ONTARIO SOILS

Physical, Chemical and Biological Properties
and
Principles of Soil Management

by

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FOREWORD

Soil and water are recognized as two basic natural resources; they are the foundations of life and civilization. Man obtains most of his food, clothing, and shelter from the products of the soil and the manner in which the soil is managed determines our present and future welfare. It is within the power of a farmer to increase or decrease the productive capacity of his soil; what he does depends on his knowledge of soil management and on the economic pressures imposed by society. The successful farmer recognizes the importance of good soil management; his management practices are specifically designed for the soil types on his farm and for his type of farming.

The purpose of this publication is to describe the properties and characteristics of soils that are influenced by soil management and to outline the basic principles for maintaining and improving soil productivity. This publication is intended to be used by all who are vitally concerned with soil productivity and food supply.
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WHAT IS A SOIL?

Agriculturally, soil is the natural medium for the growth of plants. Soil furnishes the plant an anchor for its roots as well as nutrients (including water) and oxygen for growth and reproduction. To a farmer, soil is the medium on which he expends his labors and the primary source of his livelihood.

Components of a Soil

All soils consist of four components:
- mineral material
- organic matter
- water
- air.

The mineral materials are fragments of many kinds of rocks found in the glacial debris. This mineral fraction is often referred to as the soil skeleton or fabric (Figure 1). It is made up of particles of various sizes ranging from gravel and sand, which give the soil a gritty feel, to silt and clay, which are smooth and sticky. The relative proportions of the various sized soil grains determine soil texture.

![Figure 1 — The variations in color, shape, and size of sand grains in a soil are visible through a microscope.](image)

The organic fraction of a soil consists of plant roots, organisms large and small, the remains of plants and animals, and the by-products of their decay. The stable residues, humus, resulting from the decomposition of organic matter, are microscopic in size and play an important part in holding plant nutrients and water. Poorly drained soils contain more organic material than nearby well drained soils. The organic content of clay soils is normally greater than sandy soils. A soil is classed as an organic soil (muck or peat) if the organic fraction makes up more than 20 per cent of the soil by weight.

Water is held within some of the pore spaces and as thin films around the mineral and organic
materials. A soil retains more water as the amounts of clay and organic matter increase. Soil water contains many soluble nutrients required by plants.

The principle gases in the soil atmosphere are nitrogen, oxygen, and carbon dioxide. Certain soil bacteria utilize atmospheric nitrogen and produce complex organic materials. Oxygen is essential for the growth of all forms of life. The carbon dioxide combines with soil water to form carbonic acid, which assists in the release of plant nutrients from the mineral materials.

Figure 2 — The volumetric composition of a loam soil when excess water has been removed. On a weight basis, the percentage composition of the dry soil would be: organic material 4, clay 22, silt 44, and sand 30.

Factors in Soil Development

The study of the development (genesis) of a soil from a parent material is basic to the preparation of a system for classifying soils. Once the soils in an area have been classified, their distribution, characteristics, and uses are detailed in soil survey reports and on soil maps.

The five major factors in soil development are:

- climate (temperature, precipitation)
- organisms (plants, animals, insects, microorganisms)
- parent material (mineral material from which a soil develops)
- topography (shape of ground surface)
- time (the relative duration of soil-forming processes).

Temperature and rainfall control the rates of weathering of rocks and minerals, the leaching of soluble materials from a soil, the accumulation of organic matter, the vegetation that grows on a soil, and the organisms that live in a soil. In general, climate is so significant in soil development that the broad soil regions of the
world are related to climatic regions but they are not entirely coincident because all five factors of soil development are involved.

Soil organisms include plants, animals, insects, bacteria, and fungi. The organic matter in a soil is a result of the growth and decay of these organisms. Bacteria and fungi live mainly on plant and animal residues and change the residues into a multitude of different forms. Animals and insects burrow through soil, mixing materials from different depths.

Within a given climatic zone, the physical and chemical properties of the parent materials have a dominating influence on the kind of soil that develops. Sandy materials with a low content of lime weather to acidic soils. Loamy calcitic materials develop into slightly acid or neutral soils as the calcium compounds are weathered and leached from the surface layer. Compacted clayey parent materials weather more slowly than porous sandy materials.

Topography affects soil development largely through the drainage conditions it imposes on the parent material. More water permeates the soil materials on a level area than on steep slopes, thus influencing the weathering processes, the natural vegetation, and the biological activity. Water may accumulate for long periods of time in depressional areas resulting in peat bogs or marshes — soils that are permanently wet.

Time is necessary for the development of soils from parent materials. The length of time required for the formation of a given kind of soil depends largely on the other factors of soil formation. One cannot make any useful statement in terms of years regarding the time required for soil formation.
Soil Profiles

Every soil has a profile — a succession of layers from the surface down to the parent material. These layers are known as horizons and are designated by the letters A, B, and C. This terminology is more specific than the terms subsurface or subsoil. Horizons vary in thickness from a fraction of an inch to several feet and differ from one another in color, texture, structure, reaction, and other soil properties.* The sides of a pit, along roadside cuts and ditches are good places to study the different horizons of a soil.

Soil profiles may be grouped into three drainage classes — well drained, imperfectly drained, and poorly drained. The appearance of well and imperfectly drained profiles differs from place to place; a similar kind of profile occurs on all poorly drained areas.

A well drained profile

The Ah (humus) horizon comprises the surface layer from which materials are removed by percolating waters. Organic matter is most abundant and organisms and small animals are most active in the surface horizon. If an Ae (eluviated) horizon is present, it will be found immediately below the Ah and is characteristically lighter in color than other horizons in the profile. The materials that are leached or translocated from the A horizons include calcium, magnesium, iron and aluminum compounds, organic matter, and clay. It may not be possible to identify the Ae horizon of soils in cultivated fields because it may have been mixed with the Ah horizon during plowing. Loss of the surface soil by wind or water erosion may have forced the farmer to incorporate some of the Ae with the Ah horizon to maintain a suitable depth of topsoil.

The clay and the iron and aluminum compounds removed from the A horizon tend to accumulate in the B, often referred to as the illuvial horizon. If the accumulation of clay results in a textural difference between the A and B horizons the symbol Bt is used.

The C horizon occurs beneath the B, and consists of parent material, essentially the mineral fraction from which the A and B horizons were derived.

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* For an explanation of these terms see the sections Physical and Chemical Properties of Soils.
Ah  dark grayish brown sandy loam; soft granular structure; stone-free; slightly acid.

Ae1  yellow brown sandy loam; single grain structure; slightly acid.

Ae2  light yellow brown loamy sand; single grain structure; slightly acid.

Bt  dark yellow brown loam; weak blocky structure; near neutral.

C  light brownish gray sand; single grain structure; slightly alkaline.

**Figure 3** — Well drained soils are normally found on undulating to rolling topography. Well drained coarse textured soils may occur on level topography provided the drainage is not restricted by an impervious layer.
An imperfectly drained profile

If the water permeability of the parent material is slow as a result of compaction or a high clay content, the soil will show evidence of imperfect drainage. A visible evidence of imperfect drainage is a mottling of yellow, brown, or reddish streaks or blotches along cracks or old root channels in the Btg and Ae horizons.

Sandy parent materials that are highly permeable may develop into imperfectly or poorly drained soils if they are underlain by an impervious layer of clay or a high water table.

The Btg horizon in imperfectly drained soils is not as clearly defined as in well drained soils. The colors are not as bright.

Ah  dark colored sandy loam; soft granular structure; near neutral.

Aeg  pale yellow-brown loamy sand with mottlings of dark brown; streaks of dark organic material in old root channels or by earthworm activity.

Btg  a brownish loamy sand horizon showing a slight accumulation of clay.

C   grayish parent material slightly alkaline.

Figure 4 — This sandy loam soil is found on a very slightly undulating topography.
A poorly drained profile

Poorly drained soils are identified by a deep, dark Ah that is underlain by a strongly mottled, bluish or grayish horizon. This horizon may be designated as a gley (Bg) (gley, from the Russian meaning bluish clay). The results in an accumulation of organic materials because the decomposition of the organic material is retarded by the poor aeration.

<table>
<thead>
<tr>
<th>Layer</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ah</td>
<td>9 to 12 inches in depth; almost black sandy loam; soft granular structure; near neutral.</td>
</tr>
<tr>
<td>Bg</td>
<td>yellow brown sand; mottled with yellow and brown streaks; near neutral.</td>
</tr>
<tr>
<td>C</td>
<td>grayish or olive colored sand; slightly alkaline.</td>
</tr>
</tbody>
</table>

*Figure 5 — Poorly drained soils are usually associated with level topography.*
PHYSICAL PROPERTIES OF A SOIL

Physically, a soil may be described as a porous medium comprising finely divided organic and mineral particles, rigid inactive grains (sand), and pores that contain water and gas. The proportion of the components of a soil has a major influence on its physical properties and often has a significant effect on the suitability of a soil for plant growth.

Some measurable physical properties of a soil that affect plant growth are:

- soil texture  
  plant nutrient supply; moisture content; drainage; workability
- soil structure  
  movement of air and water; size and function of pores
- soil porosity  
  relative volumes of water and air
- water flow  
  movement of water; availability of water to plant roots

Soil Texture

The mineral particles in a surface soil represent about one-half the total volume or 95 per cent of the weight of a moisture-free sample. The particles may range in size from stones to fine clay particles that are visible only with a microscope. The proportion of the separates (sand, silt, and clay) determines soil texture. Texture is a term that describes the feel of a soil when it is wetted and rolled between the fingers — sandy soils are coarse and gritty, while clay soils are sticky.

Figure 6 — Diagram showing per cent sand and clay in the different soil textural classes.
It is obvious that the "feel of a soil" is not a sound method for determining the texture of a soil. Hence, it is necessary to determine by chemical and physical means the amounts of sand, silt, and clay in a sample of soil. The size limits, actually diameter limits, of sand, silt, and clay have been established (Table 1) and knowing the percentage of any two of the separates, the conventionally accepted texture of a soil may be determined by referring to a chart, an example of which is given in Figure 6.

**Properties of the Soil Separates**

Stones, gravel, and sand occur in soil as single particles, often irregular or rounded in shape (Figure 1). They are chemically inert, or nearly so. The large spaces that occur between the particles facilitate the free movement of water and air. Soils containing much sand or gravel are porous, have a low water-holding capacity but possess good drainage and aeration, and are usually friable and easily cultivated. Quartz is the dominant mineral in sands but particles the size of sand or larger may be composed of limestone, dolomite, or igneous rocks.

The silt particles are too small to be seen without the aid of a microscope. The small spaces between particles tend to retard air and water movement. Silt, silt loam, and silty clay soils have a high water-holding capacity. Various kinds of minerals occur in the size range of silt but quartz is most frequent.

The clay is the most important mineral separate in terms of the physical and chemical properties of a soil. Because of the minute size of the particles, a unit weight of clay has an exposed surface area many times greater than the area exposed by the same weight of sand. Clay is a storehouse for plant nutrients and is responsible for the swelling, shrinking, stickiness, and the water-holding capacities of soils. Clay soils that drain slowly and are difficult to cultivate may become highly productive if the amount of decomposing organic matter is increased and the soil structure improved. The chemical properties of some minerals found in soils are discussed in the section Chemical Properties of Soils.

**Table 1— The Particle Size Distribution And Textural Class For Three Soils.**

<table>
<thead>
<tr>
<th>Soil</th>
<th>Sand 2.0 to 0.05 mm.* per cent</th>
<th>Silt 0.05 to 0.002 mm.* per cent</th>
<th>Clay &lt;0.002 mm.* per cent</th>
<th>Textural Class from Figure 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil A</td>
<td>60</td>
<td>30</td>
<td>10</td>
<td>sandy loam</td>
</tr>
<tr>
<td>Soil B</td>
<td>40</td>
<td>40</td>
<td>20</td>
<td>loam</td>
</tr>
<tr>
<td>Soil C</td>
<td>25</td>
<td>40</td>
<td>35</td>
<td>clay loam</td>
</tr>
</tbody>
</table>

* 1 inch equals 25.4 millimeters (mm.)

Rock fragments greater than 2 millimeters are classified according to size using such terms as: gravel up to 3 inches, cobbles 3 to 10 inches, and boulders greater than 10 inches.
Figure 7 — Four common types of soil structure. The smallest divisions on the scale are equivalent to two millimeters.
Soil Texture and Crop Adaptability

Soil texture alone is seldom the most important factor in determining crop adaptability in regions where the crops are climatically suited. It is true that flue-cured tobacco is grown almost exclusively on well drained, coarse textured soils because it is essential to make rather fine adjustments in fertility and moisture at critical stages in the growth of the tobacco plant but the dominant soil requisite is good drainage. Adequate soil aeration and drainage are a must for profitable potato production and consequently the better yields are often obtained on sandy soils. However, the majority of farm crops display considerable tolerance to soil texture and the chemical composition of a soil. Most crops are less tolerant of such soil conditions as inadequate aeration, poor drainage, or low fertility.

Soil Structure

Whereas texture refers to the size and the amount of the mineral particles, soil structure refers to the physical arrangement of mineral and organic particles into aggregates, granules, or peds of different shapes, sizes, and porosities. A desirable soil structure is composed of aggregates which are:

- water stable; do not collapse when wetted
- porous; as in the aggregates under grass crops
- variable in size, ranging from small (1.0 millimeter) to large aggregates (2.0 to 5.0 millimeters).

Types of Soil Structure

Two of the major types in a classification system for soil structure are:

1. Structureless, which includes the single sand grains of most coarse textured soils and the massive fragments of soil in many clay parent materials;
2. Block-like, in which the aggregates have flat or rounded surfaces and sharp or rounded corners.

A soil clod is not a structural unit but rather a mass of soil produced by tillage or digging, which usually slakes easily with repeated wetting and drying.

Table 2 — Description And Occurrence Of Four Common Types Of Soil Structure.

<table>
<thead>
<tr>
<th>Type</th>
<th>Description and Occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Single grain</td>
<td>single solid particles; in sands and sandy soils that are low in clay and organic matter.</td>
</tr>
<tr>
<td>2 Massive</td>
<td>a coherent mass of soil; no definite shape; not water stable; exhibit shrinkage and swelling; in the parent materials of many clay soils.</td>
</tr>
<tr>
<td>3 Blocky</td>
<td>rectangular faces; sharp angular corners; low porosity; firm; 5 to 50 mm. in size; in Bt horizons and parent materials of well drained, fine textured soils.</td>
</tr>
<tr>
<td>4 Granular</td>
<td>nearly spherical aggregates with rounded corners; 2 to 10 mm. in size; in surface soils well supplied with organic matter and medium to fine texture.</td>
</tr>
</tbody>
</table>
Formation of Soil Structure

An individual soil aggregate or ped is an agglomeration of minute mineral and organic particles held together by various cementing agents, such as clay, by-products of organic matter decomposition, and iron oxide. Although a farmer is not likely to change the clay or iron oxide content of a soil, he can influence the organic matter content. Because organic material is destroyed by biological activity, new organic matter must be added regularly to a soil if a good soil structure is to be maintained. The addition of easily decomposable organic material to a soil is a feature of good soil management.

Many soil organisms produce gelatinous by-products that cement soil particles into aggregates. These organisms are most active in a soil that is well supplied with organic matter and plant nutrients. Some soils require the additions of lime to adjust the soil reaction to a more favorable environment for the organisms. Soil reaction is discussed under Chemical Properties of Soils.

Crop roots and residues, especially hay and sod crops, encourage the development of a granular structure in the surface soil by the additions of organic matter and root secretions that act as cementing agents. The minute roots compress the soil particles and dehydrate the soil, an essential step in aggregate formation.

The data in Table 3 illustrate the beneficial effects of grass and organic matter on soil aggregation. In the four-year rotation, soil aggregation reached its lowest level under corn but improved under each of the hay crops. It is doubtful if the percentages of organic matter under the crops in the rotation are significantly different, except for the second-year hay.

Table 3 — The Effects of Crop Sequences on the Level of Soil Organic Matter and Aggregation in a Loam Soil After a Ten-year Period.

<table>
<thead>
<tr>
<th>Crop Sequence *</th>
<th>Organic Matter (%)</th>
<th>Aggregation % &gt; 0.5 min. **</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous sod</td>
<td>4.4</td>
<td>84.7</td>
</tr>
<tr>
<td>Continuous corn</td>
<td>3.1</td>
<td>21.6</td>
</tr>
<tr>
<td>In a four-year rotation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corn</td>
<td>4.1</td>
<td>52.3</td>
</tr>
<tr>
<td>Oats</td>
<td>4.2</td>
<td>55.9</td>
</tr>
<tr>
<td>Hay 1st year</td>
<td>4.0</td>
<td>60.9</td>
</tr>
<tr>
<td>Hay 2nd year</td>
<td>4.4</td>
<td>74.0</td>
</tr>
</tbody>
</table>

* All of the crop was removed and no manure applied.

** Aggregation is expressed as the percentage of a sample of air-dry aggregates that were water stable and > 0.5 mm. in size.
Importance of Soil Structure

The presence of a high percentage of water-stable aggregates is desirable in fine textured soils because it:

- increases porosity
- favors aeration
- aids in water movement in the profile
- increases the resistance to erosion by wind and water.

In coarse textured soils, the sand grains occur as separate individuals with large pore spaces around the particles. Normally, the coarse particles do not agglomerate in these soils.

The maintenance of good soil structure is an important objective to be considered in planning systems of soil management.

Soil Porosity and Aeration

Soil porosity is defined as the fraction or percentage of the soil volume occupied by air. The total pore space is filled with air in a dry soil and with air and water in a moist soil. In coarse textured soils, large pores occur around the individual grains of sand, but in fine textured soils, the volume and size of pores are dependent largely on soil structure.

Aeration and Capillary Porosities

The total porosity of a soil is the volume of all pores of many sizes and shapes. The relative distribution of the "large" and the "small" pores is an important soil characteristic.

The volume of large pores, the aeration porosity, is determined by measuring the volume of water that drains freely from a soil that was saturated initially. The capillary porosity is the volume of all the small pores that retain water after the large pores have emptied. The rapidity and ease with which excess water is removed from a soil, increase as the volume of aeration porosity increases.

The total porosity of clay soils that are well supplied with organic matter and are of good structure, will exceed the total porosity of sandy soils. However, fine textured soils may be compacted by improper tillage to such a degree that the total porosity may be less than in sandy soils. Aeration porosity values serve as a criterion in judging the effects of tillage or cropping practices on soil structure (Table 4).

Table 4 — Soil Porosity Values And The Weight Per Cubic Foot Of A Loam Soil Under Extreme Cultural Treatments.

<table>
<thead>
<tr>
<th>Cultural Treatment</th>
<th>Soil Porosity (percentage)</th>
<th>Weight (pounds) per Cubic Foot of Dry Soil</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total Porosity</td>
<td>Aeration Porosity</td>
</tr>
<tr>
<td>Continuous sod</td>
<td>53</td>
<td>19</td>
</tr>
<tr>
<td>Continuous corn</td>
<td>49</td>
<td>11</td>
</tr>
</tbody>
</table>
Mismanagement of a medium textured soil (continuous corn production without returning adequate amounts of organic matter) will result in a decrease in the total and aeration porosities (Table 4), and in significant decreases in organic matter and soil aggregation (Table 3). The soil structure under continuous sod was characterized by a high percentage of water-stable aggregates that contributed to the greater aeration porosity. As the total porosity of a soil is decreased, more of the soil volume is occupied by the mineral fraction and the weight per unit volume increases.

**Soil Aeration**

When the volumes of aeration and capillary porosities are about equal, the exchange of gases between the soil air and the atmosphere proceeds normally; that is, the concentration of carbon dioxide in the soil does not reach toxic levels nor does oxygen become limiting. If the supply of oxygen is limited, the roots of most plants die, the intake of water and plant nutrients is reduced, and toxic compounds of iron, manganese, and nitrogen may reach concentrations that are harmful to plant growth.

**Soil Moisture**

Moisture occurs in soil as a gas in the soil atmosphere, as a water film around the mineral and organic particles, and as free liquid in the pore space. The volume of water retained by a soil increases as the particles and pores decrease in size. While the volume of water in the soil atmosphere is negligible, it is important to realize that only in very dry soils does the relative humidity of the soil atmosphere fall below 95 per cent. The moisture in the soil atmosphere contributes to the growth and activity of the microorganisms.

**The Drainage Process**

A soil is saturated with water when all the pores are filled, a condition that seldom occurs in the surface layer of a well drained soil in the field. Water drains from the large pores and moves downward under gravitational forces. The thickness of the water films around the particles and aggregates is reduced as a pore is emptied. Drainage continues as long as bridges or saddles of moisture exist between soil particles. The rate at which water is removed by natural drainage decreases as the number of bridges decreases and as successively smaller pores are emptied. When the movement of water by natural drainage from an initially saturated soil has virtually stopped, the moisture retained by a soil is referred to as the field capacity value.

**Field Capacity**

In the preceding paragraph, the moisture at field capacity was described as the maximum amount of water a well drained soil can retain against gravitational forces. The moisture is present in two sites: (1) in relatively thick films around the mineral and organic particles that were not connected by bridges of water, and (2) in the small capillary pores that were able to hold the moisture against the gravitational pull.
If a soil with the moisture at field capacity receives additional water by rainfall or irrigation, a layer of soil (the thickness of the layer depends on the amount of water) approaches a saturated condition and the drainage process starts again. Thus, in irrigating a soil a farmer should apply enough water to raise two or three feet of soil (the rooting zone) to its field capacity value. Additional water would be lost through natural drainage.

**Permanent Wilting Point**

As a soil dries out, it becomes increasingly difficult for plants to remove water from it. If water is not added, the soil becomes so dry that the rate of moisture absorption by the roots is slower than the loss of moisture through the leaves (transpiration). At this point the plant wilts, ceases to grow, loses its rigidity, and eventually dies.

**Available, Hygroscopic, and Gravitational Water**

Water between field capacity and the permanent wilting point is available for plant use. Moisture beyond the wilting point is called **hygroscopic moisture** and is held so strongly by the soil that plant roots cannot develop enough "suction" to remove it. The moisture between saturation and field capacity is classed as **gravitational** because in well drained soils it drains away readily. Gravitational water is not considered as available water as it does not remain in a well drained soil for any great period of time. The relationships between these moisture characteristics for a clay soil and a sandy soil are illustrated in Figure 8.

**Figure 8** — *The inches of water retained in the surface six-inch layer of two soils (a clay loam and a sandy loam) at four degrees of dryness.*
CHEMICAL PROPERTIES OF A SOIL

A soil may be described as a complex of many elements and chemical combinations involving organic and inorganic materials. A knowledge of some of the fundamentals of soil chemistry enables one to understand better the mechanics and processes that affect the absorption of a nutrient by a plant.

The soil chemistry presented in this section is general in nature; more specific information is contained in the sections on organic matter and those sections dealing with the plant nutrients.

Soil Reaction and the pH Scale

A beaker of water is a mixture of:

1. hydrogen and oxygen atoms chemically combined to form HOH molecules
2. acidic hydrogen ions, H⁺
3. alkaline or basic hydroxyl ions, OH⁻.

The acidity or alkalinity of a solution is determined by the relative concentration of hydrogen and hydroxyl ions. When there are more hydrogen ions than hydroxyl ions, the solution is said to be acidic. If there are more hydroxyl ions than hydrogen ions, the solution is alkaline or basic. Solutions with equal concentrations of hydrogen and hydroxyl ions are neutral.

The pH scale was devised as a means of expressing the relative concentrations of acidic and alkaline ions in a solution. The pH scale goes from 0 to 14. At the mid-point, pH 7.0, there are equal concentrations of hydrogen and hydroxyl ions. pH values below 7.0 indicate an acidic solution in which there are more hydrogen ions than hydroxyl; above pH 7.0 the alkaline or basic ions outnumber the acidic ions.

Soil Reaction

Many soils in Ontario are naturally alkaline and contain large quantities of basic materials, such as calcium carbonate and magnesium carbonate, in the surface soil and the parent material. If the pH of a soil exceeds 8.4, the alkalinity may be due in part to other compounds, particularly sodium salts.

Soil acidity may be caused by one or more of:

- a natural condition where soils have formed from acidic parent materials or materials low in bases, e.g. some sands
- the loss of soil bases by leaching or crop removal
- the decomposition of organic residues which produce organic acids, that are a source of hydrogen ions, e.g. some sedges, grasses
- the application of chemical fertilizers, some of which are acidic in nature or leave acidic residues.
The most common corrective applied to acid soils in Ontario is the carbonate form of calcium or magnesium. Calcium chloride or calcium sulfate (gypsum) would supply calcium to a soil but in doing so would create conditions for even greater acidity.

The practical significance and methods of controlling soil reaction are discussed in the section, Changing the Reaction of Soils, or in Publication 523, Lime Acid Soils for Better Yields.

**Soil Colloids**

Soil colloids are organic and inorganic particles which are exceedingly small; it would require about 500,000 colloids to make a row one inch in length. Colloids are not soluble in water but form a suspension that may be colored but the discrete particles are visible only with a high-powered microscope. The term colloidal suspension implies a state of matter rather than a kind of matter, that is, particles of sand may be pulverized to a size that would be considered colloidal. Milk is a colloidal suspension in which the minute particles of fat are dispersed in water. Other examples of colloidal suspensions are blood and water suspensions of gelatin, glue, and starch.

The particles in a colloidal suspension are electrically charged, either positively or negatively, and when the particle charge is predominately the same throughout a suspension, the particles repel one another and the continual agitation, not visible to the human eye, keeps the particles in suspension. However, the mutual repulsion by the particles is reduced by adding a solution containing another ion, and hundreds or thousands of the individual colloidal particles come together and form a floccule — a much larger unit than a colloid. The colloidal protein, fibrin, flocculates rapidly on exposure to air and causes the sudden change from fluid blood to a clot. A colloidal suspension of clay flocculates when quicklime is added.

Clay soils swell when the colloids absorb water and shrink as the water is removed. The extent of swelling and shrinkage is directly related to the colloidal content of the soil.

**Ion Exchange and Retention**

**Cation Exchange**

Soil colloids, organic and mineral, are negatively charged. This negativity is satisfied by the adsorption of positively charged ions (cations) on the colloidal surface from the soil solution. The cations that are most frequently adsorbed are hydrogen, calcium, magnesium, potassium, sodium, and ammonium.
When the exchange sites on a soil colloid are dominated by calcium, the soil is likely to be neutral or alkaline in reaction; acid soils result when the hydrogen ion predominates. The cation exchange capacity of a soil is a measure of the amount of cations required to occupy the exchange sites. The cation exchange capacity is directly dependent on the colloidal content. A soil high in clay and organic matter has a high exchange capacity but a sandy soil has a low exchange capacity. Organic colloids have a greater cation exchange capacity than clay colloids. The exchange capacities for five soils are given in Table 5.

Anion Retention

The term cation exchange implies that only positively charged ions are involved in the exchange process. A soil contains anions, negatively charged ions, but they are not held in a soil by an exchangeable process similar to that just described. Phosphorus (P), an element essential for plant growth, occurs in the soil as an anion in association with oxygen, PO₄, the phosphate ion. If the phosphate ion combines with calcium, which it does quite readily in neutral and alkaline soils, tri-calcium phosphate is formed and the phosphorus is said to be "fixed". Tri-calcium phosphate is not soluble in water but is dissolved by many naturally occurring
soil acids, a process which releases the phosphorus in forms usable by plants. In acid soils (pH less than 6.5), iron phosphate is formed and the phosphorus is virtually unavailable to plants. Some microorganisms, particularly those associated with leguminous plants, fix atmospheric nitrogen as an anion in the soil. The nitrate form \((\text{NO}_3^-)\) of nitrogen is water-soluble and if not used immediately by plants or microorganisms, it may be lost in the drainage water. The ammonium form \((\text{NH}_4^+)\) of nitrogen participates in cation exchange reactions.

Table 5 — The Cation Exchange Capacity (C.E.C.) Of A Soil Depends On The Clay And Organic Matter Contents.

<table>
<thead>
<tr>
<th>Soil Texture</th>
<th>Organic Matter</th>
<th>Clay</th>
<th>C.E.C.* m.e.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loamy sand **</td>
<td>5.6</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>Sandy loam</td>
<td>2.3</td>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td>Loam</td>
<td>3.9</td>
<td>17</td>
<td>14</td>
</tr>
<tr>
<td>Clay loam</td>
<td>4.9</td>
<td>32</td>
<td>20</td>
</tr>
<tr>
<td>Clay * *</td>
<td>7.8</td>
<td>43</td>
<td>30</td>
</tr>
</tbody>
</table>

* The cation exchange capacity of a soil is expressed in milliequivalents (m.e.) per 100 grams of soil. A milliequivalent is defined as 1.0 milligrams of hydrogen or the amount of any other ion that will combine with or displace it. One milliequivalent weight of calcium is 20 milligrams, of potassium 39 milligrams.

** The loamy sand and the clay soils were poorly drained. This accounts for the relatively high organic matter content.

** Nutrient Availability

Soil is the chief source of the nutrients (except carbon, hydrogen, and oxygen) essential for plant growth. Each nutrient occurs in one or more chemical forms in a soil and for this reason there exist many degrees of availability. Generally, availability means the ease and rate with which a nutrient goes into solution. A plant can absorb only those nutrients that are in solution. While availability of nutrients cannot be divided into precise categories, the following arbitrary divisions are often used:

Difficultly available

- nutrients in rocks, minerals, and forms of organic matter that are released by the weathering of the rocks and minerals and by the decomposition of the organic matter

Moderately available

- nutrients in easily decomposed organic matter and some "fixed" mineral or chemical forms
- some of the cations on the exchange complex.
Readily available

- nutrients soluble in water or in the weak acids found in soils
- most of the cations on the exchange complex.

The clay and organic colloids are referred to as the storage reservoir of a soil because they hold elements such as hydrogen, calcium, magnesium, and potassium on their surfaces and by an exchange process release these ions for absorption by plants. Other elements, such as nitrogen, phosphorus, boron, and sulfur, are combined with the carbohydrates and nitrogenous compounds in a soil.

![Diagram of ion absorption by a plant root hair.](image)

**Figure 10** — A diagrammatic representation of the absorption of ions, using calcium (Ca) as an example, by a plant root hair. Ions are absorbed from:

1. organic or inorganic colloids by contact exchange, and
2. the soil solution. The ions in solution came from the exchange position on the organic or inorganic colloids or from the dissolution of the minerals, e.g. the limestone fragment. As ions are absorbed by a root, hydrogen ions (H) are released from the root. To accommodate the calcium (Ca) in an exchangeable position on the colloids, several kinds of ions (x) may be released from the colloid to the soil solution. The elements potassium, calcium, magnesium, iron, copper, manganese and zinc are adsorbed in the ionic form but nitrogen, phosphorous, sulfur, boron, and molybdenum are absorbed as complex compounds containing hydrogen and/or oxygen.
A soil with a large storage reservoir is not necessarily a fertile soil. Continued cropping may deplete available nutrients more rapidly than they are replenished. A fertile soil is one that has sufficient nutrients to produce the plant growth that may be required without further additions of one or more nutrients. Ideally, each plant nutrient should be present in a soil in varying degrees of availability so that both the immediate and long-term needs of the crop will be satisfied. Replenishment of nutrients in the storage reservoir comes from the weathering of soil minerals and from the applications of fertilizers and organic matter.

**Macro and Micronutrients**

When the chemical composition of a plant is determined, many elements will be found but there are at least fifteen that are known to be essential for plant growth. An element is said to be essential if the plant cannot complete its life cycle without it. Plant nutrients are classified as macro or micro, depending on the relative amounts (not relative importance) that are found in plants.

<table>
<thead>
<tr>
<th>Macronutrients</th>
<th>Micronutrients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon</td>
<td>Boron</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>Manganese</td>
</tr>
<tr>
<td>Calcium</td>
<td>Copper</td>
</tr>
<tr>
<td>Oxygen</td>
<td>Molybdenum</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>Iron</td>
</tr>
<tr>
<td>Magnesium</td>
<td>Zinc</td>
</tr>
<tr>
<td>Hydrogen</td>
<td></td>
</tr>
<tr>
<td>Potassium</td>
<td></td>
</tr>
<tr>
<td>Sulfur</td>
<td></td>
</tr>
</tbody>
</table>

Carbon, oxygen, and hydrogen are the main building materials in plant tissue, comprising over 90 per cent of the weight of oven-dry plant material, (approximately, carbon 45, oxygen 43, and hydrogen 6 per cent by weight). The hydrogen and oxygen are supplied mainly in the form of water, and carbon from the carbon dioxide of the atmosphere.

The concentration in plant tissue of the remaining six macronutrients shows considerable range: 1.5 to 5 per cent potassium, up to 3 per cent nitrogen and calcium, up to 1 per cent for sulfur and phosphorus, and less than 1 per cent magnesium.

A plant requires the micronutrients in small quantities for its growth processes: molybdenum less than one part in a million (1 p.p.m.), iron and manganese up to 1,500 p.p.m. and the other elements usually less than 100 p.p.m.

Plants also contain sodium, iodine, chlorine, cobalt, silicon, and aluminum but these elements have not been shown to be essential for growth nor has their function in plants been recognized.

Nitrogen, phosphorus, and potassium are three macronutrients required by plants in relatively large amounts; one or more of these nutrients is usually deficient in Ontario soils. Nitrogen, phosphorus, and potassium comprise the bulk of the nutrients bought as commercial fertilizers.
Nitrogen

A deficiency of available nitrogen probably limits plant growth more often than any other nutrient. Nitrogen is a gas that is not usable directly by plants but occurs in soil largely in complex organic forms.

Function in Plants
- promotes plant growth
- gives dark green color to plants
- increases protein content of crops
- improves the quality of leafy crops
- feeds soil microorganisms during their decomposition of organic materials.

Sources and Forms of Soil Nitrogen
The primary source of soil nitrogen is the air. Plants cannot utilize this gaseous form of nitrogen — it must be combined with other elements. This combination is brought about by one or more of the following ways.
- Discharges of lightning combine nitrogen with oxygen which is then carried into the soil by rain. The amount of nitrogen added by this means is small and variable, ranging from 2 to 10 pounds per acre per year.
- Industrial processes whereby nitrogen is combined with hydrogen to form ammonia. This is the main commercial source of nitrogen for use as a fertilizer.
- Microorganisms that live in the soil and others associated with the nodules on the roots of leguminous plants. Soil organisms may add 15 to 20 pounds of nitrogen per acre per year and the nodule organisms on the roots may add 50 to 100 pounds of nitrogen per acre per year.

Other sources of nitrogen include manures (see section on Soil Organic Matter) and chemical fertilizers containing nitrogenous compounds.

Difficultly available forms: in the complex proteins in the type of soil humus that virtually resists further decomposition.

Moderately available forms: as proteins in fresh organic matter from which nitrogen is released by microorganisms.

Readily available forms: in combination with oxygen as a nitrate or with hydrogen as ammonia. These forms represent 1 to 5 per cent of the total nitrogen in a soil and are the forms in which nitrogen is absorbed by plants.

Nitrogen Transformations
Non-leguminous plants use the mineral forms of nitrogen (nitrates and ammonia) and a negligible part of the nitrogen contained in organic combinations. Except for the additions in nitrogenous fertilizer, nitrate nitrogen (NO₃) comes from the decomposition of some organic compounds.
The transformation of organic nitrogen to the mineral form (ammonium nitrogen) is called the **mineralization** of nitrogen. The conversion is carried out by a variety of microorganisms; free energy is released in this reaction.

The transformation of ammonium nitrogen to nitrate nitrogen is referred to as the **nitrification** process and is accomplished by the autotrophic bacteria*. The steps in this process are:

\[
\text{ammonium nitrogen} \rightarrow \text{nitrites} \rightarrow \text{nitrates}
\]

Nitrites are toxic to plants and may accumulate in poorly aerated soils.

Nitrates are not fixed by any process in a soil and may be lost by leaching if not absorbed by a growing crop. The slow release of nitrogen from the organic form during the growing season is preferable to supplying the crop with its total nitrogen requirement in a readily available form all at one time. If a nitrogen fertilizer is applied, the amount may be split into two or three applications over the growing season.

The characteristics of the principal sources of commercial nitrogenous fertilizers are:

- **Nitrate of soda** (NaNO₃) 16 per cent N
  - manufactured product or natural deposits in Chile
  - not used extensively in Ontario (too costly)
- **Ammonium nitrate** (NH₄NO₃) 33 per cent N
  - half of the nitrogen in ammonium form and half as nitrates
  - a widely used source of nitrogen
- **Ammonium sulfate** (NH₄)₂SO₄ 21 per cent N
  - by-product from steel, gas, and coke industries
- **Calcium cyanamid** (CaCN₂) 21 per cent N
  - nitrogen in a non-leachable, synthetic organic form
- **Urea** CO(NH₂)₂ 46 per cent N
  - synthetic organic source of N
  - converted to the ammonium form in the soil
- **Anhydrous ammonia** (NH₃) 82 per cent N
  - a colorless, inflammable, irritating (to nose, throat, lungs) gas
  - stored in pressure tanks; liquid under pressure
  - injected into soil as a gas at atmospheric pressure
- **Nitrogen solutions**
  - water solutions of ammonium nitrate or urea or both
  - percentage of N increased by using anhydrous ammonia
  - applied to a soil in liquid form.

Calcium cyanamid and nitrate of soda are nitrogenous fertilizers that are alkaline in reaction. The other fertilizers are acidic in nature and the order of increasing acidity is ammonium nitrate, urea, ammonium sulfate, and anhydrous ammonia, the most acidic.

* See the section on Soil Biology.
Nitrogen deficiency — note firing (browning) along the centre or midrib of the leaf, and the small size of the ear.

Phosphorous deficiency — note the purple colouration in the leaves of young plants, and the small, twisted shape of the ear.

Figure 11— Nitrogen and phosphorus deficiencies in corn leaves and ears.
Potassium deficiency — note the firing (browning) along the outer edges of the leaf, and the small size and chaffy appearance of the kernels in the ear.

Normal leaf and ear — note the dark green colour in the leaf, and the well-developed kernels extending right over the end of the ear.

**Figure 11**— *Potassium deficiencies in corn leaf and ear and a normal leaf and ear.*
**Phosphorus**

The use of phosphorus-containing materials for improving soil productivity is an old practice. Animal bones were applied to the soils in England early in the 17th century and by 1815 bones were imported from Europe, broken down, and applied to the soils as a source of phosphorus.

Phosphorus is a soft waxy element that ignites if exposed to the air. In chemical laboratories, phosphorus if often stored under water. The name is derived from the fact that the element glows in the dark.

**Function in Plants**
- stimulates early root development of young seedlings
- promotes rapid and vigorous growth
- favors seed development
- encourages a stiffer straw in small grains
- increases the winter hardiness of fall seeded crops.

**Sources and Forms of Soil Phosphorus**

In a soil, phosphorus occurs in two forms: (1) as a mineral in apatite (a calcium-phosphate-fluoride compound) and as iron and aluminum phosphates, and (2) in the organic form as complex compounds of the organic matter fraction. About half the phosphorus in the soils in Ontario is in the organic matter.

When phosphorus is released from soil minerals, organic compounds or applied fertilizers, it may combine with calcium, magnesium, iron, aluminum, or organic matter, or it may be assimilated by microorganisms or adsorbed by the clay colloids. All of these processes result in the "fixation of phosphorus". Fixation is beneficial in that "fixed" phosphorus does not leach from a soil; it is detrimental in that the "fixed" phosphorus is not readily available to crops.

Difficultly available forms: in the apatite minerals, compounds of iron and aluminum, and the organic compounds that are very slowly decomposed.

Moderately available forms: in fresh organic matter and some iron, aluminum, and calcium compounds. Readily available forms: phosphates that are soluble in water and weak acids. Plants absorb phosphorus in the mineral form, primarily as a phosphate ion combined with hydrogen ($H_2PO_4$).

Soil pH is an important factor influencing the availability of phosphorus. At pH's between 6.5 and 7.5 with no free calcium carbonate in the soil, there is a tendency for the formation of tricalcium phosphate, $Ca_3(PO_4)_2$, and other phosphates which are soluble in weak acids. In distinctly acid soils, below pH 6.0, the difficultly available forms occur, iron phosphate for example.
Phosphorus Fertilizers

Deposits of materials containing phosphorus were laid down millions of years ago by shell organisms in the oceans. The phosphorus is part of a complex rock phosphate containing calcium carbonate and other elements. The rock phosphate is mined and treated with sulfuric or phosphoric acids to produce a commercial phosphorus fertilizer. The major deposits of rock phosphate in North America are in Florida, Tennessee, and several western states.

Superphosphate — 20 per cent P₂O₅, about 8.8 per cent P
  - rock phosphate treated with sulfuric acid
  - commercial product contains about 48 per cent calcium sulfate (gypsum) and traces of other elements essential for plant growth.

Concentrated or Triple superphosphate — 48 per cent P₂O₅, about 21 per cent P
  - rock phosphate treated with phosphoric acid
  - calcium compounds and traces of other elements are present.

It has been the custom to express the phosphorus content of fertilizer materials as P₂O₅, phosphorus pentoxide and refer to it as "phosphoric acid". The phosphorus in fertilizing materials is classed as available, that is soluble in a weak acid.

Potassium

In its pure state, potassium (K), kalium in German, is a soft, whitish, highly reactive metal that must be immersed in kerosene for storage. It combines with many elements and compounds and is found in all living matter. Most soils contain 2 to 3 per cent potassium.

Function in Plants
  - promotes the build-up of starch in plants
  - increases vigor and disease resistance
  - strengthens the stalks of cereals and corn
  - improves seed quality
  - increases the winterhardiness of fall seeded crops and stands of legumes.

Sources and Forms of Soil Potassium

There are four sources of soil potassium: (1) the mica minerals, muscovite and biotite, (2) the feldspars, compounds containing potassium, aluminum, silicon, and oxygen, (3) certain potassium-bearing clay minerals, and (4) organic matter. A soil may have 30,000 pounds of potassium per acre stored in the surface soil, but only a small amount may become available to plants in a growing season.
A. Potassium deficiency in alfalfa — note the white flecking around the margins of the young leaves, and the yellowing and dying of the older leaves.

B. Boron deficiency in alfalfa — note the red and bronze colouration, the death of the terminal bud, and the shortened internodes.

C. Normal alfalfa.

D. Nitrogen deficiency in grass — note the stunted growth and the light green colour.

E. Normal grass.

Figure 12 — Nutrient deficiencies in forage leaves compared with normal.
Difficultly available forms: in the micas, feldspars, and clay minerals.
Moderately available forms: some forms of fixed potassium and potassium in easily weathered minerals.
Readily available forms: potassium held by colloids as exchangeable, some potassium in fresh organic matter, and water-soluble salts of potassium. Plants absorb potassium in ionic form from the soil solution and by direct exchange with colloids.

When the concentration of potassium in the soil solution is reduced by crop removal or leaching, some potassium transfers from the exchangeable to the soluble forms. The reverse transfer occurs when soluble potassium is added to a soil. An equilibrium is maintained between these two forms. Hence, exchangeable potassium is considered readily available. However, some clay minerals "fix" the exchangeable potassium, making it less available to plants. "Fixed potassium" is not lost but is added to the reserve supply and in time may become available.

**Potassium Fertilizers**

Deposits of water-soluble potassium-bearing minerals are found in Saskatchewan and several southwestern states.

Muriate of potash (KCl) 60 per cent K$_2$O; 50 per cent K.
- accounts for most of the potassium fertilizers used in agriculture
- applied directly to the soil or in mixed fertilizers.

Sulfate of potash (K$_2$SO$_4$) 50 per cent K$_2$O; 41 per cent K.
- used for crops that may be injured by the chlorine in muriate of potash.

In the analyses of fertilizer and soil, the term "potash" refers to the oxide form, K$_2$O.

**Calcium**

Calcium is a constituent of many rocks and minerals, especially various limestones. Most soils in Ontario are adequately supplied with calcium but when the soil pH falls below 6.0, the element may be added in the form of limestone to raise the soil pH for certain crops, such as alfalfa.

**Function in Plant**
- stimulates the development of the root system
- promotes normal leaf growth
- protects plants against accumulations of toxic compounds.

**Magnesium**

The amount of magnesium in soils is generally less than calcium. The primary sources are dolomite (an alkaline compound of magnesium and calcium carbonates) and many other rocks and minerals. Magnesium may be added to a soil to overcome a plant deficiency.
Magnesium is essential for plant growth as it:

- is an important constituent in chlorophyll
- acts as a carrier of phosphorus within the plant
- assists in the movement of carbohydrates in the plant.

**Sulfur**

The chief sources of soil sulfur are the rocks and minerals (sulfides), fertilizing materials (particularly superphosphate) and organic compounds. In certain areas considerable sulfur from the atmosphere is returned to the soil with the precipitation.

Sulfur is important in plant growth because it:

- is a constituent of proteins
- influences chlorophyll development
- promotes the development of nodules on legumes.

**Micronutrients**

The micronutrients — boron, copper, iron, manganese, molybdenum, and zinc — are as essential for plant growth as the macronutrients, but the amounts required are much less. With some of these nutrients the range between beneficial and harmful amounts is very narrow. They must be used carefully, applied only when deficiencies are known to exist, and according to precise recommendations as to amount, form, and method of application for specific crops.

Deficiencies develop in a manner similar to those for macronutrients; that is, by conversion to less available forms and by leaching, erosion, and crop removal. Ordinarily, the micronutrients are not contained in commercial fertilizers except as impurities. However, many of these nutrients can be added to fertilizers when special arrangements are made with the fertilizer manufacturer.

The function and role of all the micronutrients in plant growth are not known. The following is a summarization of the available information on the function in a plant, deficiency symptoms, and methods of correcting a deficiency.

**Boron**

The exact functions of boron in a plant are not known. It has been observed that the concentrations of calcium and boron in a plant increase together and that boron deficiency symptoms are intensified by a high concentration of potassium in the plant. Deficiency symptoms include a dying of the growing tips, for example, the "rosetting" in alfalfa, cracked stem or "cat scratches" in celery, heart rot of turnip and sugar beets, and internal cork of apples. Boron may be applied to the soil directly or sprayed on the crop.
Copper

Copper is believed to be essential for various plant processes, such as respiration and chlorophyll production. Deficiency symptoms vary considerably. In some instances the application of copper salts to organic soils has resulted in yield increases in onions, spinach, and carrots.

Iron

Most soils contain an abundance of iron but it is not always readily available to plants, especially on high-lime soils. An iron deficiency usually results in leaf chlorosis, that is the tissue between the veins in new leaves is generally light in color. It is difficult to supply iron to plants in an available form but special chemical preparations containing iron are on the market.

Manganese

Manganese deficiency in crops is most likely to occur in alkaline soils and in strongly acid soils that have been limed. A deficiency results in a chlorotic condition in young tissue. In oats, the condition is called "gray speck" or "white streak". A manganese deficiency in soybeans is usually identified by the whitish leaves with green veins at the growing tip. The direct application of manganese to either fine textured or calcareous soils may not alleviate the deficiency. The foliage may be sprayed with a solution containing manganese sulfate.

Molybdenum

It has been reported that the application of one ounce of molybdenum per acre was a liberal application and would last most crops for several years. This element is required by plants and many microorganisms in minute quantities. A deficiency of the element in cauliflower and broccoli causes the "whiptail" disease, a condition where patches of leaf tissue along the midrib die or fail to form, while the leaf continues to elongate and twist. Molybdenum may be essential for the formation of nodules in legumes.

Zinc

Chlorosis of the interveinial tissue is the most commonly reported symptom of zinc deficiency. In extreme deficiencies in corn the unfolding leaves are a light yellow or white in color. Zinc is believed to be related to seed production in such crops as peas and beans. Deficiencies are corrected by adding soluble zinc compounds to the soil or by spraying the foliage with solutions containing zinc.

The diagnosis of a micronutrient deficiency in plants requires a specialist. For example, there are at least three elements that may cause chlorosis in green plants and to decide which element is primarily responsible could involve detailed and costly chemical analyses. The chemical analysis of a soil is not as
reliable in diagnosing micronutrient deficiencies as it is with the micronutrients. Chemical analysis of leaf tissue is a practical method for diagnosing deficiencies but minimal and maximal limits for the elements have not been established for all crops. In many cases, an answer may be obtained by spraying or fertilizing small field plots with the elements that are suspected of causing the deficiency and observing the results.

SOIL BIOLOGY

In addition to the plant life in a soil, other important forms of life include:

- animals (burrowing animals, earthworms, insects, snails, nematodes)
- microorganisms (bacteria, fungi, actinomycetes, algae).

The many forms of animal life in a soil live on fresh or decaying vegetation. Earthworms consume large amounts of organic matter and excrete it in a partially digested form which is easily decomposed by bacteria. Animals tend to change and aerate a soil by their burrowing and soil mixing.

Soil bacteria outnumber all other forms of microorganisms in a soil. Most bacteria are beneficial because they release plant nutrients as they carry on their life cycle. Besides moisture, heat, and essential minerals, microorganisms require carbon as a constituent of their cells, nitrogen that has been combined previously into mineral or organic forms for the protein in their body, and a supply of material that they may oxidize (decompose) to provide them with energy.

The autotrophic bacteria obtain their energy from the oxidation of simple chemical compounds, and their carbon from the carbon dioxide in the atmosphere. This group of bacteria oxidize sulfur to sulfates, and ammonium compounds to nitrites to nitrates. This conversion of ammonia to nitrates is called nitrification and the autotrophic bacteria are an important agent in this conversion.

The heterotrophic bacteria depend upon organic matter for their source of energy and supply of carbon. This group of bacteria are largely responsible for the decomposition of organic matter and the production of the gas, carbon dioxide. Also classed as heterotrophic are the symbiotic (living together) bacteria. They live in the nodules on the roots of legume plants and use the nitrogen in the atmosphere to build their body protein. The nitrogen in the nodules is made available by bacterial decomposition to the legume plant or other plants, such as grasses, that may be growing with the legume, or to a crop that may follow the legume.

Fungi break down some of the more resistant forms of organic matter such as cellulose and lignin, and certain readily decomposable compounds, including sugars, starches, and proteins. The remains of dead fungi are not readily decomposed and form a part of soil humus. Some fungi cause plant diseases such as rusts, wilts, blights, and smuts.
The primary function of soil actinomycetes is in the decomposition of the moderately resistant forms of organic matter. Actinomycetes produce antibiotics that have been isolated and are known as streptomycin, aureomycin, and others. Potato scab is caused by an actinomycete.

Soil algae are chlorophyll-bearing microorganisms and may give a moist surface soil a greenish cast. They add some organic matter to a soil.

**SOIL MANAGEMENT**

Two objectives of a soil management program for climatically adapted farm crops are to produce the greatest net returns (dollars) per acre and to maintain or improve soil productivity, both on a long term basis. It will be shown later that a management program that results in maximum crop yield is not necessarily the most profitable one.

A good soil management program involves:
- the maintenance of adequate levels of soil fertility and soil organic matter
- the use of suitable tillage methods, depending on the soil and the crop
- the control of soil moisture, when necessary, by drainage or irrigation
- the use of special measures to control erosion when crop cover alone is not adequate.

**Maintenance of Soil Fertility**

A fertile soil supplies the essential nutrients in a suitable form, in adequate amounts, and in a proper balance for the growth of plants. If the supply of available nutrients limits crop yield, it may be increased by the addition of specific chemical fertilizers. There are many possible levels of fertility in a soil. The highest level is usually established for the crops with the greatest net dollar return per acre.

**Nutrient Losses**

A low level of soil fertility results when cropping removes the available nutrients more rapidly than they are replenished. The supply of available nutrients may be reduced by the conversion to fixed forms in the soil, by leaching, and by erosion.

**Removal by Crops**

Grain crops remove more nitrogen from the soil than any other essential element. Forage and vegetable crops, with few exceptions, contain more potassium than nitrogen. The average contents of nitrogen, phosphorus, and potassium for most farm crops are given in Table 6. Except for some of the nitrogen in legumes, all of the essential elements in the plants come from the soil.
Conversion of Nutrients

The conversion or the fixation of available nitrogen, phosphorus, and potassium to less available forms occurs in all soils. The soil conditions favoring conversion generally differ for each element. The principal modes of conversion were presented earlier in the section on Chemical Properties.

Loss of Nutrients by Leaching

Losses of plant nutrients by leaching are inevitable and the extent of the losses varies with the nutrients, soil type, management, and weather. Greatest leaching usually occurs in the well drained, coarse textured soils. In Ontario, small quantities of nitrogen and potassium and greater amounts of calcium and magnesium are found in the drainage water. Phosphorus is fixed in a soil and is not lost by leaching.

Losses by Erosion

The topsoil is the most fertile layer of a soil but if left unprotected by crop cover it may be slowly removed by surface run-off, even on gentle slopes. The loss of the organic material and the mineral colloids represents losses of plant nutrients. Soil erosion is discussed later in a separate section.

Supplying Nutrient Needs

Ontario farmers apply more than one-half million tons of fertilizer each year; the tonnage used doubled during the period 1946 to 1961. From 1951 to 1961, the tonnage of nitrogen purchased increased two and one-half times, while the use of phosphorus and potassium almost doubled. On many farms fertilizers are one of the major costs in crop production. Farmers realize that commercial fertilizers are needed to obtain economical yields, unless large quantities of manure are available. The most intensive use of fertilizers occurs in southwestern Ontario where cash crops (corn, soybeans, tobacco, and vegetables) represent the major sources of farm income.

In considering the quantities of nutrients removed by the harvested portion of crops (Table 6) it is important to realize that these nutrients came from the readily available supply in the soil. A knowledge of the amount of nutrients removed from a soil by a crop is used only as a guide in estimating fertility needs; one must have a knowledge of the unique plant nutrient relationships in a soil. In determining the nutrient needs of a soil that is to grow a particular crop, the usual procedure is to

- diagnose the problem,
- determine the nutrient or nutrients needed.
Table 6 - Plant Nutrients Contained In Farm Crops.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Yield</th>
<th>Part of Crop</th>
<th>Nitrogen (N)</th>
<th>Phosphorus (P₂O₅)</th>
<th>Potash (K₂O)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barley</td>
<td>50 bus.</td>
<td>grain</td>
<td>43.6</td>
<td>18.7</td>
<td>12.5</td>
</tr>
<tr>
<td></td>
<td>2,500 lbs.</td>
<td>straw</td>
<td>18.7</td>
<td>6.2</td>
<td>37.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>62.3</td>
<td>24.9</td>
<td>50.0</td>
</tr>
<tr>
<td>Beans</td>
<td>25 bus.</td>
<td>seed</td>
<td>60.0</td>
<td>18.0</td>
<td>19.5</td>
</tr>
<tr>
<td></td>
<td>2,000 lbs.</td>
<td>straw</td>
<td>28.0</td>
<td>6.0</td>
<td>38.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>88.0</td>
<td>24.0</td>
<td>57.5</td>
</tr>
<tr>
<td>Buckwheat</td>
<td>20 bus.</td>
<td>grain</td>
<td>15.0</td>
<td>6.0</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td>5,000 lbs.</td>
<td>straw</td>
<td>62.5</td>
<td>7.5</td>
<td>57.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>77.5</td>
<td>13.5</td>
<td>60.5</td>
</tr>
<tr>
<td>Corn</td>
<td>75 bus.</td>
<td>grain</td>
<td>71.2</td>
<td>28.7</td>
<td>18.7</td>
</tr>
<tr>
<td></td>
<td>4,500 lbs.</td>
<td>stover</td>
<td>47.5</td>
<td>15.0</td>
<td>68.7</td>
</tr>
<tr>
<td></td>
<td>750 lbs.</td>
<td>cobs</td>
<td>3.0</td>
<td>0.6</td>
<td>3.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>121.7</td>
<td>44.3</td>
<td>90.7</td>
</tr>
<tr>
<td>Flax</td>
<td>15 bus.</td>
<td>grain</td>
<td>30.5</td>
<td>12.5</td>
<td>8.2</td>
</tr>
<tr>
<td></td>
<td>1,800 lbs.</td>
<td>straw</td>
<td>20.5</td>
<td>3.4</td>
<td>18.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>51.0</td>
<td>15.9</td>
<td>27.0</td>
</tr>
<tr>
<td>Oats</td>
<td>75 bus.</td>
<td>grain</td>
<td>52.5</td>
<td>22.5</td>
<td>15.0</td>
</tr>
<tr>
<td></td>
<td>3,750 lbs.</td>
<td>straw</td>
<td>22.5</td>
<td>7.5</td>
<td>52.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>75.0</td>
<td>30.0</td>
<td>67.5</td>
</tr>
<tr>
<td>Peas canning</td>
<td>1,800 lbs.</td>
<td>grain</td>
<td>66.0</td>
<td>15.4</td>
<td>18.0</td>
</tr>
<tr>
<td></td>
<td>4,500 lbs.</td>
<td>straw</td>
<td>45.0</td>
<td>8.5</td>
<td>47.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>111.0</td>
<td>23.9</td>
<td>65.7</td>
</tr>
<tr>
<td>Rye</td>
<td>30 bus.</td>
<td>grain</td>
<td>28.6</td>
<td>14.7</td>
<td>10.0</td>
</tr>
<tr>
<td></td>
<td>3,000 lbs.</td>
<td>straw</td>
<td>15.0</td>
<td>9.0</td>
<td>25.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>43.6</td>
<td>23.7</td>
<td>35.5</td>
</tr>
<tr>
<td>Soybeans</td>
<td>25 bus.</td>
<td>grain</td>
<td>110.0</td>
<td>35.0</td>
<td>40.0</td>
</tr>
<tr>
<td></td>
<td>2,500 lbs.</td>
<td>straw</td>
<td>15.0</td>
<td>5.0</td>
<td>20.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>125.0</td>
<td>40.0</td>
<td>60.0</td>
</tr>
<tr>
<td>Tobacco</td>
<td>1,500 lbs.</td>
<td>leaves</td>
<td>55.0</td>
<td>10.0</td>
<td>80.0</td>
</tr>
<tr>
<td></td>
<td>1,500 lbs.</td>
<td>stalks</td>
<td>25.0</td>
<td>10.0</td>
<td>35.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>80.0</td>
<td>20.0</td>
<td>115.0</td>
</tr>
<tr>
<td>Wheat</td>
<td>40 bus.</td>
<td>grain</td>
<td>46.6</td>
<td>21.3</td>
<td>12.0</td>
</tr>
<tr>
<td></td>
<td>3,330 lbs.</td>
<td>straw</td>
<td>20.0</td>
<td>5.3</td>
<td>28.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>66.6</td>
<td>26.6</td>
<td>40.0</td>
</tr>
<tr>
<td>Mangels</td>
<td>20 tons</td>
<td>roots</td>
<td>60.0</td>
<td>40.0</td>
<td>140.0</td>
</tr>
<tr>
<td>Potatoes</td>
<td>300 bus.</td>
<td>tubers</td>
<td>65.0</td>
<td>25.0</td>
<td>115.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>tops</td>
<td>60.0</td>
<td>10.0</td>
<td>55.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>125.0</td>
<td>35.0</td>
<td>170.0</td>
</tr>
<tr>
<td>Sugar beets</td>
<td>15 tons</td>
<td>roots</td>
<td>55.0</td>
<td>22.0</td>
<td>53.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>tops</td>
<td>60.0</td>
<td>23.0</td>
<td>92.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>115.0</td>
<td>45.0</td>
<td>145.0</td>
</tr>
<tr>
<td>Turnips</td>
<td>10 tons</td>
<td>roots</td>
<td>50.0</td>
<td>20.0</td>
<td>90.0</td>
</tr>
<tr>
<td>Alfalfa hay</td>
<td>3 tons</td>
<td>all</td>
<td>140.0</td>
<td>30.0</td>
<td>135.0</td>
</tr>
<tr>
<td>Bluegrass hay</td>
<td>2 tons</td>
<td>all</td>
<td>53.0</td>
<td>21.6</td>
<td>84.0</td>
</tr>
<tr>
<td>Millet hay</td>
<td>3 tons</td>
<td>all</td>
<td>75.0</td>
<td>27.0</td>
<td>90.0</td>
</tr>
<tr>
<td>Red clover hay</td>
<td>2 tons</td>
<td>all</td>
<td>80.0</td>
<td>20.0</td>
<td>70.0</td>
</tr>
<tr>
<td>Soybean hay</td>
<td>2 tons</td>
<td>all</td>
<td>92.0</td>
<td>28.0</td>
<td>44.0</td>
</tr>
<tr>
<td>Sweet clover hay</td>
<td>5 tons</td>
<td>all</td>
<td>185.0</td>
<td>45.0</td>
<td>165.0</td>
</tr>
<tr>
<td>Timothy hay</td>
<td>1.5 tons</td>
<td>all</td>
<td>40.0</td>
<td>15.0</td>
<td>45.0</td>
</tr>
</tbody>
</table>
Diagnose the Problem

Poor crop growth may indicate a low level of several nutrients or a deficiency of one nutrient. Crop growth may be retarded by inadequate aeration, excess moisture, or a deficiency of moisture. Virus diseases and insect injuries may cause symptoms that could be mistaken for nutrient deficiencies.

Determine the Nutrients Needed

The cause of poor crop growth is seldom determined by visual symptoms alone. Soil and crop specialists often use field plots, greenhouse trials, and soil and plant tissue tests as diagnostic tools. Ontario farmers are advised by specialists regarding the nutrient status of their soils. The advice and recommendations are based on the results of chemical tests on a sample of soil submitted by a farmer, a knowledge of the kinds of soil on the farm, and the crops that are to be grown.

Chemical Soil Tests

Chemical tests on a soil are used to estimate the amounts of:
- certain ions (potassium, calcium, magnesium) that are readily exchangeable and available to a plant
- soluble nutrients (nitrogen, phosphorus, potassium, calcium, and magnesium) and in certain instances the concentration of toxic compounds
- nitrogen that might be released from organic compounds under ideal conditions of temperature and moisture
- hydrogen ions and basic compounds as a guide to changing soil pH.

The quantity of a nutrient as shown by soil tests cannot be used directly to calculate the pounds of that nutrient needed for a given crop yield. The chemicals used to extract the nutrients do not exactly imitate the plant roots and, furthermore, the rooting system of a plant does not contact all the available nutrients in a soil as the chemical extractant does.

Soil test values are most useful when they have been calibrated for different crops under field conditions. Soil testing is a necessary tool to assist farmers in selecting the kind of fertilizer and the amount to apply.

Instructions on taking soil samples and the information to be supplied with each sample are obtainable from the County or District Agricultural Representative.

Applying Plant Nutrients

The method used to apply fertilizer to a soil will depend on:
- the differences in solubility and the chemical properties of the nutrients
- the amounts of nutrients being applied
In a soil testing laboratory a technician uses several instruments to determine the plant nutrient status in a sample of soil.

- the differences in the rooting habits of plants
- the soil conditions (texture, moisture)
- the crop being fertilized and the preceding crop.

The following is a summarization of the methods of applying fertilizers.

**Band Application**
- used for corn, beans, potatoes; wide-row crops
- placed about one inch to side of the seed and two inches below
- reduces the amount of fixation, as with phosphorus.

**Applied With the Seed**
- for small grains, such as oats, wheat
- drill drops seed and fertilizer together
- fertilizers high in nitrogen plus potassium may cause seed injury
- often the only fertilizer the crop will receive.
Figure 14 — With corn and potatoes, the fertilizer should be placed two inches to the side and two inches below the seed. The rows are about 40 inches apart.

Figure 15 — With small grains such as oats and winter wheat, the fertilizer is usually drilled with the seed. The spacing between rows is seven inches.

Broadcast Application

- for perennial crops (pastures); fertilizer spread on surface of soil
- for part of the fertilizer applied for annual crops (corn, beans).

Applying Liquid and Gaseous Forms

- requires special equipment for applying, metering, and storing
- liquids may be broadcast, banded, or applied through an irrigation system
- gaseous forms, such as ammonia, injected into moist soil
- liquid forms include single nutrients or a complete fertilizer.

Figure 16 — Injecting anhydrous ammonia as a side-dressing for corn.

At the time of planting or transplanting (tobacco, some vegetables), a dry or liquid fertilizer high in phosphorus and low in nitrogen and potassium is placed close to the seeds or plants. This starter fertilizer provides the plant with a supply of readily available nutrients for early growth. The remainder of the fertilizer may have been broadcast and worked into the soil before planting, or may have been broadcast and plowed under the previous fall or just before seeding. Under certain conditions, for example corn following a manured grass-legume sod, the starter fertilizer may be the only fertilizer applied to the soil.
Some crops may receive a supplementary application of fertilizer while they are growing. For example, nitrogen may be drilled or banded in the soil close to the row of corn plants. This application is left as late as possible but mechanical damage is likely to occur to the plants if left until they are three or four feet in height. Other examples of supplementary fertilization include the broadcasting of fertilizer several times during the growing season on pastures and the application of additional nitrogen on winter wheat in early spring.

Farm crops cannot be supplied with the quantity of macronutrients required for economic crop production by foliar applications alone. However, foliar sprays are an effective method of supplying the micronutrients to a plant, if and when required.

**Characteristics of Fertilizers**

*A fertilizer* is any natural or manufactured material added to a soil for the purpose of supplementing the nutrients furnished by a soil. The term is generally applied to inorganic compounds other than liming materials. A mixed fertilizer contains two or all of the three major plant nutrients, nitrogen, phosphorus, and potassium.

The *analysis or grade* indicates the percentage of total nitrogen (N), available phosphoric acid (P\text{2O}_5), and water-soluble potash (K\text{2O}) in a fertilizer. This conventional way of expressing the percentage composition of a fertilizer is used even though the materials are present in other forms. For example, a fertilizer analysis of 5-20-10 is guaranteed to contain 5 pounds N, 20 pounds P\text{2O}_5, and 10 pounds of K\text{2O} per 100 pounds of material. The other 65 pounds is largely calcium, magnesium, sulfur, oxygen, and hydrogen. Present-day fertilizers of the higher analyses do not contain filler to make up weight. In the section Plant Nutrients, the compositions of the sources of nitrogen, phosphorus, and potassium fertilizers were given. These analyses provide the answer to the question "Why doesn't 100 pounds of fertilizer contain 100 pounds of nitrogen plus phosphorus plus potassium?"

Fertilizer analyses of 5-20-20 and 3-12-12 have a 1:4:4 ratio of nutrients. If the results of a soil analysis show that 15 pounds of N, 60 pounds of P\text{2O}_5 and 60 pounds of K\text{2O} are required, these amounts can be supplied with 300 pounds of a 5-20-20 fertilizer or with 500 pounds of a 3-12-12 fertilizer. Normally, the high-analysis fertilizers are the best buy due to a lower price per pound of plant nutrients, less handling, and less haulage costs.

Formerly, some farmers mixed their own fertilizer, using such materials as ammonium sulfate, superphosphate, and muriate of potash. The mixture had to be used almost immediately, otherwise the materials would absorb moisture, react, and finally solidify. Presently, few farmers mix their own fertilizer but they can purchase single ingredients and apply them separately, such as plowing down superphosphate, or broadcasting muriate of potash on pastures, or nitrogen on winter wheat.
Economics of Fertilizer Use

Recommendations for the use of fertilizer are based on the results of chemical soil tests and field trials. The response of a crop to applied fertilizer is a means of determining the rate of fertilization that will:

- give the greatest returns in dollars per acre, after deducting the cost of the fertilizer, expressed as "returns above the cost of fertilizer"
- increase the returns from an investment in fertilizer, expressed as "returns per dollar spent on fertilizer"
- increase or improve crop yield.

The data in Table 7 show the yield responses that were obtained when increasing amounts of a nitrogen fertilizer were added to plots of orchard grass. It was assumed that the orchard grass would be worth $20 a ton as hay and the nitrogen would cost 15 cents per pound.

Figure 17 — The information printed on a bag of fertilizer indicates the analysis or grade, the name and address of the manufacturer, the company's brand name for the fertilizer, the registration number, the net weight, and the guaranteed minimum analysis. Some fertilizers contain micronutrients, such as boron, and this would appear as borated granular fertilizer. While not required by law, some companies list the content of calcium, magnesium, or sulfur.
Table 7 -- Yield And Monetary Returns From Fertilizing Orchard Grass.

<table>
<thead>
<tr>
<th>Nitrogen Applied lbs. per acre</th>
<th>Cost of Nitrogen at 150 per lb.</th>
<th>Yield of Hay Tons per Acre</th>
<th>Value of Increase at $20 per ton</th>
<th>Returns Above Cost of Fertilizer $ per acre</th>
<th>Returns per Dollar Spent on Fertilizer</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>$ 0.00</td>
<td>0.78</td>
<td>$ 0.00</td>
<td>$ 0.00</td>
<td>—</td>
</tr>
<tr>
<td>50</td>
<td>7.50</td>
<td>1.78</td>
<td>20.00</td>
<td>12.50</td>
<td>2.67</td>
</tr>
<tr>
<td>100</td>
<td>15.00</td>
<td>2.44</td>
<td>33.20</td>
<td>18.20</td>
<td>2.21</td>
</tr>
<tr>
<td>150</td>
<td>22.50</td>
<td>2.68</td>
<td>38.00</td>
<td>15.50</td>
<td>1.69</td>
</tr>
<tr>
<td>200</td>
<td>30.00</td>
<td>2.97</td>
<td>43.80</td>
<td>13.80</td>
<td>1.46</td>
</tr>
</tbody>
</table>

It is apparent from the data in Table 7 that fertilizing the orchard grass at the rate of 100 pounds of nitrogen per acre returned the greatest profit per acre ($18.20). Under the conditions of this experiment, the 100-pound rate was the one a farmer would normally use for greatest profit. However, fertilizing at the rate of 50 pounds per acre resulted in the greatest returns per dollar spent on fertilizer ($2.67). This lower rate of fertilization appeals to a farmer with limited capital to spend on fertilizers because he would fertilize all the fields of orchard grass at the lower rate (50 pounds per acre) rather than a few fields at the higher rate. With limited capital, it is preferable to select the rate of fertilization that produces the greatest returns per dollar spent on fertilizer. When the returns per dollar spent are as high (121 per cent) as in this experiment, a farmer might borrow money or curtail other farm operations that yield less than 121 per cent and spend the money on fertilizer.

The results from the orchard grass experiment indicate that the most economical yield of a crop may not be the same as the maximum yield.

Changing the Reaction of Soils

In the section Chemical Properties of Soils, the terms soil reaction and pH were explained and the causes of soil acidity were presented. This section summarizes the applied aspects of changing soil reaction.

Reducing Soil pH

In the presence of free limestone or dolomite, soil pH may reach 8.4; if sodium compounds are present, the pH may exceed this value. The reduction of soil pH is not practical for the production of farm crops but is practiced on a small scale for some ornamental plants, such as azalea, rhododendron. The chemicals used to lower soil pH are sulfur or soluble compounds containing it — aluminum or iron sulfates. The amounts required can be calculated from the results of soil analyses.

Increasing Soil pH

Carbonates of calcium or magnesium are commonly used to increase soil pH. In general, most crops grow satisfactorily and plant nutrients are readily available when the soil pH is 6.0 to 7.0. The amounts and compositions of the liming materials that are added to acid soils can be determined from soil analyses and a consideration of the following:

- the intensity of the soil acidity (pH)
the colloidal content of the soil
the kind and quantity of basic ions in the exchange complex
the crops to be grown
the fineness of the material to be applied
the neutralizing value of the material to be applied.

Most of the liming materials used in Ontario are broadcast on the surface, plowed down and mixed with
the soil by cultivation. Fertilizer drills and lime spreaders, as well as trucks fitted with special spreading
equipment, may be used to spread lime.

![Figure 18 — Spreading lime or fertilizer by specially equipped trucks (bulk handling) reduces labor and handling charges.]

The pH scale of soil reaction for Ontario soils.

<table>
<thead>
<tr>
<th>Increasing Alkalinity</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH below 5.5</td>
</tr>
<tr>
<td>pH 5.5-5.9</td>
</tr>
<tr>
<td>pH 6.0-6.5</td>
</tr>
<tr>
<td>pH 6.6-6.9</td>
</tr>
<tr>
<td>pH 7.0</td>
</tr>
<tr>
<td>pH 7.1-7.4</td>
</tr>
<tr>
<td>pH 7.5-8.5</td>
</tr>
</tbody>
</table>

The pH scale of soil reaction for Ontario soils.

<table>
<thead>
<tr>
<th>Increasing Acidity</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH below 5.5</td>
</tr>
<tr>
<td>pH 5.5-5.9</td>
</tr>
<tr>
<td>pH 6.0-6.5</td>
</tr>
<tr>
<td>pH 6.6-6.9</td>
</tr>
<tr>
<td>pH 7.0</td>
</tr>
<tr>
<td>pH 7.1-7.4</td>
</tr>
<tr>
<td>pH 7.5-8.5</td>
</tr>
</tbody>
</table>

- **Very Sensitive to Acidity**
  - Alfalfa
  - Sweet clover
  - Sugar beets
  - Table beets
  - Beans
  - Turnips
  - Cauliflower

- **Moderately Tolerant to Acidity**
  - Birdsfoot trefoil
  - Alsike clover
  - Red clover
  - Soybeans
  - Vetch
  - Barley
  - Wheat
  - Oats
  - Corn

- **Highly Tolerant of Acidity**
  - Tobacco
  - Rye
  - Potatoes
  - Buckwheat
  - Crimson clover
  - Sorrel
  - Poverty grass
  - Rhododendron
  - Cranberry
  - Blueberry

Table 8 — Relative Tolerance Of Plants To Soil Acidity.
SOIL ORGANIC MATTER

Organic Matter and Humus

Soil organic matter includes the remains of all plant and animal life in a soil. The main sources of organic matter are the roots, leaves, stems, and fruits of plants; the remains of insects, worms, and animals; living and dead microorganisms, and their decomposition products. These sources may be supplemented by farmyard manure, crop residues, and green manure. Chemically, organic matter consists of proteins, carbohydrates, fats, waxes, resins, lignins, and many minerals.

Humus is a term applied to that portion of the soil organic matter that has reached an advanced stage in the decomposition processes. It is a dark-colored colloidal material that virtually resists further decomposition. Chemically, humus is composed of lignins, proteins, and other materials.

Organic matter is an important soil constituent because it:

- is a natural source of nitrogen and phosphorus to acts as a storehouse for essential plant nutrients
- makes fertilizer and lime more effective
- improves the physical condition of a soil
- reduces erosion losses.

The Carbon to Nitrogen Ratio

Soil humus has a carbon (C) to nitrogen (N) ratio of about 12 to 1 (12 parts of carbon to 1 part of nitrogen). The C:N ratio of straw is about 80 to 1. Before this organic matter can be converted to humus, the carbon must be reduced or the nitrogen increased, that is, the C:N ratio has to be narrowed.

The heterotrophic bacteria* obtain energy as they decompose the organic matter. They oxidize the carbon to the gas, carbon dioxide. This reduction of the carbon content of the organic matter and narrowing of the C:N ratio continue as long as nitrogen is available to the bacteria to build up the protein in their bodies. If the organic matter is low in nitrogen, as in straw, the bacteria use any soluble nitrogen which may be in the soil. A crop growing in the soil at this time may show signs of nitrogen deficiency.

The nitrogen in the soil should be increased by adding fertilizer nitrogen when the C:N ratio of the added organic matter is wide. For example, a ton of wheat straw contains about 800 pounds of carbon and 10 pounds of nitrogen. If 30 pounds of nitrogen were added to the soil as the straw was being worked in, the C:N ratio would be reduced to 20 to 1. It has been found that if the C:N ratio of the added organic matter is around 30 to 1, there is little danger of the soil nitrogen being immobilized by bacteria.

* See the section on Soil Biology.
The amount of humus that accumulates with the decomposition of crop residues generally follows the level of soil nitrogen. The residues from most cropping systems have a wide C:N ratio that may be narrowed by adding nitrogen to a soil as the residues are being incorporated with the soil.

**Sources of Organic Matter**

**Farmyard Manure**

Farmyard manure and crop residues (straw, cornstalks, and legume-grass sod) are important farm resources for increasing crop production. Manure contains all the macronutrients (nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur) and several micronutrients (boron, copper, zinc, and manganese). In terms of plant nutrients alone, the manure produced on a farm each year is worth several hundred dollars.

Manure supplies about 500 pounds of dry matter per ton in a form that is easily decomposed by microorganisms. Manure when applied to a soil:

- increases activity of the microorganisms
- improves the physical condition of soils
- increases the water-holding capacity of soils and promotes the infiltration of rainfall
- improves soil fertility.

**Value of Farmyard Manure**

A calculation of the value of the nitrogen, phosphorus, and potassium in manure from different animals is given in Table 9.

**Table 9** — Content And Market Value Of Plant Nutrients In Different Manures.

<table>
<thead>
<tr>
<th>Kind of Animal</th>
<th>Nitrogen (N)</th>
<th>Phosphorus (P₂O₅)</th>
<th>Potassium (K₂O)</th>
<th>Total Value per Ton*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horse</td>
<td>13.1</td>
<td>4.3</td>
<td>11.5</td>
<td>2.88</td>
</tr>
<tr>
<td>Cow</td>
<td>11.4</td>
<td>2.8</td>
<td>9.7</td>
<td>2.36</td>
</tr>
<tr>
<td>Pig</td>
<td>11.1</td>
<td>6.1</td>
<td>9.0</td>
<td>2.60</td>
</tr>
<tr>
<td>Sheep</td>
<td>18.1</td>
<td>6.6</td>
<td>19.1</td>
<td>4.15</td>
</tr>
<tr>
<td>Poultry (broilers)</td>
<td>33</td>
<td>31</td>
<td>17</td>
<td>8.57</td>
</tr>
</tbody>
</table>

* Value of nutrients: Nitrogen 14, Phosphorus 10, and Potassium 5 cents per pound.

More than one-half the nitrogen and at least three-quarters of the potassium excreted by a cow is contained in the urine. Most of the phosphorus is in the feces.
The value of manure may also be calculated on the basis of its effect in increasing crop yields. This increase will vary depending on the crops grown, the fertility level of the soil, the climate, and the care with which manure is stored and handled. Results obtained at the Regional Research Station at Cayuga give an indication of the value of manure on a corn-oats-fall wheat-red clover rotation, Table 10.

Table 10 — The Effects Of Manure And Fertilizer On The Yield Of Four Crops In A Rotation — Average Of Ten Years Data.

<table>
<thead>
<tr>
<th>Crop</th>
<th>With Crop Residues</th>
<th>Manure</th>
<th>With Crop Residues</th>
<th>Manure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn (bus. per ac.)</td>
<td>65</td>
<td>73</td>
<td>74</td>
<td>80</td>
</tr>
<tr>
<td>Oats (bus. per ac.)</td>
<td>59</td>
<td>65</td>
<td>67</td>
<td>72</td>
</tr>
<tr>
<td>Fall wheat (bus. per ac.)</td>
<td>29</td>
<td>42</td>
<td>34</td>
<td>45</td>
</tr>
<tr>
<td>Red clover (t. per ac.)</td>
<td>2.3</td>
<td>2.6</td>
<td>2.5</td>
<td>2.6</td>
</tr>
</tbody>
</table>

Low fertility means a treatment in which the amount of fertilizer that was used was less than that recommended by soil testing data.

Moderate fertility was a treatment including the use of fertilizer according to soil test recommendations.

Manure applied: 10 tons on the red clover stubble and fall plowed for corn; 5 tons on each of fall wheat and red clover in the fall.

Manure accounted for increases in the yield of all crops at both levels of soil fertility.

Storage and Handling

Most farm animals use only a small part of the nitrogen, phosphorus, and potassium contained in their feed. About 70 per cent of the nitrogen, 85 per cent of the phosphorus, and 90 per cent of the potassium in the feed is excreted in the manure. Between 40 and 75 per cent of the plant-nutrient value of manure is in the liquid portion.

Losses of plant nutrients from manure occur in the following ways:
- leakage of the liquid through broken stable floors
- soaking into barnyards and feedlots
- leaching when improperly piled in the open
- not using sufficient bedding
- heating in the pile
- erosion when spread on sloping and frozen ground
- rapid drying when spread on the surface of the soil during warm, dry weather.

It has been estimated that about 25 to 30 per cent of the potential value of manure is being realized. None of these losses can be avoided entirely, but they can be reduced by careful handling. Adequate amounts
of bedding or litter should be used to provide a clean, comfortable place for animals and to absorb the valuable liquid portion of the manure. Cereal straw is the usual bedding material; its absorption capacity is increased by cutting. Wood shavings and sawdust are satisfactory. Although it is not used extensively, peat moss is one of the best litter materials because it absorbs 10 times its weight in liquid while cereal straw will hold only 2 to 3 times its weight.

If manure is spread each day, 30 to 50 per cent of the nitrogen may be lost by freezing or drying in the field. Rapidly melting snow will carry nitrogen and potassium from rolling land. Manure is usually stored until spread on the soil.

If manure is stored in the open, the pile should be well compacted and located where it will receive neither roof water nor surface water from higher land nearby. In covered feedlots or pens, manure can be allowed to build up for several months. This is an ideal way to store manure. The manure is protected from rainwater and is tightly packed. Plenty of bedding should be used to absorb the liquid. One important advantage

Figure 19 — A manure spreader and a front-end loader facilitate the handling of manure.
of storing manure in in covered areas compared with daily spreading is that the manure can be spread at a time when it is possible to plow it under almost immediately and thus avoid nitrogen losses due to drying.

The rotting of manure is a destructive process in which nitrogen is lost as ammonia and organic matter is lost as carbon dioxide. However, well-rotted manure has a better balance of nitrogen, phosphorus, and potassium than fresh manure and pound for pound rotted manure contains a higher percentage of available plant nutrients than fresh manure. For farm use, it is not economical to rot manure in order to get a more concentrated fertilizing material.

**Preserving Manure with Chemicals**

Superphosphate is used as a preservative for manure. A chemical reaction occurs with the superphosphate combining with the ammonia gas produced by fermentation in the manure pile. This reaction reduces the loss of nitrogen in the ammonia form. In addition, the superphosphate supplies phosphorus to the manure which is generally low in this plant nutrient. One to $1\frac{1}{2}$ pounds of superphosphate per mature animal per day are applied in the gutters of the stable or loafing barn areas.

In general, manure should be applied for the crops with the highest acre value. Vegetable crops usually pay a higher return than field crops. Of the field crops, corn gives high returns from 5 to 10 tons of manure per acre. New seedings that look weak in the fall often benefit from a light, evenly spread dressing (5 tons per acre). Well established legume-grass meadows give less response than pure grass meadows. In clean-cultivated orchards, on small fruit plantations, and for vegetable crops, manure should be applied in fairly heavy amounts (10 to 20 tons per acre). Here the intensive cultivation and cropping deplete the organic matter in the soil at a rapid rate.

**Manure Lagoons and Pits**

More and more farmers have discovered that labor costs and the fertilizer value of manure can be saved when it is stored and handled as a liquid.

Each farmer has his own special problems and ways of handling liquid manure, but in general the manure is conveyed to a concrete cistern or open lagoon by one or more of the following:

- scraping the yard or pen with a tractor-mounted blade
- a conveyer system in gutters or under slatted or "wire" floors
- washing the pen, yard, or gutter with pressure hoses.

The solids undergo decomposition and partial breakdown in storage under warm conditions and with plenty of oxygen. Some storages are mechanically agitated to encourage the breakdown; in others the solids are allowed to settle and are removed as a wet sludge.
The liquid may be pumped from the lagoon to a tank spreader but if solid and liquid materials are involved an auger mechanism is preferred. An outlet from the tank spreader drops the liquid and solids on a rotating fan which spreads the material over a 20- to 30-foot strip. Agitators in the tank spreader reduce the problem of plugged outlets when solids are involved.

*Figure 20 — Two methods for the storage of liquid manure.*
Handling liquid manure is similar to handling commercial fertilizer solutions. Only very dilute solutions of liquid manure may be spread directly on a growing plant; in fact, the practice is so hazardous that most farmers prefer to spread on bare soil or use hoses to direct the liquid between crop rows, particularly corn. In some situations the liquid may be spread by furrow irrigation depending on gravity flow rather than a pressurized system.

**Poultry Manure**

The pounds of plant nutrients in a ton of poultry manure depend on the produce being sold; that is, the manure from broilers contains more pounds of plant nutrients per ton than the manure from laying hens. If allowed to accumulate in pens, poultry manure decomposes rapidly, especially in warm weather, with significant losses of ammonia (nitrogen). An analysis of broiler manure, without litter and stored for about three days, is given in Table 9. On a plant nutrient basis, one ton of this manure would be equivalent to 400 pounds of an 8-8-4 commercial fertilizer.

Poultry manure, about five tons per acre, may be spread on fields that are to be cropped with corn. Too much manure may delay the maturity of corn grain. Grass and leafy vegetables respond to the high nitrogen in poultry manure; legumes tend to die out; cereal grains may lodge. Skillful management is required when using poultry manure in orchards and in small fruit plantations.

**Green Manuring**

The object of green manuring is to return to the soil the plant nutrients removed by the green manuring crop and to add easily decomposable organic matter. While green manuring supplies very little organic matter to the soil, it encourages a great increase in the microbiological activity.

Almost any crop may be used for green manuring. Legumes are much superior to non-legumes because of the nitrogen that is fixed. Hay aftermath may be plowed down as a green manure when it is not required for hay or pasture.

Fall sown rye is a common green manuring crop to precede row crops such as corn, tobacco, or potatoes. Rye should be plowed under or disked into the soil before it reaches a height of 12 to 15 inches. About 10 to 14 days are required after plowing before the succeeding crop is planted so that partial decomposition of the rye may occur. Such a delay rarely permits the planting of spring grains after rye has been used as a green manuring crop. Fall planted oats produce enough growth in the fall to protect the soil from erosion and no spring growth occurs to delay planting.

Green manuring crops are especially valuable in a vegetable production program. After harvesting an early vegetable crop, winter rye, domestic or Italian rye grass, or soybeans may be planted as a green manuring crop.
LAND DRAINAGE

Land drainage is a special management practice that removes surplus water from the soil at certain seasons of the year and also lowers the water table. It has been estimated that 40 per cent of the agricultural land area in southern Ontario is poorly drained and that 20 per cent is imperfectly drained. Land drainage is a major problem in developing agricultural areas in northern Ontario. Land is drained primarily to improve agricultural productivity and increase farming efficiency by greater crop yields, wider choice of crops, and more timely tillage and harvesting operations.

Where Needed

Soil color is a useful indication of the soil drainage conditions. A very dark surface soil is normally a reflection of poor drainage — the decomposition of organic residues is slow and incomplete due to poor aeration. A water table that is close to the surface or that fluctuates during the year results in soil horizons (Ae, B, or C) that are a mottled brown, yellow, or gray in color or causes a gley horizon.*

The occurrence of winter-killing and heaving of fall wheat, alfalfa, and clovers is the most

* These terms were defined in the first section, What Is A Soil?

Figure 21— When a growing crop is plowed under, plant nutrients and easily decomposable organic matter are returned to the soil.
frequent on soils where drainage is inadequate or where there are prolonged accumulations of water or ice on the surface.

**Types of Land Drainage**

Surface drainage is a method of collecting and removing excess water from the soil surface. Complementary practices, such as land levelling and plowing in narrow lands, assist in the collection of the water and its discharge into drainage ditches or grassed waterways. Surface drainage may be used in areas where soil permeability is too slow for a subsurface drainage system to be effective.

In subsurface drainage water moves through the soil into tiles made of fired clay or concrete, or into perforated pipes, and is discharged into a drainage ditch or a suitably prepared outlet. The planning and designing of subsurface drainage systems require a knowledge of the permeability characteristics of the soil and the crops that are to be grown.

In making a decision for or against a major expenditure on a land drainage system, a farmer should consider:

- the cash value or feeding value of adaptable crops
- the soil texture (the permeability of some clay soils is so slow that a subsurface system is not effective)
- the availability of good drainage outlets
- the proportion of good and poor land in the area to be drained.

Some of the benefits of land drainage are that it

- increases the number of climatically adaptable crops that may be grown,
 increases the resistance of a plant to drought by promoting deeper and more extensive rooting,
reduces the frequency of crop heaving and winter-killing,
improves soil aeration and soil structure,
permits earlier tillage (the soil dries out faster),
promotes earlier growth (a dry soil warms up faster).

**SOIL TILLAGE AND TILTH**

Experience has taught that a certain amount of soil tillage is required for crop production. Besides controlling weeds and incorporating crop residues, soil tillage provides a seedbed and an environment suitable for plant root growth.

**Soil Tilth**

The word *tilth* is frequently used to describe the fitness of a soil and its suitability for the germination and growth of specific seeds. A fine tilth is required for small seeds, such as grass seed, whereas a coarser tilth is suitable for the larger seeds, such as beans and corn. Tilth describes soil structure in terms of the size-distribution of the soil aggregates and their resistance to breakdown by tillage and by the action of rainfall.

The preferred sizes of aggregates range from 1 to 5 millimetres. A soil with large and stable aggregates has large stable soil pores which, ideally, extend from the surface to the water table or tile drains. Such pores ensure a rapid intake of water at the soil surface and facilitate the natural drainage of the excess water downwards. Moisture for plant use is stored in the small pores, which are distributed throughout the soil, and within the soil aggregate itself. This moisture is not removed by gravitational forces during drainage.

It is essential that the individual aggregates maintain their stability for several weeks after the seeds are planted. If the aggregates disintegrate after wetting and drying, a crust may form on the soil surface. Firm and thick crusts impede the entry of water, may restrict soil aeration, and reduce seedling emergence.

When a soil is in good tilth, there is a close contact between the seed and the aggregate, permitting moisture to move into the seed and start germination. That is why farmers prepare a "fine, firm seedbed", use press wheels on various planters, or compact the soil by different kinds of land rollers, particularly after planting spring grain under-seeded with a grass-legume mixture. It must be recognized that only the volume of soil extending an inch or so away from the seeds affects the movement of moisture to the seeds. The soil between the rows is not part of the seedbed and accordingly should be left loose to facilitate water entry and aeration.

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*Many of the terms used here were introduced in the section Physical Properties of a Soil.*
Primary Tillage

The moldboard plow is the most widely used implement for the primary preparation of a seedbed on Ontario farms. On a fine textured soil or on a dense sod, the plow is the most effective and economical implement for primary tillage. Although many implements have been tried as replacements, the plow does the best job of turning under cover crops, residues, and trash and at the same time buries weed seeds and checks the growth of perennial weeds.

When adjusted and operated properly, a moldboard plow cuts, lifts, shears, and turns the furrow slice. These actions greatly improve the tilth of clay soils, provided the moisture content is right. Working clay soils when too wet results in a poor structure and may contribute to the formation of plow pans.*

Fall plowing is preferred on most fine textured soils. The large clods break into soil aggregates as a result of freezing and thawing during the winter. A gentle rainfall causes large dry clods to develop planes of weakness which facilitate the preparation of a desirable soil tilth by further tillage. It is difficult and costly to

* Described under Deep Tillage.
prepare a good tilth if the soil is dry and cloddy. Clay soils, particularly those low in organic matter, have a very narrow moisture range when tillage is most effective.

Spring plowing is feasible on most coarse and medium textured soils provided the seeds are planted before the soil dries out. In many cases very little supplementary tillage is required and seeding follows directly after plowing. Erosion by wind or water is materially reduced by spring plowing as the soil is not left unprotected by vegetation for long periods.

Numerous experiments have failed to show significant increases in crop yields when the depth of plowing was increased beyond the normal 6- to 7-inch depth. It has been reasoned that deep plowing would...

Figure 24 — *Five common farm tillage implements.*
increase root proliferation particularly in the Ae horizon* of some soils. When part of the Ae is incorporated with the plowed layer, the result is a soil lower in plant nutrients and organic matter.

**Supplementary Tillage**

The time and amount of tillage that a soil requires depend on the season, the crops that are grown, and the growth habits of the weeds that must be killed or checked. Cultivation of fine textured soils when they are too wet may induce puddling and the formation of large clods. Sandy soils are less likely to be damaged by tillage at improper soil moisture contents.

The primary purpose of supplementary tillage on plowed land is to level, pulverize, and pack the soil before seeding. Coarse and medium textured soils seldom require more tillage than once over with a spike-toothed harrow or a double-disk harrow before seeding. If the soil is dry or if the seeds are small, a smooth or corrugated land roller may be used after seeding to firm the soil and to ensure a better contact between seed and soil. It may be advisable to firm a sandy soil with a plow packer or roller immediately after plowing to conserve moisture. Clay soils that are plowed in the fall seldom require more than disking and harrowing to prepare the seedbed in the spring. However, if the soil is worked when too wet, several operations are required to prepare a desirable tilth. Spring-toothed harrows and cultivators are used to loosen a compacted surface without disturbing the soil underneath. These implements are frequently used for after-harvest cultivation to suppress weed growth.

**Minimum Tillage**

Minimum tillage implies soil preparation methods for planting in which the number of machine operations or trips over the field is less than with conventional methods. It is not unusual for corn growers to make 10 or more trips over a field in preparation for planting. The additional tillage, especially disking and harrowing, does not ensure a better tilth but may sift the soil, leaving the fine aggregates deeper than the seeds. Excessive tillage leaves the tilth so fine that crusting or puddling may occur after a rain.

Minimum tillage methods normally apply to the preparation of a soil for seeds of corn, beans, sugar beets, and oats. With the wide-row crops a common form of minimum tillage is the wheel-track method. The land is plowed in the spring and followed by a corn planter that drills the seed and fertilizer in the soil compacted by the tractor tires. The soil between the rows remains as the plow left it. When planting oats, the plow is followed by a levelling or firming implement and then the seed drill. No further tillage is required.

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* The Ae horizon, if present, occurs under the cultivated layer, see the section, What Is A Soil?

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The principal advantages of minimum tillage are:

- a saving in labor and machinery operation
- less danger of over-tillage
- the soil between the rows is rough and porous (a condition that is conducive to maximum infiltration of water, minimum erosion, and poor germination of weed seeds).

The causes of crop failure or low plant population following minimum tillage may be one or more of the following:

- a moisture deficiency at the time of planting or soon after
- a soil tilth too coarse, resulting in a droughty soil
- over-compaction causing poor aeration.
Deep Tillage

Excessive soil compaction restricts plant growth, water movement, and soil aeration. There are three general types of soil compaction: (1) traffic pans, (2) genetic pans, and (3) compacted subsoils and parent materials (Bt and C horizons).

Traffic pans form in the bottom of a furrow when wet soil is compressed by plow or tractor wheels. Compaction is most likely to occur if the soil is tilled when it is too wet. Fortunately, most traffic pans in Ontario soils disappear with the alternate freezing and thawing during the winter. Traffic pans that resist the frost action may be shattered by deeper plowing (once is usually enough) when the soil in the pan is relatively dry and will crumble.

A genetic pan is a compacted soil layer, two to twelve inches thick, that developed naturally during the formation of the soil. In most cases, these pans may be shattered by subsoiling when the soil in the pan is relatively dry. A subsoiler is an implement equipped with a blade and shoe that cuts through the soil, lifting and disrupting the compacted layer with a minimum of disturbance to the surface soil.

In some clays, the subsoil and parent materials are so dense and compacted that drainage and aeration are impeded. Numerous experiments on such soils have shown no prolonged beneficial effect from subsoiling. The soil to the depth of the subsoiling is temporarily loosened but after one or two years it has re-consolidated.

SOIL EROSION

Erosion of soil by water occurs when particles are detached by raindrops and transported by flowing water. Erosion by wind is discussed in a later section. The erosion process is completed when the soil is deposited in a place other than its natural or original position.

Figure 26 — A raindrop hits the soil with enough energy to break a soil clod into small aggregates which are easily transported by moving water. Note the raindrop in the left photograph.
Mechanics of Erosion

Soil Detachment
In some storms the raindrops strike the soil with enough energy to blast the granules apart. Water and soil splash into the air. The results of this splashing action are often seen on walls of buildings where muddy spots occur several inches above the level of the ground. On sloping land most of this splash goes down the hill, causing more soil to be deposited at the base of the hill. On a smaller scale, the splash material tends to accumulate in small depressions.

Soil Transport
Water flowing over the land surface is the main agent by which soils are transported. The erosive action of water becomes greater with increases in
- the slope of the land,
- the volume of water,
- the amount of abrasive material (sand and gravel) carried by water.

If the water is confined in a rill or gully, its ability to erode increases as the velocity increases and as the amount of soil being transported increases.

Effects of Erosion

Some of the more common effects and results of soil erosion are illustrated in Figure 27.

Control of Erosion

Principles of Erosion Control
Three principles in the control of soil erosion are:
- reduce the velocity of runoff water
- maintain a high infiltration rate in the soil surface
- dissipate the energy of raindrops on crops or residues.

Long slopes allow flowing water to build up its velocity and hence increase its ability to erode. If an obstacle is placed in the path of the water, its velocity is reduced; in a hay field many obstacles reduce the velocity of the water and erosion seldom occurs. A farmer has no control over rainfall nor is it economically feasible to change the slope of the land but he can effect some control over the moving water by the selection of crops and by soil management.

Infiltration is the process whereby water enters the immediate surface of a soil. Coarse textured soils or soils with a high percentage of water-stable aggregates usually have a high infiltration rate. A farmer does not attempt to change the texture of a soil but he can alter soil structure by the choice of crops, the crop
Figure 27 — The effects of soil erosion.
and the cultivation practices. If water fails to infiltrate the soil surface, then it has no alternative but to run off and transport the detached soil particles.

The erosion hazard is reduced greatly when the energy in falling raindrops is dissipated on crops or mulches of crop residues, instead of on the bare soil. This is another reason why erosion seldom occurs in unpastured woodlots or in well-managed hay and pasture fields.

**Crops and Crop Rotations**

A farmer should plan his crops and rotation so that highly erodible land is kept covered with grass as long as possible. On gently sloping land, a 4- to 6-year rotation with 1 or 2 years of grain or row crops is followed. On level or nearly level soils, a 3- or 4-year rotation with two or more years of grain or row crops is common. Continuous cropping with wide-spaced row crops should not be practiced on sloping or erodible land.

**Table 11 — The Ten-year Average Of Soil And Water Losses From A Loam Soil On A Seven Per Cent Slope Under Several Cropping Practices At Guelph.**

<table>
<thead>
<tr>
<th>Cropping Practice</th>
<th>Erosion Losses Per Year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Inches of water</td>
</tr>
<tr>
<td>Continuous sod</td>
<td>Trace</td>
</tr>
<tr>
<td>Hay in a 4-year rotation of corn-oats-hay-hay</td>
<td>Trace</td>
</tr>
<tr>
<td></td>
<td>Planted with the slope</td>
</tr>
<tr>
<td>Continuous corn</td>
<td>1.2*</td>
</tr>
<tr>
<td>Corn after two years of hay</td>
<td>0.2</td>
</tr>
<tr>
<td>Oats after corn</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>Planted across the slope</td>
</tr>
<tr>
<td>Corn after two years of hay</td>
<td>Trace</td>
</tr>
<tr>
<td>Oats after corn</td>
<td>Trace</td>
</tr>
</tbody>
</table>

* Represents about 7 per cent of the total rainfall.

The data in Table 11 and the results from chemical and physical analyses in Table 3, indicate that:

- a dense cover crop (hay) effectively controlled erosion by reducing the velocity of moving water, by increasing the infiltration rate, and by absorbing the energy of falling raindrops
- under continuous corn with residues removed, erosion was serious because the soil organic matter content had decreased and the percentage of water-stable aggregates was low (see Table 3)
- under corn after two years of hay, erosion was negligible because the granular and water-stable structure following the hay crop was able to withstand the beating action of the rain
erosion under the oats was due mainly to the practice of ridge-rolling for the small grass and legume seeds.

across-the-slope planting provided numerous dams and depressions to slow down the movement of water and allow it to infiltrate.

**Strip Cropping**

Strip cropping is an erosion control measure that may be used on long, smooth slopes that are planted to grain or row crops. It consists of maintaining strips of hay alternately with strips of grain or row crops, Figure 29. The width of the strips varies from 60 to 150 feet, depending on the length and steepness of the slope, the erodibility of the soil, and the crop rotation. In other words, the greater the erosion hazard, the narrower the strips.

In field strip cropping, the strips are straight, of uniform width, and are laid out across the general slope of the land. Field strips are recommended on uniform slopes where it would appear that no greater control of erosion would be attained by contour strips, Figure 29A.

![Figure 28](image-url)

**Figure 28** — *Strips of winter barley underseeded with a grass-legume hay mixture. The cultivated strips will be planted to corn. The grass waterway carries surplus water safely downhill.*
If it is necessary to lay out strips that follow a contour* more precisely than field strips do, a type of contour strip cropping may be used. A procedure for laying out two types is suggested.

* A contour is an imaginary line connecting points of equal elevation on the surface of the soil. In the field, a contour is marked with a row of stakes or a shallow furrow.

1. Curved and even-width strips, Figure 29B.
   - Stake out a key contour (K.C.) at the steepest part of the field.
   - Lay out even-width strips above and below the key contour.
   - The second key contour will result in a correction strip which is usually left in sod.
   - Continue laying out strips from the second key contour.

2. Curved and uneven-width strips, Figure 29C.
   - Upper and lower edges of all strips follow a contour.
   - Results in uneven-width strips with odd-shaped areas (point rows) that present problems in cultivation, seeding, and harvesting.
   - Not used in Ontario.

The advantages of strip cropping are as follows:
   - reduces the velocity of the water flowing over the surface
   - increases the time for water to infiltrate
   - encourages a farmer to use a crop rotation
   - facilitates contour cultivation.

Grass Waterways
Grass or sod waterways are specially prepared water courses that remove surplus water without causing erosion. Many open ditches or gullies that are impassable to machinery may be changed to grass waterways by re-shaping and seeding to grass and legumes (Figure 28).

A grass waterway is a broad channel with gently sloping sides and is shaped by plowing or grading. The larger the area that is drained, the wider the waterway must be; a channel less than 20 feet in width is seldom recommended. After the channel has been shaped, a mulching with straw or manure and a light seeding of oats will hold the soil in place until the grass and legumes become established. Waterways should be established when the remainder of the field is in hay.

It is essential that the waterway be kept in a grass-legume mixture and harvested for hay. The strips should be fertilized regularly, not be used as lanes and not disturbed by plowing or cultivation.

Diversion Ditches
Diversion ditches or diversion terraces are low embankments of soil thrown up on slopes for the purpose of diverting surface water away from the land farther down the slope. These channels, about 30 feet in width, are left permanently in sod regardless of the crops above or below.
FIELD STRIP CROPPING
- straight and even-width strips at right angles to the slope
- adaptable to uniform slopes
- corn and hay strips alternate
- gores or irregular areas kept in hay, seldom in corn

CONTOUR STRIP CROPPING
- curved and even-width strips at right angles to the slope
- serious deviations from contour remedied with correction strip

CONTOUR STRIP CROPPING (Exact)
- curved and irregular width strips
- upper and lower edge of each strip on the contour
- awkward situations for plowing, planting and harvesting, for example, point rows in a row crop

Figure 29 — An illustration of three types of strip cropping.
The sides of the ditches are gently sloped and present no difficulty in hay removal.

Three situations where diversion ditches are used:
- to break up long uniform slopes if strip cropping is not controlling erosion
- to divert water while gullies are being repaired or while grass waterways are being established
- to protect buildings or property from periodic flooding.

The water from diversion ditches may be discharged into established grass waterways and from there to unpastured woodlots or into a sod field where erosion and gullying will not develop.

**Gully Erosion and Control**

Gullies are formed when large volumes of water are confined to a narrow channel. They may develop in all types of soil but are most common in Ontario in sandy soils where intertilled crops such as corn, soybeans, or tobacco are grown. Deep gullies have formed in clay soils adjoining river channels and lakeshores.

Some of the common situations that lead to gullies being developed are:
- wheel tracks in loose soil
- dead furrows
- livestock paths
- neglected natural water courses
- discharging water from yards or waterways onto soils without adequate plant cover.

Gully erosion is seldom controlled by dumping stones, brush, or old wire fencing in the channel. The water flows around the rubbish and gouges out the side or accumulates behind an obstacle and when suddenly released, creates a worse gully. To stop gullying and allow the sides and bottom to be covered with vegetation, it is necessary to reduce the velocity of the water along the full length of the gully by one or more of the following:

- a series of check dams of logs, boards, or sandbags placed across the gully at frequent intervals
- placing 1 to 3 feet of straw in the channel and anchoring it down by brush 8 to 10 feet in length with the trunk end placed up stream.

Large gullies, such as occur along lakeshores, require costly remedial measures. The gully walls must be pushed in, graded, and stabilized by vegetation, stonework, or concrete structures.
Wind Erosion

In Ontario, wind erosion or soil drifting is generally a localized problem and is confined mostly to sandy, muck, and peat soils. Drifting may occur on any soil if it is cultivated while very dry, as in summer fallowing.

Except for the shifting sand dunes along some lake shores, the sandy soils now subject to wind erosion were once forested. When these soils were cleared and cultivated, the organic matter was rapidly depleted and the bare soil began drifting.

The principal means of control include the following practices:

- planting windbreaks using two or more rows of trees with different growth habits, such as Carolina poplar and white spruce
- using strips of different crops at right angles to the prevailing wind direction
- sowing cover crops of winter rye after harvesting such crops as tobacco, potatoes, or vegetables.

Large areas of drifting soil may be stabilized by planting rapidly growing trees (certain species of

![Figure 30](image)

Figure 30 — A stone and timber structure that has effectively stopped gully erosion. The upper bed of stone reduces the velocity; the lower bed absorbs the energy as the water flows over the low dam.
poplars) to afford some protection while conifers become established. "Blow-outs" develop in sandy soils that have been over-grazed. A preventive measure against wind erosion is to keep the soil adequately covered with trees or grass.

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