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Site Preparation for Restoring Forest Cover on Oil and Gas Sites

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Canada

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Preface

Silviculture is the practice of controlling the establishment, growth, composition, health and quality of forests at the stand level to meet diverse needs and values. Silvicultural practices can have a strong and beneficial impact on reclaiming areas associated with in situ extraction of oil and gas resources.

Site preparation, forest regeneration and vegetation management are all important aspects of silviculture and reclamation. Multiple techniques and practices can optimize the success of reclamation, which depends on many factors, including the physical, chemical and biological properties of the site.

Some of the great wealth of silviculture knowledge traditionally used by the forest industry will be explained in a series of guidebooks, fact sheets and videos.

This guidebook explains site preparation techniques. The Natural Resources Canada Canadian Forest Service (NRCan-CFS) developed this guidebook to help with the successful restoration of disturbed in situ sites.

Disclaimer: This guidebook provides only advice on best practices. We urge the reader to confirm regulatory compliance before choosing the best technique or tool.

Multiple techniques and practices can optimize the success of reclamation, which depends on many factors . . .

1. Introduction

What is site preparation and why do we use it?

Site preparation – also referred to as surface preparation – aims to create suitable growing conditions on disturbed sites to promote the establishment and growth of forest vegetation. Most sites that have experienced industrial disturbance require site preparation for successful re-establishment of desired forest vegetation.

Conditions that hinder vegetation survival and growth, either through lack or excess of some element or factor, are called growth limiting factors. All plants require light, air, water, and nutrients to grow and survive. However, plants will grow best in conditions that meet their growing requirements, which can vary by species. Lack or excess of any of the required growing conditions can significantly reduce the growth of targeted vegetation and can lead to establishment failure.

Site preparation is used to overcome limiting factors by improving soil temperature, nutrient availability, soil drainage, and aeration, and by reducing competition. It leads to enhanced survival and growth of target species. Depending on the site and respective treatment objectives, site preparation is used to:

- **create suitable planting or growth microsites** (e.g. by exposing mineral soil)
- **enhance the physical properties of the surface soil** (e.g. by reducing compaction and improving soil porosity)

Site preparation typically involves manipulating one of the following: surface soil, woody material (e.g. coarse woody debris), organic material or nutrients. This is accomplished by using a variety of methods and equipment and occurs prior to revegetation. Techniques used will vary among sites depending on the reclamation objectives for land uses (e.g. planting, seeding or natural regeneration), target species and growth goals.

Site preparation is commonly used to create suitable microsites for planting or plant growth, reduce soil compaction, decrease water run-off and erosion, and reduce vegetative competition of undesirable species. Site preparation is not necessarily required on all sites and may not be beneficial on minimally disturbed sites because these sites often have topsoil in place with intact seed banks and vegetative propagules needed for revegetation. Generally speaking, treatment objectives for northern sites target techniques that improve drainage and increase soil temperature, such as creating mounds. For dry sites, on the other hand, techniques to improve access to water are deployed, such as creating depressions.

Site preparation is used to overcome limiting factors by improving soil temperature, nutrient availability, soil drainage, and aeration, and by reducing competition.

The following techniques for site preparation are discussed in detail in this guidebook:

- decompaction
- soil stripping
- mounding
- scalping
- scarification
- mixing
- disc trenching
- plowing

2. Treatment options

Site preparation modifies the site to overcome limiting factors and creates favourable conditions for seedlings and suitable germination spots for seeds. Plants need adequate but not excessive moisture and oxygen in the rooting zone, sufficient light for their physiology, and nutrients for optimum growth. These factors can be manipulated through site treatments.

Site preparation involves physically altering slash, duff and soil layers through methods such as scalping, trenching, plowing, mixing and mounding. These terms are explained below. Soils may also be modified by adding organic matter and nutrients.

Site conditions can often vary over a small geographic area (even within one disturbed site such as an oil sands exploration site). To obtain the best result, the site preparation method must be matched to these variable conditions (see *Site Assessment for Restoring Forest Cover on Oil and Gas Sites* [to be published soon]).

Before selecting the most suitable treatment or equipment, it is important to assess the main characteristics of the site, including the water regime, soil texture, slope, slash conditions and potential competitive species. It is important to consider these site characteristics as well as the desired post-treatment site conditions and microsites when choosing the treatment. In many cases, limiting factors can be predicted by using ecosite classifications.

It is important to consider the time of year when planning for mechanical site preparation. This is especially important for northern climates where the ground is frozen for the majority of the year. Some machines can operate in both unfrozen and frozen soil conditions while others cannot.

Regardless of when mechanical site preparation takes place, it is important that the majority of planting is done following treatment to reduce the effects of vegetative competition.

Black spruce is planted in the winter occasionally, but only under specific circumstances (e.g. directly after the ground is treated and before it freezes again). The success and survival rate of winter planting is somewhat lower than regular spring or summer planting. For more information on planting, see *Regeneration Techniques for Restoring Forest Cover on Oil and Gas Sites*.

Directly following site preparation treatments, an assessment should be carried out to determine whether the treatment objectives have been met. Objectives will vary depending on the site conditions and treatment type. It is important to conduct these assessments to ensure that enough suitable planting microsites have been created and that they are in a suitable condition for the successful regeneration of the desired plant assemblages.

2.1 Decompaction

Decompaction is an important step in which compacted soils are fractured and loosened to improve the soil's physical properties. This process increases soil porosity and aeration so that plant root systems can extend and develop. Equipment such as ripper shanks, winged subsoilers and excavators can be used to decompact soil.

Compaction created by industrial development or by incorrect timing of reclamation or site preparation efforts reduce the porosity of soil and alter the soil structure. These changes reduce the hydrologic functions of the soil.

Soil compaction that is 10 to 20 centimetres (cm) below the surface does not recover naturally, and therefore requires treatment. Even light machine traffic can hinder the hydrologic functions of the soil, which are unlikely to be restored by natural processes (such as the freeze-thaw cycle), especially in a relatively short period.

Mineral soils rich in silt and clay are prone to soil compaction, as are wet soils. Organic soils and soils that have coarser textures (high percentage of sand) are less affected. The type of equipment that was used, the timing of use and the frequency also have significant effects on soil compaction. Heavy equipment is more likely to cause damage than light equipment, and in general, wheeled equipment can cause greater ground pressure than tracked machines. Machine traffic on frozen ground has less impact on soil compaction.

Decompaction aims to restore productivity to degraded soils and occurs either as part of ongoing field operations or as treatment for high-priority sites that were degraded in the past. Soil decompaction restores macropores in soils and reduces soil strength. An appropriate tillage depth is similar to the rooting depth of trees growing on undisturbed sites in the vicinity.

Extremely compacted old roads may require deeper decompaction than less compacted areas. Non-native competitive vegetation will often readily colonize recently treated soils. Therefore a vegetation management plan is a necessary feature of all site preparation activities.

2.1.1 Winged subsoiler technique

How it works

The winged subsoiler represents a class of tillage implements specifically developed to deep plow compacted soils without inverting the topsoil. These implements are effective across a wide range of soil moisture regimes and clay content. This treatment creates large voids, which allow the freeze-thaw cycle to penetrate deeply into the soil profile and improve the hydrological function of the soil. Over time, freezing and thawing loosens the soil to considerable depths as the water in the soil changes from frozen to liquid and vice versa.

Key considerations

Plowing at depths greater than 60 cm provides the best improvement to the hydrological function of the soil and the largest decrease in soil bulk density. Shallower

Figure 1. Winged subsoiler

Figure 2. Overlapping passes with a pair of winged subsoilers: (a) first pass, (b) second overlapping pass

(a) (b)

plowing depths (less than 60 cm) create less desirable furrows composed of a mix of subsoil and top-soil (where present), which may also accelerate the closure of adjacent furrows.

It is recommended to travel in parallel straight lines with a winged subsoiler with overlapping passes between the furrows to maximize the tillage surface per site (Figure 2). The speed of plowing should not exceed 3 kilometres per hour (km/hr).

Whenever possible, avoid treating soils that have a high moisture content because this will form tunnels under the surface and cause little to no real fracturing of soil clods.

Surface soils that are extremely dry and compacted (e.g. old roads) may require lowering the body of the plow below the surface of the soil. This method avoids damaging the equipment and allows the winged subsoiler to access deeper layers. Otherwise, a first treatment using ripper shanks (described below) may be necessary to allow the winged subsoiler to access the deeper layers of the soil that are easier to fracture. Extremely compacted soils may require large and more powerful crawler tractors (e.g. larger than a D7).

2.1.2 Straight ripper shank technique

How it works

The straight ripper shank technique is often used in reclamation and uses a readily available tool that can attach to a wide range of crawler tractors (Figure 3). Ripping is usually carried out with one or two vertically mounted shanks.

Figure 3. Straight ripper shank in the outside pockets of a multi-shank toolbar

Key considerations
This technique is most effective when the soil is dry and the clay content is low.

Where soils are highly compacted, cross-ripping with the straight ripper shank technique is recommended to further fracture hardened soil clods.

2.1.3 Standard mounding technique

How it works
Decompaction can also be accomplished with a standard mounding technique in which soil is scooped from the hole and placed on the ground beside it. This is done with an excavator that has a digging bucket or mounding rake mounted on it.

Figure 4. Standard mounds

Key considerations
It is recommended to let the mounds settle during the winter to reduce the number of air pockets in the soil.

Mounds should be planted during the following growing season.

The standard mounding technique can be used in frozen or unfrozen conditions. It is recommended to shatter the scooped soil to accelerate decompaction (Figure 4).

2.1.4 Rough and loose mounding

How it works

Rough and loose mounding is a variation of the standard mounding approach and uses the same equipment. The primary distinction is how the scooped soil is handled. The scooped soil is placed partially in the excavated hole and partially on the adjacent soil surface. The effect of this approach is a highly heterogeneous soil surface that is visually more similar to the winged subsoilers than the standard mounding (Figure 5).

Key considerations

The rough and loose mounding technique can be used in frozen or unfrozen conditions (Table 1).

It is comparatively slower than other techniques that use shanks and dozers. However, the availability of equipment or site accessibility can make this a good option.

Table 1. Soil decompaction options

Soil conditions			
Tool / technique			Type of operation
	Frozen	Unfrozen	
Winged subsoiler	✘[1]	✔	Straight lapping passes
Straight ripper shank	✔[2]	✔	Lapping passes or cross-ripping
Standard mounding	✔[3]	✔	Soil is placed adjacent to the hole
Rough and loose mounding	✔[3]	✔	Soil is placed partially in the hole

Notes:

[1] Winged subsoilers are effective under partially frozen conditions (less than 15 cm of surface frost).

[2] This tool is most effective when the soil is dry and has a low clay content.

[3] Equipment operation becomes difficult under wet conditions.

Figure 5. Rough and loose mounding

2.2 Soil stripping (soil salvage)

Soil stripping, also known as soil salvage, is carried out to conserve topsoil (and in some cases subsoil) for future reclamation activities on land that is scheduled for disturbance.

Before the soil is disturbed, it is important to determine the type, extent, depth, location and quality of soils in the area (see *Site Assessment of Oil and Gas Sites for Return to Forest Cover*).

This information helps determine whether the soil is suitable for salvage and how much should be, or can be, salvaged effectively. If soil salvage is appropriate for a site, the soil is removed or stripped and stockpiled for later use. If different soil types are salvaged, they are stockpiled separately. After industrial activities have been completed, the surface of the site is graded to the original contours. The topsoil is placed on the graded surface (or replaced subsoil, where applicable) to provide a suitable growth medium.

The type of surface soil must be considered when determining salvage depths, timing and equipment. Surface soil can be divided into three categories: upland surface soil, shallow organics and deep organics.

Upland surface soil consists of the L, F and H organic horizons and the underlying A mineral, also known as LFH mineral mix. Upland surface soil is the most valuable reclamation material available for use as cover soil. It provides an important and unique source of organic matter, plant nutrients, woody debris, soil microbes and bacteria. It is essential to the maintenance of nutrient cycles and for sustaining healthy, productive forests.

If upland surface soil is removed and stored carefully and returned to the site in a timely manner, it can also provide seeds, plant propagules and soil biota to the site.

There is much less surface soil than peat-mineral mixes in many areas of the boreal forest. Therefore, efforts to salvage surface soil should be maximized in areas that are rich in surface soils to ensure that there is adequate soil volume available. If removed materials can be stored in close proximity to the edge of a disturbed area, it eliminates the need for full site disturbance during final reclamation.

Key considerations

Despite its widespread use, soil stripping can have negative consequences for the regeneration potential of a site. Soil stripping disturbs root systems and limits the potential for vegetative reproduction, such as aspen suckering. The length of time from disturbance to reclamation is also a major factor: the longer a site is disturbed, the smaller the chances of vegetative reproduction.

Soil stripping may also slow natural revegetation processes for certain species and increase the risk of soil degradation, whereas treatments that do not strip the soil do not cause these problems.

Mixing upland surface soil with other reclamation materials during salvage should be avoided to ensure that segregated materials are available for direct placement opportunities. The most effective way to prevent mixing reclamation materials during salvage is to segregate different reclamation materials. Surface soils with an abundant seed bank of competitive species may negatively affect reclamation progress and increase operational costs.

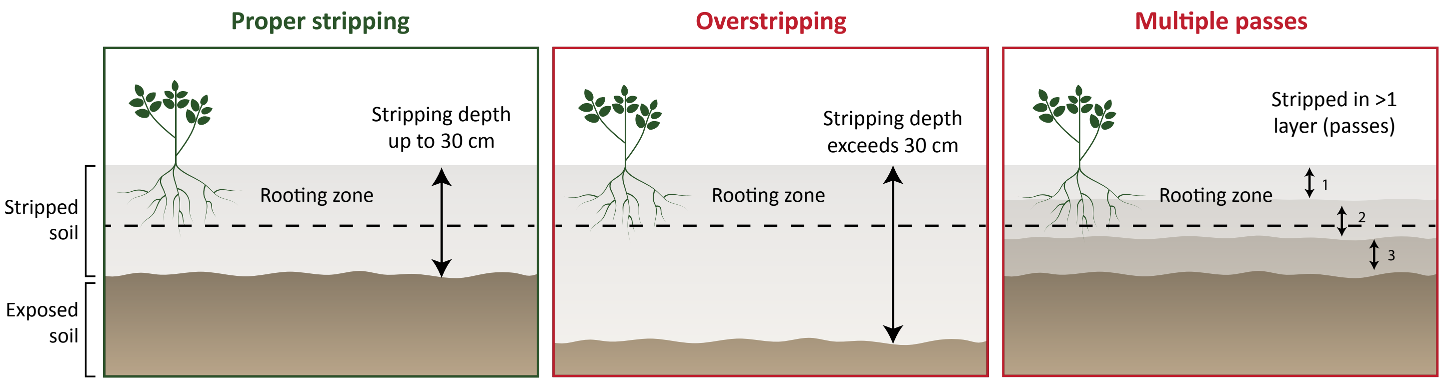
Stockpiling topsoil in large piles for more than eight months can reduce seed and root viability and also negatively affect chemical, biological and physical properties of the soil.

In general, when reclamation will take place shortly after the disturbance, the operational plan should be to avoid soil stripping as much as possible. However, if soil stripping is necessary, operators should decide on the appropriate or optimal approach.

In most cases, one single, larger pass is better at providing the best conservation of propagules. However, in certain cases, making multiple shallow stripping passes is the appropriate way (Figure 6).

Overstripping is a common risk and should be avoided. The assessment done of the site before it is disturbed will inform the decisions about stripping. The quantity of soil

Figure 6. Proper stripping techniques



collected with the root zone should be sufficient to bury most roots in the spoil pile and reduce exposure of the roots to the elements.

Surface layers, including woody debris, the root zone and upper subsoils should be stored in separate stockpiles to avoid mixing of these layers. Excessive mixing of the surface layers can influence the soils suitability for supporting seedling growth. Replacing surface layers from a single mixed pile of soil results in a greater amount of woody debris mixed into the mineral soil layer. This combination tends to form an undesirable mix in which naturally occurring tree seedlings would be exposed to greater risks of drought and dislodgement from the soil.

Although the practice of placing strippings in a single pile may be attractive because it is an efficient use of space, it is not recommended because of the negative effects on both naturally occurring and planted trees.

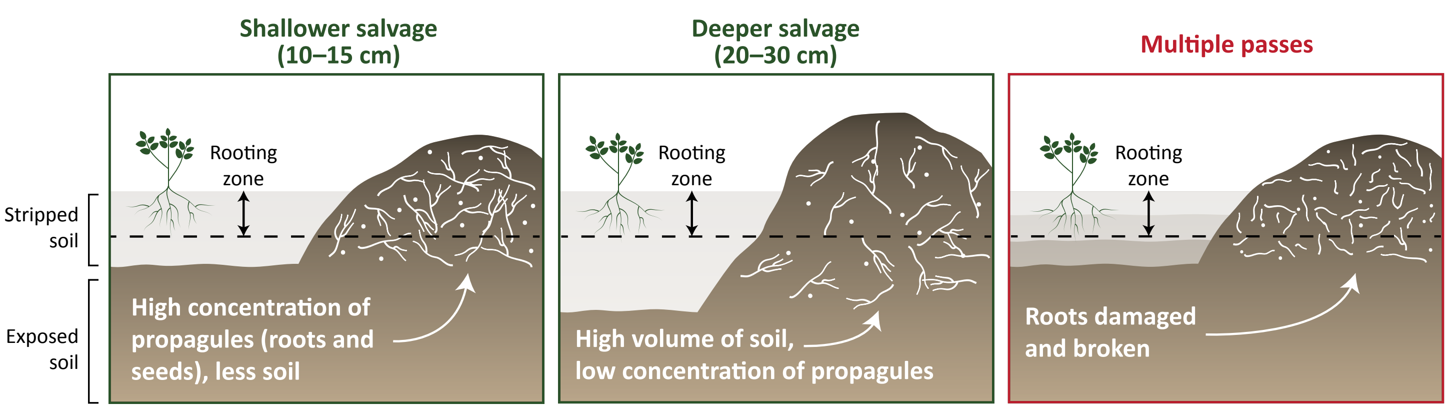
Salvage depth is important because it affects the physical, chemical and biological properties of the surface soil (Figure 7). Using a single prescribed salvage depth for all soil types may not optimize the potential of salvaged surface soil.

For example, salvaging surface soil to greater depths (20 to 30 cm) increases the volume of material available for reclamation. Unfortunately, the increased depth limits the soil's suitability as a propagule source for revegetation and may reduce its organic matter content.

Salvaging shallower depths of surface soils (10 to 15 cm) generally increases the proportion of viable propagules in these materials, but reduces the volume recovered for reclamation use.

These examples demonstrate different approaches for managing and using salvaged surface soil. For upland surface soil, operators generally salvage the entire LFH horizon and A mineral horizon. However, the optimal salvage depth affects soil quality and how different types of soils and ecosites affect plant establishment.

Figure 7. Proper salvage depth



Equipment considerations
Surface soils are typically salvaged by using excavators and crawler tractors. Excavators strip surface soil by using the bucket to lift the soil and place it into a windrow or pile. Scrapers are used on larger sites. Crawler tractors strip soil with the blade during single or multiple passes and push the soil into a pile or windrow.

Salvage equipment should be chosen carefully to enable accurate stripping of soil layers while also adjusting to changes in the depth of the surface soil.

Using an excavator for surface soil salvage instead of a crawler tractor minimizes the destruction of roots found within the surface soil-subsoil interface. These roots are often destroyed by the blade on the equipment during salvage and when they are exposed to freezing and desiccation.

Salvaging surface soil with a soil scraper often results in uneven stripping and admixing, especially on uneven sites. It is difficult to adjust the equipment position and cut depth to accommodate on-site variations in salvage depth.

Salvaging deep organics only occurs during winter months because of trafficability issues. Excavators salvage deep organic soils and peat mineral mixes. Mulchers, rototillers and rotovators in combination with crawler tractors, bobcats and excavators salvage the upper 10 to 30 cm of organic soils for use as a propagule source.

For larger projects, mulchers are more effective at salvaging donor material.

Salvage timing considerations
The best time to salvage surface soil is when propagules are dormant to reduce the loss of propagule viability. For example, on exploration sites, do not strip too far in advance of drilling).

Salvaging surface soil when the ground is frozen improves trafficability and reduces the potential for compaction. Winter salvage increases the risk of mixing if there is deep frost and soil comes out in lumps that contain surface soil and subsoil.

The time of year that salvage activities occur affects the amount of damage to vegetative propagules. Plants that reproduce asexually are least likely to be damaged during fall and winter operations because they are dormant, and the carbohydrate reserves in their root systems are highest. Most boreal plants have seeds that ripen in late summer or early fall, and salvaging surface soil after seeds have ripened increases the pool of viable seeds.

Salvage should be restricted or suspended in adverse ground conditions or while prevailing weather conditions create an increased risk of soil loss, mixing or degradation.

For example, salvaging surface soil on large sites in windy conditions exposes the soil to wind erosion. Salvaging during wet conditions increases the risk of compaction, admixing, water erosion and degradation of the soil structure. Placing wet surface soil into stockpiles further degrades the viability of propagules and the quality of surface soil.

2.3 Mounding

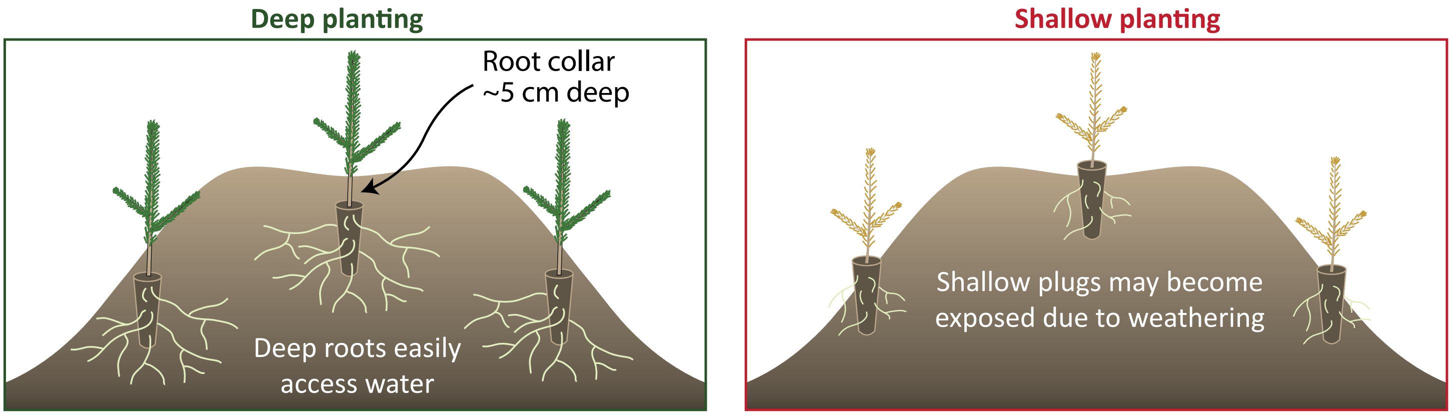
Mounding is the mechanical creation of a discrete, raised planting spot or microsite similar to what exists naturally (pit and mound microtopography) in natural forest sites.

When correctly prescribed, mounding can create planting spots that favour seedling establishment. Mounding is often applied in the boreal and subboreal forests of Canada because it is particularly suited to the wet and cool areas that often characterize the sites of in situ oil sands operations.

Mounding treatments typically disturb about 10 to 30% of the ground surface area. Consequently, they may be a good compromise between minimal disturbance and high disturbance treatments.

Raised planting spots are usually good growing sites for seedlings, especially in cold, moist climates. Mounding helps increase soil and air temperature, creates loose and oxygen-rich mineral soil, and increases drainage, all of which promote favourable early root growth and seedling establishment.

Figure 8. Deep planting on mineral soil mounds



Note: Planting location (top or side of mounds) depends on the site.

Mounds can also help control competing vegetation, retain nutrients in surface organic layers, increase light availability to the seedlings, and reduce the hazard of snow press and frost damage. Although all types of raised planting spots enhance soil temperature and aeration, their effectiveness in providing adequate soil water, nutrients, vegetation control and light varies with the site.

Key considerations

The ideal size, shape and makeup of mounds varies with local site and soil conditions and with the machinery and techniques used to create them. Two of the most important features are the amount and distribution of organic matter within the mound and the depth of the mineral soil capping.

On heavy, clay soils, mounds require only 10 to 15 cm of mineral soil capping. However, on wet soils with thick forest floor (LFH), mounds can be as large as required to elevate the seedling root system above restrictively high water tables. In most cases, mounds should not exceed 20 to 30 cm in height after settling.

Mineral mounds should not be built higher than 40 cm nor be higher than 20 to 30 cm after settling. Organic mounds can be 1 to 1.5 metres high when created because they will be about 40 cm when settled.

Bigger mounds are being experimented with in some restoration applications, and results indicate that large mounds can be successful.

Mounds must be wide enough to control competing vegetation. In all cases, mounds should be formed with flat to concave tops and gently sloping sides and should have good contact with the humus or soil layers below. Concave tops are especially important on sites subject to seasonal drying because they help collect rainwater and prevent the mound from drying out.

Deep planting almost always applies when planting on mounds. For deep planting, the seedling is planted with the root collar (i.e. top of the plug) buried about 5 cm in mineral soil or humus. Deep planting also protects roots from being exposed because of weathering of the mound surface after planting (Figure 8).

Mounding is not recommended in drought-prone locations because seedlings may experience moisture stress when elevated planting spots desiccate during dry periods. If mounding is used in drought-prone locations, consider spot selection to ensure mounds are established in areas with greater moisture availability.

Seedlings should be planted deep enough to ensure that the roots have access to a continuous supply of soil moisture at the base of the elevated planting spot.

Inappropriate mounding or improper (shallow) planting can make seedlings vulnerable to drought and can also increase the risk of frost heaving in finer-textured soils (high clay and silt percentage). For instance, loose mounds can be full of air pockets, and cone-shaped mounds can be prone to rapid drainage, both of which are unfavourable to establishing seedlings.

It is important to understand climatic conditions of the disturbed site being treated because certain climates are more suitable for mounding than others.

Erosion, root exposure, root restriction and root deformation are also concerns with mounds.

When forming mounds, avoid capping over slash or other debris, which would interfere with root egress from the mound and increase the risk of the mound drying out. Also avoid creating steep-sided mounds (slopes greater than 20%).

In areas with low snowfall, less insulation and earlier snowmelt around mounds can cause winter injury to newly planted seedlings that are not acclimatized to the site.

It is important to understand climatic conditions of the disturbed site being treated because certain climates are more suitable for mounding than others (Table 2).

Table 2. Suitable climatic conditions for mounding

Climatic conditions	Suitability for mounding
Short growing season and cool temperatures	✔
Warm, dry growing seasons with significant risk of summer drought	✘
Cool, shady north-facing slopes, especially at higher elevations	✔
Sunny, exposed south-facing slopes and ridges	✘
Frost pockets and areas of cold air drainage	✔

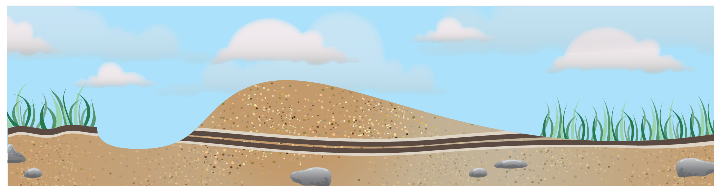
Selecting the right mound type

The choice of an appropriate mound type depends on the site characteristics and the objectives of the site preparation treatment.

Inverted humus mounds

These types of mounds are created by placing a scoop of topsoil and the underlying mineral soil upside down (see Figure 9). This is the most common and easily employed method of mounding. It is suitable for fine-textured soils but not recommended for drought-prone sites.

Figure 9. Inverted humus mound



Mineral soil mounds

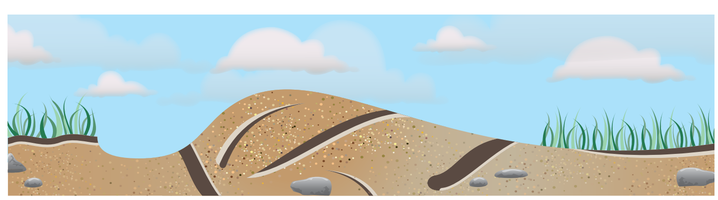
Mineral soil mounds are created by placing mineral soil in a raised planting spot. This method is well-suited for cold and drought-prone sites where nutrients are abundant in the subsoil (Figure 10).

Figure 10. Mineral soil mound

Mixed surface organic matter and mineral soil mounds

Mixed surface organic matter (also known as humus) and mineral soil are composed of organic matter and mineral soil. This type of mound is well-suited for sites that are relatively dry and have few nutrients. It is not recommended for sites that have abundant competing vegetation present (Figure 11).

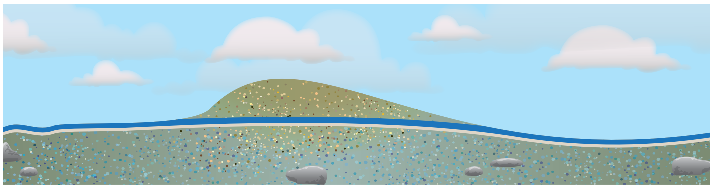
Figure 11. Mixed surface organic matter and mineral soil mound



Peat mounds

Peat mounds are commonly used in soils that are prone to being waterlogged for the entire growing season. Planting in this scenario allows a seedling to develop its roots in a much drier and warmer microsite than the surrounding conditions. This method is well-suited for deep peat soils (Figure 12).

Figure 12. Peat mound



Equipment considerations

Excavator mounding attachments are the most versatile, but costly, type of mounding equipment. They can create any type and size of mound, even on sites that have a thick humus layer and abundant woody debris.

Mounding attachments such as a mounding rake or spoon work well on wet sites because excavators tend to have low ground pressure. Also, the attachments can push woody debris aside with the teeth on the back of the rake.

On extremely wet sites, mounding can be combined with ditching, a technique that allows water to run away from a mound. However, ditching must be approached with caution and carefully planned to avoid mineral soil erosion and possible stream sedimentation. It is the most efficient and cost-effective treatment, especially on small and isolated sites (e.g. in situ sites).

In deep peat (organic) soils, an excavator with a bucket may be preferable.

In addition to excavator attachments, a range of pull behind mounders are available for use with a crawler tractor. While excavators can work on steeper ground, crawler tractors are restricted to slopes of less than 30%.

The added power of a crawler-mounted pull-behind mounder (e.g. Bracke), combined with a slash parting V-plow or rake, can successfully mound on sites with moderate to heavy slash loadings.

Skidder or pull-mounted mounders are most suitable on gentle slopes (less than 20%) that are easily accessed. However, they are not recommended on extremely wet sites or on sites that have a thick humus layer or abundant woody debris. This is because the equipment cannot create large enough microsites that are far enough above the water table.

Skidder-mounted mounders are more efficient and cost-effective for extensive areas (e.g. large openings or long linear features).

Excavator mounding is more expensive than using mounders pulled behind skidders or crawler tractors. However, they are cost-competitive on sites that have the following conditions:

- small isolated sites
- abundant slash loading
- high stumps and many obstacles
- thick humus layer
- a slope of greater than 25%
- abundant brush
- wet
- need a variety of mound sizes and types

Pattern

The pattern used for mounding depends on the mounding coverage required for the site. This coverage is based on the site objectives.

There is no set pattern for mounding – operators generally work across the site as needed. One clear exception is mounding on linear features. Here a pattern similar to a five of diamonds playing card is required across the entire width of the feature to ensure movement corridors are not created.

Prior to planting, it is recommended to let the mounds settle over the winter to reduce the number of air pockets in the soil. However, if left too long, the mounds could be occupied by undesired vegetation. The best time for planting is therefore early in the spring or summer following mounding.

Figure 13. Scalped area

2.4 Scalping

During scalping, surface organic layers are removed in patches or continuous strips to expose the underlying mineral soil. This treatment creates a flat or depressed planting spot with exposed mineral soil. It is usually used in conjunction with mounding in undulating terrain where moisture conditions change quickly from very wet to very dry (e.g. along seismic lines).

Scalping is most effective on well-drained dry sites with medium-textured soils. In these sites, such treatments can be deep enough to help control competing vegetation, yet not result in other problems such as waterlogging (puddling) or inhibition of seedling root growth. Scalps should only be deep enough to remove unfavourable litter and duff layers and to expose well-decomposed organic or favourable mineral soil horizons (Figure 13).

Exposed mineral soil created by scalping warms faster than the undisturbed soil beneath the insulating organic layers. Increased soil temperature is generally beneficial because roots grow faster in warmer soils than in colder soils. In addition, the exposed mineral soil provides a microsite for seed germination and establishment.

Wide, continuous scalps provide greater increases in soil temperature and moisture than small patches or narrow trenches; however, they displace more soil nutrients from the microsite. Increased soil temperature generally improves seedling growth, can facilitate water uptake and can reduce frost damage to seedlings.

Depending on the equipment used, scalping can produce a range of planting spots. Often a small mound of inverted humus or sod, with some mineral soil, is formed.

On moist sites, seedlings should be planted on the shoulder of the exposed mineral soil, adjacent to the inverted humus.

On dry sites, the seedling may be planted in the bottom of the scalp.

On sites prone to frost heaving, seedlings need to be planted into the inverted humus with sufficient mound capping. Planting near the edge of the scalp may optimize the benefits of warming, which increases access to nutrients from organic matter.

Key considerations
Matching the depth of scalping to the site is critical. Care must be taken to avoid scalping too deep or too wide – especially on nutrient-poor sites that have a thin humus layer.

The size of the patch created by scalping is also important. Removing nutrients beyond seedling roots or exposing unfavourable soil substrates can lead to poor seedling performance. Seedlings in scalped soil do not initially have access to the nutrients in the relatively fertile surface layers removed by scalping. The patch must be small enough that the roots of seedlings planted in the middle of it can reach the nutrients in the soil surrounding the scalp during the first growing season.

Optimum patch size varies with site. Large patches are needed where surrounding vegetation excessively shades seedlings or when the competing vegetation is pressed down by snow onto the seedling (snow press). It is recommended to not scalp soil in areas prone to landslides or erosion.

Soil texture is also an important factor influencing the performance of seedlings planted in scalped soil. Medium- and moderately coarse-textured soils generally do not inhibit root growth. However, fine-textured, compacted subsurface soil exposed in scalped patches may restrict seedling root growth. In this situation, seedlings become chlorotic (i.e. show signs of stress) because roots take years to access nitrogen in the adjacent surface organic layers.

Scalping is not recommended on wet sites because seedling roots may become saturated. Deep scalping in fine-textured soils may also result in waterlogged patches and in restricted root extension. Seedling root systems may be so shallow in scalped, fine-textured soil that the saplings are unstable. Frost heaving can also be a problem for seedlings planted in exposed, fine-textured mineral soil.

Equipment considerations
Buckets, forks, rakes and powered attachments mounted to the boom of an excavator can be used for scalping. Pulled or skidder-mounted implements are recommended on most sites with good trafficability, gentle slopes and moderate forest floor thickness. Skidder-mounted implements (e.g. Bracke scarifier) have high productivity and low treatment costs.

Standard buckets that have teeth or rakes are all that is required for scalping. Excavators generally have lower productivity and higher treatment costs than those pulled by skidders. Excavators are used for scalping only on sites that have steep slopes, abundant slash or high stumps or that require a variety of site preparation treatments (e.g. during linear restoration).

Frost heaving can also be a problem for seedlings planted in exposed, fine-textured mineral soil.

Patterns
During scalping, patches of mineral soil are exposed in a continuous row or systematic patch pattern.

In continuous rows, the scalps should be spaced evenly along the contour of the site. The interval of rows depends on the number of planting spots required for the site.

In patch patterns, topsoil is removed in small patches to expose mineral soil, which creates an ideal planting spot for seedlings.

Scalping should generally be deep enough to remove only the LFH layer. Scalped microsites should be planted in the season following treatments to ensure seedling success in areas with competing vegetation.

2.5 Scarification

Soil scarification involves removing surface organic layers (humus, grass and/or vegetation) to expose and loosen mineral soil. The ground surface is scuffed with equipment directly or by implements dragged behind. This treatment creates a flat or depressed microsite with exposed mineral soil.

Scarification is used more often on larger contiguous areas instead of scalping. It is suitable where vegetative competition is low, where there is a seed source from adjacent forests and where cones are present on the ground or in logging debris.

Scarification is used to

- create suitable seedbeds
- distribute cone or seed materials by mixing or partially scalping the forest floor
- promote fast development of the root system of a planted seedling
- promote the possible release of seeds from serotinous cones when temperatures are high enough

Scarification results in

- higher mineral soil temperatures
- less risk of frost
- more light getting to the seedling
- a more balanced supply of oxygen and water in the soil

This treatment is suitable in areas where light site preparation is required, such as on dry or thin humus sites.

Key considerations
Patch scarification creates scalped, depressed and prepared spots, a level hinge, and a raised, loose mound. Removing organic layers creates a microsite that promotes seedling survival and growth on mesic sites

Figure 14. Skidder with rake

that have uncompacted loamy soils. On drier sites, the preferred planting spot may be in the depression while on moister sites, the preferred spot may be at the hinge.

Generally, this treatment does not provide adequate vegetation control where competition is aggressive, nor is it successful on wet or very dry sites where trenches or berms and mounds are more suitable. Patch scarification typically disturbs approximately 10 to 30% of the ground surface area and retains more soil nutrients in proximity to the seedling than strip scarification.

During scarification, avoid extensive removal of organic material, particularly on infertile, coarse-textured soils with a thick organic layer and on clayey or silty soils prone to frost heave. Improper scarification can result in soil erosion and compaction, damage to remaining trees, uprooting or damaging seedlings, unwanted expansions of weeds or invasive plants, reduced supply of soil nutrients and a greater risk of frost heaving.

Equipment considerations
The most common types of scarifiers are towed behind a skidder or crawler tractor. They run on wheels that, in addition to supporting the frame, brake the ripping wheels. Units that run on wheels can be coupled by means of a winch and paid out or drawn in as necessary.

The ripping wheel arms are always pivoted to allow vertical movement, and lateral movement is sometimes also possible. In the latter case, the arms are said to be raked. Raked units operate more smoothly and are better able to follow the contours of the ground. The ripping wheel arms are raised during transport (Figure 14).

Anchor chain drag scarifiers are large, specially constructed steel chains dragged behind a prime mover. The configuration of the scarification unit varies widely depending on the site conditions and scarification objectives.

A series of large link ship's anchor chains are attached parallel to one another to a straight or V-shaped drawbar (V-bars) or to a triangular skid boat. Large spikes are welded spirally across the middle of the chain links. Shackles or clevises hold the drag together.

The chains are frequently used in combination with other drag scarification devices such as tractor pads and shark fin barrels. Shark fin barrels are constructed as watertight units with four spiral rows of blades or fins welded to the drum surface. They require a swivel in the front and rear to allow them to rotate freely. Shark fins are used to orient slash and expose mineral soil in thicker forest floor conditions.

The Bracke two-row scarifier produces intermittent scarification with minimal soil disturbance and an elevated, aerated microsite. The mattock wheel rotates at approximately half the tire speed, which causes the teeth to dig, scalp and invert the exposed mineral soil. When the mattock hits an immovable obstacle, the tire slips to absorb the shock load before scarification resumes.

Patterns
Concentric patterns are recommended for drag scarification because they can help minimize the time spent turning because turning is difficult with this treatment method. The operator begins along the outer edge of the disturbed site and continues to go around until the whole area is treated.

Drag only within one year of harvest because later use could uproot and kill established germinants. A pre-treatment assessment will determine the number and distribution of germinants or seedlings.

2.6 Mixing

Mixing treatments incorporate surface organic layers with the underlying mineral soil, leaving the nutrients of the organic layers immediately available to germinants or planted seedlings in otherwise poor sites. Mixing generally exposes mineral soil, which raises soil temperature. It also improves the ability of the surface materials to retain moisture, thus improving the seedbed.

Figure 15. Soil mixer

When executed appropriately, soil mixing can

- control competing vegetation
- increase soil temperature and aeration
- decrease soil bulk density
- improve the soil-water relationship
- retain nutrients stored in surface organic layers

For fine-textured soils, mixing may be a more satisfactory treatment than scalping. Incorporating organic matter into the mineral soil produces planting spots that are less compacted than those in exposed, fine-textured subsurface soil.

Mixing also averts the problems of restricted root growth and waterlogging, which are commonly associated with scalping. Fine mixing, spot mixing and coarse mixing are three common types of mixing.

2.6.1 Fine mixing

Fine mixing of soil is used on sites that have high potential for competing vegetation. wherein this scenario, high rotation speed is required to chop propagating plant parts into pieces small enough to deter re-sprouting.

Fine mixing requires that the equipment travel slowly to allow sufficient time to chop up the soil and vegetation. It is suitable for fine-textured soils that have few cobbles or boulders.

This treatment will result in shrubby vegetation complexes, such as willow or aspen, being replaced by herbaceous vegetation and grass. This shift in vegetation complex may not be desirable on certain ecosites. Fine mixing treatments typically disturb up to 100% of the ground surface area.

2.6.2 Spot mixing

Spot mixing is prescribed for sites where mixing is biologically appropriate, but where debris, stumps or other obstacles prohibit use of strip mixing implements. Spot mixing is also used on sites where minimal soil disturbance is required. Spot mixing implements are usually mounted on excavators because excavators can work on a wide range of sites.

2.6.3 Coarse mixing

Coarse mixing is accomplished using large implements that heap clods of surface organic and mineral soil layers into a bed. Coarse mixing provides little control of competing vegetation, but is beneficial where low soil temperatures and/or high soil water tables inhibit seedling growth. On sites with high competing vegetation potential, coarse mixing must be followed by planned brushing treatments. Coarse mixing treatments typically disturb up to 100% of the ground surface area.

Key considerations

Inadequate mixing can stimulate competing vegetation. The effectiveness of mixing treatments for controlling competing vegetation depends on the intensity of mixing and the aggressiveness of the competing vegetation.

Fine mixing is unsuitable for stony, coarse-textured, wet soils with a thin humus layer. Spot and coarse mixing techniques may only be effective in promoting seedling growth when competing vegetation is not aggressive. Otherwise, spot and coarse mixing may increase competition from weed plants because it improves soil fertility without sufficiently reducing re-sprouting potential.

Mixing may cause long-term depletion of nutrients by making them excessively available in the first few years after treatment. Nutrients not taken up by plants may be lost to the ecosystem through leaching. Mixing only the planting spots rather than the entire site appears to avoid this problem.

Mixing equipment incorporates surface organic matter into the mineral soil to improve nutrient status, to increase soil temperature and to improve soil physical properties. Prepared spots may be raised or level. Raised spots may be created by a bedding attachment.

Most soils would benefit from this treatment, but operational constraints restrict the applicability of mixing.

2.7 Disc trenching

Trenching creates continuous or intermittent furrows or trenches. During this treatment, the organic layer and some underlying mineral matter are removed and deposited in berms beside the resulting trench, offering a variety of planting positions.

The layers are in a roughly mixed state over the undisturbed forest floor beside the trench. Disc trenchers employ rotating discs with downward pressure to produce two parallel trenches that create a mixed mineral and organic side cast over the undisturbed forest floor. Trenching treatments typically disturb approximately 25 to 50% of the ground surface area.

Disc trenching mixes soil and humus in a way that favours growth while at the same time providing the micro-relief needed for successful establishment of seedlings. Trenching is most suitable for moist (not wet) conditions or where cold wet patches are interspersed with areas of better drainage.

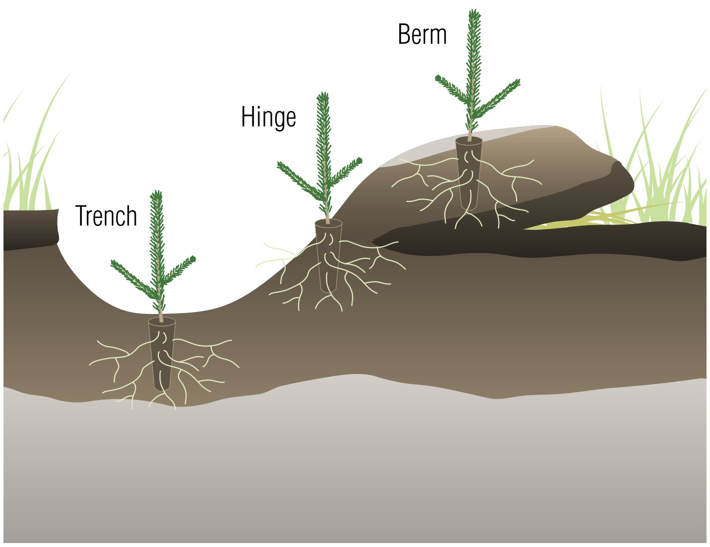
After trenching, several planting positions (microsites) are available to the planter (see Figure 16). These positions include the trench, the hinge and the berm.

The trench position can be used when moisture conservation is required on dry sites.

The hinge position at the junction of the trench and berm is favourable on sites with intermediate (mesic) moisture regimes.

The mineral soil/surface organic matter berm position provides a raised spot that may be partially mixed or generally inverted with a mineral soil capping. This raised microsite is suitable for moist sites.

Figure 16. Planting microsites created by trenching



Key considerations
The results of trenching vary, depending upon site factors, the type of trencher and what machine settings are used. The trench profile can be adjusted by changing the disc angle, vertical pressure and travel speed.

When the disc is at an angle closer to perpendicular to the direction of travel, it produces a wider, flatter trench. When the disc angle is closer to parallel to the direction of travel, it produces a deeper, narrower trench.

Increasing the vertical pressure and decreasing the travel speed produces a deeper trench and a well-formed berm.

Wide, continuous trenches provide greater increases in soil temperature and moisture than do small patches or narrow trenches, however, they displace soil nutrients. Small trenches retain soil nutrients near the seedling, but will not create as great an increase in soil temperature.

Trenching is not recommended for cold and wet or steep sites. On rangeland (domestic or wildlife) or on sloped sites where erosion from water channelling is a concern, trenching should be performed only intermittently. Raised side berms may also be prone to desiccation on drier sites. This treatment is also not suitable for small sites of less than 5 hectares (ha) because the prime mover needs room to manoeuver and follow the most cost-effective pattern.

Disc trenchers can be grouped into three distinct categories: passive trenchers; trenchers that have hydraulic down pressure but passive discs; and trenchers that have hydraulic down pressure and powered discs.

The most common trenchers used in western Canada have hydraulic down pressure and powered discs. They are recommended for sites with heavy slash on a relatively deep humus layer or any other application requiring good disc penetration or berm formation. For proper operation, disc trenchers should be operated at travel speeds less than 5 km/hr. On sites with abundant slash, a V-rake can be used to align the slash immediately prior to trenching. Some powered-disc trenchers can trench intermittently. These trenchers are recommended for trenching slopes that are too steep to treat by contouring.

Ponding in contoured trenches may occur, though usually the trenches have enough interruptions so that drainage is not affected. Erosion potential is higher if perpendicular passes are used on steep slopes. Perpendicular passes should be limited to coarse-textured soils and combined with intermittent trenching to reduce potential site degradation such as erosion or slumping.

Equipment considerations
Disc trenchers can be mounted on a variety of prime movers. When selecting the prime mover, the following considerations are important:

- matching the prime mover to the site conditions (i.e. slopes, slash loading, trafficability)
- meeting the hydraulic requirements of the disc trencher
- matching the transmission to high drawbar pull requirements at slow travel speeds (especially if a slash-parting device is to be used as well)

Patterns
The treatment pattern for the prime mover is restricted by the terrain. On broken terrain, blocks must be treated in subunits. On slopes up to 30%, trenches can be contoured with the slope. With contouring on steeper slopes, it is difficult to maintain uniform spacing between passes since the tendency is that the machine slides downhill when avoiding obstacles.

To meet site preparation objectives and provide suitable planting spots, the machine operator can alter the disc angle, down pressure, disc spacing, machine speed and the spacing between passes. Because the sun is predominantly in the southern half of the sky for most of the day, the direction in which trenches are oriented can have an effect on microsite conditions. North-South trenches create consistent light conditions. Within east-west trenches, the south-facing hinge is the warmest position, while the trenches shaded by a southern berm tend to be cooler.

On cool sites where soil warming is desired, trenches should be in a north-south pattern. Where east-west tranches are unavoidable, planters should select south- or southwest-facing microsites, if possible.

On hotter, drier sites, where lack of soil moisture and high temperatures may harm seedlings, east-west trenches are preferred, and planters should select cool microsite positions, if possible.

Disc trenching is most effective from May to October on unfrozen soils that have no snow cover. However, soils frozen to a 5-cm depth or that have snow up to 15 cm can be treated effectively.

2.8 Plowing

Plowing creates continuous elevated planting berms, providing long-term soil loosening. A large area of uniform and relatively obstruction-free (rocks, slash, stumps, etc.) land is required for this treatment. Plowing treatments typically disturb approximately 30 to 65% of the site surface area.

Plowing can create acceptable raised microsites for planting. It loosens soil and provides good drainage, which provide sufficient soil oxygen for seedlings and increased soil temperatures. Plowing is recommended for wet sites that have thick duff layers and for areas that have thick, inactive humus layers that have slower nutrient cycling rates. Seedlings should be planted on the elevated microsite created by plowing.

Key considerations
On dry sites, smaller two-row ripper plows can be effective. Seedlings planted in the bottom of the furrow can benefit from some degree of frost protection caused by radiation of heat from the soil at night and increased moisture availability.

Plowing can severely affect the soil's nutrient regime and water balance. Therefore, it is considered unsuitable for nutrient-poor or dry sites. Plowing may not control competing vegetation such as grass. The deep furrow associated with this treatment can cause asymmetric root systems because roots will not cross the dense, often wet, fine-textured soils at the bottom of the furrow. It is not recommended for broken or rugged terrain, slopes of less than 25% or dry sites with thin humus layers. Plowing too deeply into unfavourable substrates (e.g. compacted layers (hardpans) or nutrient-poor mineral soils) can also result in poor seedling performance.

Equipment considerations

Ripper plows are modified standard ripper teeth mounted on the back of a crawler tractor and were designed specifically for treating wet ground when it is frozen. The most common plow design is a double mouldboard type with replaceable cutting edges, which attaches to the ripper shank of the crawler tractor. The ripper tooth digs into the soil, while the plow attachment displaces soil on either side. Smaller, two-row ripper plows were designed to create planting furrows on dry sites.

A cut-over plow cuts through the soil and directs the material to the sides. It creates a furrow that is 20 to 60 cm deep and has a top width of up to 80 cm. On each side of the furrow, mineral soil is exposed on the shoulders. The shoulder may be up to 60 cm wide.

V-plows are crawler tractors that have large V-shaped blades mounted to the C-frame. The shape of the blade allows it to clear a path in front of the prime mover without continually backing up and piling soil.

Rear-mounted plows are used to remove vegetation and organic layers where deep or extensive disturbance is required. Usually such implements create an overturned berm and trench, but the treatment profile depends on the individual attachment.

Objectives vary with the implement and site. Planting spots can be prepared at the top of the overturned material, on the scalped, level portion or in the scalped, depressed trench, depending on the requirements of the site and the species.

Pattern

Plowing should occur in parallel, straight lines with overlapping passes between the berms, which enables the plow to capture otherwise unplowed soils. The first pass of a pair of plows will cover 30 to 35% of the area. Lapping the first pass will create 1 metre-wide furrows and cover a minimum of 65% of the area. The second pass generally fractures all of the soil between the first pass furrows. The efficiency of the second pass plowing is improved if the furrows are straight and evenly spaced. At the end of the furrow, it is advised to minimize shallow plowing by lifting the plow out of the ground.

When plowing gentle slopes, it is recommended to make the first pass downslope. The first pass always requires the most power; the plowing will be deeper and more efficient if the first pass is downslope. The lapping second pass will be easier going uphill after the first pass has been completed. Small cyclic changes in the depth of plowing (3 to 5 cm) can reduce the power required for plowing and increase speed. Crawler tractors should raise the plowing implements out of the ground before turning.

Plowing should be scheduled so that treated soils will be moist when the soil freezes.

Except for short distances, turning the crawler tractor around will generally provide better control than backing between the furrows of the first pass to make the second pass. Backing between furrows requires the crawler tractor to remain on the inter-furrow soil. Otherwise, the crawler tractor will drift into the existing furrow and reduce the tillage benefit of the first pass.

Rip plows should be operated at depths greater than 60 cm because shallower plowing increases the mixing of soil layers. Hence, more subsoil comes to the surface and is mixed with the topsoil, which reduces the benefit of tilling forest soils.

Plowing should be scheduled so that treated soils will be moist when the soil freezes.

2.9 Organic amendments

In addition to physically altering slash, duff and soil layers through a variety of mechanical methods, soil amendment applications can be implemented during the site preparation stage. The purpose of applying amendments is to improve the physical, biological and chemical conditions of the soil (including texture, bulk density, moisture and nutrients) to promote tree growth and development.

The addition of organic amendments, such as compost, mechanical pulp sludge and biochar, has many benefits including

- increasing the amount of soil organic matter (SOM) in the soil, which in turn improves the soil's capacity to hold moisture and improves soil aeration
- decreasing bulk density
- increasing pH buffering capacity
- increasing cation exchange capacity
- increasing the macro-nutrients in the soil
- increasing the micro-nutrients in the soil

These beneficial effects help to ameliorate the undesirable soil conditions faced in many post-disturbed sites and further accelerate the growth of trees and other desirable species.

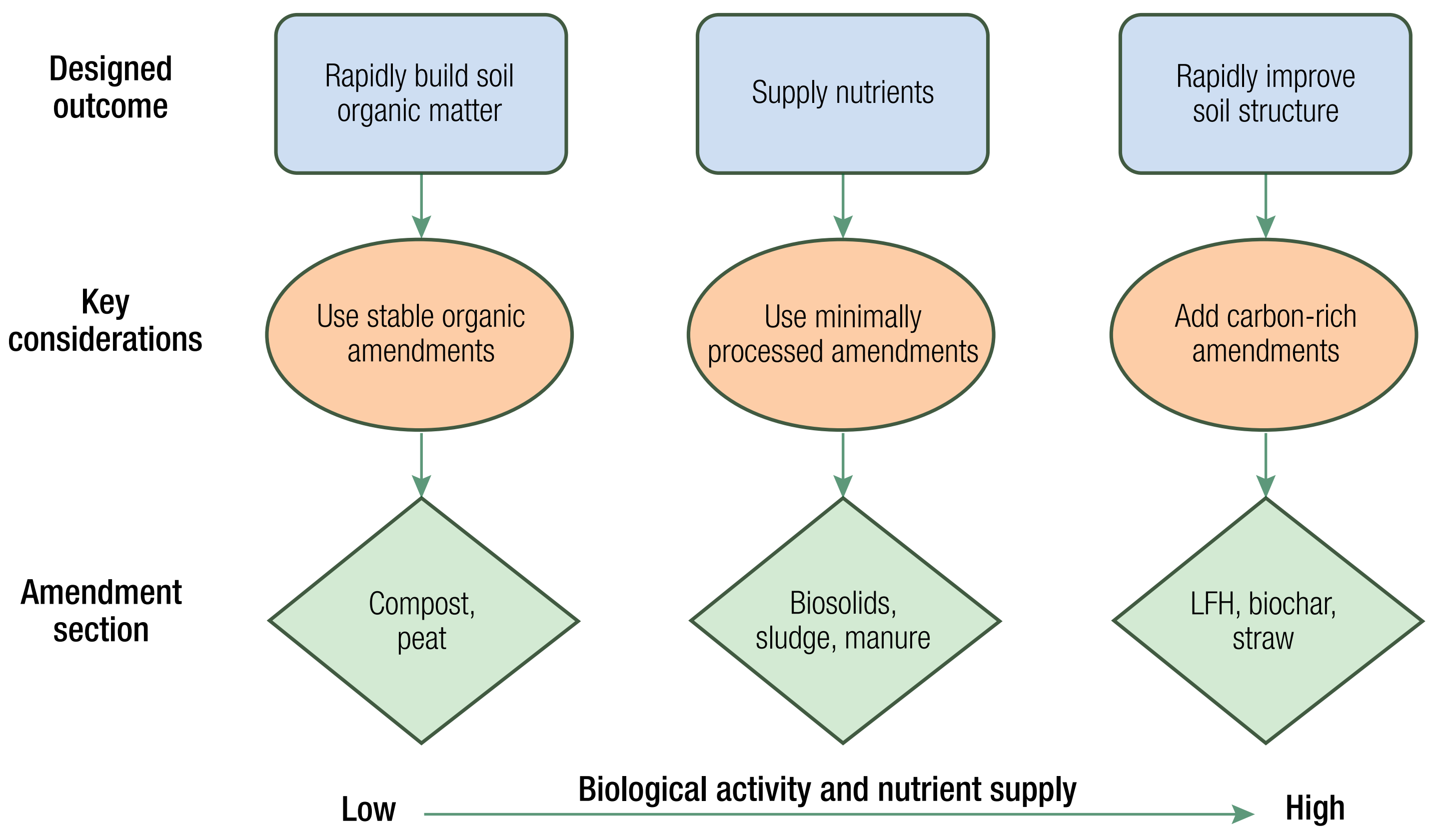
Key considerations

Amendment addition must be approved in the conservation, reclamation and closure plan for each site. It is important to note that site certification for sites that have received amendments are often delayed to ensure the site is self-staining. Compared to conventional fertilizers, most organic amendments can provide stable nutrient concentrations to plants over a longer period of time, with the added benefits of improving the physical, chemical and biological properties of the reclaimed soil.

These beneficial effects help to ameliorate the undesirable soil conditions . . .

Several types of organic amendments are available for use in reclamation. Some amendments have more labile carbon and nutrients than others, therefore amendment selection should be based on the desired reclamation outcome (Figure 17).

Figure 17. Amendments for specific outcomes



Source: See the "References" chapter, adapted from Cooperband, 2002

For amendments with a low C:N ratio (such as animal manure), biodegradation will release nitrogen (in the forms of NH_4^+ and NO_3^-) to the soil. This is an important process in the northern boreal forest, where increased availability of inorganic forms of nitrogen are directly linked to greater above and below ground biomass in mature conifer tree stands.

Overall, the literature suggests a strong relationship between the amount of SOM content in the soil (by percentage of dry weight) and tree height. This is the effect of improved water holding capacity and available nutrients. The organic carbon in amendments will be broken down by microorganisms and residing vegetation to smaller and more readily available organic compounds.

Another consideration when selecting amendments and the appropriate application rate is the types of species planted in each scenario. How long an organic amendment is effective is uncertain, especially at low application rates. Conversely, adding SOM may change how the soils function in comparison to natural systems; growth trajectories may be different from the natural system.

A rich organic layer does not produce ideal growth conditions for all tree species. Releasing labile nutrients may stimulate the growth of agronomic grasses and weeds that would outcompete the tree species, and some woody species can be impeded by too much organic amendment.

For example, aspen growth is impeded by a thick soil organic layer (greater than 25 cm at the landscape scale), and after fire, a soil organic layer that exceeds 2 to 10 cm can impede aspen establishment from root suckering.

Other secondary effects of having a thick soil organic layer (i.e. decreased soil temperature) are lower assimilation rates, reduced above-ground biomass (in terms of leaf and shoot growth) and a cessation of root growth and reproduction.

Furthermore, key factors such as the amount and rate of litter and woody debris that naturally accumulate over time with revegetation need to be considered when selecting the appropriate amendment to use in reclamation.

Another consideration when selecting amendments and the appropriate application rate is the types of species planted in each scenario.

Deciduous trees (such as aspen) produce more litter than conifer trees. Furthermore, litter from most conifers decomposes slowly but this litter slowly thickens the soil organic layer. If rebuilding the SOM in the soil is the desired outcome, it is important to select an amendment that will support tree development and litter accumulation based on the type of trees planted in these reclamation scenarios.

Table 3. Properties of select amendments

Amendments	General properties	Guidelines for use	Precautions for use
Compost	• pH ~5.5–8.0 • Moisture content ~35–55% • Soluble salt <1.25 deciemens/metre • High organic matter content • Source of nutrients • Improves soil structure • Increases water-holding capacity • Supplies beneficial soil microbes • Pathogen-free • Weed seed-free	• Apply at least one month prior to planting to increase stability • Application rate: 10–40 tonnes/ha (t/ha) incorporated to 15 cm	• Salt damage may occur in coarse soils with low organic matter and cation exchange capacity. • Can contain high ammonium, salts and other phytotoxic elements • Application must be evaluated on a case by case basis because guidelines for compost application in forests are not available.
Commercial peat	• Mesic peat is more effective than fibric peat. • High water holding capacity • Add to soil as often as required. • High rates are required.	• Spread freshly excavated materials into the top 20 cm of mineral soil or 25 cm of tailings sand. • Lime may be required to correct for the acidification of peat. • Fertilizer may be required to achieve a desirable C:N ratio. • Avoid layering to prevent negative effects on vertical moisture movement.	• Low pH (3.7–4.5) may acidify soil. • Can contain weed seed or non-native seed • Non-renewable resource • High C:N ratio, poor source of plant nutrients • May release greenhouse gases after application because of decomposition
Biosolids (Class A and B)	• High organic matter content • Improved soil structure • Increased water-holding capacity • Source of nutrients • Low cost • Reduces landfilling	• Characterize the target material prior to application. • Application rate: 25–85 t/ha incorporated to 15 cm • Consider adding buffer strips to protect local water resources and neighbouring land uses. • Can reapply after 3 years if requirements are met • Can be applied only on slopes up to 9% • Only recommended for soils with a pH >6.5	• Contains pathogenic organisms • May contain heavy metals or organic toxins • Biosolids treated with lime can cause alkaline pH soils. • Excessive nutrient loading or nutrient imbalances can occur if biosolids are improperly applied. • May have odours and attract wildlife • Expensive to move long distances
Pulp and paper sludge	• High organic matter content • Apply to mineral soils, not organic soils • Improved soil structure • Increased porosity, aeration, drainage and rooting depth on fine-textured soils • Increased water-holding capacity • Slow release of nitrogen • Increased nutrient-holding capacity • Reduces amount of waste incinerated or landfilled at pulp and paper mills • Low cost	• Do not apply to soils with a pH <6.0. • Application rate: 60–185 t/ha of bone dry sludge • Can be applied on slopes up to 15% • Can reapply after 2–4 years if requirements are met	• Lime residuals may increase soil pH. • Can have high C:N ratio, which reduces nitrogen availability to plants • Expensive to move large distances

Table 3. Properties of select amendments *(continued)*

Amendments	General properties	Guidelines for use	Precautions for use
Animal manure	• Increased plant growth and productivity • Source of nutrients • Provides nitrogen throughout the season • Increases microbial activity • High organic matter content • Improved soil structure • Increased water filtration and water-holding capacity • Increased cation exchange capacity • Reduced wind and water erosion	• Use composted manure (has a higher percentage of plant nutrients in a readily available form). • Do not apply it to snow, frozen ground or areas prone to flooding. • Inject it into soil to avoid odour and insect problems. • Application rate: 10–20 t/ha for poultry manure; 80–150 t/ha for dairy manure • Apply raw or composted forms. • Allow rain to leach out salts before planting.	• High salt content (Na^{+}) • Potassium can build on the soil surface. • Can contain weed seeds and pathogens • Moisture and nutrient contents are very variable. • Nutrients in manure are difficult to balance, which results in excessive nutrient loading or imbalances. • Odor issues • Expensive to move large distances • Limited availability in the oil sands region
Crop residues (hay, straw, etc.)	• Use as mulch for trees and shrubs. • High C:N ratio	• Apply straw in the fall to immobilize the nitrogen and prevent loss in the spring. • Use light disc straw to anchor it. • Several smaller applications are most effective. • Application rate: 1.5–7.5 cm on soil surface, incorporated to 15 cm	• Difficult to spread. • Expensive to move long distances • Nitrogen fertilizer may be required to reduce high C:N ratios. • Limited availability in the oil sands region • May be difficult to acquire weed-free straw
Biochar	• Enhances crop productivity • Reduces bulk density and increases porosity • Reduces nutrient leaching • Reduces soil acidity • Improves fertilizer efficiency • Reduces soil erosion • Provides a micro-environment for soil microbes to grow	• Application rate: 15–40 t/ha (depending on soil type) • Often applied with another nutrient source (i.e. compost or fertilizer)	• Expensive to make and ship • Energy-intensive to make • Large volumes needed because of low bulk density • Loss caused by wind • May contain polycyclic aromatic hydrocarbons or heavy metals

Sources: See the "References" chapter, Adapted from Bates and Lafleur, 1999; Bekele et al., 2013; Cooperband, 2002; Hoffman et al., 1993; Land Resources Network Ltd., 1993.

2.10 Fertilization

Similar to adding amendments, using fertilizer is a technique that can be implemented during the site preparation stage to enhance the development of tree growth on nutrient-deficient sites. Fertilizer use must be approved in the conservation, reclamation and closure plan for each site. Additionally, there is often a delay in site certification following fertilization to ensure the fertilizer effects have dissipated. Nitrogen and phosphorus have been reported to be most relevant to tree growth in reclaimed ecosystems.

Key considerations

To reduce the economic and environmental costs of fertilizer application, it is strongly advised to synchronize nutrient supply with tree seedling growth rates. Delivery rates should increase with exponential seedling growth rates.

Nutrient management in reclaimed ecosystems should follow the guiding principles of 4R Nutrient Stewardship: Right Source, Right Rate, Right Time, Right Place.

Aside from conventional fertilizers that supply nutrients that are readily available, there are enhanced efficiency fertilizers that are marketed to maximize plant growth while reducing management cost of fertilizers. Two types of enhanced efficiency fertilizer products are commercially available in Alberta: controlled release fertilizers and fertilizer stabilizers. Their mode of action along with advantages and limitations are listed in Table 4.

Table 4. Conventional and enhanced efficiency fertilizers

Fertilizer types	Mode of action	Advantages	Limitations
Conventional fertilizers	• Most fertilizers are in a form that is readily available to plants or in a form that is rapidly hydrolyzed by soil enzymes to ammonia, and then converts to plant-available form.	• Nutrients are available immediately to plants.	• Low rates of fertilizer recovery • Potential environmental contamination via leaching • Risk of root damage if applied directly to the seedling root zone • Potential to dramatically increase competition from surrounding vegetation
Controlled-release fertilizers	• Coated granular fertilizers that physically restrict nutrient release to a managed rate by allowing slow decomposition of the coating or through a semi-permeable coating	• Nitrogen is released for weeks to months and can last for up to 2 years. • Planting tree seedlings and fertilizing can occur simultaneously. • Limited risk of seedling damage and delayed emergence when applied in high concentrations • Can be applied directly to the seedling root zone for trees and shrubs of interest • Reduced losses through leaching and volatilization • Reduced competition from annual grasses and weeds	• Majority of nutrients are not immediately available to plants
Fertilizer stabilizers	• Urease inhibitor is applied in conjunction with urea, liquid urea ammonium nitrate or manure. It inhibits the hydrolysis of urea-N to ammonium-N whereas the NI inhibits the biological oxidation of ammonia-N to nitrate-N. • The nitrification inhibitor is used with anhydrous ammonia, mixed with liquid fertilizers and liquid manure, etc. or impregnated on urea or dry fertilizer blends. It selectively delays the microbial-mediated conversion of ammonium to nitrate by interfering with the metabolism of nitrifying bacteria, thus reducing nitrogen losses through leaching.	• Reduced nitrogen losses through leaching and volatilization • Reduced detrimental effects of excessive nitrogen on seedlings • May increase growth compared to conventional surface application of urea fertilizer • Higher coverage per tonne of product compared to conventional surface application of urea • Allows fall application of fertilizer • May decrease potential nitrification, contributing to GHG production and nitrogen loss	• Some of these products are expensive and their benefits to tree seedlings are still under investigation. • Benefits of stabilizers are ONLY applicable when used with liquid fertilizers or liquid manure, and these are typically not used in reclamation. • Some stabilizer products are not compatible with applying fertilizer in the spring.

Although fertilization can promote seedling growth, it may also increase the growth of undesirable or noxious weeds. An increased number companies are choosing to use enhanced efficiency fertilizer products (particularly controlled-release fertilizers) instead of the conventional immediately available fertilizers.

The biggest advantage of using controlled-release fertilizer products is one of logistics: planting tree seedlings and fertilization can occur simultaneously. Pre-packaged, controlled-release fertilizers can be placed near the plant without damaging the roots, thus allowing more cost-efficient delivery of nutrients over time. This will also reduce vegetative competition by undesirable species.

Fall application of controlled-release fertilizers may provide an indirect economic benefit by allowing more flexibility on when reclamation activities can occur. In addition, nutrients are slowly released for up to two years, coinciding with the period of root growth. This assures that seedlings receive an adequate supply of nutrients while they become established without personnel having to conduct additional site visits to re-apply fertilizer.

An alternative to applying fertilizers to the site is to nutrient-load the seedlings prior to planting. The enhanced growth is expected to enable greater use of above-ground resources (light, etc.) to increase photosynthesis and early establishment. What the best nitrogen-loading rate is to promote seedling stem and root growth when the seedlings are transplanted under field conditions varies depending on the tree species. Discussion with nursery and seedling providers is necessary to determine whether nutrient-loading of seedlings is applicable for the species type, age and size of seedlings required for revegetation and whether it is cost-effective for the number of seedlings required.

Pre-packaged, controlled-release fertilizers can be placed near the plant without damaging the roots . . .

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