, which raises the pH of the parent materials above 5.5. These soils are classified into the Eutric Brunisol great group (Figure 10.9) (Smith et al., 2011). In low lying areas, water collects and forms large fens and bogs. In these wetlands peat builds up due to the permanent water saturation and soils of the Mesisol great group of the Organic order occur (Bedard-Haughn, 2010). These soils have intermediate levels of decomposition of organic materials (Figure 10.10).

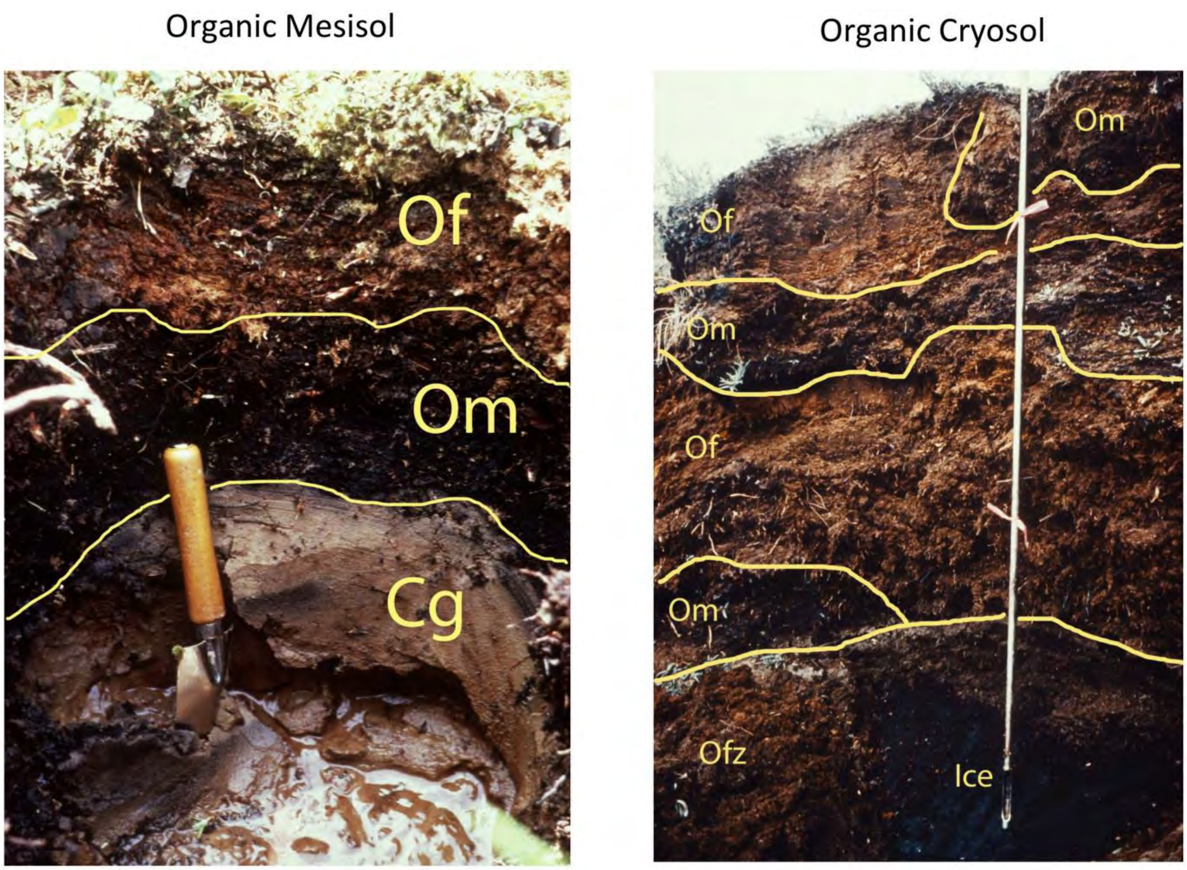


Figure 10.10. Organic and Cryosolic soils. Both soils have a thick buildup of peat in either largely undecomposed (Of) or moderately decomposed (Om) layers. The Organic Cryosol has permafrost within 1 m of the surface (note – total length of white tape is 1.2 m). © "Mesisol: Ken Van Rees (Saskatchewan Center of Soil Research); Cryosol: Saskatchewan Center of Soil Research" is licensed under a CC BY (Attribution) license.

The dominant soil of the Canadian Shield itself are Dystric Brunisols (Figure 10.9) that develop in the acidic (pH < 5.5) sand and gravel parent materials characteristic of this region. Like the

Eutric Brunisols, the Dystric Brunisols soils are very sandy soils and soil formation is limited to reddening of the B horizon and, in some cases, formation of a bleached Ae horizon. In moister forested regions of Canada, these conditions lead to formation of soils of the Podzolic order (Sanborn et al., 2011). There are also significant areas where exposed rock is the dominant surface with only scattered pockets of soils interspersed in the landscape.

Finally, the near-level landscapes of the Hudson Plains ecozone are mainly occupied by organic soils that have a layer of permafrost (i.e., permanently frozen soil) within the soil profile. These soils have thick organic layers but, because of the permafrost, are classified into the Cryosolic order (Figure 10.10) (Tarnocai and Bockheim, 2010).

SOILS AND LAND USE

Soil properties have a major impact on agricultural capability throughout the Prairie Provinces. The agricultural capability of soils throughout southern Canada was evaluated by the Canada Land Inventory (CLI). The criteria used in the CLI system were based on soil and climate and remain generally applicable although cropping systems used in the region have changed greatly since the period of the CLI inventory (roughly 1965-1975). At that time the dominant crop was spring wheat and summerfallow (i.e., a year of fallow with tillage of the soil to suppress weed growth following a year of wheat) was the dominant tillage practice. Currently, a much wider range of crops (e.g., canola, pulse crops, flax) is grown, and the great majority of producers practice continuous cultivation with high amounts of crop residue left on the soil surface (i.e., conservation tillage or no-till).

In the CLI rankings, classes 1 through 4 are considered to be capable of sustained use for cultivated field crops. In class 1 land, there are no significant constraints to crop growth, whereas in class 3 and 4 areas the range of crops is restricted and special management measures are needed to conserve the soil. Classes 5 and 6 are only suitable for forage production and are most commonly used for grazing of livestock.

The major soil property that determines agricultural capability in the CLI system is soil texture due primarily to its effect on water availability. Secondary properties of relevance are unfavorable soil structure associated with Solonetzic soils and the presence of salinity in the soil profile. Soils that have experienced erosion of the organic-rich A horizons through time are also downgraded – organic matter has many beneficial properties including a high water-holding capacity and high nutrient supplying power.

All agricultural regions of the Prairie Provinces experience a water deficit (as discussed above) and hence the ability of the soil to hold water during dry periods is critical. This property is termed the available water capacity. Generally, fine textured soils (clay, heavy clay, silty clay, clay loam) retain the highest amounts of water even in drought conditions and have high available water capacity. Medium-textured soils (silty clay loam, sandy clay loam, loam, silt loam, fine and very fine sandy loam) have lower ability to hold water during droughts but have slightly higher available water capacity. Medium-coarse sandy loam, loamy sand, and sand soils have both very low ability to hold water during droughts and low available water holding capacities and hence are the lowest rated for agriculture.

The second major factor that determines the CLI class is the climate. In the Prairie Provinces, both moisture and heat can be limiting. Agriculture and Agri-Food Canada developed agro-climatic regions throughout Canada based on three climate factors: Mean annual precipitation, average number of frost-free days, and degree days above 5.5°C (Table 10.1 and Figure 10.11). The latter is a cumulative measure of the period when the temperature is high enough for significant plant growth. The class limits will have shifted somewhat due to climate change but the general pattern would be unchanged.

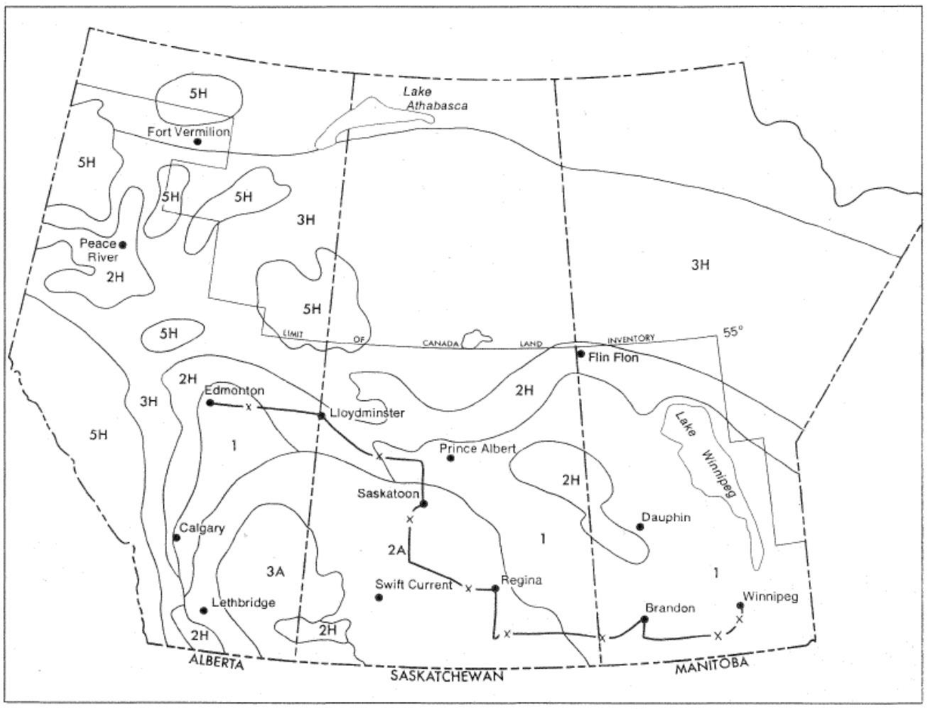


Figure 10.11. Agro-climatic regions of the agricultural areas of the Prairie Provinces. Reproduced from Michalyna et al. (1978) and licensed under the Open Government Licence – Canada.

Soil texture is directly inherited from the parent materials in the Prairie Provinces; hence, a clear link between agricultural capability and the soil classes described above. At the driest end of the spectrum are the Regosolic soils formed in sandy glacio-fluvial sediments or sand dune areas, which typically have CLI classes of 5 or 6. At the other end of the spectrum are Vertisol soils, which inherently have clay or heavy clay textures and typically have CLI class 1 or 2 ratings throughout the main agricultural region.

The capability ratings for Chernozemic soils depends primarily on texture and on climate zone. The general pattern is clear from Figure 10.12: fine-textured soils are the best agricultural soils in each climate region and coarse textured soils the worst. The range is greatest for medium-textured soils developed on glacial till, which are the most common in the region.

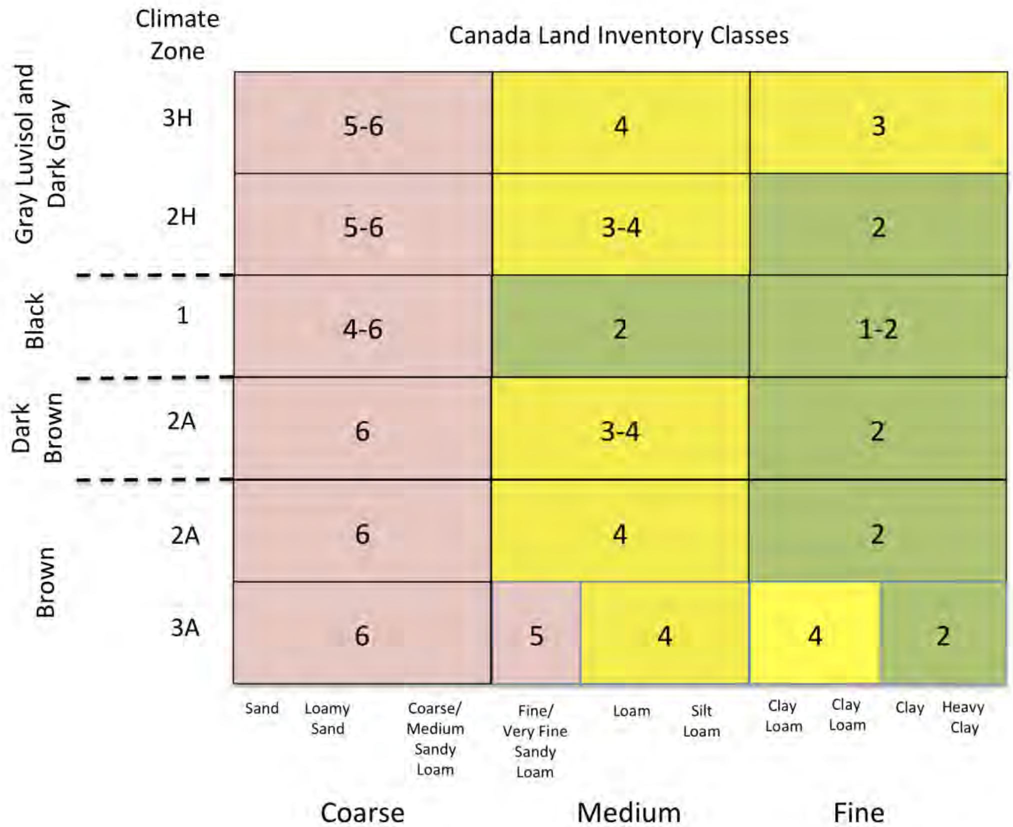


Figure 10.12. Matrix of Canada Land Inventory (CLI) classes associated with soil zones, soil textures, and agro-climatic zones in the Prairie Provinces. © Dan Pennock, Univ. of Saskatchewan is licensed under a CC BY (Attribution) license.

Gray Luvisolic soils have a number of limitations for annual crop production (Pettapiece et al., 2010). The Gray Luvisols occur in zones 2H and 3H (Figure 10.11) where lack of heat and frequent frosts limit growth. The Gray Luvisols lack an Ah horizon and typically have silty textured surface mineral horizons; both factors contribute to problems with seedbed preparation and crop growth generally. Compared to Chernozemic and Vertisols soils they are also deficient in nitrogen, phosphorus, and sulphur. The Gray Luvisols and related soils in the Aspen Parkland region are widely used for forage crop production and grazing – about two-thirds of western Canada's cattle and more than 80% of the forage crops are produced in this region (Thorpe and Anderson, 2010).

Secondary soil properties that strongly affect agricultural capability are factors such as the presence of high sodium soils or salinity, both of which are generally associated with class 5 or 6 soils. The Bn or Bnt horizon associated with the Solonetzic soils are difficult for plant roots to penetrate and hence only the horizons above these horizons can be fully exploited by roots for nutrients and water. As well, the Ah and Ae horizons above the dense B horizons have often experienced erosion, and the variable depth of surface soil over the B horizon often gives crops on Solonetzic surfaces a wavy appearance due to lower growth on thin soils and higher growth on thicker soils. Salinity has a severe effect on crop growth and on highly saline soils growth of any plant except saline-tolerant species is impossible.

An important landscape factor that affects the rating of medium-textured soils is topography – generally the rougher the topography, the lower the rating. Many medium-textured glacial till landscapes have many knolls and wetlands associated with them, and these cause difficulties in farm operations and uneven plant growth. Rough topography generally causes a given area to drop by at least one class in the CLI rating.

Soil properties also play an important role in determining land capability for forest harvest operations. Forest harvest has increased in Alberta since the early 2000s (from 82 thousand hectares (t ha-1) in 2005 to 92 t ha-1 in 2016). However, it has declined in Saskatchewan (42 t ha-1 in 2005 to 22 t ha-1 in 2016) and Manitoba (14 t ha-1 in 2005 to 8 t ha-1 in 2016) (all statistics from Natural Resources Canada). In total, this represents about 13% (2005) to 15% (2016) of total forest area harvested in Canada.

The Canada Land Inventory also rated soils for forest capability in the portion of the forest where commercial forestry existed. The highest class of land in the Prairie Provinces was only class 3 due to climate constraints for tree growth throughout the region. Generally, forests on Gray Luvisol soils are rated as class 4 (Alberta and Manitoba) or Class 5 (Saskatchewan) with small areas rated one class higher in all provinces. Forests on both Eutric and Dystric Brunisolic soils are generally rated as class 6 due to significant growth constraints. Detailed ecosite guides have been prepared for each province (see Suggestions for Further Reading) that rate soils on soil texture and soil drainage – generally well-drained, fine- and medium-textured soils are the most highly rated in the forest landscape.

Wetland soils in the Prairie Provinces are key contributors to two transnational and global issues: the protection of waterfowl in North America and the removal of carbon from the atmosphere by increasing soil organic carbon levels (carbon sequestration). In the former grassland areas of the Prairies, the complex hummocky land surfaces have countless wetlands that are occupied by Gleysolic soils or, in some cases, saline soils. These wetlands are the seasonal home for vast numbers of migratory waterfowl, and protection of Prairie wetlands is essential for preservation of waterfowl habitat. The North American Waterfowl Management Plan (NAWMP) is a major agreement among Mexico, the USA and Canada and protection of Prairie wetlands is a key aspect of this transnational plan.

Gleysolic wetlands and especially Organic soils are repositories for large amounts of carbon. Drainage of these wetlands for agriculture causes mineralization of this carbon and its release (as carbon dioxide) to the atmosphere. The restoration of wetlands and of the wetland vegetation that surrounds them has the potential to draw carbon from the atmosphere and hence lessen the growth in carbon levels caused by human activity. The 2019 report by the

Intergovernmental Panel on Climate Change on climate change and land has highlighted the role that carbon sequestration by soils could play in greenhouse gas mitigation (Section 4.9.4 IPCC, 2019).

Finally, soils of all types have been extensively affected by resource extraction activities throughout western Canada. In Alberta alone, there are 422,000 km of oil and gas pipelines, 343,000 well sites (176,000 active wells, 90,000 inactive wells, and 77,000 abandoned wells) and 895 km2 have been disturbed by surface mining for oil sand production (as of 2013); oil sand tailing ponds and associated structures totaled 220 km2 . (Sources: Agdex 878-4; Alberta Energy–Oil & Gas Liabilities Management; and Alberta Energy–Oil Sands, Coal and Mineral Operations). In all cases, legislation requires that the sites be reclaimed by replacing soil and re-establishing vegetation on the disturbed site so it can support activities similar to those it could have supported before it was disturbed. In situations where contamination has occurred the soils must be remediated (or cleaned up) to meet specific soil and groundwater standards. All of these steps require knowledge of soil properties and soil distribution, ensuring a continuing role for soil scientists from decades to come.

HUMAN IMPACT ON SOIL DISTRIBUTION

Regosols and Anthroposols

The most widespread impact of human activity on soil horizonation (and hence classification) is due to human-induced increases in soil erosion, especially erosion caused by tillage in agricultural landscapes (FAO, 2019). Tillage causes mixing of the surface layer to the depth of tillage (typically between 10 to 25 cm). The tilled surface layer is denoted with a p (ploughed) suffix (Ap). As erosion removes surface soil, ploughing incorporates B and C horizons into the Ap horizon, which can limit plant growth where a growth-limiting B or C horizon exists. Often tillage erosion and mixing eliminates the B horizon totally, and the Ap/C or Ap/Cca sequence is classified into the Regosolic soil order (Figure 8.23). Soil catenas in agricultural landscapes commonly include Regosolic soils in the most eroded positions. Deposition of soil at the base of the slope causes over thickening of the A horizon in the depositional positions but typically this has little effect on the classification of the soil.

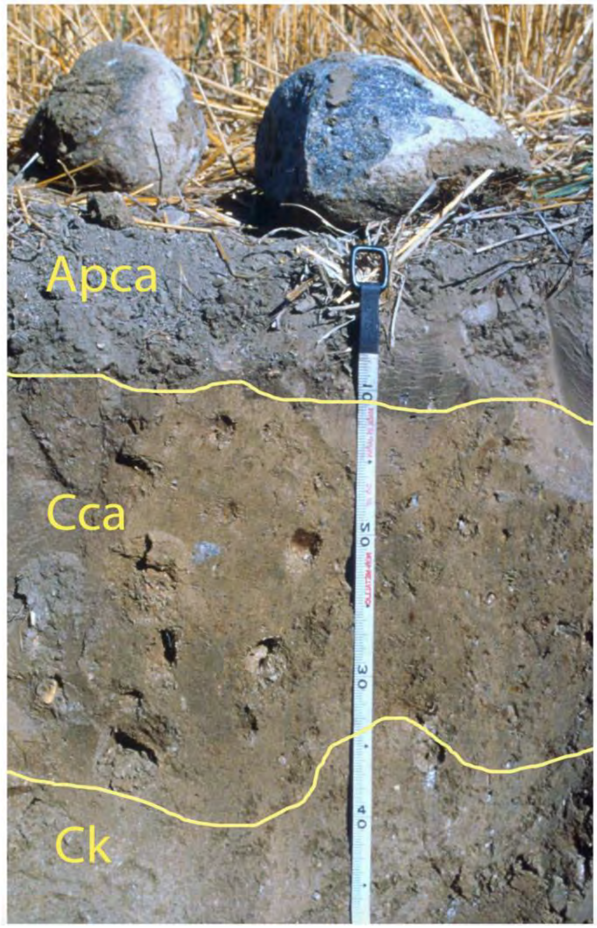


Figure 8.23. Orthic Regosol. In the native state this soil would have been a thin Chernozemic soil. Tillage erosion has removed the B horizon and incorporated the Cca horizon into the surface Apca layer. This process causes formation of Regosols on the knolls of eroded cultivated fields throughout Canada. © Dan Pennock, Univ. of Saskatchewan (Saskatchewan Centre for Soil Research), is licensed under a CC BY (Attribution) license.

A second type of widespread human impact on soils is caused by removal, storage and replacement of soil material associated with various forms of resource exploitation – for example, trenching for pipelines or removal of surface material to allow mining of bitumen in the oilsands or mineral resources elsewhere. The highly disturbed or reconstructed soils can not be adequately described using the terminology of the CSSC, and Naeth et al. (2011) suggested that a new order called the Anthroposols should be adopted to describe them. The diagnostic horizon of the Anthroposols would be the D (for disturbed) horizon. Many other national and international systems of soil classification have already adopted orders to account for these soils. The Anthroposol order has not been officially adopted into the CSSC at the time of writing (summer of 2019).

Overview Of Classification Methodology for Determining Land Capability For Agriculture

The CLI agriculture product shows the varying potential of a specific area for agricultural production. It indicates the classes and subclasses according to the Soil Capability Classification of Agriculture, which is based on characteristics of the soil as determined by soil surveys. The mineral soils are grouped into 7 classes and 13 subclasses according to the potential of each soil for the production of field crops. Organic soils are not a part of the classification and are shown as a single separate unit (0).

These agricultural capability maps can be used at the regional level for making decisions on land improvement and farm consolidation, for developing land-use plans, and for preparing equitable land assessments.

Some of the important factors on which agricultural classification is based are: 1) The soils will be well managed and cropped, under a largely mechanized system. 2) Land requiring improvements, including clearing, that can be made economically by the farmer, is classed according to its limitations or hazards in use after the improvements have been made. Land requiring improvements beyond the means of the farmer is classed according to its present condition. 3) The following are not considered: distances to marker, kind of roads, location , size of farms, type of ownership, cultural patters, skill or resources of individual operations, and hazard of crop damage by storms. 4) The classification does not include capability of soils for trees, tree fruits, small fruits, ornamental plants, recreation, or wildlife. 5) The classes are based on the intensity, rather than kinds, of their limitations for agriculture. Each class includes many kinds of soil, and many of the soils in any class require unique management and treatment. 6) Land given a capability classification of 6 or 7 will never warrant irrigation since the benefits derived from irrigation would be negligible. For this reason, capability Classes 6 and 7 will always appear in the non-irrigated portion (Classes A to C) of a land unit classification.

You can find out more about the CLI mapping project at geogratis.

Land Capability Class Descriptions for Agriculture

The classes indicate the degree of limitation imposed by the soil in its use for mechanized agriculture. The subclasses indicate the kinds of limitations that individually or in combination with others, are affecting agricultural land use.

Classes

Note: To see a further description of each class, visit here.

Classes	Description
Class 1	Soils in this class have no significant limitations in use for crops.
Class 2	Soils in this class have moderate limitations that restrict the range of crops or require moderate conservation practices.
Class 3	Soils in this class have moderately severe limitations that restrict the range of crops or require special conservation practices.
Class 4	Soils in this class have severe limitations that restrict the range of crops or require special conservation practices.
Class 5	Soils in this class gave very severe limitations that restrict their capability in producing perennial forage crops, and improvement practices are feasible.
Class 6	Soils in this class are capable only of producing perennial forage crops, and improvement practices are not feasible.
Class 7	Soils in this class have no capacity for arable culture or permanent pasture.
Class 0	Organic Soils (not placed in capability classes).

Subclasses

Note: To see a further description of each class, visit here.

Subclasses	Description
C	Adverse climate
D	Undesirable soils structure and/or low permeability
E	Erosion
F	Low fertility
I	Inundation by streams or lakes
M	Moisture limitations
N	Salinity
P	Stoniness
R	Consolidated bedrock
S	Combination of subclasses
T	Topography
W	Excess water
X	This Subclass is comprised of soils having a limitation resulting from the cumulative effect of two or more adverse characteristics

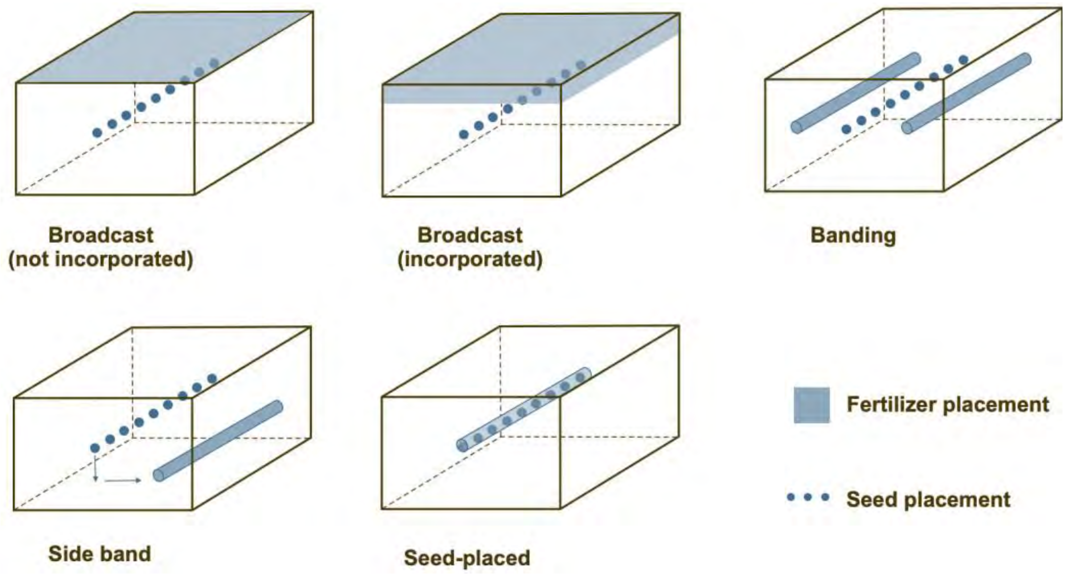
Soil Fertility

Information for using fertilizers to supplement nutrient requirements under the various cropping and soil-climate conditions in Alberta.

Introduction

Proper nutrition is essential for satisfactory crop growth and production. Nutrient requirements of crops and the ability of soils to supply nutrients vary widely. In this section you'll find information for using fertilizers to supplement nutrient requirements under the various cropping and soil-climate conditions throughout the province.

For more information, see Soil fertility – Overview.



Fertilizer application placement methods

Macronutrients

The macronutrients obtained from the soil include:

- nitrogen (N)
- phosphorus (P)
- potassium (K)
- sulphur (S)

Learn about their application methods, deficiency symptoms, fertilizer types and more.

Micronutrients

The remaining essential elements needed by plants are known as micronutrients because plants use them in relatively small amounts.

Learn more about micronutrients.

The Prairies

The Prairies—Alberta, Saskatchewan, and Manitoba—are home to 80% of Canada's farmland. The region was once also home to vast expanses of native grasslands. The Northern Great Plains are now one of the world's most threatened ecosystems. The Nature Conservancy of Canada estimates that more than 80% of Canada's prairie grasslands have been lost to cultivation, urbanization, and industrial development.[61]

According to Statistics Canada, no-till has been adopted throughout the Prairies at rates between 40% and 75% of cropland hectares prepared for seeding in Alberta, greater than 75% in most of Saskatchewan and up to 90% in some regions of the province, and between 40 to 50% in southwestern Manitoba, as illustrated in Figure 9 for 2021. David Burton, Distinguished Research Professor, Faculty of Agriculture, Dalhousie University, summed up this approach: "Diversify our rotations and reduce our disturbance. That's one of the things that Western Canada has succeeded in doing. That helps the soil retain that organic matter."[62] However, some witnesses cautioned the committee that no-till practices in the Prairies were moving backwards and that more acres are reverting to tillage.[63]

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59 AGFO, Evidence, 4 May 2023 (Paul Pryce, Director of Policy, BC Agriculture Council).

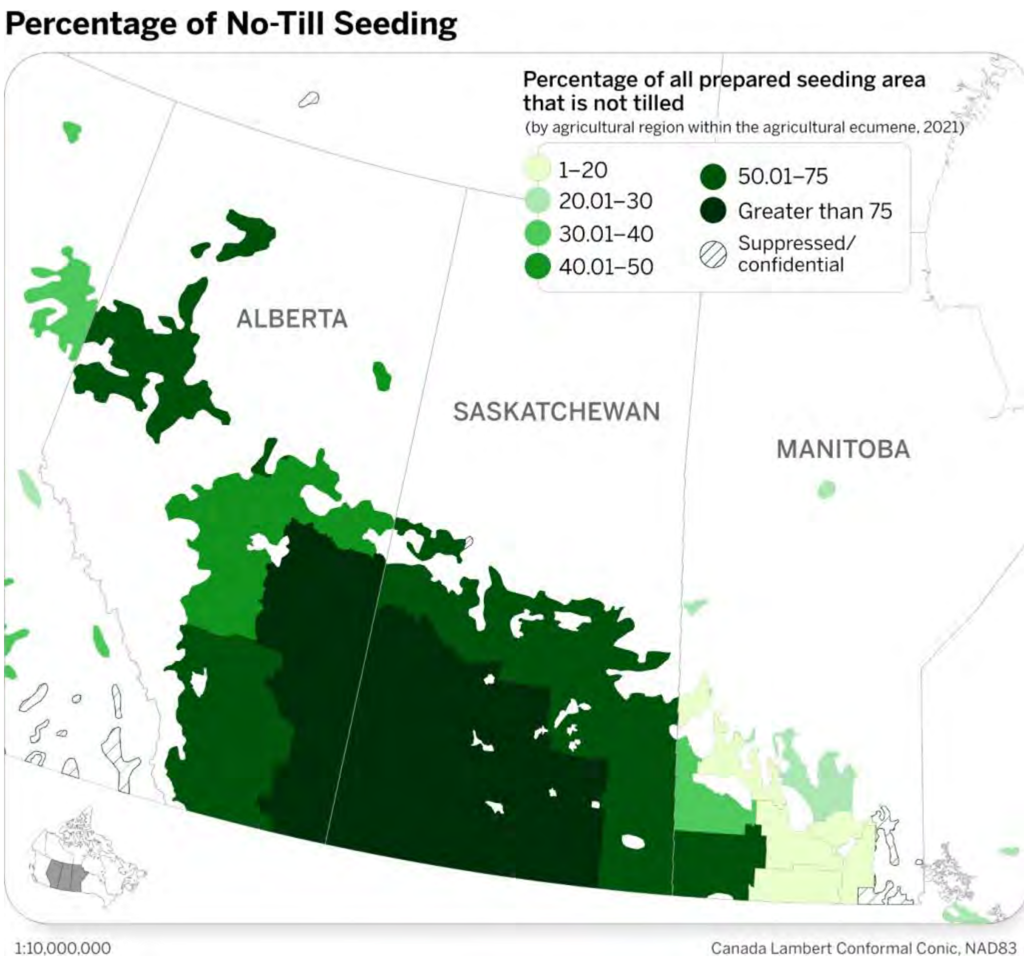
60 Ibid.

61 AGFO, Evidence, 23 November 2023 (Reynold Bergen, Science Director, Beef Cattle Research Council, Canadian Cattle Association); Evidence, 13 February 2024 (Melanie Bos, Agriculture Policy Manager, Nature Conservancy of Canada).

62 AGFO, Evidence, 20 October 2022 (David Burton, Distinguished Research Professor, Faculty of Agriculture, Dalhousie University, As an individual).

63 AGFO, Evidence, 22 September 2022 (Cedric Macleod, Executive Director, Canadian Forage and Grassland Association); and Evidence, 27 September 2022 (David Lobb, Professor, Department of Soil Science, Faculty of Agricultural and Food Sciences, University of Manitoba, As an individual).

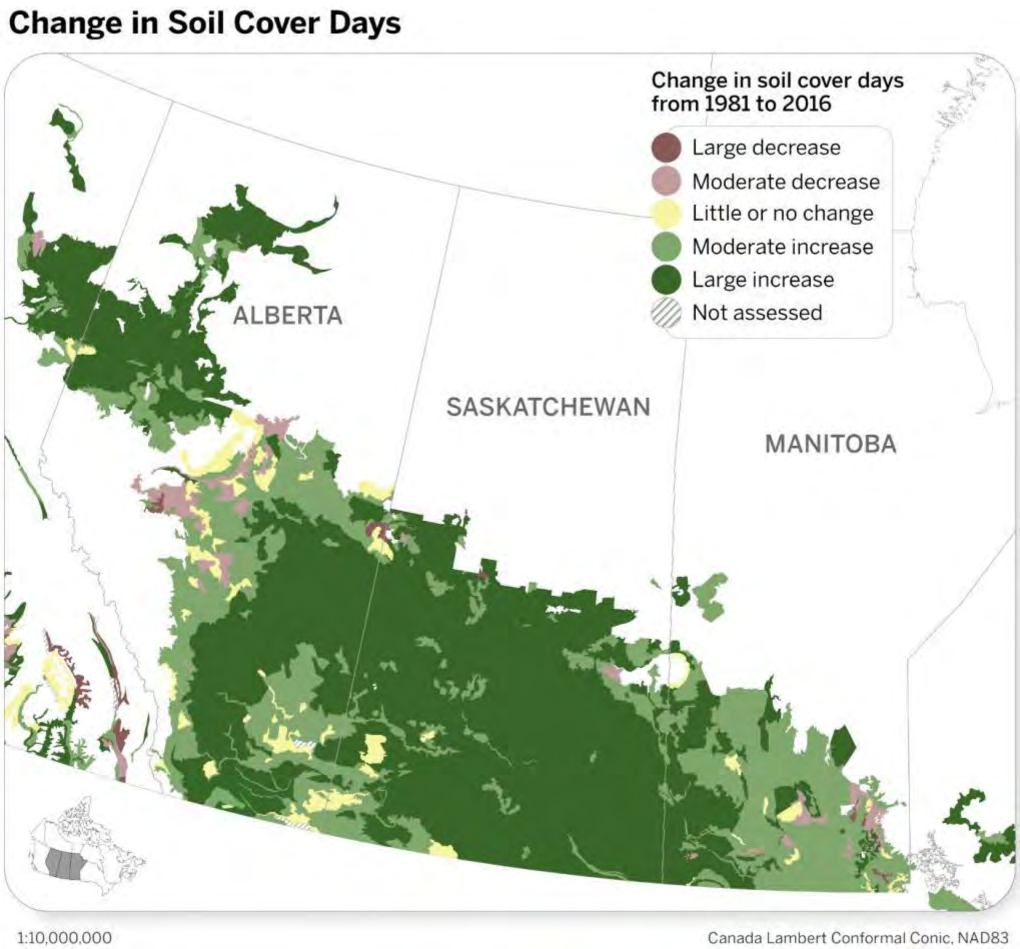
Figure 9 - Percentage of Hectares Prepared For No-Till Seeding: Prairies (2021)



Sources: Map prepared in 2024 using data obtained from Statistics Canada, "Table 32-10-0367-01: Tillage and seeding practices, Census of Agriculture, 2021," Database, accessed 28 November 2023; and Statistics Canada, *2021 Census – Boundary files*. The following software was used: Esri, ArcGIS Pro, version 3.2.2. Contains information licensed under *Statistics Canada Open Licence*.

The map in Figure 10 illustrates the change in soil cover days for the Prairies from 1981 to 2016. Many agricultural areas in Alberta and Saskatchewan exhibit large increases, whereas Manitoba exhibited moderate increases in soil cover days.

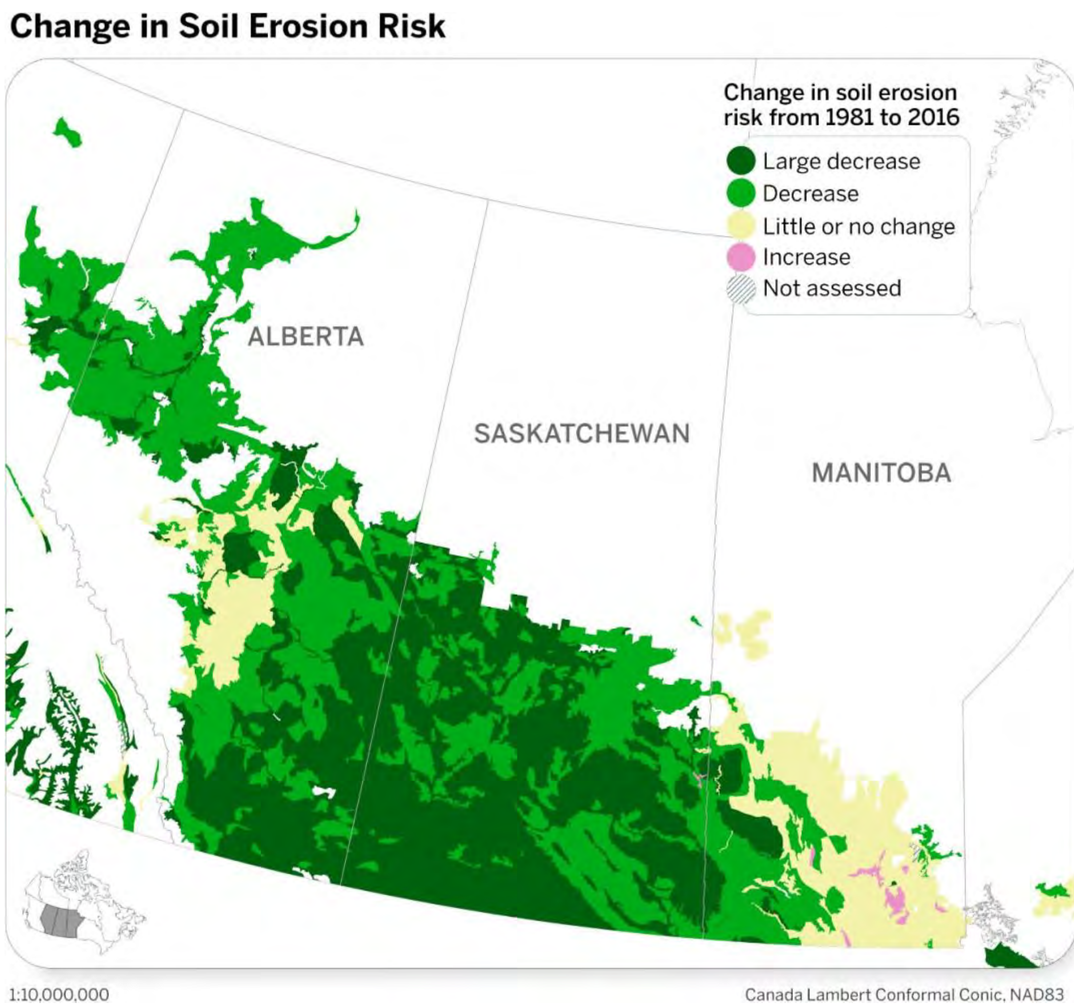
Figure 10 – Change in Soil Cover Days: Prairies (1981 to 2016)



Sources: Map prepared in 2024 using data obtained from Agriculture and Agri-Food Canada, *Agri-Environmental Indicator – Soil Cover Days*, 16 December 2020; and Statistics Canada, *2021 Census – Boundary files*. The following software was used: Esri, ArcGIS Pro, version 3.2.2. Contains information licensed under *Open Government Licence – Canada* and *Statistics Canada Open Licence*.

From 1981 to 2016, large decreases in soil erosion risk appeared in southern Alberta and Saskatchewan, with little or no change in southern Manitoba, and mostly a decrease in all other areas, as shown in Figure 11.

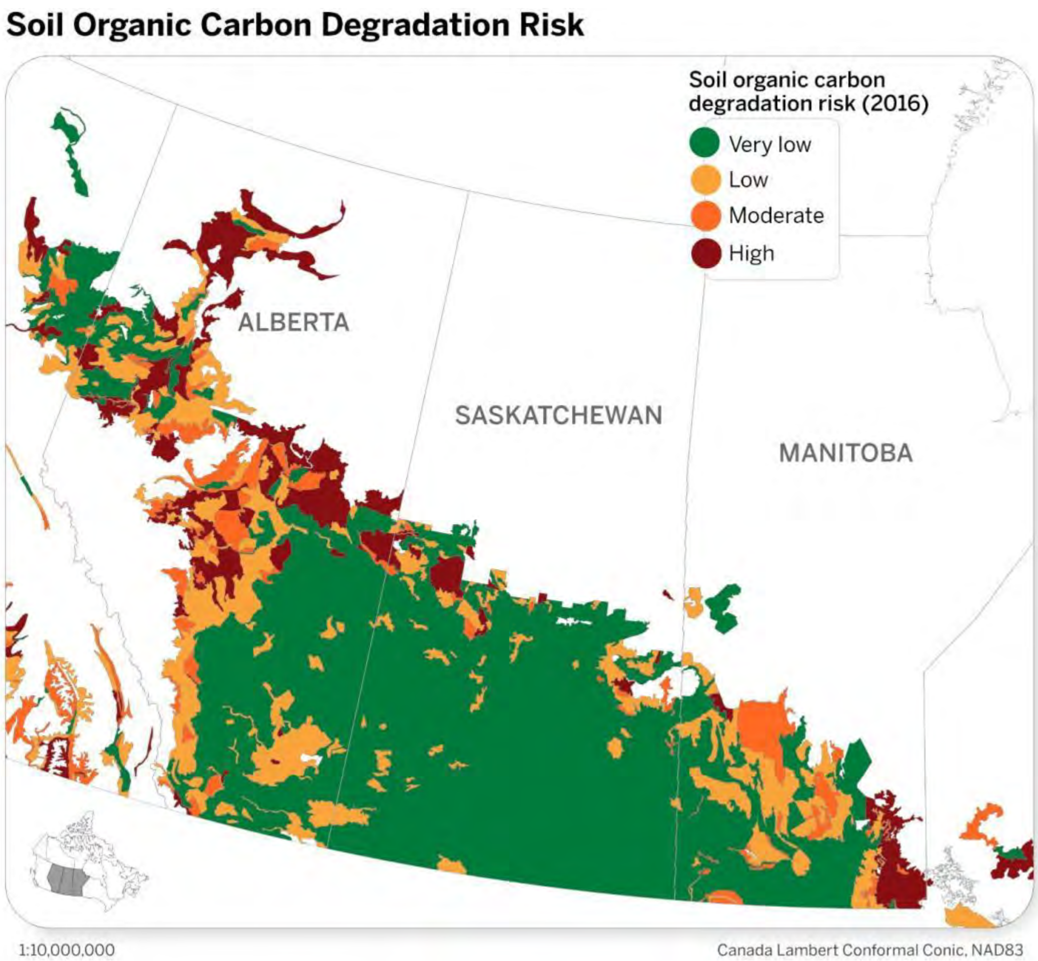
Figure 11 – Change in Estimated Risk of Soil Erosion: Prairies (1981 to 2016)



Sources: Map prepared in 2024 using data obtained from Agriculture and Agri-Food Canada, *Agri-Environmental Indicator – Risk of Soil Erosion*, 18 January 2021; and Statistics Canada, *2021 Census – Boundary files*. The following software was used: Esri, ArcGIS Pro, version 3.2.2. Contains information licensed under *Open Government Licence – Canada* and *Statistics Canada Open Licence*.

As mentioned by several witnesses, no-till stops soil degradation from decreasing soil health and also increases soil organic carbon. Figure 12 presents the estimated risk of soil organic carbon degradation for the Prairies in 2016. Areas in northern Alberta and eastern Manitoba appear to be at highest risk while southeastern Alberta, south-central Saskatchewan and southwestern Manitoba were at lowest risk.

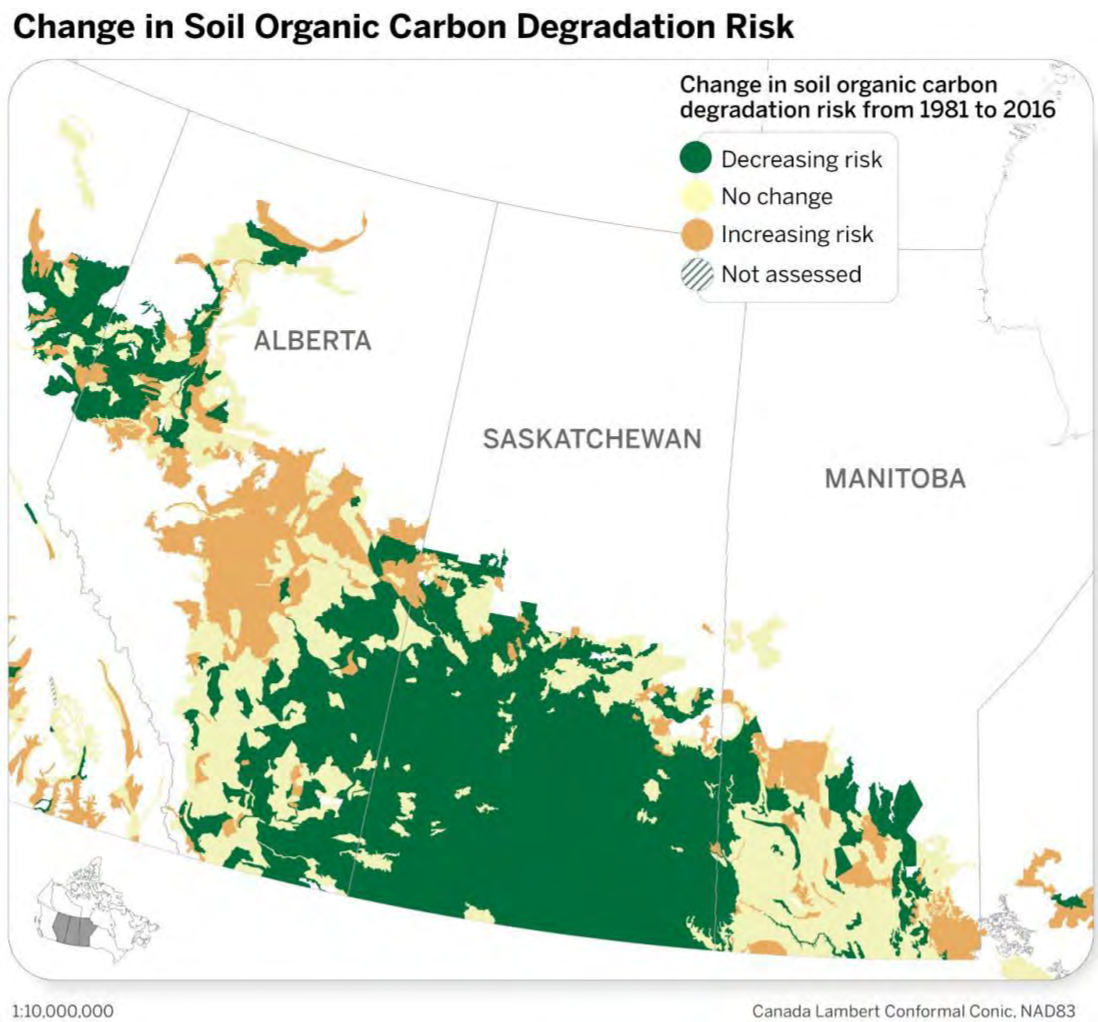
Figure 12 – Soil Organic Carbon Degradation Risk: Prairies (2016)



Sources: Map prepared in 2024 using data obtained from Agriculture and Agri-Food Canada, *Agri-Environmental Indicator – Soil Organic Matter*, 18 January 2021; and Statistics Canada, *2021 Census – Boundary files*. The following software was used: Esri, ArcGIS Pro, version 3.2.2. Contains information licensed under *Open Government Licence – Canada* and *Statistics Canada Open Licence*.

With respect to the estimated change in the overall level of risk of soil organic carbon degradation from 1981 to 2016, a large swath of southern Alberta and Saskatchewan, as well as northwestern Alberta, were classified as having decreasing risk, southern Manitoba as mostly experiencing no change and central Alberta as having some increasing risk, as shown in Figure 13.

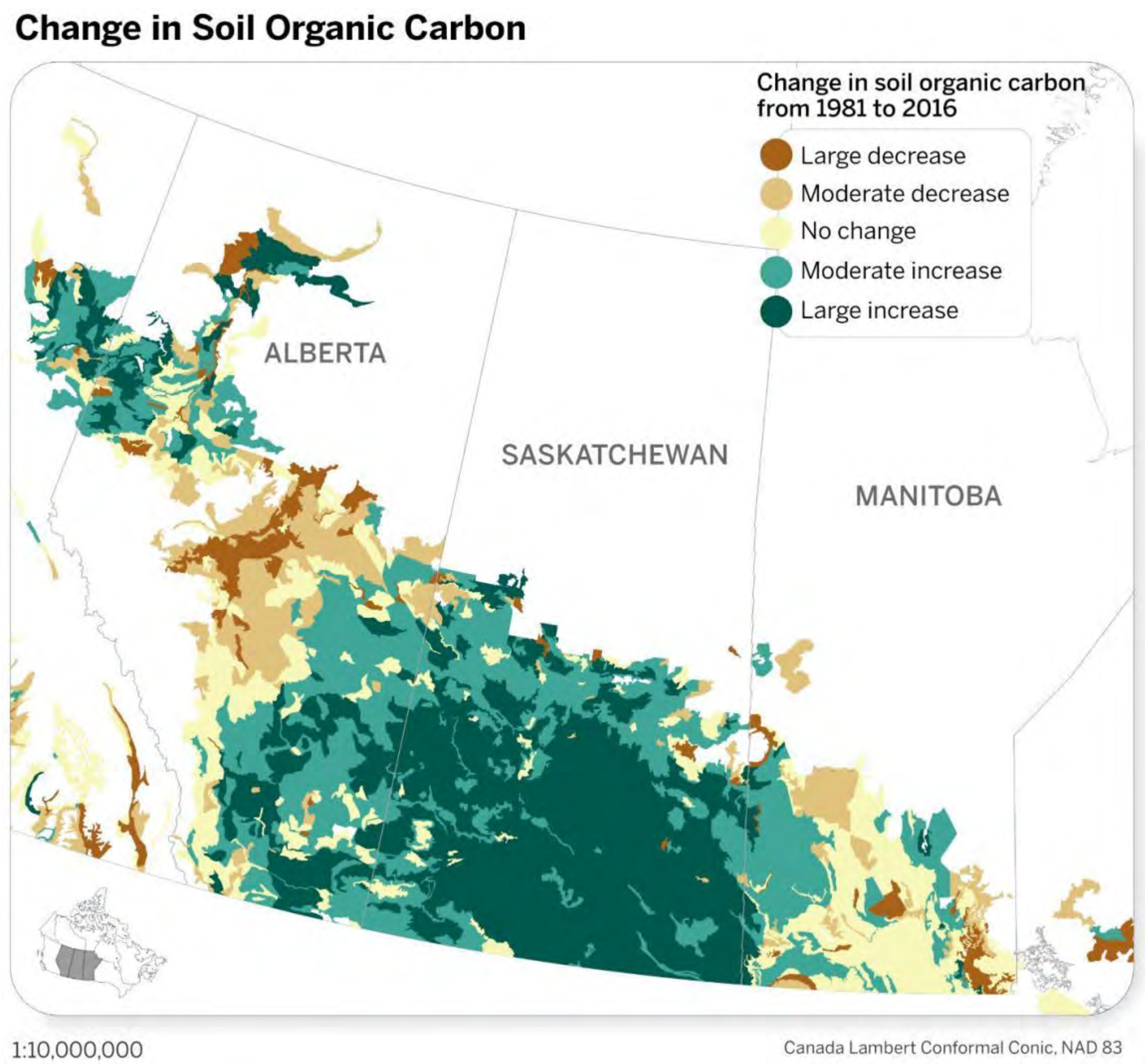
Figure 13 – Change in Soil Organic Carbon Degradation Risk: Prairies (1981 to 2016)



Sources: Map prepared in 2024 using data obtained from Agriculture and Agri-Food Canada, *Agri-Environmental Indicator – Soil Organic Matter*, 18 January 2021; and Statistics Canada, *2021 Census – Boundary files*. The following software was used: Esri, ArcGIS Pro, version 3.2.2. Contains information licensed under *Open Government Licence – Canada* and *Statistics Canada Open Licence*.

Regarding the change in soil organic carbon over time, Figure 14 shows a patchwork of changes throughout the Prairies from 1981 to 2016, with areas of moderate and large decrease and no change in central Alberta and southern Manitoba. Areas of moderate and large increase are shown in Alberta, southern Saskatchewan, and southwestern Manitoba.

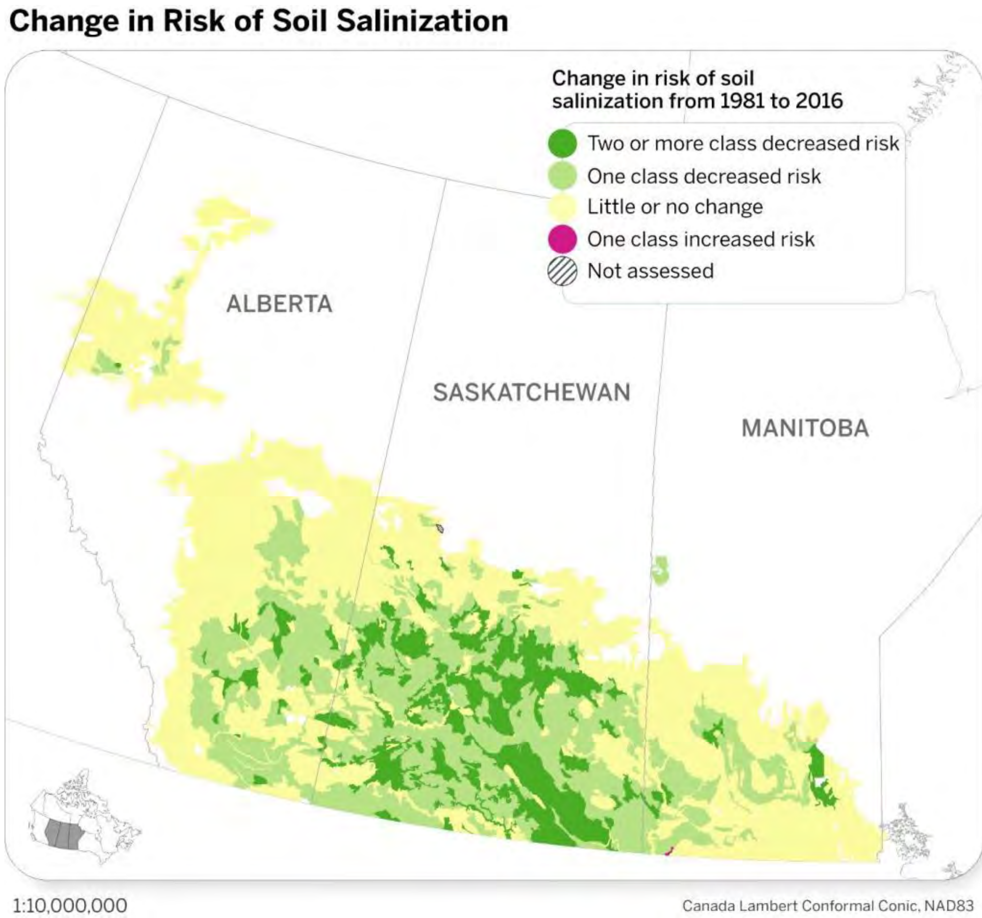
Figure 14 – Change in Soil Organic Carbon: Prairies (1981 to 2016)



Sources: Map prepared in 2024 using data obtained from Agriculture and Agri-Food Canada, *Agri-Environmental Indicator – Soil Organic Matter*, 18 January 2021; and Statistics Canada, *2021 Census – Boundary files*. The following software was used: Esri, ArcGIS Pro, version 3.2.2. Contains information licensed under *Open Government Licence – Canada* and *Statistics Canada Open Licence*.

Figure 15 illustrates the change over time in the estimated risk of the accumulation of soluble salts on agricultural lands in the Prairies from 1981 to 2016. At high levels, the accumulation of these salts in soil and groundwater can inhibit the growth of many crop species. Agricultural areas in southern Saskatchewan exhibit moderate to large decreases. Alberta and Manitoba exhibit decreases and little or no change relatively equally. One small area in southwest Manitoba exhibits an increased risk of salinization.

Figure 15 – Change in Risk of Soil Salinization: Prairies (1981 to 2016)



Sources: Map prepared in 2024 using data obtained from Agriculture and Agri-Food Canada, *Agri-Environmental Indicator – Risk of Soil Salinization*, 17 November 2020; and Statistics Canada, *2021 Census – Boundary files*. The following software was used: Esri, ArcGIS Pro, version 3.2.2. Contains information licensed under *Open Government Licence – Canada* and *Statistics Canada Open Licence*.

On its fact-finding mission in Saskatchewan at Discovery Farm Langham, the committee saw first-hand how salinity-affected soils were vulnerable to salt-tolerant weeds such as kochia and foxtail barley. During its hearings, the committee heard that soil salinity is generally stable in Manitoba, but that it can also fluctuate.[64] It also heard that, in Alberta, soil salinity is forgotten in many areas, especially in a wet cycle, and that it becomes an issue as soon as a dry cycle comes.[65] Witnesses said that putting in forages, collaborating, and looking at research, the economics and the regionality of the issues is where they can do the most work for managing salinity.

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64 AGFO, *Evidence*, *20 April 2023 (Marla Riekman, Land Management Specialist – Soils, Manitoba Agriculture, Government of Manitoba).*

65 AGFO, *Evidence*, *20 April 2023 (Trevor Wallace, Provincial Nutrient Management Specialist, Natural Resource Management Branch, Alberta Agriculture and Irrigation, Government of Alberta).*

Alberta

Alberta has approximately 49 million acres of farmland, or one-third of Canada's total. This includes
1.8 million irrigated acres, more than 70% of the country's total. The province is home to about 22 million acres of forage and 27 million acres of annual crop production. According to AAFC, between 2018 and 2022 Alberta's top three crop and livestock commodities by average farm cash receipts were: cattle and calves ($5.5 billion), canola ($3.1 billion), and wheat ($2.5 billion).[66]

Tall grass grows in a field in Alberta with rolling hills in the background.

Trevor Wallace, Provincial Nutrient Management Specialist, Natural Resource Management Branch, Alberta Agriculture and Irrigation, Government of Alberta, informed the committee that Alberta's soils are "well-functioning," less susceptible to erosion, and more resilient to stress. Wallace explained that farmers have reduced summer fallow; adopted reduced tillage, including livestock in production systems; implemented intensive and rotational grazing practices; and diversified rotations by including legumes and perennials.[67]

66 Government of Canada, *Overview of Canada's agriculture and agri-food sector*.

67 AGFO, *Evidence*, 20 April 2023 (Trevor Wallace, Provincial Nutrient Management Specialist, Natural Resource Management Branch, Alberta Agriculture and Irrigation, Government of Alberta).

These practices have helped to increase soil organic matter and soil carbon levels; however, Wallace cautioned that the work is far from complete as some soils are eroding and becoming more saline, acidic, or compacted. For example, soils such as the Gray Luvisols require more careful management and are at greater risk of degradation. Gray Luvisols typically occur under boreal or mixed forest vegetation and in forest-grassland transition zones in a wide range of climatic areas.[68] Weather, disease, pests, oil and gas-related activities, and evolving production practices impact the soil's ability to function. "Without thoughtful management," said Wallace, "these factors will undermine our gains."[69]

Wallace said that financial incentives such as those delivered by the Sustainable CAP must be supported, as well as applied on-farm testing of new practices; adoption and long-term maintenance of beneficial management practices; business risk management tools that provide operational risk protection when changing practices; and opportunities for ecological goods and services.[70]

> *"But soil is represented by nobody. All the commodity groups depend on soil, but none of the commodity groups are directly soil focused. It's all part of the system, and there have been a lot of initiatives by them to maintain and improve our soils. But it is not like they have a voice at the table sometimes directly from soil on some of its needs — nor funding or checkoff dollars — to support programming like this. Right now, it is falling on the shoulders of individual producers. They are collecting data and improving their systems, and we are just not aggregating it up to provincial."*
>
> *Trevor Wallace*[71]

Saskatchewan

Saskatchewan holds over 40% of Canada's total cropland and one third of Canada's native grass and forage land. According to the 2022 National Inventory Report, Saskatchewan producers sequestered almost 13 million tons of carbon in 2020, almost 80% of the province's total agriculture emissions. Recent research commissioned by the Global Institute for Food Security found that Saskatchewan's net carbon footprint for canola and wheat production was more than 60% lower than competitive jurisdictions and for dry field peas, it was 95% lower.

According to AAFC, between 2018 and 2022 the top three crop and livestock commodities by

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68 *Government of Canada, Gray Luvisol (GL).*

69 *AGFO, Evidence, 20 April 2023 (Trevor Wallace, Provincial Nutrient Management Specialist, Natural Resource Management Branch, Alberta Agriculture and Irrigation, Government of Alberta).*

70 *Ibid.*

71 *Ibid.*

average farm cash receipts for Saskatchewan were: canola ($5.8 billion), wheat ($4.0 billion), and cattle and calves ($1.5 billion).[72]

From left, senators David M. Arnot, Sharon Burey, Paula Simons, Rob Black and Brent Cotter tour the Glacier FarmMedia Discovery Farm in Langham, Saskatchewan.

Rick Burton, Deputy Minister of Agriculture, Government of Saskatchewan, told the committee that about 95% of the province's land seeded to annual crops is done using zero or minimum tillage, representing a major increase from 36% in 1991.[73] This is a higher percentage than any other province or territory. Burton said Saskatchewan producers have also adopted a diverse crop rotation, including oilseeds, pulses, and cereals. Growing a rotation of crops fertilized with balanced nutrients contributes to producing optimum yields, thereby helping to optimize carbon sequestration, nutrient cycling, and soil structure.

Jocelyn Velestuk, Farmer, Grain Growers of Canada, highlighted that long-term studies, such as the Prairie Soil Carbon Balance Project, have reported that there is still incremental positive carbon change, even 30 years after Saskatchewan farmers switched to no-till/continuous cropping practices: "The gains occur even deeper in the soil profile than originally thought. Saskatchewan farmers sequester enough carbon in the soil every year to be equivalent to removing 10 million cars from the roads."[74]

Rick Burton also said Saskatchewan is investing more than $35 million annually in agriculture research and innovation, with $6.4 million directly impacting soil health and research into soil health and an additional $22 million indirectly supporting soil health through breeding and other related activities.

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72 Government of Canada, Overview of Canada's agriculture and agri-food sector.

73 AGFO, Evidence, 30 March 2023 (Rick Burton, Deputy Minister of Agriculture, Government of Saskatchewan).

74 AGFO, Evidence, 9 March 2023 (Jocelyn Velestuk, Farmer, Grain Growers of Canada).

Jocelyn Velestuk mentioned that most soil survey mapping and data collection occurred in the 1980s in the Prairies and that it has been tabulated into an online mapping platform in Saskatchewan:

"Specific agricultural areas can build and improve on the soil survey digital maps with improved LiDAR data and other layers of data to get a better understanding of soil properties, such as soil organic carbon, and to help direct sample points for soil fertility measurements in the field. Ground truthing the data is also important to improve these maps."[76]

> *"Our producers are contributing to soil conservation and management, and they are making substantial contributions to global food security. Yet, federally, producers are not always recognized for these contributions."*
>
> *Rick Burton*[75]

In terms of barriers, Candice Pete-Cardoso, Director, Indigenous Land Management Institute, University of Saskatchewan, informed the committee that, traditionally, First Nations vary widely in the number and capacity of staff involved in making land management decisions, with implications for caretaking of soil health:

"For many First Nations across the Prairies, there may be a single land manager who is responsible for an expansive range of duties, one of which may be negotiating and administering permits and leases with producers to rent reserve farmland. However, if the land manager leadership or members of a land advisory committee don't have a strong foundation in agriculture, including soil management, soils have the potential to be degraded."[77]

Rick Burton mentioned that the province had recently hired a senior Indigenous adviser and set up an Indigenous unit to help engage with First Nations and Métis communities in Saskatchewan: "We have a team of regional specialists, called the Building and Strengthening Indigenous Supports group, which is trying to build relationships to help Indigenous communities take advantage of the agriculture opportunities that exist for them and where they are seeing interest in expanding those."[78]

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[75] *AGFO, Evidence, 30 March 2023 (Rick Burton, Deputy Minister of Agriculture, Government of Saskatchewan).*

[76] *AGFO, Evidence, 9 March 2023 (Jocelyn Velestuk, Farmer, Grain Growers of Canada).*

[77] *AGFO, Evidence, 9 February 2023 (Candice Pete-Cardoso, Director, Indigenous Land Management Institute, University of Saskatchewan, As an individual).*

[78] *AGFO, Evidence, 30 March 2023 (Rick Burton, Deputy Minister of Agriculture, Government of Saskatchewan)*

Critical Ground - Why Soil is Essential to Canada's Economic, Environmental, Human, and Social Health

Chapter 4: The Role of Agroforestry and Its Impacts on Soil Health

Introduction

Agroforestry is a unique land management approach that intentionally blends agriculture and forestry to enhance productivity, profitability, and environmental stewardship. The committee learned that agroforestry is a key tool for Canada’s farmers, ranchers, woodland/woodlot owners, Indigenous communities, and others who want to use sustainable strategies that enhance agricultural practices and protect soil, water, and air.

Nadir Erbilgin, Professor and Chair, Department of Renewable Resources, University of Alberta, told the committee that agroforestry is a simple way of improving soil health. “[Agroforestry] really optimizes the numerous benefits arising from the biophysical and even biochemical interactions among the crops and livestock with the trees.” [202] Furthermore, E.P. (Ted) Taylor, Soil Resource Specialist, Soil Resource Group, explained that the main linkages of agroforestry to soil health are: long-term cover of soils, continuous and substantive additions of organic matter, and, carbon sequestration.[203]

Overall, the committee heard that agroforestry has a positive long-term impact on soil health in Canada when properly planned and managed.

“Farmers Like Trees”: Types of Agroforestry Systems in Canada

Agroforestry is practiced in different ways throughout Canada and varies according to region, climate, as well as the specific goals of landowners.

In a written brief, Raju Soolanayakanahally, Research Scientist, Agriculture and Agri-Food Canada (AAFC), outlined the five most common agroforestry practices in Canada:

1. **shelterbelts/windbreaks**: Rows of trees or shrubs planted around or within fields and livestock facilities to protect crops, livestock and soil from wind and snow accumulation while also improving biodiversity.

    - British Columbia (Peace River region), Prairies (Alberta, Manitoba, Saskatchewan) and Great Lakes region.

2. **riparian tree buffers**: A strip of forested land adjacent to a flowing body of fresh water (e.g., stream, lake, wetland). Physically separates agricultural activities from sensitive aquatic areas.

    - Nova Scotia, Ontario, Prince Edward Island, Quebec.

3. **alley cropping/tree intercropping**: A practice in which crops and trees are interplanted throughout a field. Arable crops are grown between rows of high-value trees to maximize benefits and productivity per unit area of land.

- New Brunswick, Ontario, Quebec.

4. **silvopasture**: The intentional integration of pasture, livestock, and trees. Provides shade and winter shelter for livestock; increases pasture acreage and diversity, use of existing farm woodland, forage availability during droughts; diversifies livestock diet; and improves animal welfare.

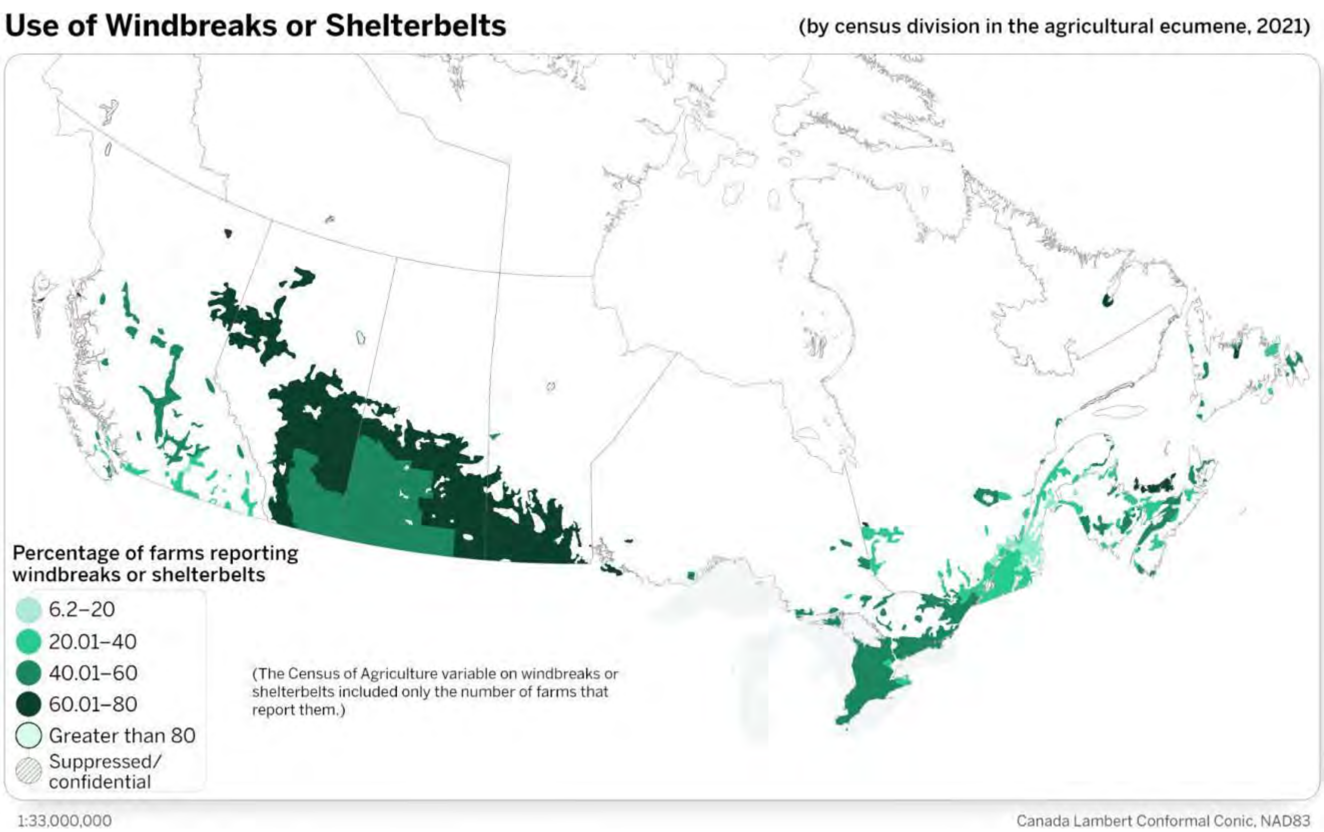
    - British Columbia (interior) and Quebec.

5. **farm woodlands or woodlots**: Private enterprises use this farming practice to grow non-timber forest products on private lands, supplement family income, and allow biodiversity to re-establish within woodlands.

    - Ontario, Quebec.[204]

According to Statistics Canada Census of Agriculture, in 2021, the most significant areas with windbreaks or shelterbelts are in the Prairies, exhibiting between 40% and 80% with two small pockets in the northern part of the provinces having more than 75%. Central and Atlantic Canada range between 6.2% and 60% with the lowest numbers in southern Quebec, the higher numbers mostly in southern Ontario and the highest in Prince Edward Island (see Figure 28).

Figure 28 – Percentage of Farms Reporting the Use of Windbreaks or Shelterbelts in Canada

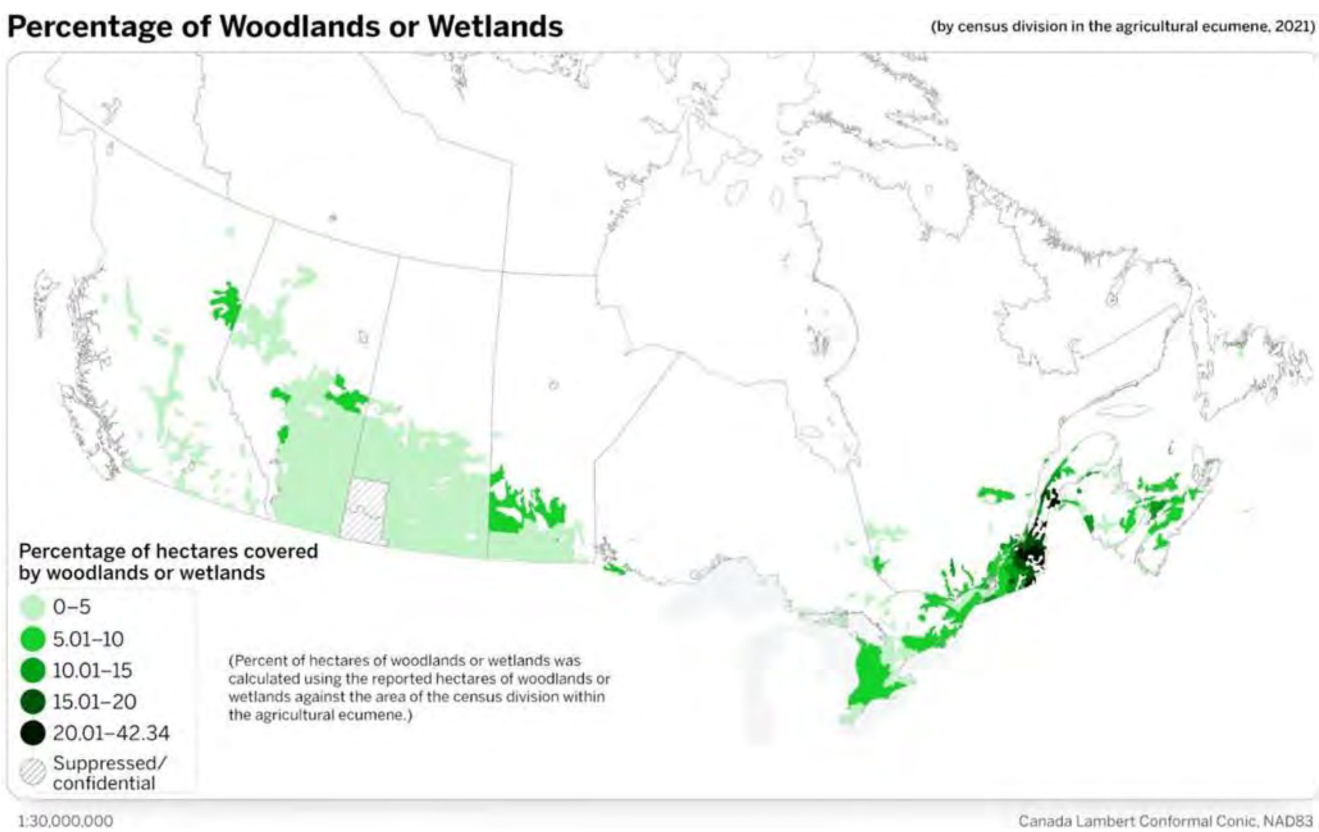


Note: The Census of Agriculture variable on windbreaks or shelterbelts included only the number of farms that reported them.

Sources: Map prepared in 2024 using data obtained from Statistics Canada, "Table 32-10-0369-01: Land practices and land features, Census of Agriculture, 2021," Database, accessed 12 March 2024; and Statistics Canada, 2021 Census – Boundary files. The following software was used: Esri, ArcGIS Pro, version 3.2.2. Contains information licensed under Statistics Canada Open Licence.

The 2021 Census of Agriculture reported that British Columbia, the Prairies, and Ontario exhibit 10% or less of hectares covered by woodlands or wetlands, while data in Atlantic Canada reveal one region in Nova Scotia on the border of New Brunswick with up to 15%. Southern Quebec, south of the St. Lawrence, exhibits some of the highest values up to 42.34%, as illustrated in Figure 29.

Figure 29 – Percent of Hectares Covered by Woodlands or Wetlands in Canada



Note: Percent of hectares was calculated using the reported hectares of woodlands or wetlands with only the area of the census division within the agricultural ecumene.

Sources: Map prepared in 2024, using data obtained from Statistics Canada, "Table 32-10-0249-01 Land use, Census of Agriculture, 2021," Database, accessed 12 March 2024; and Statistics Canada, 2021 Census – Boundary files. The following software was used: Esri, ArcGIS Pro, version 3.2.2.
Contains information licensed under the Statistics Canada Open Licence.

Economic and Environmental Benefits

In terms of economic benefits, the committee learned that agroforestry practices can help farmers and ranchers increase their crop yields and reduce energy, fertilizer, heating, and snow removal costs.

Agroforestry also allows farmers and ranchers to develop specialty agricultural and wood products, which can provide diverse income streams and increased wealth in rural communities. Witnesses listed many examples of specialty agricultural products such as honey, maple syrup products, medicinal herbs, mushrooms, nuts, and wild berries.

Witnesses also highlighted examples of specialty wood products, including biomass for energy; firewood, sawlog timber, veneer, utility hardwoods for pallets; conifers for fence posts; on-farm use woods for corrals, fences, wagon building; and recreational use woods for decks or fences, among others.

In a written brief, Raju Soolanayakanahally reported that a recent quantification of carbon stocks with agroforestry systems in central Alberta from hedgerows, shelterbelts, and silvopastures revealed that 699.9 million tons (Mt) of carbon were stored across 9.5 million hectares (Mha) of land and valued at $102.7 billion based on a Canadian carbon tax rate of $40 per ton of CO_2 equivalent in 2021."[205]

The committee also heard about the many environmental benefits and essential ecosystem services that agroforestry and woody vegetation offer, including:

- clean air and water;
- climate change mitigation by sequestering carbon dioxide from the atmosphere and reducing GHG emissions;
- soil rehabilitation;
- crop diversification which reduces risks associated with monoculture soil degradation, pests, and disease; and,
- improved biodiversity by providing wildlife habitat, nesting sites for birds, refuge for beneficial insects and pollinators, and habitat protection for fish and other aquatic ecosystems.

Specifically, agroforestry systems such as shelterbelts increase crop yields by providing wind protection and improving water-use efficiency. Riparian buffers help to stabilize eroding banks and shorelines; reduce sediment flow into water bodies to protect water quality; and absorb nutrients (nitrogen, phosphorous) and pesticide compounds. Silvopasture can offset methane emissions from cattle through the carbon-capture capabilities of trees and shrubs.[206]

Raju Soolanayakanahally added that through the integration of agroforestry, we can further enhance the physical, chemical, and biological properties of our soils, providing essential environmental services such as:

- using trees with deep roots to bring up vital nutrients for crops and vegetation, and,
- adding organic matter to the soil through litter to support soil biodiversity and functions

such as nutrient cycling, soil health and land productivity.[207]

Several witnesses told the committee that farmers and ranchers face many barriers to adopting agroforestry practices such as: accessing suitable tree species, costs for equipment, implementation, and planting; and, weed management.

Witnesses also described the barriers that stem from the lack of government funding for agroforestry such as:

- lack of crop insurance for growing trees;
- lack of a viable carbon market for trees sequestrating carbon;
- lack of government funding and research for agroforestry;
- lack of a strategic framework or policy for agroforestry; and,
- lack of Indigenous knowledge transfer on agroforestry practices.

The committee also heard that there is a jurisdictional dilemma with regards to who is responsible for agroforestry on agricultural land in Canada. Ken Van Rees, Professor Emeritus, Forest Soils, University of Saskatchewan, said that a clear outline for agroforestry is needed.

> *"During my 20 years of doing this research, no one at Agriculture Canada and Natural Resources Canada wanted to take responsibility for growing trees on agricultural land. We need to sort this out. That is why the PFRA [Prairie Farm Rehabilitation Administration] Shelterbelt Centre was a key piece to doing that."*
>
> *Ken Van Rees*[208]

The PFRA produced millions of trees onsite and provided them for free to landowners across the prairies for planting.

In a similar vein, Kevin Boon, General Manager, B.C. Cattlemen's Association, pointed out a jurisdictional dilemma regarding agroforestry in British Columbia:

"In essence, we utilize it and need to manage it as agroforestry. But the responsibility for that, because it is Crown land, falls on the provincial government, and much of it is managed by regulation and not necessarily by science. We see some problems with that."[209]

> *"The problem is everybody is looking for a quick fix. Trees take a while to grow and be established. We need to move out of this mentality of a quick fix and look at agroforestry's long-term value. Agriculture Canada has not been funding agroforestry nearly to the extent that it should be."*
>
> *Paul Renaud*[210]

Paul Arp said that soil mapping at one-metre resolution is the solution as better maps allows people to plan better: "[…] mapping the land at the one-meter resolution allows you to see where to place what parts of the agroforestry component that you wish. You would know beforehand if you have land that is suitable for this and suitable for that."[211]

Paul Arp explained further: “If you know where to grow which trees and where to establish which crops for agriculture production, and not only that but also how to deal with the wetland issue — not so much the protection of the wetland but more generally the protection of biodiversity or the expansion into biodiversity goals — it would be fundamental to keep us sustainable and self- sufficient.” [212]

Paul Renaud agreed about the need for enhancing soil mapping:

> *“Hold AAFC and ECCC accountable for answering this question: Why is it that we do not know the net carbon footprint of agriculture in Canada? That would require them to understand the amount of land covered by trees, possibly to expand the wonderful program that Dr. Arp is doing in terms of mapping land use across Canada, not just in New Brunswick, so that we can get facts that we can put on the table to understand and make informed decisions.”*
>
> *Paul Renaud*[213]

Renaud also suggested that the Government of Canada redirect the carbon tax revenue that is collected from carbon emitters and use it to incentivize those who sequester carbon.

> *“Can you imagine if we started paying that dairy farmer in Perth $100,000, how his neighbours and other dairy farmers in Canada would react? They would jump on board. They would want more trees; they would look at ways to cut their emissions. This would generate such an amazing transformative effect that it would be astounding.”*
>
> *Paul Renaud*[214]

202 AGFO, Evidence, 27 September 2022 (Nadir Erbilgin, Professor and Chair, Department of Renewable Resources, As an individual).

203 AGFO, Evidence, 2 November 2023 (E.P. (Ted) Taylor, Soil Resource Specialist, Soil Resource Group).

204 Raju Soolanayakanahally, Research Scientist, Agriculture and Agri-Food Canada, Brief submitted to AGFO, 2 November 2023.

205 Raju Soolanayakanahally, Research Scientist, Agriculture and Agri-Food Canada, Brief submitted to AGFO, 2 November 2023

206 Ibid.

207 Ibid.

208 AGFO, Evidence, 2 November 2023 (Ken Van Rees, Professor Emeritus, Forest Soils, University of Saskatchewan, As an individual).

209 AGFO, Evidence, 2 November 2023 (Kevin Boon, General Manager, B.C. Cattlemen’s Association).

210 AGFO, Evidence, 2 November 2023 (Paul Renaud, Chief Executive Officer, The Lanigan Group).

211 AGFO, Evidence, 2 November 2023 (Paul Arp, Professor, Forest Soils, Forestry and Environmental Management, University of New Brunswick, As an individual).

212 Ibid.

213 AGFO, Evidence, 2 November 2023 (Paul Renaud, Chief Executive Officer, The Lanigan Group).

214 Ibid.

Key Topic #4: Field Skills

13. Identify characteristics of soil pit or soil sample, including horizons, color, structure, texture, and special features.
14. Measure slope using a clinometer.
15. Use a soil triangle to evaluate the texture of a soil.
16. Utilize field tools to provide on-site soil analysis, including:
    a. Auger
    b. Munsell soil color chart
    c. Particle sieve
    d. pH test kit
17. Apply knowledge of soil properties and characteristics to make management recommendations.

Study Resources

Resource Title	Source	Located on Page
Horizons	*Soils of Canada, Canadian Society of Soil Science*	93
The Canadian System of Soil Classification, Chapter 1 Rationale of Soil Taxonomy in Canada	*Soil Classification Working Group. 1998. The Canadian System of Soil Classification, 3rd ed. Agriculture and Agri-Food Canada Publication 1646*	95

Horizons

The action and interaction of soil-forming processes as influenced by soil-forming factors gives rise to distinct soil horizons. These layers are assigned distinctive alphabetic symbols as a form of shorthand for their characteristics. The horizon description system begins by splitting soil horizons into two distinct groups: organic and mineral horizons. Organic horizons are those that contain 17% or more organic carbon; mineral horizons have less than 17% organic carbon.

The major symbols used in describing mineral soil layers in Canada are shown in the following tables. The assignment of mineral soil layers to each horizon is done by comparing the properties of the horizons in the field to a list of distinctive characteristics, called diagnostic properties.

Table 1: Basic description of mineral soil horizons in the Canadian System of Soil Classification (Agriculture Canada Expert System on Soil Survey, 1987).

Master Horizon	**Suffixes**	**Basic Description**
A		Mineral horizon formed at or near the soil surface
	Ah	Accumulation of soil organic matter (SOM)
	Ae	Removal of clay, SOM, iron, or aluminum
B		Horizon formed by accumulation of material removed from Ae horizon or by alteration of the parent material
	Bh	Accumulation of SOM
	Bf	Accumulation of iron and/or aluminum
	Bss	Presence of slickensides (smooth clay coating caused by stress in high clay soils)
	Bv	Vertic horizon caused by turbation (mixing) of material in high clay soils
	Bt	Accumulation of clay
	Bn	Strong soil structure and sodium accumulation
	Bg	Mottling and gleying due to water saturation
	Bm	Slight colour or structural changes from the parent material
C	C	Horizon with little evidence of pedogenic activity

	Cca	Accumulation of Ca and Mg carbonates
	Cs	Accumulation of soluble salts
	Ck	Presence of original Ca and Mg carbonates
	Css	Presence of slickensides
	Cg	Mottling and gleying due to water saturation
R		Consolidated bedrock
W		Water layer

Table 2: Basic description of organic soil horizons as classified in the Canadian System of Soil Classification. Reference as in Table 1.

Master Horizon	**Suffixes**	**Basic Description**
O		An organic horizon developed mainly from bog vegetation; it is more commonly called peat. These materials are usually water saturated.
	Of	Composed of fibrous materials of readily recognizable origin
	Om	Organic materials in an intermediate (or mesic) stage of decomposition; some have a recognizable form, but the remainder is highly decomposed
	Oh	Organic material which is highly decomposed (in a humic state); the origin of the material is unrecognizable
L, F, H		Organic materials that occur from the accumulation of leaves, twigs and woody materials and which overlies a mineral soil; commonly found in well to imperfectly drained forest environments.
	L	Leaf litter, readily recognizable
	F	Partially decomposed leaf and twig material (folic material)
	H	Humic material; decomposed organic materials with no original structures evident

Canadian System of Soil Classification

Chapter 1: Rationale of Soil Taxonomy in Canada

During some 80 years of pedological work in Canada, concepts of soil and systems of classification have progressed as a result of new knowledge and new concepts developed in Canada and elsewhere. Here an attempt is made to enunciate the current rationale of soil taxonomy based on the historical material outlined in the previous section and on recent publications on pedology in Canada.

The nature of soil

The concept of soil in Canada and elsewhere (Cline 1961; Knox 1965; Simonson 1968) has changed greatly since 1914 when the first soil survey was started in Ontario. No specific definition is available from that early work, but clearly soil was thought of as the uppermost geological material. Texture was apparently considered to be its most important attribute. Currently, soil is defined in general terms by pedologists as the naturally occurring, unconsolidated, mineral or organic material at the earth's surface that is capable of supporting plant growth. Its properties usually vary with depth. They are determined by climatic factors and organisms, as conditioned by relief and, hence, water regime acting on geological materials and producing genetic horizons that differ from the parent material. In the landscape, soil merges into nonsoil entities such as exposed, consolidated rock or permanent bodies of water at arbitrarily defined boundaries. Specific definitions of soil and nonsoil are given in Chapter 2.

Because soil occurs at the surface of the earth as a continuum with variable properties, it is necessary to decide on a basic unit of soil to be described, sampled, analyzed, and classified. Such a unit was defined by United States' pedologists (Soil Survey Staff 1960) and is accepted in Canada. Called a pedon, it is the smallest, three-dimensional body at the surface of the earth that is considered to be a soil. Its lateral dimensions are 1-3.5 m and its depth is 1-2 m. The pedon is defined more specifically in Chapter 2.

Nature and purpose of soil classification

Soil classification systems are not truths that can be discovered but rather are methods of organizing information and ideas in ways that seem logical and useful (Soil Survey Staff 1960). Thus no classification system is either true or false; some systems are more logical and useful for certain objectives than others. A classification system reflects the existing knowledge and concepts concerning the population of soils being classified (Cline 1949). It must be modified as knowledge grows and new concepts develop.

Both the theoretical and practical purposes of soil classification have been discussed in the literature (Cline 1949, 1963; De Bakker 1970). The general purpose of soil classification in Canada may be stated as follows:

- to organize the knowledge of soils so that it can be recalled systematically and communicated, and that relationships may be seen among kinds of soils, among soil properties and environmental factors, and among soil properties and suitabilities of soils for various uses.

The related purposes of soil classification are to provide a framework for formulating hypotheses about soil genesis and the response of soil to management, to aid in extending knowledge of soils gained in one area to other areas having similar soils, and to provide a basis for indicating the kinds of soils within mapping units. Soil classification is essential to soil surveys, to the teaching of soils as a part of natural science, and to meeting the practical needs related to land use and management.

The overall philosophy of the Canadian system is pragmatic; the aim is to organize the knowledge of soils in a reasonable and usable way. The system is a natural, or taxonomic, one in which the classes (taxa) are based upon properties of the soils themselves and not upon interpretations of the soils for various uses. Interpretations involve a second step that is essential if the information is to be used effectively. If the taxa are defined on the basis of soil properties, and if the boundaries of these classes, or of combinations of them, are shown on a map, interpretations can be made on the basis of properties implied in the class definitions.

Misconceptions about soil taxonomy

Misconceptions about the functions of a system of soil taxonomy are evident periodically. Some of these are listed to warn users of the Canadian system against unrealistic expectations.

1. It is a misconception that a good system results in the assignment of soils occurring close together to the same taxon, at least the higher categorical levels. This is neither possible, nor desirable, in some areas. Pedons a few metres apart may differ as greatly as pedons hundreds of kilometres apart within a climatic region.
2. Another common misconception is that a good national system provides the most suitable groupings of soils in all areas. This is not possible because criteria based upon properties of the whole population of soils in the country are bound to differ from those developed on the basis of properties of soils in any one region. Criteria developed for a national system will inevitably result in areas where most of the soils have properties that straddle the boundary line between two taxa.
3. The idea that if the system was soundly based there would be no need for changes every few years is erroneous. As new areas are surveyed, as more research is done, and as concepts of soil develop, changes in the system become inevitable to maintain a workable taxonomy.

4. Another unfortunate hope is that a good system will ensure that taxa at the order level at least can be assigned unambiguously and easily in the field. Actually, in a hierarchical system the divisions between orders must be defined just as precisely as those between series. With pedons having properties close to class boundaries at any taxonomic level, classification is difficult and laboratory data may be necessary.
5. The assumption is made by some that a good system permits soils occurring within mapped areas to be classified as members of not more than three series. Clearly, this is not reasonable because the number of taxononic classes occurring within a mapping unit depends upon the complexity of the pattern of soils in the landscape, on the scale of the map, and on the narrowness of class limits.
6. The idea that a good system is simple enough to be clear to any layman is erroneous. Unfortunately, soil is complex and, although the general ideas of the taxonomy should be explainable in simple terms, the definitions of taxa must be complex in some instances.
7. Another misconception is that a good system makes soil mapping easy. Ease of mapping depends more upon the complexity of the landscape, the access, and the predictability of the pattern of soils within segments of the landscape than upon taxonomy.

Attributes of the Canadian system

The development of soil taxonomy in Canada has been toward a system with the following attributes:

1. It provides taxa for all known soils in Canada.
2. It involves a hierarchical organization of several categories to permit soils at various levels of generality to be considered. Classes at high categorical levels reflect, to the extent possible, broad differences in soil environments that are related to differences in soil genesis.
3. The taxa are defined specifically so as to convey the same meaning to all users.
4. The taxa are concepts based upon generalizations of properties of real bodies of soils rather than idealized concepts of the kinds of soils that would result from the action of presumed genetic processes. The criteria chosen define taxa in accordance with desired groupings of soils. The groupings are not decided upon initially on the basis of arbitrary criteria.
5. Differentiae among the taxa are based upon soil properties that can be observed and measured objectively in the field or, if necessary, in the laboratory.
6. The system can be modified on the basis of new information and concepts without destroying the overall framework. Periodically, however, the entire framework of the system will be reevaluated.

Although taxa in the Canadian system are defined on the basis of soil properties, the system has a genetic bias in that properties or combinations of properties that reflect genesis are favored as differentiae in the higher categories. For example, the use of the terms chernozemic A and podzolic B imply genesis. The reason for the genetic bias is that it seems reasonable to combine, at high categorical levels, soils in which particular horizons developed under similar dominant processes resulting from broadly similar climatic conditions. Classification is not based directly on presumed genesis because soil genesis is incompletely understood, is subject to a wide variety of opinion, and cannot be measured simply.

Bases of criteria for defining taxa at various categorical levels

The bases for differentiating taxa at the various categorical levels are not clear cut. In a hierarchical system of soil classification, logical groupings of soils that reflect environmental factors cannot be obtained by following any rigid systematic framework in which all taxa at the same categorical level are differentiated based on a uniform specific criterion, such as acidity or texture. The fact that criteria must be based on soil properties, rather than directly on environmental factors or use evaluation was recognized by some pedologists almost three-quarters of a century ago (Joel 1926). The general bases of the different categorical levels, which are presented below, can be inferred from a study of the system. They apply better to some taxa than to others; for example, the statement for order applies more clearly to Chernozemic and Podzolic soils than to Regosolic and Brunisolic soils.

Order

Taxa at the order level are based on properties of the pedon that reflect the nature of the soil environment and the effects of the dominant, soil-forming processes.

Great group

Great groups are soil taxa formed by subdividing each order. Thus, each great group carries with it the differentiating criteria of the order to which it belongs. In addition, taxa at the great group level are based on properties that reflect differences in the strengths of dominant processes, or a major contribution of a process in addition to the dominant one. For example, in Luvic Gleysols the dominant process is considered to be gleying, but. clay translocation is also a major process.

Subgroup

Subgroups are formed by subdividing each great group. Therefore, they carry the differentiating criteria of the order and the great group to which they belong. Subgroups are also differentiated on the basis of the kind and arrangement of horizons that indicate conformity to the central concept of the great group (e.g., Orthic), intergrading toward soils of another order (e.g., Gleyed, Brunisolic), or additional special features within the control section (e.g., Ortstein, Vertic).

Family

Taxa at the family level are formed by subdividing subgroups. Thus, they carry the differentiating criteria of the order, great group, and subgroup to which they belong. Families within a subgroup are differentiated based on parent material characteristics, such as particle size, mineralogy, calcareousness, reaction, and depth, and on soil climatic factors.

Series

Series are formed by subdividing families. Therefore, they carry all the differentiating criteria of the order, great group, subgroup, and family to which they belong. Series within a family are differentiated on the basis of detailed features of the pedon. Pedons belonging to a series have similar kinds and arrangements of horizons whose color, texture, structure, consistence, thickness, reaction, and composition fall within a narrow range. A series is a category in the taxonomic system; thus, it is a conceptual class in the same sense as an order.

A pedon is a real unit of soil in the landscape; a series is a conceptual class with defined limits based on the generalization of properties of many pedons. A particular pedon may be classified as a series if its attributes fall within the limits of those of an established series. However, it is not, strictly speaking, a series because the attributes of any one pedon do not encompass the complete range of attributes allowable within a series. Thus, it is not correct to study part of a pedon and to declare, "this is X series." Rather it should be stated, "this pedon has properties that fall within the limits of the X series," or "this pedon is classified in the X series."

Relationship of taxonomic classes to environments

A general relationship exists between kinds of environments and taxa at various levels in the system. This follows from the basis of selecting diagnostic criteria for the taxa; the primary basis at the higher levels is to select properties that reflect the environment and properties resulting from processes of soil genesis. Although the system may look like a key with classes defined precisely but arbitrarily on the basis of specific properties, it is one in which the taxa reflect, to as great an extent as possible, genetic or environmental factors.

The Podzolic order, for example, is defined based on morphological and chemical properties of the B horizon. However, these properties are associated with humid conditions, sandy to loamy parent materials, and forest or heath vegetation. Although the great groups within the order are defined on the basis of the amounts of organic C and extractable Fe and Al in the B horizons, they have broad environmental significance. Humic Podzols are associated with very wet environments, high water tables, periodic or continuous reducing conditions, hydrophytic vegetation, and, commonly, a peaty surface. Ferro-Humic Podzols occur in areas of high effective precipitation, but they are not under reducing conditions for prolonged periods. Humo-Ferric Podzols generally occur in less humid environments than the other great groups in the order. An interrelation of climatic and vegetative factors, parent material, and relief determines the occurrence of the different classes of Podzolic soils. Similarly, general relationships exist between other orders, great groups, and soil environmental factors. However, these relationships are much less clear for some Regosolic and Brunisolic soils than they are for most soils of other orders. At lower categorical levels, in general, relationships between soil taxa and factors of the soil environment become increasingly close.

Relationship of the Canadian system to other systems of soil taxonomy

The numerous national systems of soil taxonomy might be looked upon as indications of the youthfulness of soil science. Knowledge of the properties of the soils of the world is far from complete, therefore it is not possible to develop an international system of classification for the whole population of known and unknown soils. Probably even after such a system has been developed, national systems will remain in use because they are familiar and are thought to be more useful for the restricted population of soils within the country. The soil units defined for the FAO-UNESCO world soil map project are useful in international soil correlation, but they do not constitute a complete system of soil taxonomy (FAO 1985). The closest approach to a comprehensive system of soil taxonomy is that produced by the Soil Survey Staff of USDA (1994), which has been under development since 1951. Like previous U.S. systems, it has had a major influence on soil taxonomy in Canada and elsewhere.

The Canadian system of soil taxonomy is more closely related to the U.S. system than to any other. Both are hierarchical, and the taxa are defined on the basis of measurable soil properties. However, they differ in several respects. The Canadian system is designed to classify only soils that occur in Canada and is not a comprehensive system. The U.S. system has a suborder, which is a category that the Canadian system does not have. In the Canadian system Solonetzic and Gleysolic soils are differentiated at the highest categorical level as in the Russian and some other European systems. These soils are differentiated at the suborder or great group level in the U.S. system. Perhaps the main difference between the two systems is that all horizons to the surface may be diagnostic in the Canadian system, whereas horizons below the depth of plowing are emphasized in the U.S. system. This may be because 90% of the area of Canada is not likely to be cultivated.

Summary

The Canadian system is a hierarchical one in which the classes are conceptual, based upon the generalization of properties of real bodies of soil. Taxa are defined on the basis of observable and measurable soil properties that reflect processes of soil genesis and environmental factors. The development of the system has progressed with the increasing knowledge of the soils of Canada obtained through pedological surveys carried out over an 80-year period. The system has been influenced strongly by concepts developed in other countries, but some aspects are uniquely Canadian. The system is imperfect because it is based on a limited knowledge of the vast population of soils in the country. However, the system does make it possible to assign soils throughout Canada to taxa at various levels of generalization and to organize the knowledge of soils in such a way that relationships between factors of the environment and soil development can be seen. It is possible to define the kinds of soils that occur within units on soil maps, and to provide a basis for evaluating mapped areas of soil for a variety of potential uses.