B.C. Agricultural Drainage Manual

Chapter 2

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The primary purpose of the B.C. Drainage Manual is to provide farmers as well as water management professionals and consultants with technical information on the design, installation and maintenance of agricultural drainage systems.

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Soil 2

2.0 The Role of Soil

Soils are a dynamic natural body, a thin mantle on the surface of the earth which supports plant life, and in turn, the life of all land animals. In many cases, soil acts as a control mechanism in an ecosystem. The soil plays a major role in the ecological balance of the whole environment, with an important influence on the quality and quantity of ground and surface waters. The soil itself is alive with countless plant and animal life forms adapted to live in the soil environment, and to promote soil fertility.

In nature, soils change and develop very slowly. When brought under cultivation, they undergo very rapid changes which affect their physical, chemical and biological properties. The objective of soil management is to maintain soils in a physical, chemical and biological condition favourable for crop growth. Whatever is done to soil affects it in some way, and all practices must be considered as part of soil management.

Water management plays an important role in the overall management of soil. Whether by addition through irrigation systems or removal by drainage systems, water must be managed in soil for land to be productively cultivated. This part of the drainage manual deals with soil water management in general terms. The practical aspects of soil management as they relate to removal of water through drainage are covered in more detail in later chapters.

2.1 Soil Composition

Soils are found in a wide variety of forms. They are generally composed of mineral materials derived from a transported parent material or weathered rock, with some accumulation of organic matter or humus and a large population of soil organisms. Soils, as well as being made up of mineral and organic constituents, have pores which may hold air and water. These components vary in content depending on the parent material and the state of soil development. Soils can be divided into two broad soil types based on the their development: mineral soils or organic soils. Both are developed from the accumulation and decomposition of plants. Mineral soils are dominantly mineral matter and contain less than 15% organic matter in the topsoil layer. Organic soils contain over 30% organic matter in all layers of the soil. In these soils, organic matter may be completely decomposed, as muck, or only partially decomposed as in peat soils.

The mineral components of soil are divided into three broad size classes (sand, silt and clay) which are used to describe a soil's texture. Mineral components larger than sand are not included in the texture name, but are referred to in the descriptive modifiers given to the soil textural class (i.e., gravely sand). The organic components of a soil are also not referred to in the textural class description unless the soil is defined as an organic soil. The organic constituents do play a role in the development of soil structure. The composition of a typical well structured, drained, silt loam soil is shown in Figure 2.1.

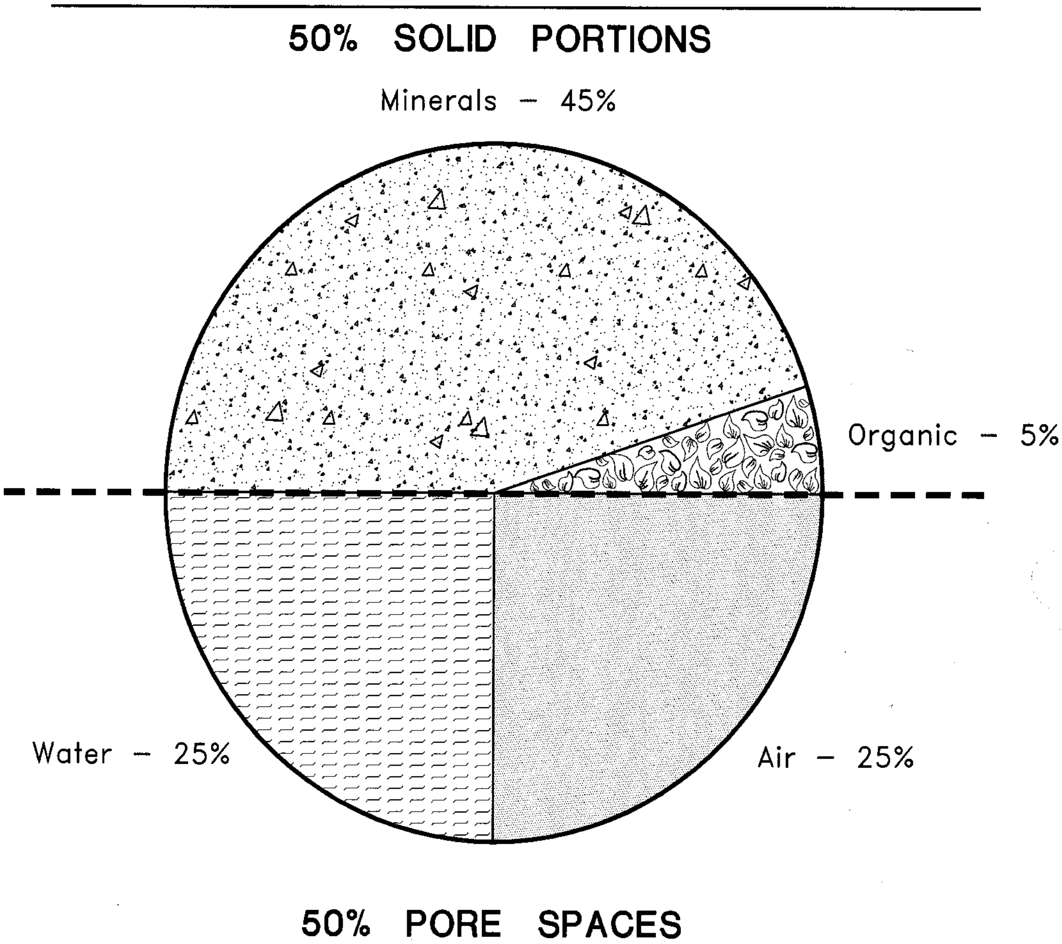
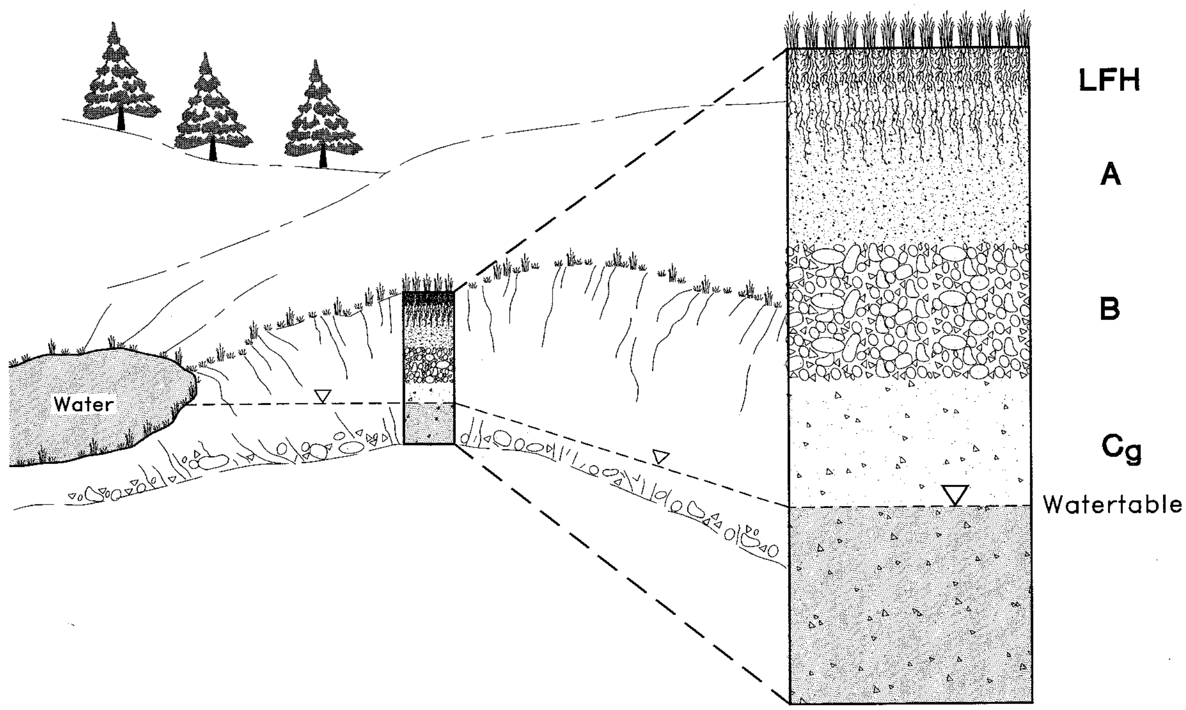


Figure 2.1 Drained, Silt Loam Soil

2.2 Soil Profile

Soil is developed in a continuum of time and place, in the presence of a parent material and landscape, and all under the influence of climate. Soils cannot be understood solely by looking at the surface layer. Dig a hole and explore the profile! A soil profile is a picture of a soil from a particular place in a landscape at a particular time. Figure 2.2 shows a soil profile from within a continuum of soils in a landscape. The soil profile is an indication of how the soil developed and gives insight into how the soil can be managed.



Adapted from: BCMAFF, 1994.

Figure 2.2 Soil Profile

All soils have a distinct profile, that is, a series of layers or zones from the surface down to the parent material. In a native soil, these layers or zones are called horizons and are given a letter description according to the Canadian System of Soil Classification. Each horizon is then further described by a series of subclasses depending on the soil formation processes which have influenced the development of that soil.

The surface soil, usually referred to as topsoil, is given the letter A. The A horizon is normally characterized by the accumulation of organic matter or humus from the growth of plants and the activity of soil organisms. The layer immediately above the A horizon in an undisturbed, non-cultivated or forest soil is often referred to as the LFH layer. It is a layer of accumulated litter, fiber and humus. The layer of soil immediately below the topsoil, often referred to as the subsoil, is given the designation B. The subsoil may have some accumulation of organic residues, however, it is generally characterized as a layer of leaching and/or accumulation of minerals or salts from the topsoil.

The so-called parent material, or C horizon, is the poorly weathered material from which the soil is developed. In poorly drained soils, the B and C horizons often have the subclass "g" assigned to them. The "g" refers to the gleying or gray-blue colouring of the soil which is associated with waterlogged conditions. Gleyed layers may also have colouring that gives them a mottled appearance. This mottling is the result of fluctuating water tables and the subsequent chemical reactions which cause oxidation and reduction of iron compounds in the soil.

2.3 Soil Physical Properties

The physical properties of the mineral and organic matter making up the solid portion of the soil have a marked influence on the size and number of pore spaces that may exist in the soil under different conditions. This in turn affects the soil's water-holding capacity, aeration, internal drainage, the ease of tillage and root growth. It also influences soil temperature and the availability of plant nutrients.

In addition to these effects, the physical nature of soil materials also determines such properties as soil consistence and strength. Consistence is the term used to describe how the soil particles hold together under force. Some knowledge of the physical properties of soil is required in understanding the effects of agricultural practices, such as drainage, on the soil. Also, knowledge is required on how management can improve soil properties for agricultural purposes. The physical properties important in soil management are described in the following sections.

2.4 Soil Texture

Soil texture is defined in terms of the size distribution of the mineral components in soil. These mineral components are simply small fragments of rock, mineral materials derived from rock or deposits of minerals from solution, which have been altered by water and chemical reactions in the soil. Soil particles are grouped into four particle sizes: clay, silt, sand and gravel. Table 2.1 outlines the size range of particles in each group. Gravel size particles are not included in the textural names given to the soil. The hydraulic conductivity, a measure of the ability of water to move through soils, depends to a large extent on the soil texture. Therefore, soil texture is one of the prime characteristics on which drainage design is based.

Table 2.1 Soil Particle Size and Characteristics

Particle	Size	Properties
Gravel	2 mm - 7.5 cm	Rounded, coarse rock fragments. Single grained and loose.
Sand	0.05 mm - 2.0 mm	Somewhat rounded, single grained and loose. Can be felt as grit.
Silt	0.002 mm - 0.05 mm	Rounded, generally forms clods, easily broken, floury when dry, soapy or buttery, but not sticky when moist or wet.
Clay	Less than 0.002 mm	Flat particles, forms hard clods when dry, sticky and plastic when moist or wet.

In describing soils, texture refers to the relative percentage of sand, silt and clay sized particles in the soil material. It is generally estimated in the field with the "hand feel method." In most instances, hand texturing can separate the three particle sizes of sand, silt and clay. In some cases, the adventurous may wish to try mouth texturing to separate gritty silt from clay. Soil textures are shown in the textural triangle in Figure 2.3.

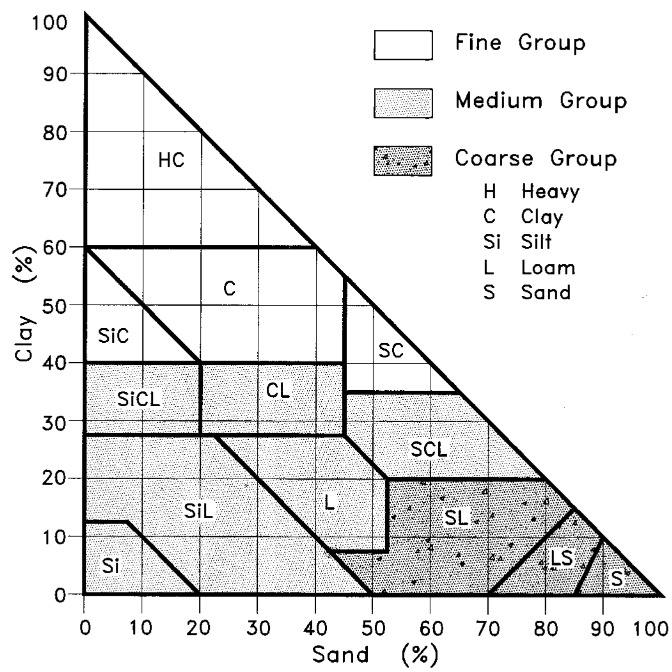


Figure 2.3 Soil Texture Diagram

Soil textural names are often grouped into three main subgroups: fine, medium and coarse. These subgroups aid in defining concerns related to the impact of texture on water movement between soil layers, slope stability in ditches and plugging of drainlines. It is often convenient to place soil textures or types into four main groups and describe the important properties common to each group, as in Table 2.2

Soil texture may be further described using modifiers which indicate a dominant or additional feature of the soil. In the many areas of the province, soils are often described as gravely or very gravely. That is 20 to 50% and 50 to 90%, respectively, by volume of gravel size coarse fragments in the soil. Other modifiers could be mucky silt loam or very fine sandy loam. Mucky, in this case, refers to a significant content of well decomposed organic soil mixed into the mineral silt loam soil.

Although the soil characteristics referred to as stoniness phase and coarse fragment percentage are not often discussed in terms of drainage, they are important soil parameters when describing soil structure, cultivation and overall land use. Stoniness phase is the percentage of stones or rock fragments found on the soil surface and refers to the interference level of stones to normal farm cultivation activity. Coarse fragment percentage refers to the

Table 2.2 Physical Characteristics of Soil Textural Groups		
Soil Textural Group	**Soil Textures and Types**	**Characteristics**
Coarse to Moderately Coarse	Gravel Sand Loamy Sand Sandy Loam Fine Sandy Loam	Loose and friable when moist or wet. Loose to soft when dry. Very high proportion of large pores. Low water-holding capacity. Good bearing strength and trafficability when wet. Tends to form weak clods when cultivated. Easy to maintain good tilth.
Medium	Very Fine Sandy Loam Loam Silty Loam Silt	Slightly sticky and plastic when wet. Friable to firm when moist, soft to slightly hard when dry. Moderately easy to maintain good tilth. Moderately good trafficability and bearing strength when wet. Tends to form small to medium, slightly firm clods when cultivated. High proportion of medium to small pores, high water-holding capacity and available water.
Moderately Fine to Fine and Very Fine	Sandy Clay Loam Clay Loam Silty Clay Loam Sandy Clay Clay Silty Clay Heavy Clay	Sticky and plastic when wet. Friable to firm when moist, hard to very hard when dry. High proportion of small pores. Moderately difficult to maintain good tilth. Poor trafficability when wet. Tends to form large, firm clods when cultivated. High water-holding capacity, but less available water than medium-textured soils.
Organic Soils	Muck and Peat	Variably sticky, usually non-plastic, friable, slightly firm when dry. Very high water-holding capacity. Poor trafficability when wet. Tends to form small to medium clods when cultivated. Easy to maintain good tilth.

amount of stones or rock fragments in the whole soil profile or a particular layer below the surface. Coarse fragment percentage is a characteristic which impacts soil water movement and storage as well as the usable volume of soil that crop roots can explore. Refer to Tables 2.3 and 2.4 for more detail on stoniness and coarse fragment definitions.

Soil texture is a permanent soil characteristic. Texture will not change unless a large quantity of soil material of another texture is added, such as might occur during land clearing, very deep plowing into the subsoil which is of a different texture or alteration of the soil due to flooding and the subsequent deposition of sediment.

Table 2.3 Soil Stoniness Phases			
Stoniness Phase	**Name**	**% Stones on Surface**	**Impact**
S0	Non-stoney	< 0.01	None
S1	Slightly stoney	0.01 to 0.1	Slight to no hinderance to cultivation
S2	Moderately stoney	0.1 to 3	Some interference with cultivation
S3	Very stoney	3 to 15	Stones result in serious handicap to cultivation
S4	Exceedingly stoney	15 to 50	Stones must be cleared to permit cultivation
S5	Excessively stoney	> 50	Too stoney to permit cultivation

Table 2.4 Coarse Fragment Categories			
Shape and Kind of Fragments	**Size Range (All Shapes)**		
Rounded and subrounded fragments (All kinds of rock)	Up to 7.5 cm in diameter Gravelly	7.5 to 25 cm in diameter Cobbly	Over 25 cm in diameter Stony
	Size Range (Flat Fragments)		
Thin flat fragments (Thin, flat sandstone, limestone and schist)	Up to 15 cm in length Channery	15 to 38 cm in length Flaggy	Over 38 cm in length Stony

2.4.1 Field Determination of Soil Texture

As mentioned above, the relative proportion of sand, silt, and clay particles can be estimated through the "hand feel method". Sand can always be felt as individual grains, but silt and clay generally cannot. Dry silt feels floury while wet silt is slippery or soapy, but not sticky. Dry clay forms hard lumps, is very sticky when wet, and plastic when moist.

Soils found in British Columbia generally have a mixture of sand, silt and clay, so the graininess, slipperiness, or stickiness varies depending upon how much of each particle size is present. With increased amounts of clay, soil particles bind together more strongly, form stronger 'casts', and longer, stronger 'worms'. With increased sand and silt, the soil binding strength decreases, and only weak to moderately strong casts and worms can be formed. Cast is the form or shape a small volume of soil takes after it is squeezed in a hand as seen in Figure 2.4. This soil has 39% silt. A worm is the shape a small volume of moist soil takes when it is rolled between the fingers of one hand and the palm of the other. Figure 2.5 shows a worm from a soil with 58% clay.

Figure 2.4 Moist Cast – Hand Texture

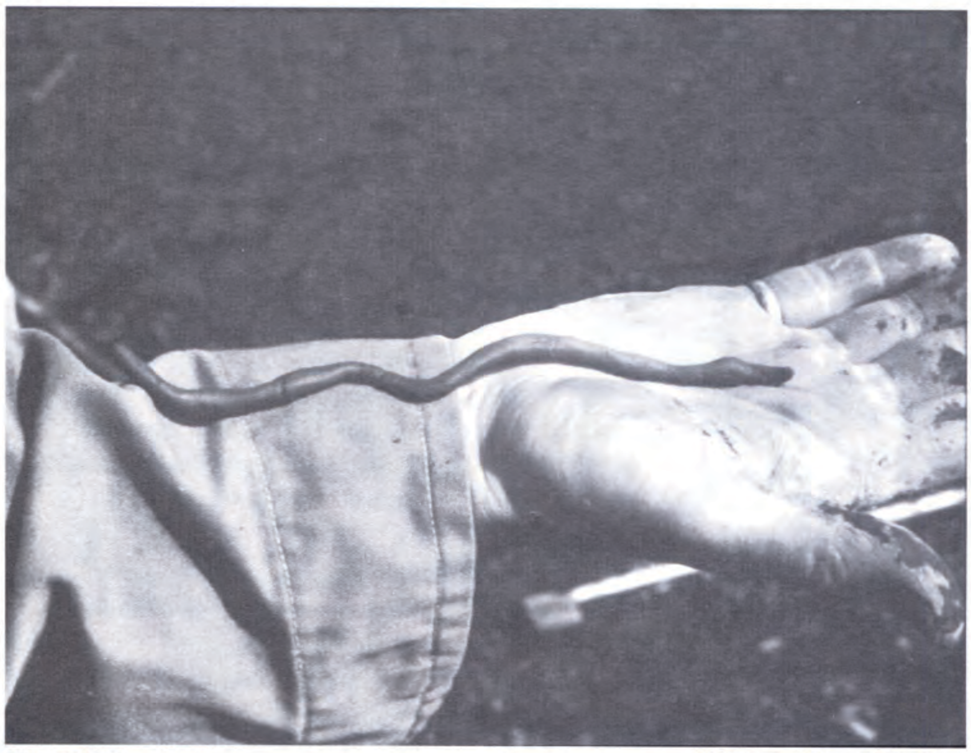


Figure 2.5 Worm – Hand Texture

Field determination of soil texture is subjective and can only be accomplished consistently with training and experience. The following briefly describes tests to assist in field determinations. Figure 2.6. on page 14 outlines field determination of soil texture in more details.

Graininess Test: Rub the soil between your fingers. If sand is present, it will feel "grainy". Determine whether sand comprises more or less than 50% of the sample.

Moist Cast Test: Compress some moist soil by clenching it in your hand. If the soil holds together (i.e. forms a "cast"), then test the durability of the cast by tossing it from hand to hand. The more durable it is, the more clay is present.

Stickiness Test: Wet the soil thoroughly and compress it between the thumb and forefinger. Determine the degree of stickiness by noting how strongly the soil adheres to the thumb and forefinger upon the release of pressure, and how much it stretches. Stickiness increases with clay content.

Worm Test: Roll some moist soil between the palms of your hands to form the longest, thinnest worm possible. The more clay present, the longer, thinner and more durable the worm will be.

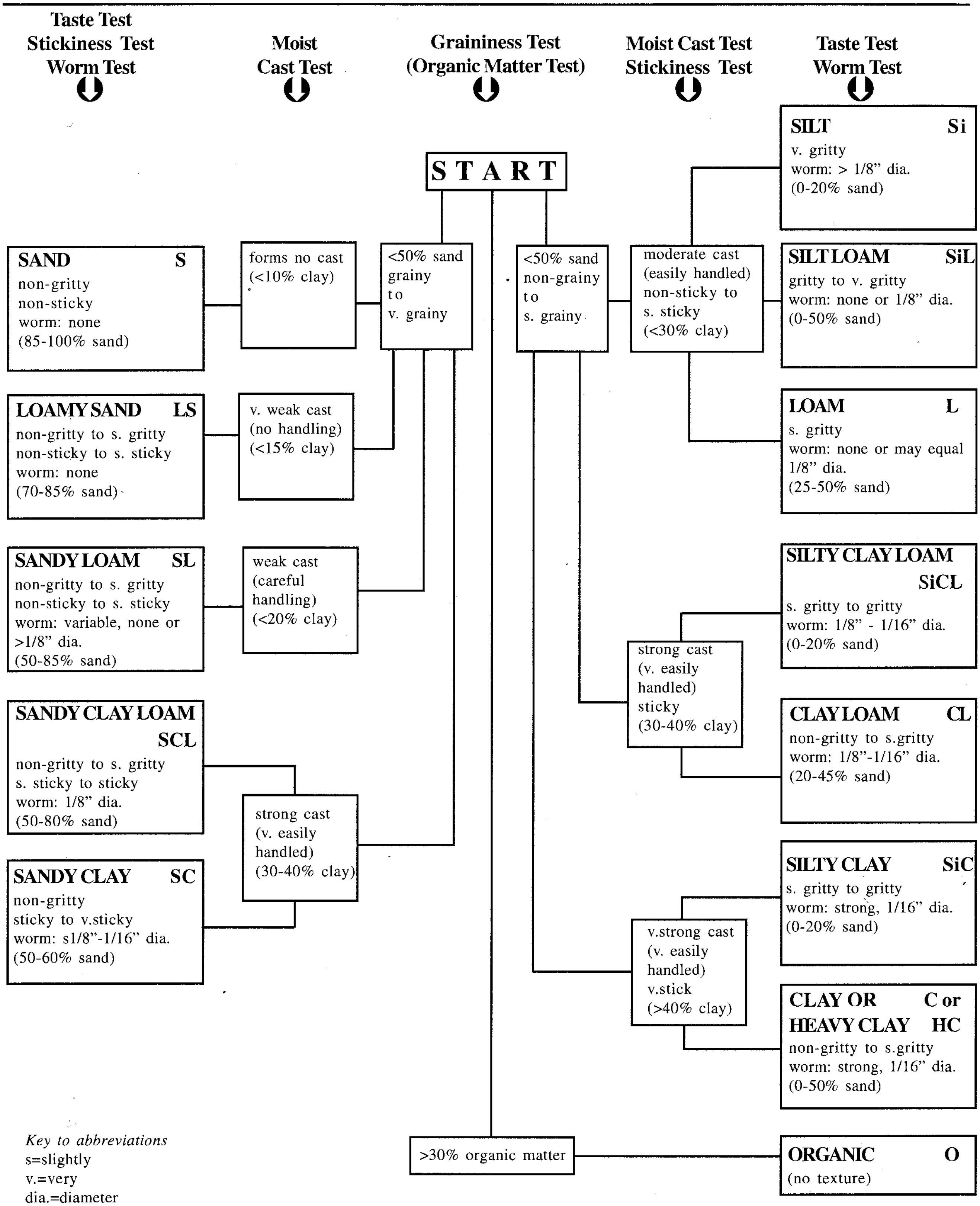
Taste Test: Work a small amount of soil between your front teeth. Silt particles are distinguished as fine "grittiness", unlike sand which is distinguished as individual grains (i.e. graininess). Clay has no grittiness.

Some caution should be used in texturing soils that may have a high organic matter content. Well decomposed organic matter (humus) imparts silt-like properties to the soil. It feels floury when dry and slippery when moist, but not sticky or plastic. However, when subjected to the taste test, it feels non-gritty. It is generally very dark in colour when moist or wet, and stains the hands brown or black.

Humus-enriched soils often occur in wet sites or in grasslands. As with gravel, humus is not used as a determinant of soil texture. The estimated silt content of humus-enriched mineral soils should be reduced. "Organic" soil samples are those that contain more than 30% organic matter (17% organic carbon). Soil texture is not determined on organic soils. The degree of decomposition in an organic soil can be determined by the Van Post method, and the Humus Form description found in "Describing Ecosystems in the Field" (Luttmerding et al., 1990). They will not be discussed in this manual. The degree of decomposition in an organic soil will have some impact on water movement. Well decomposed peat or muck will have lower internal drainage rates in comparison to undecomposed peat.

2.4.2 Particle Size Distribution

Particle size distribution is another component of soil texture that plays a significant role in designing a drainage system. Consideration must be given to the actual distribution of the various particle size fractions of the soil. Size ranges for sand, silt, clay and gravel particles have been previously discussed. Soil textural names are given based on the percent of sand, silt, and clay fractions. However, the distribution of particle sizes within the sand size range plays a role in the need for filters and the potential use of a drainage system for subirrigation.



Source: Luttmerding et al. 1990.

Figure 2.6 Field determination of soil texture

There are several laboratory methods used to determine particle size. In most cases, a combination of sieve analysis and sedimentation plus pipetting are used. Procedures usually entail sieving of soil samples through a sieve stack after the removal of carbonates, organic matter, soluble salts and possibly any iron oxides which may be present. These constituents may interfere with the true determination of particles size distribution as they can create aggregates that act like larger soil particles.

The sieve stack normally contains a range of sieve sizes which fractionate the sand particle size range. This stack of sieves should contain #4, #10, #40, #200 but may also contain #20, #60, #100 and #140. The combination of these sieve sizes separates particles from 5 mm down to 0.08 mm. An initial wet sieving process is used to separate silt and clay particles from the sand fraction. Either a sedimentation cylinder plus pipette or hydrometer method are used to determine the percentage of silt and clay. These methods are all described in "Soil Sampling and Methods of Analysis" (Carter, 1993).

D_{85}

Once the percentage of the various size ranges for sand and the percent of silt and clay have been determined, the data can be graphed to determine factors such as $D_{85.}$ D_{85} is the specified diameter for which 85% of the particles are smaller. The data presented in Table 2.5 were collected from a blueberry farm on the Matsqui Prairie in Abbotsford as an example, Figure 2.7 shows a graphic representation of the particle size distribution. The D85 line is marked on the graph. From this line, the D_{85} for each of the sample is as follows: Sample 1: 0.009 mm (9.0 µm), Sample 2: 0.035 mm (35 µm), and Sample 3: 0.08 mm (80 µm). As a result of the 120+ cm layer (Sample 3) containing less than 20 % clay a filter would be recommended if the design drain depth was lower than 120 cm. Referring to Table 10.6 we find that a thick velour type filter is required. This soil would be slightly to moderately suitable for subirrigation. Refer to Chapter 12 for more discussion of subirrigation suitability and design.

Table 2.5 Example Particle Size Distribution (Percent passing by weight)

Sample #	Depth (cm)	Dry Sieve	Wet Sieve		Pipette	
		2.00 mm	0.250 mm	0.125 mm	0.053 mm	0.002 mm
1	40 - 75	100	100	99.9	98.7	58.9
2	75 - 120	100	99.9	99.7	93.5	22.5
3	120+	100	99.8	96.0	61.2	11.9

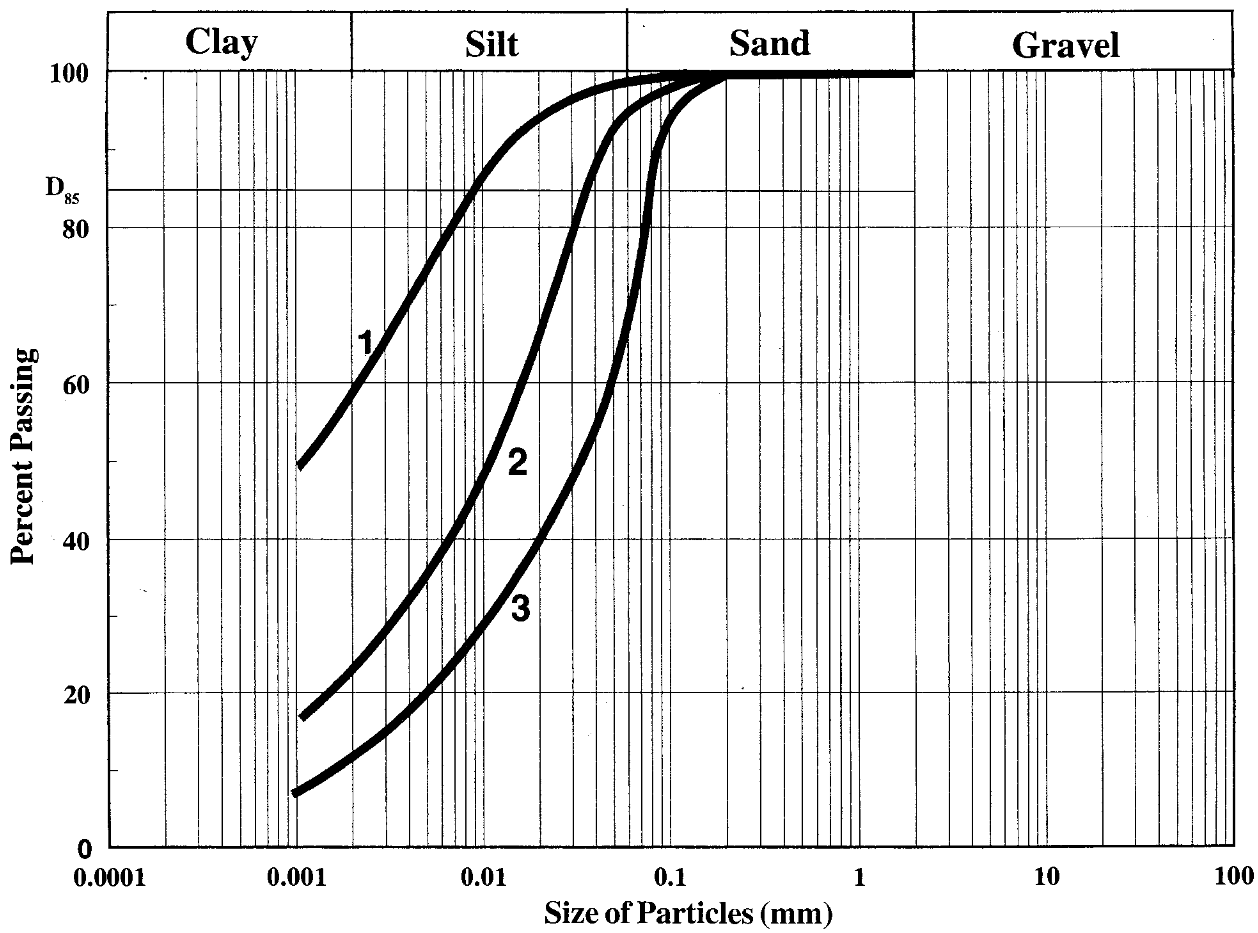
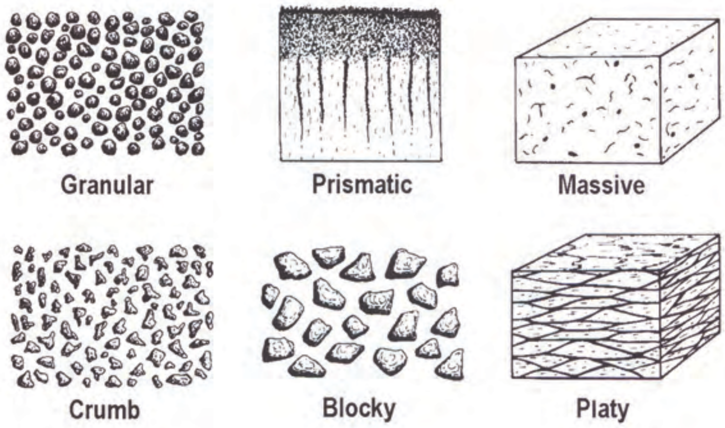


Figure 2.7 Example Particle Size Distribution

2.5 Soil Structure

Soil structure is the arrangement of soil particles and peds (soil aggregates) into recognizable particles or lumps. In soils, individual sand, silt and clay particles become more closely packed and bonded together to form larger particles called aggregates. This bonding is usually the result of a combination of chemical and physical activity from the secretion of organic compounds such as sugars and pressure of plant roots moving through the soil. Soil structure refers specifically to the type and arrangement of aggregates found in soils. Aggregates occur in almost all soils, but their strength, size and shape varies considerably among soil types. The type and degree of structure is determined from visual observation of the profile and manner of fracturing when breaking off segments. Figure 2.8 illustrates six different structural classes for soils. Figure 2.9 illustrates an example of a soil with fine blocky to crumb soil structure.



Adapted from: Irwin, 1991.

Figure 2.8 Examples of Soil Structural Classes

Figure 2.9 Crumb Structure

Some of these aggregates may persist in stable forms which are not easily broken down by water or physical forces. The greater the degree of aggregation or better structured the soil, the better air and water relationships within the soil. In soils under cultivation, most aggregates at the surface tend to break down under the forces of rainfall, tillage and traffic. Soil structure also influences the internal drainage of the soil, affects its water-holding capacity, temperature and resistance to the growth of plant roots and the emergence of seedlings. Soils with structures that are blocky, granular or crumb like will tend to allow greater movement of water through the soil profile. Columnar or massive structures will inhibit water movement.

Structure is an important factor in the permeability of the soil, particularly in fine-textured soils which require cracks and cleavages for movement of air and water. Coarse-textured soils may tolerate periods of high water table without sustaining serious damage. Fine-textured soils require good structure and may receive extensive structural damage from poor drainage.

Soil structure formation or the formation of aggregates and structural pores in the soil is influenced by several factors. These include the growth of plant roots, activities of soil organisms, wetting and drying, freezing and thawing, and tillage.

2.5.1 Plant Roots

The growth of plant roots is one of the most important agents in the formation of aggregates and pores. Growing roots expand and force individual soil particles closer together; they extract water from the soil, causing the mass to shrink and cracks to develop. Dead roots leave numerous pores and channels. The result of this process is the development of many aggregates and pores. The most favourable and stable soil structure is developed under a perennial (minimum 3 to 4 years) grass or grass legume crop although a winter annual cover crop can significantly increase soil aggregate stability in the surface (0-5 cm) soil layer.

Figure 2.10 shows how grass or legume crops can increase the number of fine water stable aggregates (>0.25 mm) present in the soil. The figure also indicates the impact of the use of an organic amendment or soil conditioner such as manure along with specific crops. Figure 2.11. indicates the impact of cover crop roots on the mean weight diameter of soil aggregates over one winter. The fine and abundant rooting system of the ryegrass had the greatest impact on improving soil aggregate size and stability. Plant roots excrete simple sugars and resins that bind soil particles. The resulting aggregates, or good soil structure, increases the number of water stable aggregates and large pores near the surface of the soil.

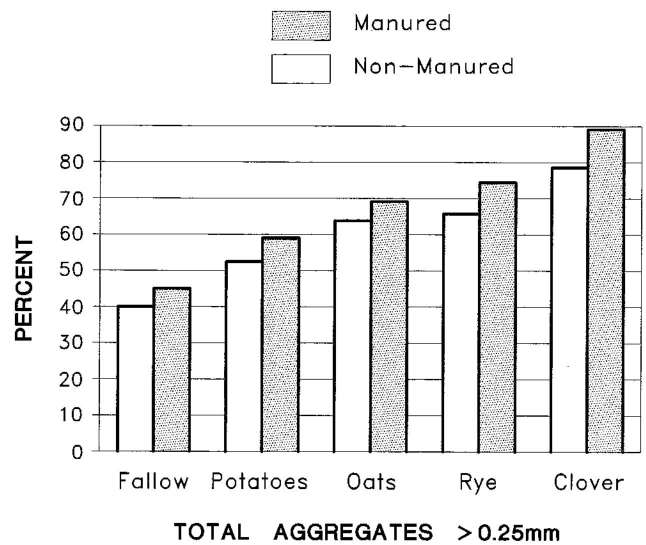
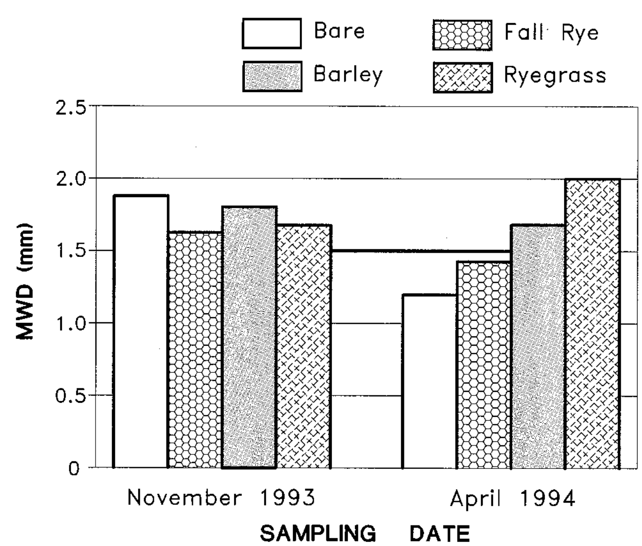


Figure 2.10 Effect of Cropping Practices on Soil Aggregation



Adapted from: Hermawan, 1995.

Figure 2.11 Effect of Cover Crop on Mean Weight Diameter (MWD) of Soil Aggregates

2.5.2 Soil Organisms and Organic Matter

Soil is alive with a multitude of microorganisms, insects, worms, bacteria, fungi as well as living and decaying organic matter and plant roots. Organisms control the cycling of nutrients within a soil. Soil organic matter consists of dead roots, leaves, stems, manures, the bodies of insects, worms and animals, living and dead microorganisms and substances derived from them. Soil organic matter is the total of all of this matter in various stages of decomposition. As organic material is added to the soil, it is decomposed by soil microorganisms. The rate of decomposition is rapid at first, but as the process slows the organic material becomes less recognizable and eventually humus is formed. Humus is dark-brown to black in colour and imparts this colour on most topsoil layers. It acts as a cementing agent, binding fine soil particles together into granules or aggregates. This improves the soil's physical condition. Aeration, water percolation, water-holding capacity, nutrient levels and resistance to erosion are all increased with higher organic matter levels.

Soil aggregate stability is proportional to its organic matter content. As a general rule, soils with high organic matter content have more stable aggregates than soils with low organic matter content. The effect of various crops and the addition of manure on the formation of stable aggregates is shown in Figure 2.10.

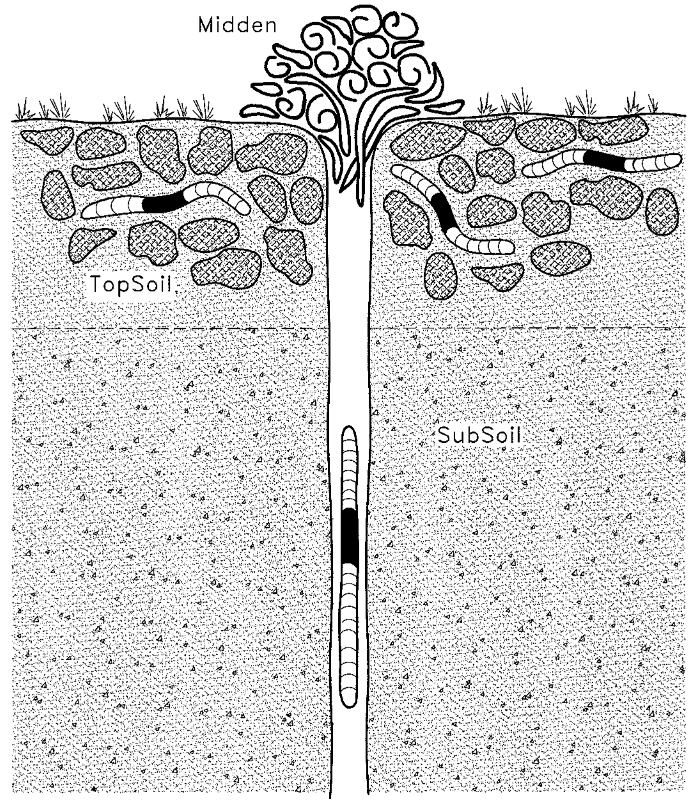
By their movement through the soil, the larger soil organisms, such as earthworms and soil insects, leave small channels and promote good soil structure. Figure 2.12 shows how earthworms burrow deep into the subsoil, moving organic matter from the surface downward and mineral material upward. These channels also allow for significant movement of air and water. Table 2.6 indicates the impact of drainage on the population of earthworms. Although worms like moist soils, their survival is restricted by poor drainage. Soil water content, in drained fields that have deep burrowing worms present, is always lower after a rainfall event than in those fields which contain no deep burrowing worms.

Table 2.6 Biomass of Earthworms in Plots of the Boundary Bay Water Management Research Project

Date	Undrained g/m^2(S.D.)	Drained g/m^2(S.D.)
March 1983	1.6 (1.8)	35.6 (6.7)
March 1984	0.2 (0.6)	19.4 (5.0)

S.D. = Standard Deviation

Source: Timmenga, 1992.



Adapted from: Ernst, 1995.

Figure 2.12 Effect of Worm Activity

When soil organisms decompose organic matter, cementing agents such as sugars and gums are formed. These substances serve to bind soil particles together as aggregates, but in time, these substances are themselves decomposed by other soil organisms. Therefore, in order to maintain a constant supply of cementing agents to promote soil structure, soils must have a continuous replenishing of organic matter, otherwise, the original structure will deteriorate.

In soils under cultivation for annual crops, the structure deteriorates faster than it can be built up by plant roots and organic matter. Organic matter can be added to the soil in many forms including manures, composts, crop residues, cover crops and various crop rotations. However, it is a combination of these inputs and the activity of microorganisms that create the more stable forms of organic matter which enhance soil structure. Drainage is important in regulating the amount of organic matter in the soil. Organic matter tends to accumulate more rapidly at the surface of poorly drained soils. This is the result of a deficiency of oxygen necessary for microorganisms to decompose plant and animal residues. Low temperatures, high rainfall and poorly drained conditions favour organic matter buildup, which tends to be in undecomposed forms such as peat. In better drained soils, the surface soil tends to contain less organic matter or the organic matter present tends to be predominantly in the humus form. Climatic conditions, especially temperature and rainfall, exert a strong influence on the amount of organic matter contained in a soil and the activity of soil microorganisms.

2.5.3 Impacts of Clay

Clay particles are an important agent in soil aggregate formation. These are the particles smaller than 0.002 mm that impart a sticky feel to the soil. In sandy soils, a small percentage of clay may be the chief agent binding sand particles together. In soils which are dominantly clay, aggregates may tend to be larger than desirable for the preparation of a seedbed. In such soils, the addition of generous amounts of organic matter tends to promote smaller aggregates. Appropriate use of tillage at soil moisture levels below field capacity is important to prevent creation of massive soil structure in clays. On a small scale, limited use of sand may be practiced in conjunction with organic matter additions to improve aggregate formation.

2.5.4 Soil Water - Wetting and Drying - Freezing and Thawing

Prolonged saturation of the soil will eventually weaken and 'dissolve' soil aggregates and cause pores to be filled with finer particles. After drainage, the soil may become very compact, retarding water and air movement and restricting root growth. The water table in perennially wet soils must be controlled by artificial drainage before good structure can be achieved.

In drained soils, alternate wetting and drying and freezing and thawing of the soil mass has a very important effect on structure. When soils freeze, water in the pores expands, forcing aggregates apart. Moist or dry soil aggregates break down into smaller particles when they are wetted, unless the wetting is very gradual. As wet aggregates dry out, they shrink and crack, breaking down into smaller aggregates. When soil aggregates are large, several centimeters in diameter, this process may be desirable. In soils with small or very weak aggregates, these processes may destroy most of the structure.

Tillage implements, operating in wet soils, can also rapidly destroy structure simply by mechanical forces acting upon soil aggregates. Aggregates tend to be smeared or radically deformed by tillage or traffic under wet conditions. Even on a weakly structured dry soil, tillage can have a detrimental effect on the soil structure.

2.5.5 Puddling and Crusting

By the action of water or mechanical forces, the granular or crumb structure in the plow layer of clay soils may become completely broken down into a solid mass with no large pores. Such a soil is said to be puddled. This is the result of the high plasticity and cohesion of clay particles which tend to act independently when subjected to force under wet conditions.

When the puddled surface dries out, a hard crust forms. This crust may prevent seedlings from emerging, and tend to seal off the soil surface. The formation of this surface seal or massive structureless layer at the soil surface has the greatest impact on water and air movement within a soil. The layer prevents the infiltration of air and water creating surface ponding and poor drying. After tillage, a crusted soil exhibits a massive hard cloddy structure. Figure 2.13 shows a puddled soil that is in a saturated condition.

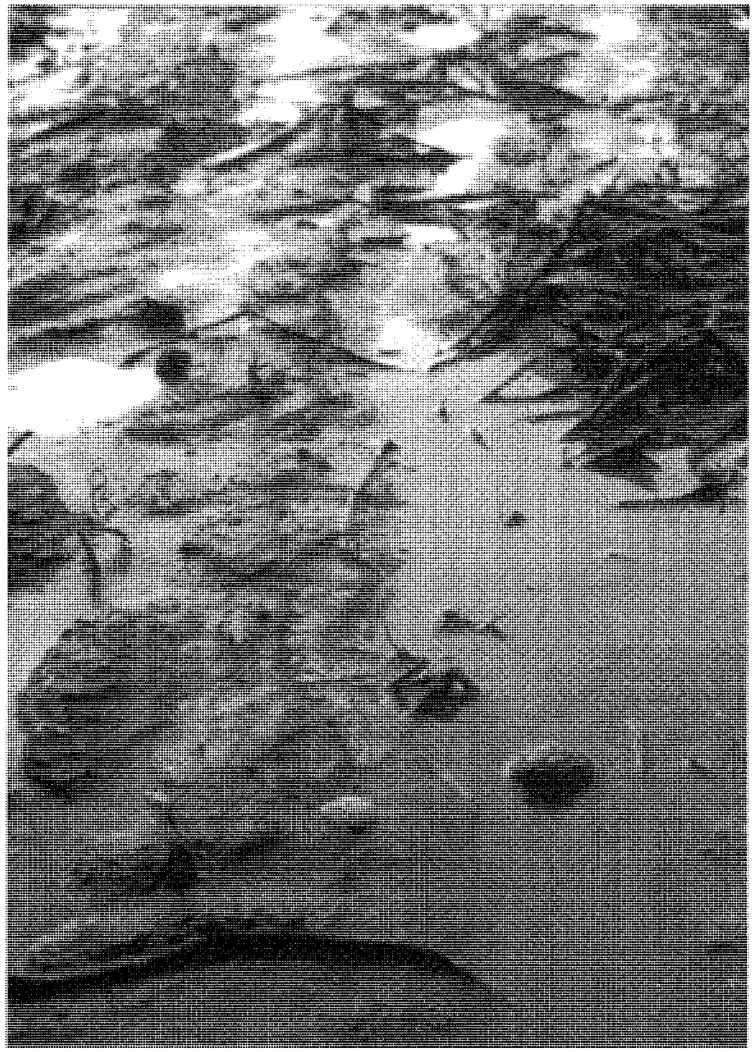


Figure 2.13 Surface Ponding on a Puddled Soil

2.6 Plasticity

It is generally accepted that when a soil contains above 15% silt or clay and is manipulated under moist conditions, it will exhibit plasticity or stickiness. Plasticity refers to the ability of the soil material to be molded and retain its molded shape. It is a measure of the cohesion of soils with particle sizes below the sand texture size. Plasticity results from the plate-like structure of the clay particles in combination with the lubrication of water trapped between the clay particles. Plasticity gives an indication of how a soil will respond to tillage and drainage. Stickiness in soil is normally felt when the soil is quite wet. The adhesion forces of the soil are greater than the cohesion forces (plasticity).

When hand texturing a soil, the feeling of plasticity or stickiness can aid in determining the soil texture. Plasticity can also be measured in a lab and the soil given a plasticity index. If the index is greater than 20, the soil has a high clay content. The soil will exhibit shrinkage, swelling and cracking properties. Clay soils usually have a range of 20 to 40 and silt soils have a range of 10 to 20. If the index is less than 5, there is a high risk that sedimentation problems may occur in drains.

2.7 Porosity and Aeration

The soil porosity, or percent pore space, is the portion of the soil mass occupied by air and water. Porosity is determined by both soil texture and structure, and therefore, porosity is influenced by practices which alter soil structure. The size and distribution of pores in the soil is very important in determining the rates of air and water movement in soils, as well as influencing root growth. Plant roots require a balance of air and water for optimum growth. A good soil, air and water balance is required to promote the growth of worms and microorganisms that enhance soil structure. Figure 2.14 shows a schematic representation of pores.

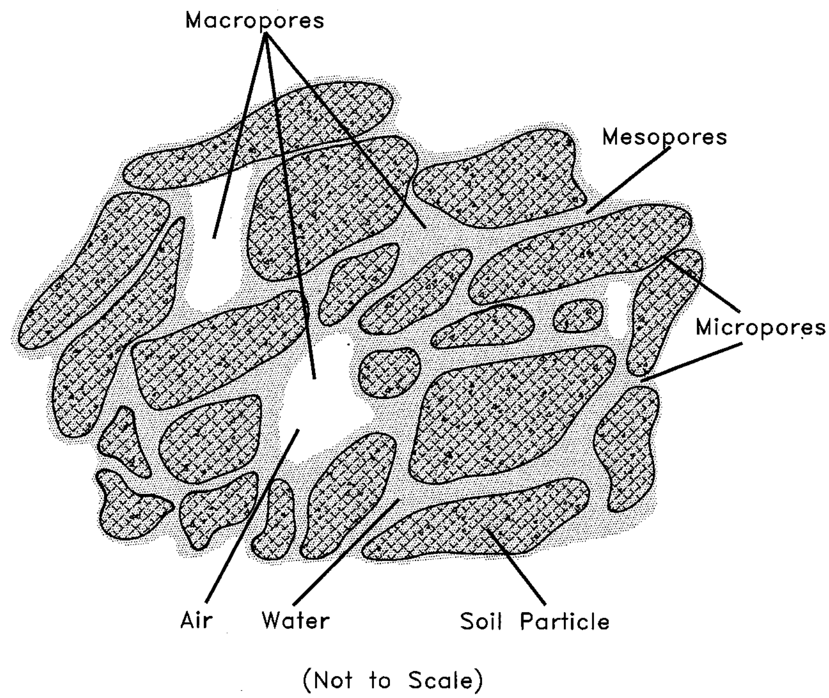


Figure 2.14 Porosity

Very small (micro) pores (micropores) tend to restrict air and water movement while large (macro) pores (macropores) promote good air and water movement. Water movement in macropores tends to be by gravity. Meso or intermediate pores are responsible for conducting water rapidly through the soil under non-gravitational force. Table 2.7 gives an indication of the relative size range of macro, meso and micropores.

Table 2.7 Range of Soil Pore Sizes

Class	Size Range	Function
Macropores	> 100 μm	Drainage & aeration (gravity flow)
Mesopores	30 - 100 μm	Water conduction (rapid capillary flow)
Micropores	30 - 3 μm	Water retention (slow capillary flow)

1 micron (μm) = 0.001 mm

Source: Irwin, 1991.

Sandy soils have a low porosity (35 to 50% by volume), but the pores are relatively large. As a result of this, sandy soils tend to be rapidly drained, retain little water, are poorly structured and well-aerated. Medium and fine-textured soils have higher porosity (40 to 60% by volume), and a high proportion of the pores are small. These soils tend to retain more water, drain more slowly and are less well-aerated. Structure and porosity restrict air and water movement in finer-textured clay soils approaching 60% porosity with a predominance of small pores. In these soils, it is desirable to create larger pores by promoting a granular structure.

In addition to the effects of texture and structure on soil porosity, the activities of soil organisms is of equal importance. The burrowing activities of worms and soil insects result in the formation of larger pores which are beneficial to most soils. Practices which encourage the activity of soil organisms are of practical significance in the management of finer-textured soils.

Aeration is a measure of the amount or ability of air to move through the soil. Air movement generally occurs in the macropores, so texture and structure are important to soil aeration. Poorly structured, compacted or fine-textured soils will tend to have poor aeration. Aeration is impacted by water tables in the soil. High water tables restrict the soil air supply and cause plants to establish shallow rooting systems. During drought conditions, as the water table drops, shallow rooted crops are often unable to reach necessary soil moisture. A drained soil promotes deeper plant root growth by lowering the water table during excessive rainfall or spring runoff conditions. The lowered water table provides better aeration of the soil. Plants require the correct nutrients in sufficient amounts for optimal growth. Manure is broken down by aerobic microorganisms and taken up by plants through the root system.

In waterlogged soils, aerobic bacteria are replaced by anaerobic bacteria. Anaerobic organisms reduce manure to forms that are not available to the plant. For example, nitrates are reduced by anaerobic bacteria to gaseous forms which are lost from the soil. Drainage enables plants to utilize inorganic fertilizers more effectively.

2.8 Soil Compaction

Soil compaction refers to the disruption and reduction in the size and number of large pores within the soil. The presence of excess soil moisture at the time of any field operation is the main factor leading to soil compaction. Once a soil is compacted, the bulk density and the strength of the soil are increased. For construction purposes, a compacted soil is ideal, but under normal crop production, a compacted soil can be a serious problem. Penetration into the soil by tillage implements and crop roots is restricted. The movement of air and water through the soil is hampered, causing the soil to remain wet and cool long into the growing season. The effects of compaction are dependent on the amount of root zone that is compacted, the continuity of the compacted zone and the susceptibility of the soil or the crop's rooting characteristics to compaction.

Many areas in British Columbia suffer from this debilitating condition, which can be the main obstacle to good crop production. Because compaction is such a serious threat, a closer look should be taken at ways to recognize compaction and its effects.

2.8.1 Recognizing Soil Compaction

Soil compaction occurs when a force compresses the larger soil pores and reduces the air volume of the soil. The continuity of the pores from the surface of the soil to deeper depths is disrupted, and thus, the transmission of water through the soil, and gases between the crop's roots and atmosphere is reduced. Measurements of compaction damage to agricultural soils can be based on changes in density, strength or visual estimates of structure. Three of the methods are discussed below.

Bulk Density

The measurement of a soil's bulk density provides a relative value of soil compaction. The porosity of a soil can be related to the bulk density measurement, with further laboratory procedures. Bulk density is expressed as mass per unit volume of soil (usually g/cm^3). Variation in bulk density can occur on a year to year basis, as freezing and thawing, wetting and drying cycles, and cultivation can alter the basic structure and porosity of a soil.

The bulk density of high organic mineral soils and peat is much lower than that of mineral soils. Table 2.8 gives some examples of soil bulk density measurements from a selection of mineral soils. When a soil is in a compacted condition, the bulk density can be increased by about 15%.

Table 2.8 Examples of Average Mineral Soil Bulk Densities

Soil Type	Bulk Density (g/cm^3)
Well structured high organic loam soil	0.9
Silt loam	1.1
Medium to fine-textured loam	1.3
Sand	1.5
Compacted soil or clay subsoil	1.3 - 1.6

Penetrometer Method

Another method of measuring soil compaction uses a penetrometer. Penetrometers measure soil strength and their movement through the soil has been related to the soil's resistance to root penetration. Plant roots, however, grow around obstacles and can exert tremendous local pressure on soil pores, so that penetrometers can only provide a relative root resistance value.

Penetrometers can give quick results in the field, and many measurements can be taken in a short time. However, the use of penetrometers and interpretation of the results requires considerable skill, especially if soils are in the initial stages of compaction. Factors which affect penetration resistance as measured by penetrometers are cone angle, cone diameter (surface area), and rate of soil penetration; soil factors which affect soil strength or resistance are water content, structure and bulk density. Penetrometers are useful in finding hard layers that will obviously obstruct root development or water flow through a soil.

Table 2.9 is a rough guide to penetrometer resistance values in megapascals (MPa) and soil compaction through the rooting zone. These penetrometer readings are averages and were obtained using a penetrometer with a 60% cone angle. Figure 2.15 is a composite picture of a 60° angle cone and penetrometer with a dial type gauge for measurement.
Although using penetrometers is much easier and quicker in the field, the

Table 2.9 Impact of Soil Resistance Values on Crop Yield

Effect of Compaction on Crop Yield	Soil Resistance Value (MPa)
Low	1.0
Medium	1.0 - 1.5
Severe	2.0 - 3.0

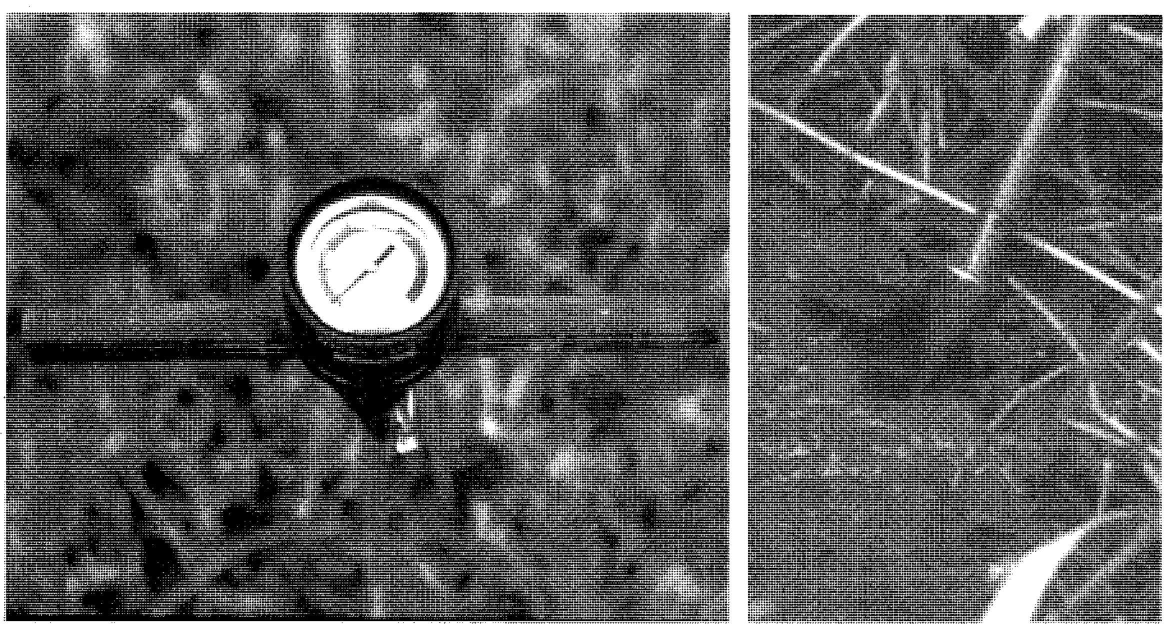


Figure 2.15 Dial Type Gauge on 60° Cone Penetrometer

number of factors that come into play in interpreting their results makes them as difficult to use as the bulk density method. If proper sampling techniques are used, the bulk density method may give a more accurate result for any particular site in the field. Because both technical methods have limitations, the visual method may be the quickest and best alternative.

Visual Method

Often the best method of determining soil compaction is visual observation of both the soil and crops. Cloddy seedbeds, increased surface water ponding, loss of granular soil structure and reduced pore spaces through the soil are good visual indicators of compaction. Digging an observation hole in the field and observing rooting depths and patterns helps to determine if the crop is exploring the total soil volume or is restricted. Probing soil layers with a knife can indicate compacted zones and help determine where rooting or water flow has been curtailed. Figure 2.16 is a dramatic representation of a compacted layer from under a harvested annual crop.

Depressed crops, stunted or contorted root systems and a tendency to show

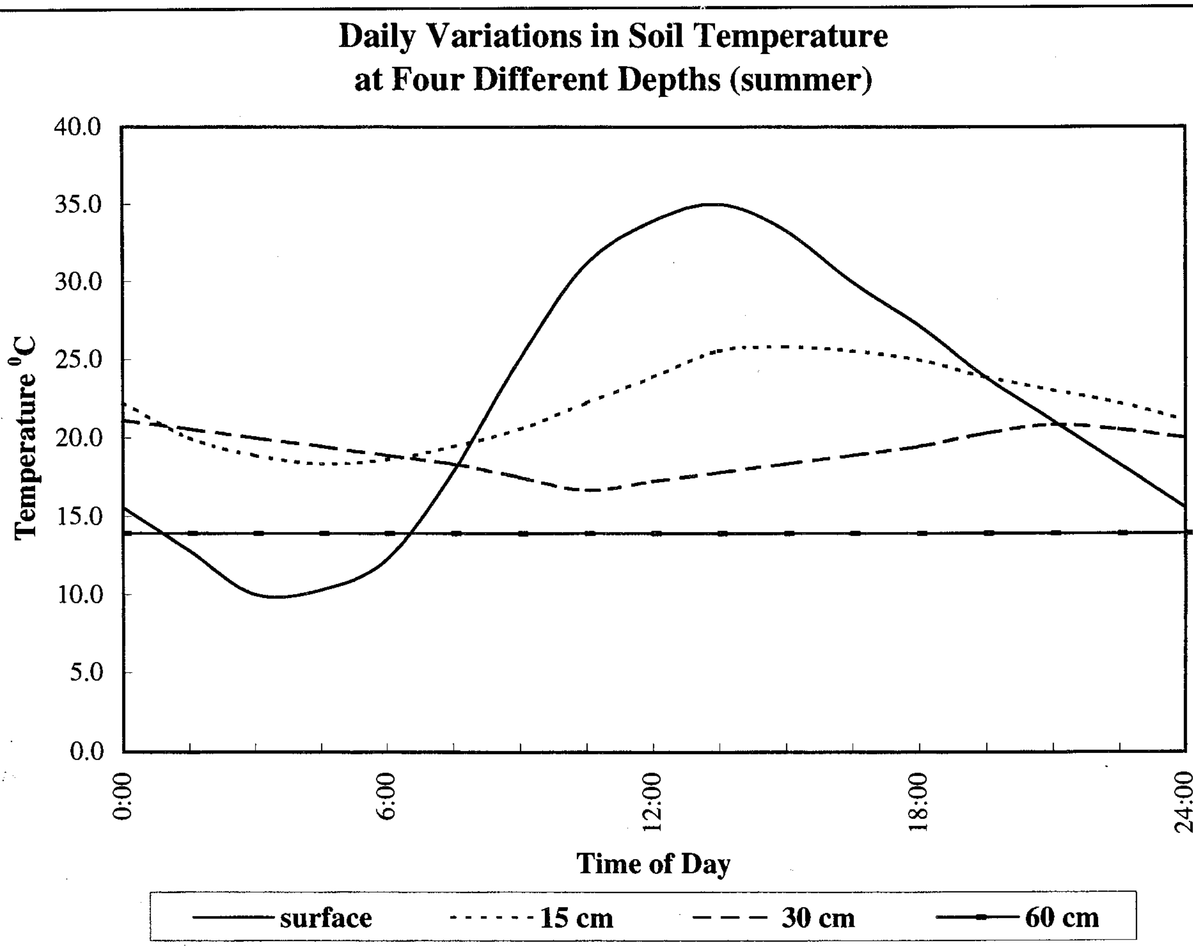
Figure 2.16 Compacted Surface (crust) Layer

yellow colouring, during or after large rainfalls (poor aeration), indicate compacted soils. Shifts in weed population are also good indicators. In addition, root rot diseases may increase with surface compaction.

2.9 Temperature

Soil temperature plays a key role in crop production. Plants need heat to germinate and to develop to their full potential. Soil temperature also plays an important role in the activity of soil microorganisms and the availability of plant nutrients as many chemical reactions are temperature dependent. As an example, corn seeds will germinate up to eight days more quickly in soils that are 15°C than soils that are 10°C.

Because of the high specific heat of water, it takes approximately five times as long to raise the temperature of a wet soil than it does a dry soil, hence the term "cold-wet soil". The temperature of the upper layer of a wet soil can be as much as 6°C lower than the surface of a moist soil. Soil temperature decreases with depth in the soil. Figure 2.17 shows how soil temperatures near the surface vary over the course of a day, while at a depth of 60 cm, the temperature remains fairly constant.



Adapted from: Hausenbuiller, 1972.

Figure 2.17 Example of Daily Temperature Variations in Soil

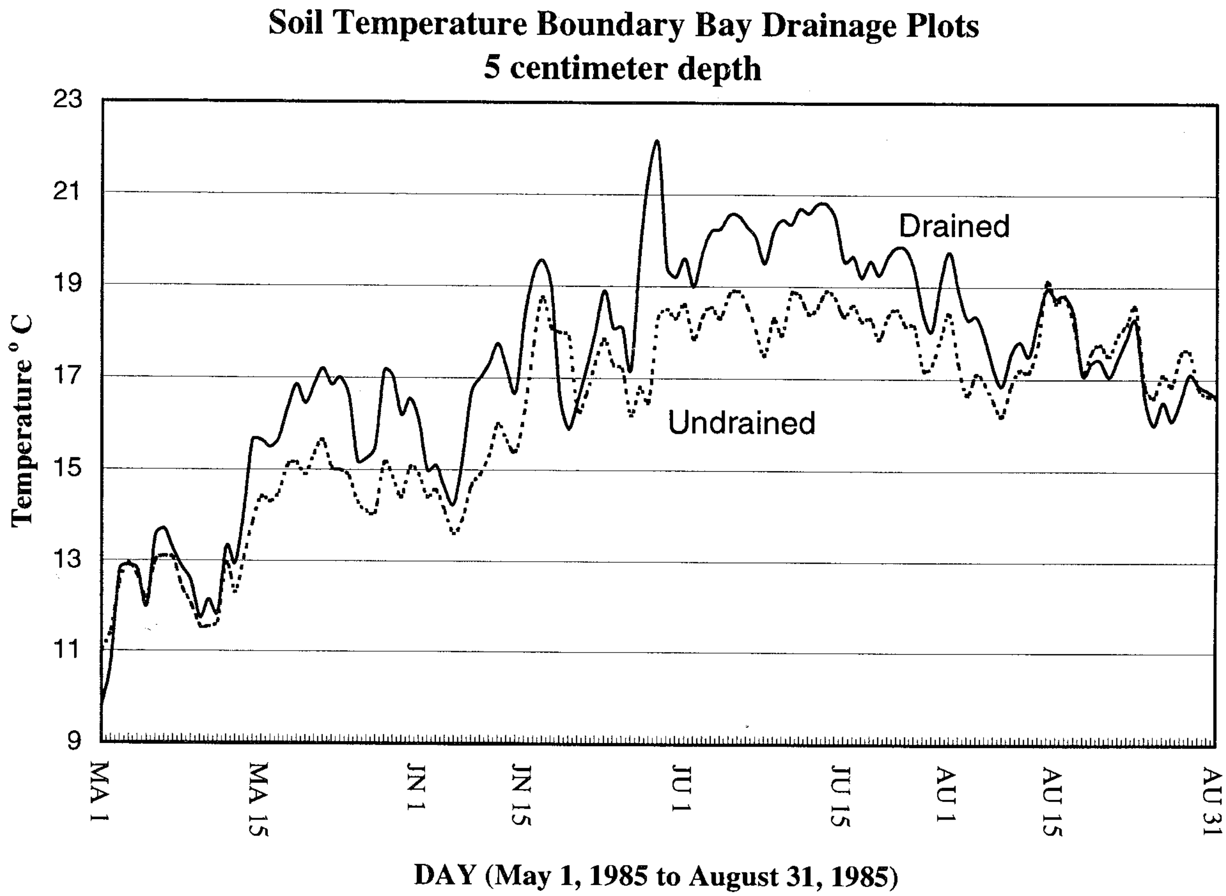


Figure 2.18 Soil Temperature Boundary Bay

When a soil is drained the soil temperature rises more quickly, increasing the number of growing days per season. Figure 2.18 shows how drainage can help to increase soil temperatures. If the soil surface is covered with mulch or a crop canopy, the surface soil temperature will not become excessively high. The evapotranspiration from the crop or mulch will reduce the surface soil temperature.

2.10 Colour

Soil colour is one of the strongest indicators of poor drainage or a fluctuating water table. Shading, brightness, uniformity or mottling and the overall colour of the soil provide insight into the movement of water and chemical compounds through the soil. Soil colours are most easily seen when the soil is moist. The parent material from which the soil is developed, gives the soil its main colour. Well drained and aerated, non-marine soils, generally have a brown colour. Redness in the soil indicates the presence of iron. Large amounts of organic matter in the humus form impart a black colour to the soil.

The best indication of a fluctuating water table is the presence of soil mottling. Soil has background colours which are shades of grey, blue, brown and red. Mottles have a similar range of colours including black, yellow brown, grey or red. Mottles or mottling refers to the non-uniform spots or streaks of colour on the background colour. Mottles are formed when the water table moves up and down over a period of time. This creates saturated and drained conditions. Under saturated conditions, oxygen becomes depleted and the population of anaerobic bacteria becomes dominant. These bacteria and other chemical processes, known as reduction, create iron and manganese compounds that give the soil a bluish-grey colour. When the soil becomes drained, aerobic conditions exist. These iron and manganese compounds are now exposed to the air causing them to oxidize (rust) giving points in the soil a red brown mottled appearance. Figure 2.19 is a good example of red brown mottles on a grey background.

The zone that remains permanently saturated or wet during the year is usually grey. The zone where the water table fluctuates is mottled. The thickness of the mottled zone and the sharpness and abundance of the mottles gives an indication of the frequency, duration and height to which the water table rises.

Figure 2.19 Mottles Within a Soil Clod

2.11 Natural Soil Drainage Classes

Natural soil drainage classes refer to the rate, both speed and amount, at which water moves out of a soil. Water flow can be over the surface or downwards by percolation. Soil drainage class is not specifically measured by permeability, groundwater level or seepage, however these criteria can influence the soil water regime. Soil profile morphology usually reflects soil drainage. An example of soil profile morphology that could be used to determine soil drainage class would be colour and mottling. Although colour is a valuable field tool, it can be deceiving as the profile may exhibit the morphology of a poorly drained soil, but due to changes in the regional drainage, either natural or artificial, the soil may actually be imperfectly drained. Position in the landscape and vegetation, along with other soil characteristics may be used in the field to determine soil drainage class.

The following definitions (adapted from Describing Ecosystems in the Field, Luttmerding et al., 1990) can be used to determine natural soil drainage class:

Rapidly drained – water is removed from the soil rapidly in relation to supply. Excess water flows downward if the underlying material is pervious. There may be subsoil flow on slopes during heavy rainfall events. Soils generally have low available water storage capacity, and are usually coarse-textured, or shallow or both.

Well drained – water is removed from the soil readily, but not rapidly. Excess water generally flows downward into pervious layers or laterally as subsurface flow. Soils have intermediate available water storage capacity. Soils are intermediate in both texture and depth. On slopes, subsurface flow may occur for short durations.

Moderately well drained – water is removed from the soil slower than it is supplied. Excess water is removed slowly due to low perviousness, shallow water table, lack of gradient within the site or a combination of these factors. Soils have an intermediate to high water storage capacity and are usually medium to fine-textured.

Imperfectly drained – water is removed from the soil at a rate which is much slower than the supply to a point that the soil remains wet for a large part of the growing season. Excess water from precipitation moves downward slowly. Presence of a water table or ground water will alter the downward flow of water and cause this type of soil to remain wet for a significant part of the growing season. Water storage capacity is high unless ground water or subsurface flow is present. These soils tend to have a wider range of available water storage, texture, and depth, and are commonly gleyed.

Poorly drained – water is removed from the soil at a very slow rate. These soils tend to stay wet for most of the year. Excess water is evident in the soil much of the time. Subsurface or groundwater flow and precipitation account for the water source and a perched water table may be present. These soils have a wide range of water storage capacity, texture, depth, and are gleyed.

Very poorly drained – water is removed from these soils so slowly that the water table remains at or near the soil surface for most of the year. Excess water is present most of the time. Groundwater flow and subsurface flow are the main source of water unless the condition is the result of a perched water table where the water supply is precipitation. These soils have a wide range of water storage capacity, texture, depth, and are gleyed.