SECTION 10: Abiotic Factors and Their Influence on Forest Ecosystem Establishment

TABLE OF CONTENTS

10 ABIOTIC FACTORS AND THEIR INFLUENCE ON FOREST ECOSYSTEM ESTABLISHMENT 1
Approach and Structure 1
Introduction 1
10.1 THE 23 ABIOTIC CONSTRAINT VARIABLES 1
Topographic Position 2
Crest and Upper Slope 2
Middle Slope 3
Lower Slope 3
Toe 4
Depression 4
Level 4
Slope Gradient 4
Evapo-transpiration Potential 5
Cold Air Drainage 5
Permafrost 6
Winter Desiccation Hazard (Winter Injury) 7
Root Restricting Layer or Exposed Bedrock 7
Depth to Calcareous Zone 7
Soil Reaction or pH 8
Soil Effective Texture 8
Coarse Fragments 10
Surface Organic Matter Depth 10
Mor Humus Form 11
Organic Matter Decomposition 13
Ah Horizon (>5 cm) 14
Ae Horizon (>2 cm) 15
Soil Dark Coloured (Munsell colour value < 4) 16
Soil Light Coloured (Munsell colour value > 6) 16
Water Table Depth (Gleying) 17
Mottles Present 18

Seepage Present/Depth *20*
Floodplain (Flooding Hazard) *20*
Mineral Soil *21*
Organic Soil *21*
10.2 MOISTURE AND NUTRIENT REGIME 22
10.2.1 MOISTURE REGIME 22
10.2.2 NUTRIENT REGIME 23
10.2.3 EDATOPE 25
10.3 THE SEVEN ABIOTIC LIMITING FACTORS 26
Moisture Regime Low Limiting Factor *27*
Moisture Regime High Limiting Factor *27*
Nutrient Regime Low Limiting Factor *27*
Cold Soil Limiting Factor *27*
Frost Pocket Limiting Factor *28*
Frost Heave Limiting Factor *28*
10.4 LITERATURE CITED 30

10 ABIOTIC FACTORS AND THEIR INFLUENCE ON FOREST ECOSYSTEM ESTABLISHMENT

APPROACH AND STRUCTURE

This section of the Silviculture Guide addresses the abiotic factors that dictate site conditions which may inhibit the establishment, growth, and development of plants (especially trees). This section describes 23 abiotic variables used to diagnose site and their functional relationship with moisture and nutrient regime. It also describes how these variables generate seven abiotic limiting factors that can inhibit forest ecosystem establishment, tree survival, and tree growth.

INTRODUCTION

Evaluating ecological site quality is an integral part of forest management and successful silviculture planning. Ecological site quality is aggregate of factors determining the capacity of a site to produce forests; site quality encompasses climatic, soil (edaphic), and biological factors. The moisture and nutrient regimes of the soil are fundamental to survival and prosperity of all organisms on a site, particularly plant species. Thus, the ecological function of a site is largely determined by the availability of water and nutrients for plant establishment, growth, and development.

Silviculturists are primarily concerned with the establishment, survival, and growth of forest trees. (This should not be considered a dismissal of the range of ecosystem services accruing to renewed forests which frequently influence or modify silvicultural practice.) On any particular site, an excess or shortage of soil water can be limiting to tree establishment and growth, with the presence and severity of the constraint depending on the intensity of the constraining factor and the plant species affected. In the boreal and foothills forests of Alberta, a lack of nutrients commonly impacts tree establishment and growth; very rarely are excessive nutrients problematic. Other factors that may limit tree establishment and growth include cold soil, frost pockets, frost heave hazard, and winter desiccation. Thus, the seven limiting factors to plant establishment and growth in these regions are:

1. Low soil moisture regime
2. High soil moisture regime
3. Low soil nutrient regime
4. Cold soil
5. Frost pockets
6. Frost heave hazard
7. Winter injury

10.1 THE 23 ABIOTIC CONSTRAINT VARIABLES

This section discusses the 23 twenty-three abiotic constraint variables and how they influence ecological site quality, with a focus on forest ecosystem establishment and development to age 15.

TOPOGRAPHIC POSITION

Topographic position is the relative location of a site on the landscape from ridge crest to depression (Figure 10.1). It influences many other ecological site conditions such as moisture regime, nutrient regime, exposure to wind, potential erosion, soil development, and organic matter build-up. Generally, greater organic matter build-up and more advanced soil development occur as one moves from upper to lower slope positions (see Figure 10.2). A brief description of the topographic position classes follows.

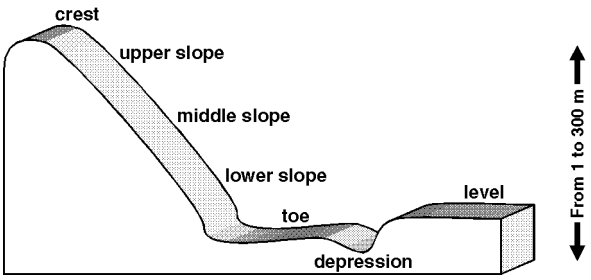


Figure 10.1. Representation of topographic position along a slope profile (Beckingham et al. 1996).

CREST AND UPPER SLOPE

The crest is the convex uppermost portion of a hill. It usually is convex in all directions with no distinct aspect. The upper slope is generally the upper portion of the slope of a hill immediately below the crest. The upper slope has a convex surface profile with a specific aspect.

The crest and upper slope positions receive water only from precipitation and tend to shed water relatively quickly. They tend to have shallow soil profiles due to natural erosion and gravitational effects. The crest and upper slope positions have greater exposure to wind and evaporative demand than other topographic positions. This results in dry soils with shallow organic matter layers that limit moisture and nutrient availability for plant growth.

Figure 10.2. Soil catena illustrating increased accumulation of organic matter and deeper soil development from slope crest to lower slope (University of Saskatchewan, 2002).

MIDDLE SLOPE

The middle slope is the area between the upper and lower slopes where the slope has a straight or somewhat sigmoid surface profile with a specific aspect. Middle slopes generally receive moisture, nutrient, and material inputs from higher elevations, but to a lesser degree than lower slopes and slope toes. Other factors being equal, middle slopes tend to be intermediate between upper and lower slopes in moisture, nutrients, organic matter build up, temperature, evapo-transpiration, soil development, and exposure to wind.

LOWER SLOPE

The lower slope is the sloped area near the base of a hill. It generally has a concave surface profile with a specific aspect. Being at the base of a hill, the lower slope is in a zone of material accumulation where mineral and organic materials can be moved down the slope by gravitational forces and/or water run-off. Lower slopes tend to receive water from higher elevation slope positions. This water can come from both surface run-off and subsurface discharge or seepage. Seepage waters enhance the moisture status of a site, and are often laden with nutrients, which improves the nutrient regime of most lower slopes.

TOE

The toe is below and adjacent to the lower slope and is clearly demarcated by an abrupt decrease in the slope. The slope toe is a zone of material accumulation and has many of the characteristics of the lower slope position, such as the potential for enhanced moisture and nutrient availability through the presence of seepage water.

DEPRESSION

A depression is any area that is concave in all directions; usually at the foot of a hill or in a generally level area. Depressions receive water from the topographically higher areas that surround them and tend to be prone to water ponding and flooding. Loss of water from depressions depends on soil permeability. Where soils are relatively permeable, water is removed through percolation and infiltration, whereas relatively impermeable soils will lose water dominantly through evapo-transpiration. Depressions are also subject to cold air drainage. With relatively wet soils and cold temperatures, depressions tend to accumulate organic matter because the rate of organic matter deposition is higher than the rate of decomposition. Organic matter is an excellent insulator and further contributes to cold soil temperatures.

LEVEL

A level site is an area where the surface profile is generally horizontal with no significant aspect. This means that there is little relief to facilitate the drainage of water. Since there is little slope to modify moisture regime, the permeability of the soil and parent material exerts considerable control over the water balance of the site. Level surfaces having coarsely textured soils are permeable to vertical water movement and tend to become dry. The presence of finely textured material at or near the surface slows or restricts downward water movement, markedly increasing water availability to plants.

SLOPE GRADIENT

Slope gradient is the steepness of a slope, and is, most often, measured in percent. Percent slope is the elevation gain of the slope divided by the horizontal span of the slope multiplied by 100. Generally, slopes in excess of 12 to 15 percent are considered steep.

Slope gradient affects the degree and rate that water, snow, and soil will be shed. The steeper the slope, the faster it will shed water and the less water will be available to plants. Maximum water absorption by a soil occurs on a flat surface with no slope. Slope gradient, along with aspect, has a strong influence on the incidence of solar radiation at a site. Steeply inclined south facing slopes receive greater amounts of solar radiation than level surfaces at any given point in time, because the sloping surface reduces the angle of incidence and concentrates the same amount of radiation onto a smaller area (Strong and Carnell, 2000). Similarly, north facing slopes cause an increase in the angle of incidence and disperse the solar radiation over a larger area, thus reducing the amount of radiation a north slope receives as

compared to level terrain. The amount of solar radiation received by a slope affects many other related factors, including air and soil temperature, soil water, and PAR (photosynthetically active radiation) which are important to the establishment, growth and development of plants (Barnes et al. 1998). Relatively steep slopes (> 15%) will contribute to low moisture regime on a site and may increase the risk of frost heave due to the increased frequency of freeze-thaw cycles.

EVAPO-TRANSPIRATION POTENTIAL

Evapo-transpiration is the sum of evaporation and plant transpiration. Evaporation accounts for the movement of water to the air from sources such as the soil, canopy interception, and waterbodies. Transpiration accounts for the movement of water within plants and the subsequent loss of water as vapour, largely through stomata in their leaves. Sites with increased temperature, frequency and intensity of wind, and incidence of solar radiation have greater water loss through evapo-transpiration, and may be droughty. In addition, sites with a high evapo-transpiration potential may have increased hazard of winter desiccation and windthrow.

COLD AIR DRAINAGE

Cold air drainage and frost pockets are commonly found in areas where air from higher elevations chills due to radiational cooling or contact with snowpacks, and then drains downslope (Heidorn 2007). This occurs primarily in low-lying terrain, hollows and drainage bottoms where cold air can pool (Figure 10.3). Once the air has reached its resting level, it may continue to cool through radiational heat loss to even lower temperatures. Such areas are more susceptible to frost than the surrounding terrain and are therefore known as frost pockets.

Of course, when the air temperature falls below freezing, it can damage plants caught in the pool or chilled in the passing flow. In rugged terrain such as that found in the western cordillera, cold-air/frost pocket regions can produce completely different micro-ecosystems with a substantially shorter growing season over relatively short distances. Cold air drainage flows can occur even with terrain differences of only a meter (Heidorn 2007).

Cold air drainage contributes to the limiting factors of cold soils and frost pockets. Cold air drainage, especially when associated with frost, can inhibit or impair plant establishment, survival, growth, and development.

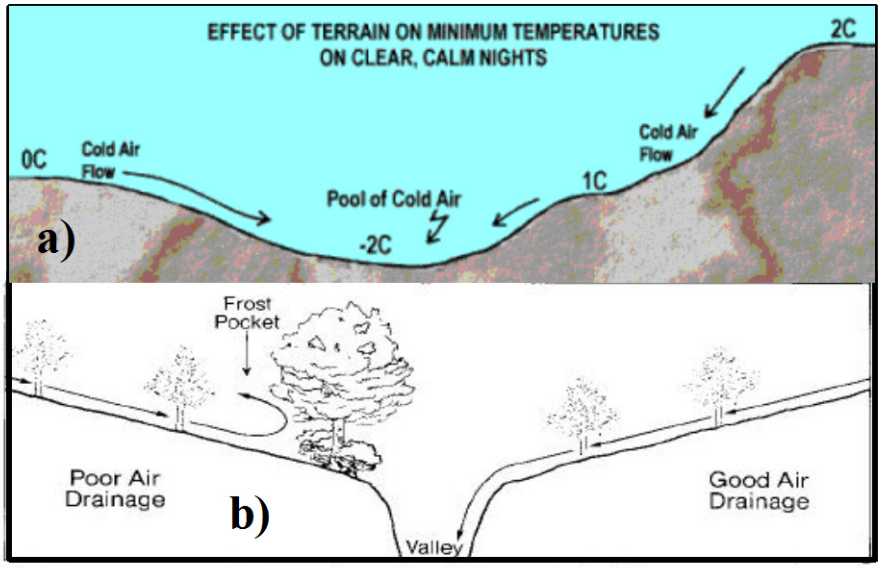


Figure 10.3. Illustration of the affect of terrain on cold air drainage and the formation of frost pockets. a) cold air pooling in low lying areas, b) cold air pooling due to a drainage barrier (From: Silver, 2002).

PERMAFROST

Permafrost or permafrost soil is ground that stays at or below the freezing point of water (0°C or 32°F) for two or more consecutive years. Ice is not always present, as may be the case in nonporous bedrock, but it frequently occurs and it may be in amounts exceeding the potential hydraulic saturation of the ground material. Most permafrost is located at high latitudes (e.g. North and South poles), and alpine permafrost exists at high altitudes. Overlying permafrost is a thin layer of ground called the active layer that seasonally thaws during the summer. Plant life can be supported only within the active layer because growth can occur only in soil that is fully thawed for some part of the year.

In Alberta's Boreal Forest and Foothills Natural Subregions, permafrost is commonly discontinuous and only occurs in local areas where there is a considerable build-up of organic matter that insulates the soil from both solar radiation and relatively high summer ambient temperatures.

The presence of permafrost can contribute to excessive moisture, nutrient limitations, cold soil, and increased risk of frost heave in mineral soils. In Alberta, permafrost tends to occur in wet areas where enough organic matter accumulates to insulate the soil and prevent it from fully thawing during the summer. Consequently, frozen soil inhibits the infiltration of water into the soil, thus, contributing to high soil water and in turn organic matter accumulation through slow organic mater decomposition. The active layer in frozen soils tends to be cold, which limits plant establishment and growth. In addition, cold soils reduce the rate of organic matter decomposition and nutrient cycling, which are both temperature-dependent processes.

WINTER DESICCATION HAZARD (WINTER INJURY)

Significant injury of plant tissues can occur when they become dried out, or desiccated. This occurs when transpiration exceeds moisture absorption, which then results in wilting and damage to the plant tissues. Winter desiccation injury occurs when solar warming of tree crowns that are exposed above the snow pack causes leaves to transpire excessive moisture when roots are frozen and unable to replace moisture. Winter injury to white spruce seedlings is discussed in detail in Section 9

ROOT RESTRICTING LAYER OR EXPOSED BEDROCK

In this Guide, the root restricting layer variable is defined as the depth (cm) from the ground surface to a root-restricting layer such as bedrock, strongly compacted, or strongly cemented, material. If bedrock is at or near the soil surface, or if there is a root-restricting layer in the upper soil profile, there could be moisture and nutrient regime limitation on the site. The depth to the root-restricting layer indicates how much unconsolidated material is available for plant rooting as well as for storing moisture and nutrients for uptake and utilization by plants.

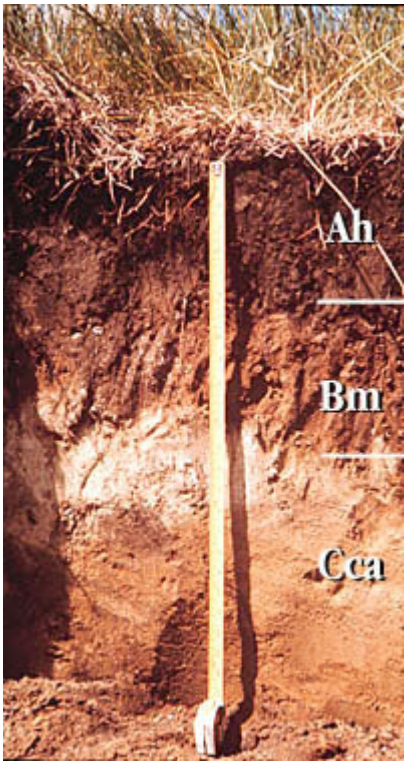


Figure 10.4. Soil profile of a chernozemic soil. Note the whitish colour carbonates that have accumulated in the Cca horizon (University of Saskatchewan, 2002).

DEPTH TO CALCAREOUS ZONE

The depth to the calcareous zone is the depth (cm) to the zone of either inherent or secondary carbonate accumulation. The zone is often identified by either the presence of white crystals (Figure 10.4) and/or strong effervescence on application of 10% hydrochloric acid. Excessive accumulations of calcium carbonate can be limiting to plant establishment and growth, especially when it occurs close to the soil surface. In particular, the presence of a hard, relatively impervious carbonate layer has a strong effect on forest productivity, especially conifer growth and development.

Nutritional and physiological problems in trees growing on calcareous soils may be related to either high concentrations of carbonate or bicarbonate ions, or to deficient or excess nutrient elements (Kishchuk 2000). High carbonate ion (CO_3^{-2}) concentrations may have an adverse effect of seedling emergence and growth (Maynard et al. 1997) as well as on mycorrhizal development (Lapeyrie and Bruchet 1986). All plants growing on calcareous soils are susceptible to iron chlorosis due to iron deficiency, but species vary in tolerance (Loppert 1994). Excessive calcium can reduce tree growth due in part to the inhibition of iron and manganese uptake. This has been shown in spruce (Duchaufour 1960), pine (Ellis and Whitney, 1975) and aspen (Wall et al. 1971). White spruce is less susceptible to excess carbonates than pine or black spruce, while deciduous trees such as aspen, balsam poplar and paper birch are relatively unaffected by excessive calcium

carbonate-induced nutrient deficiencies (Strong and Carnell 2000). The high pH associated with calcareous soils modifies the availability of numerous macro- and micro-nutrients. See Section 1.3.9 for information about pH effects on nutrient availability.

SOIL REACTION OR PH

Soil reaction refers to the activity of hydrogen ions in the soil. It is measured in units of pH, which is the logarithm of the reciprocal of hydrogen ion activity (Bates 1956). It is an expression of the acidity or alkalinity of the soil on a scale of 1-14. The chemical environment of the soil can be acid, neutral or alkaline. The ideal state is close to neutral, which is the status of pure water, but generally there are influences which generate acidity (e.g. the movement through the soil of strong acid ions such as sulphate or nitrate) or alkalinity due to the accumulation of strongly basic ions (such as calcium and sodium) (Dalgliesh and Foale 2006). The lower the pH number, the higher the concentration of hydrogen ions; a drop of 1 unit of pH represents a ten-fold increase in the concentration of hydrogen (acid) ions.

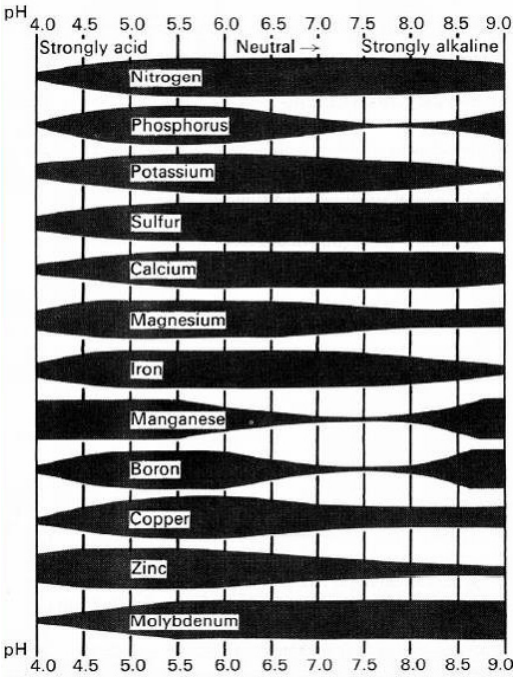


Figure 10.5 Effect of soil pH on the relative availability of 12 different nutrients.

The pH scale provides a useful indicator of some aspects of chemical properties and behaviour of the soil that affect plant growth. Alkaline soils generally contain a majority of ions of the bases calcium, magnesium, potassium and sodium, which originate largely from the hydrolization of salts (Kimmins 1996). Acidic soils commonly form through the mineralization of acidic rock (e.g. Precambrian shield) as a by-product of the metabolism of soil organisms (e.g. carbonic acid) and through decomposition of organic matter to form humic acids (Kimmins 1996). Both high and low pH soils are unfavourable to plant growth. A high degree of acidity (below pH 5.5) may trigger the release of a toxic form of aluminium or manganese, while strong alkalinity (above pH 8.0) impairs uptake by the root of scarce trace element cations, such as copper, iron, manganese and zinc (Dalgliesh and Foale 2006) (Figure 10.5).

SOIL EFFECTIVE TEXTURE

Texture of soil refers to the size of mineral particles, ranging from fine to coarse. There are three categories of sizes: clay, silt, and sand (Figure 10.6). The relative proportion of sand, silt, and clay particles in the soil determines its texture and is commonly expressed as one of 14 textural categories in a soil textural triangle (Figure 10.7). A balanced soil (loam) contains about 40% sand, 40% silt and 20%

clay and is preferred for growing most plants. For mineral soils, Effective Texture is the texture of the finest-textured soil horizon that is at least 10 cm thick located 20–60 cm below the mineral soil surface.

Texture is one of the most important soil characteristic; it influences many other properties of great significance to plant establishment and growth.

Sandy soils tend to be low in organic matter content and native fertility, low in their ability to retain moisture and nutrients, low in cation exchange and buffer capacities, and rapidly permeable (i.e., they permit rapid movement of water and air) (Brown 2003). Water infiltrates sandy soil and percolates quickly and easily. As a result, sandy soils are generally dry and infertile. The dryness of sandy soil contributes to a shortage of nutrients because of less vegetative growth and, therefore, less organic matter is produced.

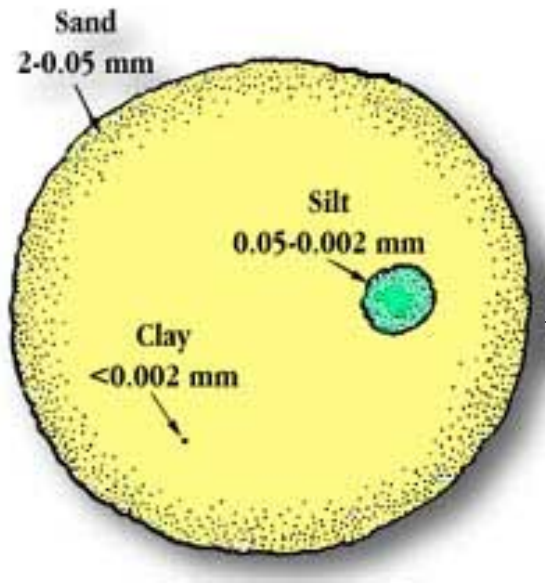
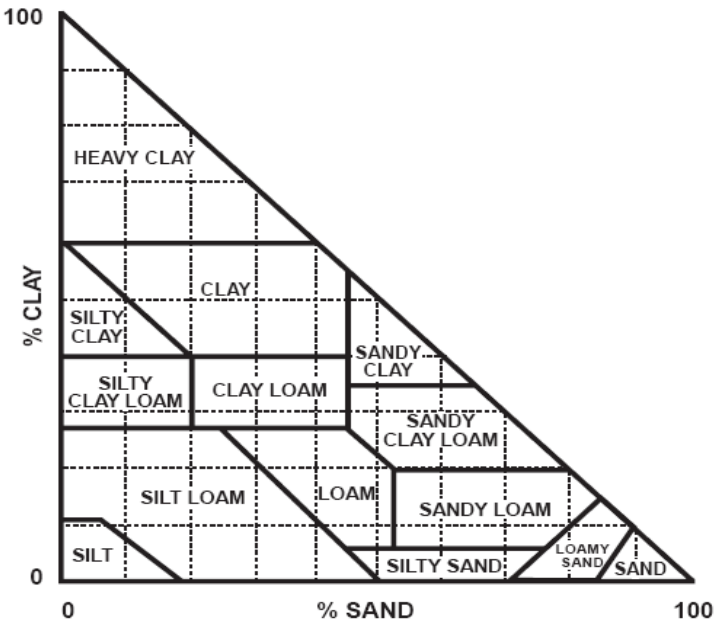


Figure 10.6. Illustration of the relative size differences between sand, silt, and clay. Sandy soils have a higher volume to surface area ratio than silty soils, which have more than clay soils. Sandy soils have larger pore spaces but less pore space volume compared to silt and clay soils (University of Saskatchewan, 2002).



Effective Texture Class	Texture Code	Texture
1	S	sand
1	LS	loamy sand
2	SL	sandy loam
2	SiS	silty sand
3	Si	silt
3	SiL	silt loam
3	L	loam
4	SCL	sandy clay loam
4	CL	clay loam
4	SiCL	silty clay loam
4	SC	sandy clay
4	C	clay
4	SiC	silty clay
4	hC	heavy clay

Figure 10.7. Soil textural triangle and textural codes and classes. (From Beckingham et al. 1996).

As the relative percentages of silt and/or clay particles become greater, properties of soils are increasingly affected. Finer-textured soils are generally more fertile, contain more organic matter, have higher cation exchange and buffer capacities, are better able to retain moisture and nutrients, and permit less rapid movement of air and water (Brown 2003). All of this is beneficial to plants, up to a point. When soils are so fine-textured as to be classified as clayey, however, they are likely to exhibit properties that may be somewhat limiting to tree establishment and growth.

Heavy clays are like soft plastic when wet and are hard when dry. They have a large total pore space (almost twice as much as a sandy soil), although individual pores have a small diameter and are tortuous (U of Sask 2002). This type of soil can hold a lot of water, but water movements are slow due to high surface tension forces. Clays are often waterlogged, poorly aerated, and cool. Clay soils absorb and release water (to plants) very slowly, and air movement within the soil is also very slow. These conditions mean that clay soils take longer to warm than coarser soils. As discussed previously, colder temperatures can inhibit tree establishment and reduce growth.

Many forest soils in Alberta's boreal forest are very high in clay and are very susceptible to soil massing or compaction when tracked during wet conditions. Massing and/or compaction result in a loss of soil porosity and a further reduction in soil infiltration and water movement capacity resulting in soil that remains wet for lengthy periods following snow melt or rainfall.

COARSE FRAGMENTS

Coarse fragments are measured as the volumetric percentage of rocks and rock portions larger than 2 mm in diameter that occur in the soil matrix. The occurrence of excessive amounts of coarse fragments limits the amount of fine fraction (silt and clay) in the soil, which decreases its nutrient and water holding capacities (Strong and Carnell 2000).

SURFACE ORGANIC MATTER DEPTH

Soil organic matter is any material in the soil that was originally produced by living organisms. At any given time, it consists of a range of materials varying from the intact original tissues of plants (mainly) and animals to the substantially decomposed mixture of materials known as humus (Dunn 2003). The original tissues contain a wide range of organic compounds, which typically decompose at different rates releasing nutrients that can be used by plants. Organic matter is a pivotal component of the soil because of its role in physical, chemical, and biological processes (Table 10.1). Soil organic matter contributes to soil aggregate formation, increases the amount of soil water available to plants, and supplies most of the nitrogen used in annual growth of forest ecosystems (Barnes et al. 1998). Organic matter also protects against erosion and helps support a healthy and diverse set of microscopic plants, animals, fungi, and other micro-organisms.

The amount of organic matter on a site depends on the balance between organic matter production and decomposition. The rate of decomposition of organic matter depends on the soil's temperature,

moisture, aeration, pH and nutrient levels. In general, for upland boreal sites, the greater the depths of surface organic matter, the higher the potential for the site to have a high nutrient status and adequate to abundant moisture.

Table 10.1. Physical, chemical, and biological functions of soil organic matter (Sparrow et al. 1999; Cotching et al. 2001, 2002).

Physical functions	Chemical functions	Biological functions
Bind soil particles together in stable aggregates	Major source of cation exchange capacity	Food source for microbes and small animals
Influence water holding and aeration	Source of pH buffering	Major reservoir and source of plant nutrients
Influence soil temperature	Binding site for heavy metals and pesticides	

MOR HUMUS FORM

Humus consists of soil horizons located at or near the soil surface which have formed from organic residues, either separate from, or intermixed with, mineral materials. Humus form can be composed of entirely organic or both organic and mineral horizons. Although only the presence or absence of Mor humus form is used in this guide, we will give a brief overview of the major humus forms here.

Factors such as abundance and activity of soil organisms tend to produce a characteristic organic profile morphology or forest humus form (SoilWEB, 2006). Forest humus form classification is based on the sequence, properties, and inferred origin of organic horizons (usually just the H horizon) and the Ah horizon (if one is present). A description of organic soil horizons common to upland sites can be found in Table 10.2. Common humus forms in our region include mors, moders, and mulls (Figure 10.8 and Figure 10.9).

Table 10.2. Description of upland soil organic horizons (after: Soil Classification Working Group. 1998).

Horizon	Description
L, F, and H	These organic horizons developed primarily from the accumulation of leaves, twigs, and woody materials with or without a minor component of mosses. They are normally associated with upland forested soils with imperfect drainage or drier.
L	This organic horizon is characterized by an accumulation of organic matter in which the original structures are easily discernible.
F	This organic horizon is characterized by an accumulation of partly decomposed organic matter. Some of the original structures are difficult to recognize. The material may be partly comminuted by soil fauna as in moder, or it may be a partly decomposed mat permeated by fungal hyphae as in mor.
H	This organic horizon is characterized by an accumulation of decomposed organic matter in which the original structures are indiscernible. This horizon differs from the F by having greater humification due chiefly to the action of organisms. It is frequently intermixed with mineral grains, especially near the junction with a mineral horizon.

Mor: A mor is humus form that displays diagnostic F and H horizons, with a distinct boundary evident between the organic and mineral layer (Beckingham et al. 1996). There is little or no intermixing of organic and mineral horizons. Mors are the most common forest humus form in the boreal forest and lower foothills of Alberta. This humus form arises under conditions of low biological activity in the soil, with acidophilic fungi being the primary decomposers. The mineralization of organic matter proceeds slowly and creates layers, which maintain a structure of vegetable material and may become quite thick (Stevenson 1982). The carbon to nitrogen (C:N) ratio of mor humus is always more than 20, or even up to 40, and its pH is acidic.

Moder: A moder humus form displays all of the diagnostic organic horizons with varying degrees of intermixing between the organic and mineral horizons, producing a gradual transition between the horizons (Beckingham et al. 1996). Moders are a transitional form of humus between mor and mull and are a type of medium humified humus. Acidophilic fungi and soil organisms participate in transformations of plant residues. The C:N ratio of moders equals approximately 15-25 (Stevenson 1982). The mineral-organic complexes that are produced are labile and weakly bounded with mineral portion of soil.

Mull: A mull humus form commonly lacks the diagnostic F and H horizons (Beckingham et al. 1996). There is considerable mixing of organic material into the surface mineral horizon thereby creating a relatively thick Ah horizon. Usually many soil organisms are present, but it may also form as a result of the decomposition of dense root networks. Insect droppings and earthworms are usually abundant. Mulls have well-humified organic matter, which is produced in very biologically active soil. This type of humus is characterized by neutral pH, a C:N ratio nearing 10, and a stable mineral-organic complex (Stevenson 1982).

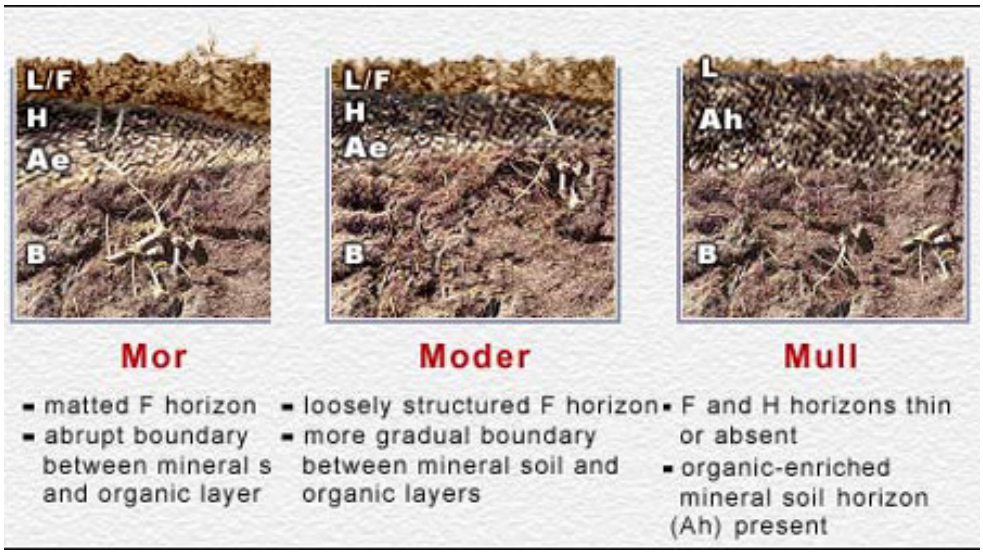


Figure 10.6. Examples of mor, moder, and mull humus forms with associated characteristics (From: Distance Education and Technology Continuing Studies, The University of British Columbia).

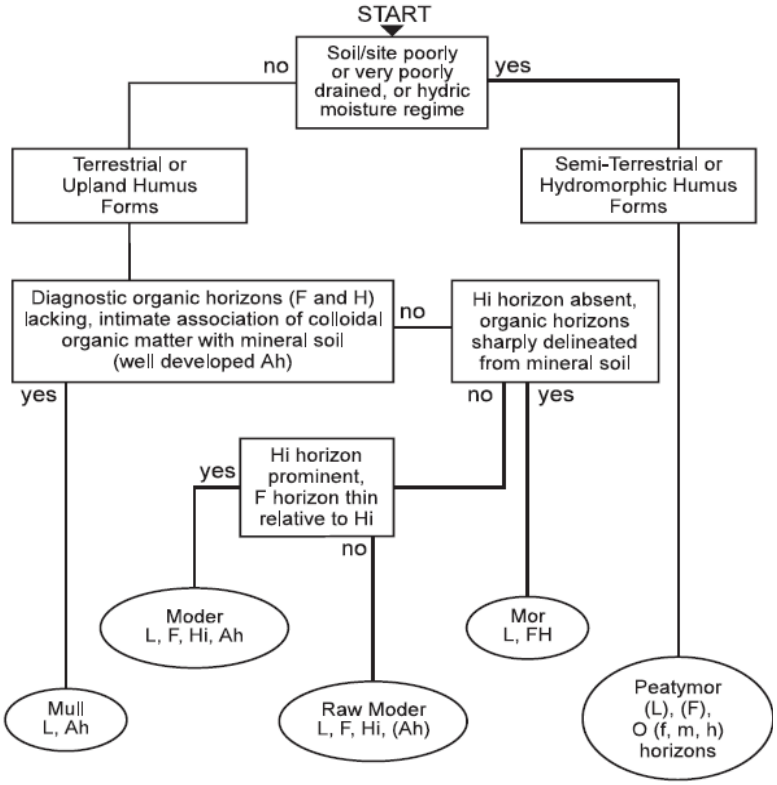


Figure 10.9. Humus form classification (Beckingham and Archibald, 1996; modified after Bernier, 1968).

ORGANIC MATTER DECOMPOSITION

Organic soil horizons occur in organic soils and commonly at the surface of mineral soils. They may be present as overlying parent materials or occur at any depth beneath the surface in buried soils. They contain more than 17% organic C (about 30% or more organic matter) by weight (Soil Classification Working Group 1998). The Organic Matter Decomposition variable is applied to soils that are greater than twenty centimetres (20 cm) thick. These may or may not be classified as organic soils based on the *Canadian System of Soil Classification* (Soil Classification Working Group 1998); however, the concepts used in evaluating the level of organic matter decomposition from this system are applied.

Organic matter decomposition in boreal wetlands is controlled primarily by soil temperature, moisture, fertility, and organic matter quality (Heal et al. 1981, Trettin et al. 1996). The rate of organic matter decomposition increases as soil temperature and nitrogen concentration increase, where litter is low in lignin (deciduous leaves), where pH is not acidic, and where aerobic conditions occur. Nutrients mineralized from that organic matter comprise the primary nutrient supply for plant uptake in most ecosystems (Trettin et al. 1996, Damman 1978, Van Cleve et al. 1983, Van Cleve and Yarie 1986).

Generally, the more decomposed the organic material, the higher the availability of nutrients for plant growth. The Guide recognizes the following three classes of decomposition for organic soils:

1. Poorly decomposed (Of, Fibric)
2. Moderately decomposed (Om, Mesic)
3. Well decomposed (Oh, Humic)

The following descriptions of organic matter decomposition classes, which depict the degree of decomposition of organic matter, are based on the *Canadian System of Soil Classification* (Soil Classification Working Group 1998).

Fibric peat material (light brown or blonde in colour) is at an early stage of decomposition (slightly decomposed). Much of the material can be recognized as to its plant origin. It is usually classified in the von Post scale of decomposition as class 1 to 4. A fibric horizon (Of) has 40% or more of rubbed fiber by volume. Rubbed fiber is the fiber that remains after rubbing a sample of the layer about 10 times between the thumb and forefinger.

Mesic peat material (brown in colour) is at an intermediate stage of decomposition (moderately decomposed) between fibric and humic materials. The material is partly altered both physically and biochemically. It does not meet the requirements of either a fibric or a humic horizon, has a rubbed fiber content ranging from 10% to less than 40%. It is usually classified in the von Post scale of decomposition as class 5 or 6.

Humic peat material (dark brown to black in colour) is in an advanced stage of decomposition (well decomposed). The horizon has the lowest amount of fiber, the highest bulk density, and the lowest saturated water-holding capacity of the O horizons. It is very stable and changes little physically or chemically with time unless it is drained. This material contains few, if any, recognizable fibres and is usually classified in the von Post Scale of decomposition as between classes 7 to 10.

AH HORIZON (>5 CM)

The end product of decomposition is humus, a black crumbly material that is resistant to further decomposition. It is a complex chemical substance that stores nutrients, holds moisture, and improves soil structure. Ah horizons are associated with Mull and Modor humus forms where the organic material is well decomposed (H as opposed to L or F horizons) and intermixed with the mineral fraction. An Ah horizon is a mineral horizon that is enriched with organic matter, has a colour value at least one unit lower than the underlying horizon or 0.5% more organic carbon than the parent material or both (Soil Classification Working Group 1998). The dark colour of Ah horizons is attributed to its relatively high organic matter content. By definition, Ah horizons contain 17% or less organic carbon by weight (Soil Classification Working Group 1998).

An Ahe horizon is an Ah horizon has undergone eluviation as evidenced, under natural conditions, by streaks and splotches of different shades of gray and often by platy structure (Soil Classification Working Group 1998). It may be overlain by a dark-coloured Ah and underlain by a light-coloured Ae.

The Ah horizon is characterized by intimate mixing of organic matter and mineral material, and it grades almost imperceptibly into underlying organic horizons (Kimmins 1997) (see Fig. 10.10). The humus mineral complex of the Ah horizon contributes to soil aggregate formation and increases the amount of soil water available to plants, and supplies most of the nitrogen used in annual growth of forest ecosystems (Barnes et al. 1998).

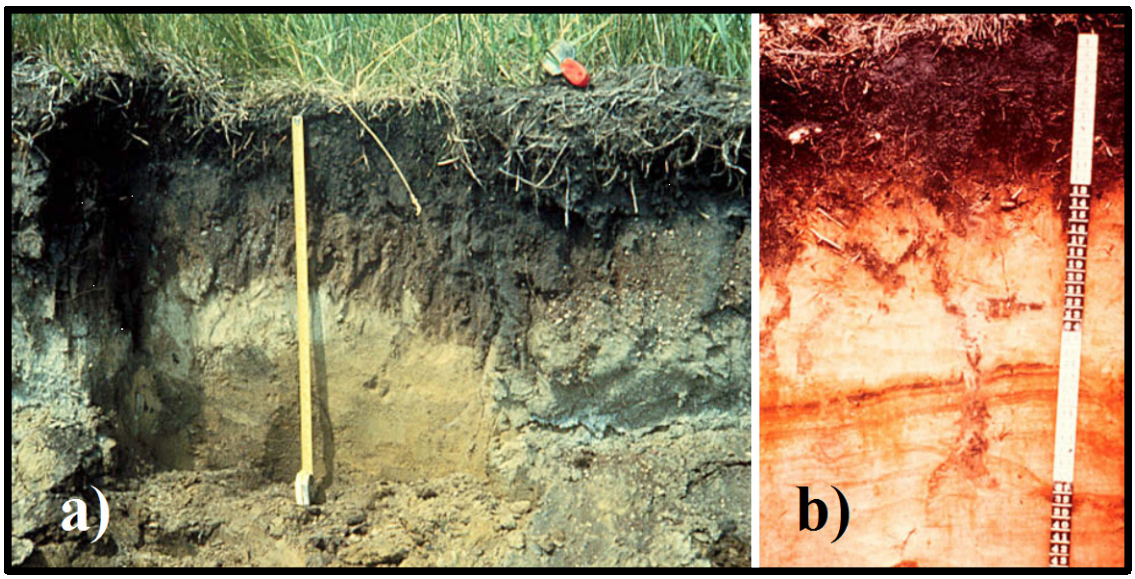


Figure 10.10. Example of two soils with Ah horizons that illustrate the intimate mixing of organic and mineral materials. a) Chernozemic soil Order, b) Gleysolic Order. (From: University of Saskatchewan, 2002).

AE HORIZON (>2 CM)

An Ae horizon is characterized by the eluviation of clay, Fe, Al, or organic matter alone or in combination. When dry, it is usually higher in colour value by one or more units than the underlying B horizon (Fig. 10.11). Luvisolic and Brunisolic soils both have Ae horizons and are the most common soils in the uplands of the Boreal Mixedwood and Lower Foothills Natural Subregions. Ae horizons are relatively acidic, have a lower nutrient status than darker coloured horizons, and contain very little organic matter. Thus, the greater the depth of the Ae horizon, the higher volume of the soil is composed of a relatively nutrient-poor substrate. This means that the presence of a relatively well developed Ae horizon (> 2 cm) is indicative of a poor nutrient regime.

SOIL DARK COLOURED (MUNSELL COLOUR VALUE < 4)

Soil colour provides insight into many physical and chemical properties of soils, particularly organic mater content and the degree of eluviation of clay, Fe, Al, or organic matter alone or in combination. Dark colored surface horizon(s) of mineral soils reflect organic matter additions; this is the primary interest of silviculturists in soil color. The organic matter is dominantly from leaf, stem, and root litter and the products of their decomposition. A deep surface soil that is dark in colour usually contains relatively greater amounts of organic matter than a thin light-coloured surface soil. These organic matter enriched soil horizons affect an array of physical, chemical, and biological soil properties. Soil organic matter contributes to soil aggregate formation and increases the amount of soil water available to plants, and supplies most of the nitrogen used in annual growth of forest ecosystems (Barnes et al., 1998).

The soil is dark coloured if it has a value of less then four in the Munsell soil colour chart system (Figure 10.12) (Munsell Colour 2000).

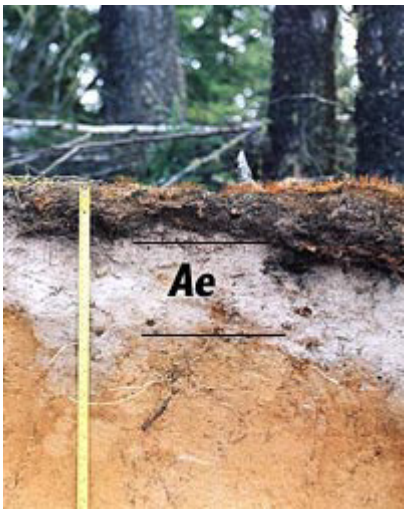


Figure 10.11. Brunisolic soil with a well developed, light coloured Ae horizon indicative of the leaching downward of organic matter, clay, iron compounds and other nutrients (From: University of Saskatchewan, 2002).

SOIL LIGHT COLOURED (MUNSELL COLOUR VALUE > 6)

Soil colour provides insight into many physical and chemical properties of soils, particularly organic matter content and the degree of eluviation of clay, Fe, Al, or organic matter alone or in combination. Surface horizon(s) of mineral soils that are light in colour, reflect eluviation of clay, Fe, and Al. Light coloured soil tends to have little organic matter, little clay, and reduced quantities of nutrients compared to dark coloured soils. Thus, light coloured surface soil horizons do not have the benefits of enrichment with organic matter and tend to store and release less nutrients.

The soil is light coloured if it has a value of greater than six in the Munsell Soil Colour Chart system (Figure 10.12) (Munsell Colour 2000).

Figure 10.12. Munsel colour chart for 10 YR (Hue) illustrating dark coloured soil (value < 4) and light-coloured soil (value > 6).

WATER TABLE DEPTH (GLEYING)

The Water Table Depth is the current depth (cm) of the water table from the soil surface. A shallow water table indicates that the site is prone to imperfect to very poor drainage and could be flooded for a portion of the year. With a high-water table plants may be subjected to anaerobic conditions within the root zone, or the water level in the soil may reduce the volume of soil material available as growth medium. Plant roots require oxygen. Anaerobic conditions develop when exchange is inadequate, causing roots to lose their ability to absorb nutrients and water and to lack the vigor necessary for new soil exploration. Above ground, photosynthetic rates decline, stomata close, and shoot growth slows. Studies have shown that this deterioration of tree health occurs when root zone oxygen content falls

below 10% (Kozlowski, 1985). As well as having the potential to inhibit tree growth, a shallow water table and saturated soil are prone to deterioration through soil compaction and displacement by machinery traffic.

Figure 10.13 depicts a soil with a water table at a depth of about 80 cm. Notice the build-up of organic matter in the surface horizons.

Studies have shown that ground water table levels rise in response to forest canopy removal (Heikuranen, 1966; Peck and Williamson, 1987). This means that if a site has a pre-harvest water table near the surface it will probably be closer to or at the soil surface subsequent to harvest.

Water tables in Alberta soils are generally highest in the spring (April) and lowest in the fall (late September). This fluctuation is evidenced in the soil profile by colour. Soil horizons that contain yellow, brown and red mottles are subjected to shorter periods of wetting than horizons with grey, green, olive and blue colours (also referred to as gleying), which indicates persistent saturation with water (Strong and Carnell 2000). Figure 10.14 illustrates the reddish colour of mottles in a grey blue matrix of gley. Figure 10.15 illustrates the relationship among soil drainage, seasonal water table, long-term water table, mottles, and gley. The zone of prominent mottles is found between the seasonal water table and the long-term water table while the zone of gley (anaerobic conditions) is found below the long-term water table.

Figure 10.13. Soil profile of a Gleysolic soil illustrating the presence of a water table (From: GDC).

MOTTLES PRESENT

Soil colour can be an indication of depth to water table even if a water table is not present. Soils may be dry when pits are dug (this is certainly the case in Alberta autumn), but the colour of the soil may indicate a higher seasonal water table (New Hampshire Association of Conservation Districts, 2001). The soil matrix colour and soil mottle colour indicate both the depth to the seasonal high water table and the natural soil drainage class. Soil mottles are small splotches of red and/or gray colours within the soil matrix colour (Figure 10.14). Mottles are essentially rust in the soil, and are formed by the same process (iron oxidation) as when a steel or iron tool is exposed to water, and splotches of rust form on it (New Hampshire Association of Conservation Districts, 2001). The wetting and drying process forms rusty gray colours in the soil which are called mottles. Mottles result from the oxidation of iron and other minerals

around oxygen-rich zones in the soil such as root channels or macropores (Bigley and Hull, 2000). The wetting and drying that causes iron oxidation in the soil is a result of seasonal water table fluctuation. It is in this zone of fluctuation that soil mottles are formed. Soil mottles do not occur as individual splotches or variations of colour within a soil layer; there is always more than one splotch.

Figure 10.15 illustrates the relationship among soil drainage, seasonal water table, long-term water table, mottles and gley. The zone of prominent mottles is found between the seasonal water table and the long-term water table while the zone of gley (anaerobic conditions) is found below the long-term water table.

Figure 10.14. Example of grey coloured soil matrix with patches and splotches of mottles (From: New Hampshire Association of Conservation Districts, 2001).

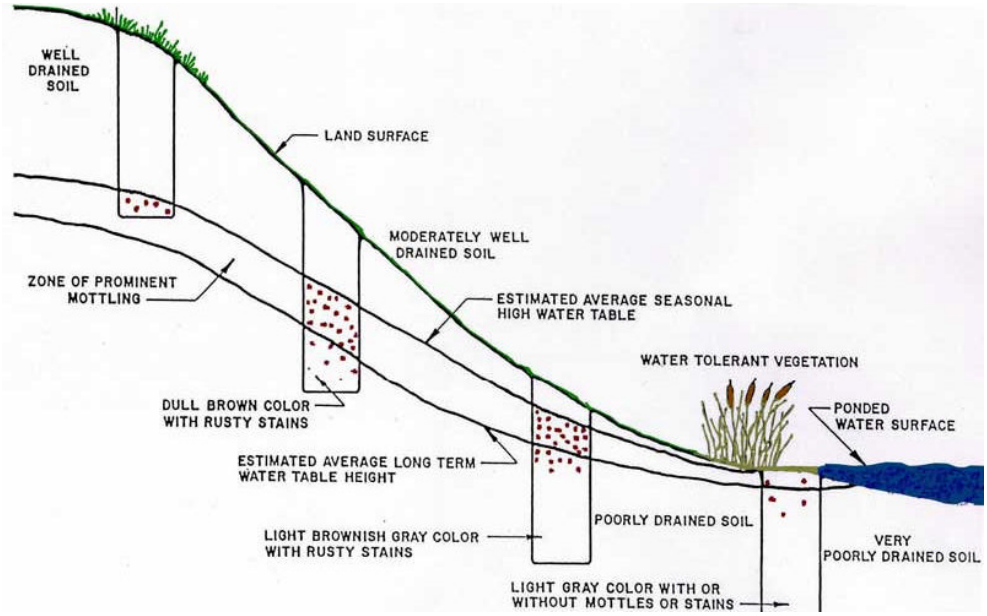


Figure 10.15 Illustration of relationship between soil drainage, seasonal water table, long-term water table, mottles, and gley (From: New Hampshire Association of Conservation Districts, 2001).

SEEPAGE PRESENT/DEPTH

Lower slopes tend to receive water from higher elevation slope positions. This water can come from both surface run off and subsurface discharge or seepage. Seepage waters enhance the moisture status of a site and are commonly laden with nutrients, which will improve a site's nutrient regime. Inorganic nutrients such as calcium, magnesium, and sulfur are frequently found in seepage waters (Borneuf, 1983).

Figure 10.16. Seepage discharge area dominated by a white spruce canopy with a carpet of horsetail (from Toop and Cruz 2002).

If there is a discontinuity in materials (e.g. texture), or a less permeable layer in the soil profile or subsoil, seepage waters may accumulate and flow along this boundary and increase the quantity of seepage waters in the lower slope and discharge areas. Ground water seepage can enhance both moisture and nutrient regimes resulting in considerably better tree growth and ecosystem productivity than upland sites that do not receive nutrient-rich seepage waters.

Dominantly lateral groundwater flow results in moist sites with a moderately enriched assemblage of nutrients, typical of middle to lower topography on gentle slopes. Transient groundwater recharge or seepage may occur after heavy rain or during spring run-off. Humus is well developed in these seepage areas (Toop and Cruz 2002).

Regions of groundwater discharge occur in relatively topographically low areas, particularly in valley bottoms, near rivers, streams, and ponds. Groundwater seepage and high water tables are characteristic of very moist to wet nutrient-rich areas, which result in a diverse shrub and forb layer. Balsam poplar, willow, swamp birch, snowberry, baneberry, dogwood and horsetail (Figure 10.16) are key indicator species of moist to wet, nutrient rich conditions (Toop and Cruz 2002).

FLOODPLAIN (FLOODING HAZARD)

Flooding is the periodic saturation of a site's soil through rising water levels (See also Section 9). It may occur annually or every several years (frequency), and the saturated soil conditions may last for several hours to several weeks (duration). A site on a floodplain that is periodically inundated with flood waters may receive a deposit of nutrient-rich alluvium. Floodplain sites tend to have more available moisture and nutrients than flat sites that do not experience periodic, temporary flooding.

MINERAL SOIL

The Guide defines a mineral soil by the absence of sufficient organic material for it to be an organic soil (see below). Mineral soils tend to be in upland areas or in areas that are subjected to a relatively high intensity and frequency of disturbance. Mineral soils, as their names suggests, are composed of mineral materials and tend to be drier than organic soils. Mineral soils contain less than 17% organic carbon (< 30% organic matter) by weight (Soil Classification Working Group 1998). If the surface organic matter over the mineral materials is mesic or humic and less than 40 cm thick, or if the surface organic matter is fibric and less than 60 cm thick, it is also considered a mineral soil (Figure 10.17).

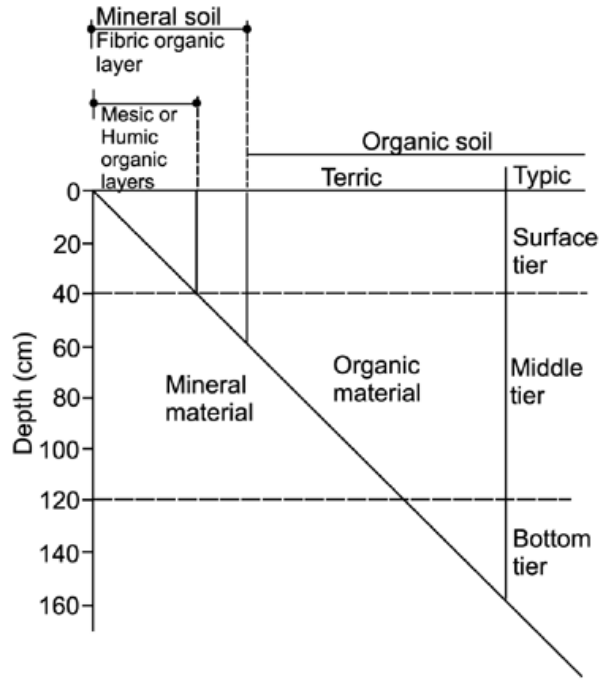


Figure 10.17. Differences between mineral and organic soils (Soil Classification Working Group 1998).

ORGANIC SOIL

By contrast, organic soils are composed largely of organic materials. They include most of the soils commonly known as peat, muck, or bog or fen soils (Soil Classification Working Group 1998). Most organic soils are saturated with water for prolonged periods. They are widespread in poorly and very poorly drained depressions and level areas in regions of subhumid to perhumid climates and are derived from vegetation that grows in such sites (Soil Classification Working Group 1998). Organic soils contain more than 17% organic carbon (30% or more organic matter) by weight and meet the following specifications (Soil Classification Working Group 1998).

For organic materials (O) that are commonly saturated with water and consist mainly of mosses, sedges, or other hydrophytic vegetation, the specifications to be called an organic soil are as follows (from Soil Classification Working Group 1998):

1. If the surface layer consists of fibric organic material with or without mesic or humic Op horizons thinner than 15 cm, the organic material must extend to a depth of at least 60 cm.
2. If the surface layer is mesic or humic, the organic material must extend to a depth of at least 40 cm.
3. If a lithic contact occurs at a depth shallower than 40 cm, the organic material must extend to a depth of at least 10 cm. Mineral material less than 10 cm thick may overlie the lithic contact, but the organic material must be more than twice the thickness of the mineral layer.

4. The organic soil may have a mineral layer thinner than 40 cm on the surface provided that the underlying organic material is at least 40 cm thick.
5. Mineral layers thinner than 40 cm that begin within a depth of 40 cm from the surface may occur within an organic soil. A mineral layer or layers with a combined thickness of less than 40 cm may occur within the upper 80 cm.

For folic materials (L, F, and H) not usually saturated with water there must be

1. Forty centimeters or more of folic materials if directly overlying mineral soil or peat materials.
2. Greater than 10 cm of folic materials if directly overlying a lithic contact or fragmental materials.
3. More than twice the thickness of a mineral soil layer if the mineral layer is less than 20 cm thick.

10.2 MOISTURE AND NUTRIENT REGIME

Moisture and nutrient regime are characteristics of a site that describe the relative availability of moisture and nutrients for plant growth. Their value can be determined by evaluating many of the abiotic constraint variables described in Section 10.1. Moisture and nutrient regime are the result of the interaction of various groups of variables or different magnitudes of the same variables to provide the same net ecological function (Beckingham et al. 1996).

10.2.1 MOISTURE REGIME

Moisture regime represents the available moisture supply for plant growth on a relative scale. It is assessed through an integration of plant species composition and abundance as well as soil and site characteristics (Beckingham and Archibald 1996). Moisture regime ranges from very xeric (1) to hydric (9) (Table 10.3). Moisture regime can be determined in the field with assistance of an ecosite classification field guide (e.g. Beckingham and Archibald 1996; Beckingham et al. 1996) or the *Ecological Land Survey Site Description Manual* (Alberta Environmental Protection 1996).

Ecological moisture regime integrates many interrelated environmental and biotic factors, which in combination determine the actual amount of moisture available to plants on a relative scale (Alberta Environmental Protection, 1996). To determine moisture regime, it is important to integrate the following: topographic position, slope gradient, soil drainage, depth of organic matter, soil texture, coarse fragments, soil depth, water table depth, depth of mottles, and presence of seepage.

Table 10.2. Moisture Regime and identifying characteristics (Beckingham et al. 1996).

Moisture regime	Description	Primary water source	Topographic position	Effective texture	Soil drainage	Depth to impermeable layer	Surface organic thickness	Slope gradient
Very xeric (1)	Water removed extremely rapidly in relation to supply; soil is moist for a negligible time after precipitation	Precipitation	Ridge, crest, shedding	Very coarse (gravel-S); abundant coarse fragments (>50%)	Very rapid	Very shallow (<0.5 m)	Very shallow (<3 cm)	Very steep (>70%)
Xeric (2)	Water removed very rapidly in relation to supply; soil is moist for brief periods following precipitation	Precipitation	Ridge, crest, shedding		Very rapid to rapid	Very shallow (<0.5 m)	Very shallow (<3 cm)	Very steep (>70%)
Subxeric (3)	Water removed rapidly in relation to supply; soil is moist for short periods following precipitation	Precipitation	Upper slopes shedding	Coarse to moderately coarse (LS-SL); moderate coarse fragments	Rapid	Shallow (<1.0 m)	Shallow (3–5 cm)	Steep (31–70%)
Submesic (4)	Water removed readily in relation to supply; water available for moderately short periods following precipitation	Precipitation	Upper slopes shedding		Rapid to well	Shallow (<1.0 m)	Moderately shallow (6–9 cm)	Steep (31–70%)
Mesic (5)	Water removed somewhat slowly in relation to supply; soil may remain moist for significant but sometimes short periods of the year; available soil water reflects climatic input	Precipitation in moderate to fine-textured soils and limited seepage in coarse-textured soils	Midslope rolling to flat	Medium (SiL-L) to fine (SCL-C); few coarse fragments	Well to moderately well	Moderately deep (1–2 m)	Moderately deep (10–15 cm)	Slight to Moderate (2–30%)
Subhygric (6)	Water removed slowly enough to keep the soil wet for a significant part of the growing season; some temporary seepage and possible mottling below 20 cm	Precipitation and seepage	Lower slopes receiving	Variable depending on seepage	Moderately well to imperfect	Deep (>2 m)	Moderately deep to deep (10–40 cm)	Slight (2–9%)
Hygric (7)	Water removed slowly enough to keep the soil wet for most of the growing season; permanent seepage and mottling present; possibly weak gleying	Seepage	Lower slopes receiving	Variable depending on seepage	Imperfect to poor	Variable	Deep (16–40 cm)	Slight (2–9%)
Subhydric (8)	Water removed slowly enough to keep the water table at or near the surface for most of the year; organic and gleyed mineral soils; permanent seepage less than 30 cm below the surface	Seepage or permanent water table	Depressions and level receiving	Variable depending on seepage	Poor to very poor	Variable	Very deep (>40 cm)	Slight (2–9%)
Hydric (9)	Water removed so slowly that the water table is at or above the soil surface all year; organic and gleyed mineral soils	Permanent water table	Depressions and level receiving	Variable depending on seepage	Very poor	Variable	Very deep (>40 cm)	Flat (<2%)

10.2.2 NUTRIENT REGIME

Nutrient regime is an index of the relative amount of essential nutrients that are available for plant growth. The determination of nutrient regime requires the integration of many environmental and biotic parameters. Soil nutrient regime occurs on a relative scale ranging from very poor (A) to very rich (E). Nutrient regime can be determined in the field with assistance of an ecosite classification field guide (e.g. Beckingham and Archibald, 1996; Beckingham et al., 1996) or the *Ecological Land Survey Site Description Manual* (Alberta Environmental Protection, 1996).

Ecological nutrient regime integrates many interrelated environmental and biotic factors, which in combination determine the actual quantity of nutrients available to plants on a relative scale (Alberta Environmental Protection, 1996). To determine nutrient regime it is important to integrate the following: soil texture, soil coarse fragment content, soil depth, humus form, presence of Ah horizon, presence of Ae horizon, soil pH, depth to carbonates, and presence of nutrient rich seepage waters. Figure 10.18 provides a summary of some of the variables that influence the availability of nutrients for plant growth.

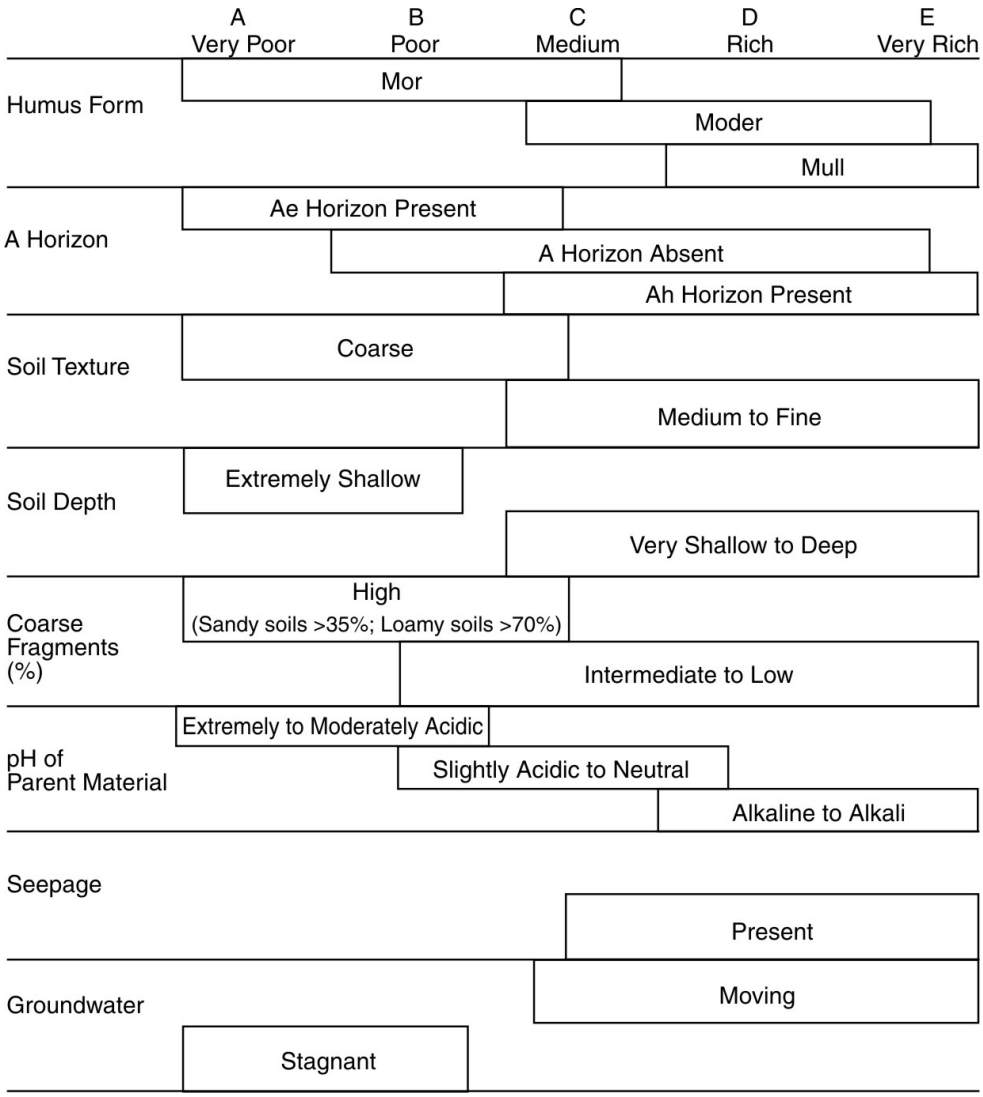


Figure 10.18. Nutrient regime characteristics (From Beckingham et al. 1996).

10.2.3 EDATOPE

An edatope is a soil moisture/nutrient grid that displays the potential ranges of combinations of moisture regime and nutrient regime (Beckingham and Archibald, 1996). Each location on the edatope defines a specific combination of soil moisture and nutrient conditions. Figure 10.19 depicts an edatope with the location of ecosites from the central mixedwood region of northern Alberta. The edatope presented in Figure 10.20 is slightly different than the northern Alberta ecosite classification edatope. It is used throughout the Silviculture Guide to present information about the distribution, adaptation, productivity, and potential deployment of plant species relative to moisture and nutrient regime.

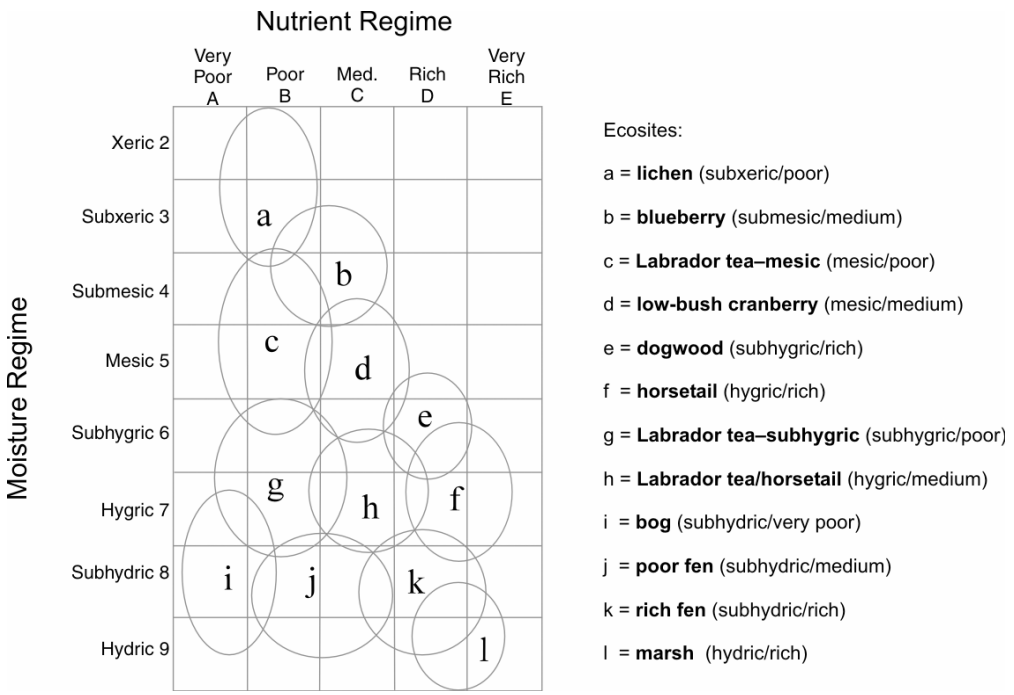


Figure 10.19. Edatope illustrating the moisture and nutrient conditions of ecosites from northern Alberta.

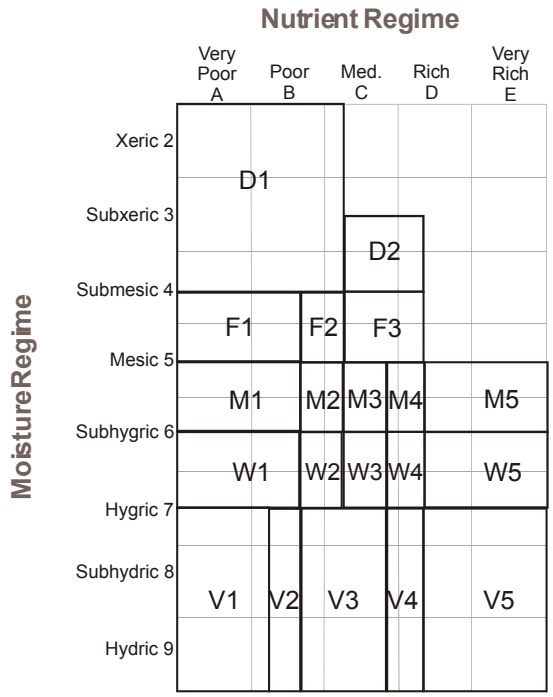


Figure 10.20. Edatope used in the Alberta Silviculture Guide. (D=dry; F=fresh; M=moist; W=wet; V=very wet).

10.3 THE SEVEN ABIOTIC LIMITING FACTORS

This section describes the seven abiotic limiting factors that can limit or inhibit the establishment, growth and development of forest ecosystems. The limiting factors are assessed by identifying the abiotic constraint variables that are present on a site (see Section 10.1). The seven abiotic limiting factors are:

1. Moisture Regime (MR) low (xeric to sub-mesic)
2. Moisture Regime high (sub-hygric to hydric)
3. Nutrient Regime (NR) low (very poor to medium)
4. Cold soil
5. Frost Pocket
6. Frost Heave
7. Winter Injury

The Abiotic Constraint Diagnostic Table (Table 10.3) utilizes the factors described above in section 10.1 and 10.2 to diagnose the presence and potential severity of the seven limiting factors. The diagnostic table is a simplification of the Abiotic Constraint Diagnostic Tool that was included with version one of the guide.

MOISTURE REGIME LOW LIMITING FACTOR

Moisture regime low limiting factor identifies moisture regimes that are potentially limiting to the establishment, growth, and development of forest ecosystems because of a lack of moisture. It primarily diagnoses sites that are submesic and drier with severity of the limitation increasing as moisture regimes become drier. See Section 10.1 and 10.2 for a description of abiotic constraint variables and moisture regime, respectively.

MOISTURE REGIME HIGH LIMITING FACTOR

Moisture regime high limiting factor identifies moisture regimes that are potentially limiting to the establishment, growth, and development of forest ecosystems because of excess moisture. It primarily diagnoses sites that are subhygric and wetter with severity of the limitation increasing as moisture regimes become wetter. See Section 10.1 and 10.2 for a description of abiotic constraint variables and moisture regime, respectively.

NUTRIENT REGIME LOW LIMITING FACTOR

The nutrient regime low limiting factor identifies nutrient regimes that are potentially limiting to the establishment, growth, and development of forest ecosystems. It tends to diagnose sites that are nutrient poor and very poor. See Section 10.1 and 10.2 for a description of abiotic constraint variables and nutrient regime, respectively.

COLD SOIL LIMITING FACTOR

Heat is both absorbed at and lost from the surface of the soil. Temperature at the surface can change in daily cycles. The soil transmits heat downward when the temperature near the surface is higher than the temperature below and heat upward when the temperature is warmer within the soil than at the surface (Soil Survey Division Staff 1993). Soil temperatures at various depths within the soil follow cycles. The cycles deeper in the soil lag behind those near the surface (Soil Survey Division Staff 1993). The amplitude and depth of temperature cycles will be depressed the deeper the organic matter is on the soil surface. Mean annual temperature is one of several useful values that describe the temperature regime of a soil. Variables such as the presence of cold air drainage, low evapo-transpiration, the presence of permafrost, and high water tables are related to and diagnostic of cold soil temperatures.

Respiration, as a controlled and multiple-stepped combustion of carbohydrates, provides energy for various cellular activities, as well as carbon skeletons for biosyntheses of functional and structural substances (Huang et al. 2005). In roots, respiratory energy is used for nutrient uptake, growth and maintenance, and symbiotic processes and defense (Martinez et al. 2002). Cold soils limit the respiration rate in roots and reduce the amount of energy available for nutrient uptake, root growth, and root maintenance, as well as for symbiotic processes and defense. Respiration of young roots is much higher

and much more sensitive to temperature than old roots (Desrochers et al. 2002). This means that tree seedlings may be particularly sensitive to cold soils.

The cold soil limiting factor identifies soil temperature profiles that are potentially limiting to the establishment, growth, and development of forest ecosystems. See Section 10.1 for a description of abiotic constraint variables.

FROST POCKET LIMITING FACTOR

The frost pocket limiting factor identifies areas where frost and cold air temperatures are potentially limiting to the establishment, growth, and development of forest ecosystems. Section 10.1 describes cold air drainage and the formation of frost pockets.

FROST HEAVE LIMITING FACTOR

Soil frost heaving is the result of the formation of ice lenses in the soil caused by a segregation of the soil water. Ice lenses grow by drawing in liquid water from the unfrozen soils from below. Frost heave hazard is the risk of newly planted trees being forced out or partly out of the soil as ice lens formation causes an uplift of the surface soil. Frost heaving may greatly reduce growth and survival of forest tree seedlings, particularly in regions where freezing and thawing are accompanied by high soil moisture regimes (Goulet 1994).

The most susceptible soils are those with intermediate permeability and water tension (Heidmann 1976). Sandy soils are very permeable but exhibit low tension due to larger air spaces between particles. Conversely, clay soils exhibit high tension but low permeability (Racey et al. 1989). Fine-textured surface horizons with a high silt content and imperfect drainage are especially susceptible. Topographic position can be an important determinant of frost heave susceptibility, with depressions being most susceptible (Corns and Annas 1986).

A few methods, such as fertilizing, choice of planting spots, sowing or planting at the proper time, shading, and use of mulches appear to be effective in controlling frost heaving (Goulet, 1994). Resistance to frost heaving increases with seedling size, as the ability of a seedling to anchor itself increases (Goulet, 1994). Frost heave hazard may be reduced by maintaining brush and ground cover, or an intact organic layer around tree seedlings (Singh 1976, Comeau et al. 1982, Corns and Annas 1986, Goulet 1994).

The frost heave limiting factor identifies soil conditions that are potentially limiting to the establishment of trees by planting. See Section 10.1 for a description of abiotic constraint variables.

Table 10.3. Abiotic Constraint Diagnostic Table.

	MR low	MR high	NR low	Cold soil	Frost pockets	Frost heave hazard	Winter Injury
Coarse Fragments >50%	++	--	+++			--	
Coarse Fragments 20 to 50%	-	-	++				
Cold Air Drainage-Yes	-			++	+++	+	++
Depth to Calcareous Zone (< 15 cm)			++				
Depth to Calcareous Zone (< 15 to 50 cm)			+				
Evapotranspiration Potential-High	+	--		--		--	++
Evapotranspiration Potential-Low	-	+		++	++	+	
Extent of temporary standing water hazard >15%	---	+++					
Extent of temporary standing water hazard 5-15%	--	++					
Insulating surface organic layer	-			+++			
Mottles Present (< 30 cm)	--	+++				+	
Mottles Present (30 to 60 cm)	-	+				+	
Permafrost-Yes	-	+++	+++	++++	++	+++	
pH < 5			++				
pH 5 to 6			+				
Position-DEPRESSION	-	++		++	+++	+	--
Position-LOWER or TOE	-	++	--	++	+		
Position-RIDGE CREST or UPPER	-	--	++	-	---	--	+++
Root Restricting Layer or Bedrock (< 30 cm)	-	++	+++				
Root Restricting Layer or Bedrock (30 to 40 cm)	-	+	++				
Seepage Not Present		-					
Seepage Present	--	+++	--			++	
Slope Gradient (> 35%)	++	--		-	--	--	
Slope Gradient (15 to 35%)	+	-		-	-	-	
Soil Effective Texture-Coarse (S, LS)	++	--	+++			---	
Soil Effective Texture-Fine (SiCL,CL,SC,SiC,C,hC)	-	++	--			+	
Soil Effective Texture-Silty (SiL,Si)			-			+++	
Water Table Depth < 30 cm or Gleying < 15 cm	---	++++		++		++	
Water Table Depth > 30 cm or Gleying 15 to 30 cm	--	+++		-		+	
Winter Desiccation Hazard-Yes							++++

Positive indicators (+) and negative indicators (-) are shown. Magnitude of indication is derived from the Abiotic Constraint Diagnostic Tool provided with version one of the Guide.

Note: it is possible for a site to contain both positive and negative diagnostic indicators or no indicators at all. The table is a support tool and does not replace professional judgement.

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