FOREST PRACTICES

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Silviculture Note 16

Forest Floor Planting: A Discussion of Issues as they Relate to Various Site-limiting Factors

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Introduction

Planting in undisturbed forest floor materials has recently attracted the interest of silviculturists across interior British Columbia. This shift in focus regarding planting substrates has accompanied a provincial decline in mechanical site preparation (MSP) brought about by factors such as rising treatment costs, an increase in machine-free zones, and increased logging on steep terrain. Recent attention to the benefits of microsite planting and a relaxation of screefing standards have also contributed to the change in philosophy. A number of organizations now plant operationally in forest floor materials, but little information is available to assist them in determining when and where this technique is appropriate.

In 1997, to more clearly define the issues surrounding forest floor planting, the Forest Practices Branch distributed a questionnaire to solicit information from silviculturists and planting contractors who had relevant experience or opinions. This report addresses issues raised by the questionnaire, and although a lack of directly related research made it difficult to arrive at firm recommendations, general information is provided about the properties of forest floor materials and their suitability as planting substrates on sites with various limiting factors.

Emphasis is placed on assessing the suitability of forest floor planting in terms of limiting factors to seedling growth, on a site-by-site basis.

A variety of terms are commonly used to describe this practice (i.e., duff planting, raw planting, F and H planting, red rot planting), but in this discussion the term ‘forest floor planting’ will mean planting a seedling with at least a portion of the root plug in undisturbed forest floor materials.

Highlights of Questionnaire Responses

Many respondents to the questionnaire were enthusiastic about forest floor planting, but in most cases, implementation of the practice was too recent for conclusions to be drawn. A few organizations in the Prince George and Vancouver forest regions have been planting in forest floor substrates for several years, however, and after careful monitoring, they consider the practice suitable for many sites in their management areas. Most of the proponents of forest floor planting mentioned nutrient availability, good conditions for root egress, and the potential for positioning seedlings on high microsites as the major benefits to forest floor planting. However, concern about the risk of drought was expressed repeatedly, particularly by respondents from the Cariboo, Kamloops, and Nelson regions. Practitioners did not want to draw conclusions about forest floor planting on the basis of the generally moist conditions of the past few summers. Other benefits of forest floor planting, unrelated to seedling performance, were also mentioned, such as fewer joint-related injuries to tree planters and reduced planting costs.

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Although the questionnaire focussed on planting in undisturbed forest floor materials, it was clear from responses that the issues of planting substrate, microsite selection, and MSP overlap. Some respondents approved of using organic substrates within mechanically prepared microsites, but felt strongly that better seedling performance could be achieved by planting prepared sites than by planting in the forest floor on undisturbed sites. Other respondents had concerns about Forest Practices Code violations and hoped that good microsite selection on undisturbed sites could reduce the amount of MSP required.

The questionnaire identified two issues needing clarification:

- The suitability of forest floor materials for establishment of planted seedlings was sometimes confused with their suitability as a substrate for continued root growth after establishment.

Many respondents cited the abundance of natural roots in the forest floor as evidence that those materials are good planting substrates. However, the most important factor for survival and early growth of planted seedlings is water uptake (Örlander *et al.* 1990), and although the loose structure and low bulk density of forest floor materials are conducive to root egress, it is critical to consider the physical properties of these materials as they relate to moisture availability during the first weeks after planting.

- Physical properties of substrates and their arrangement in the microtopography both contribute to the microsite environment.

Respondents commented that the opportunity to select raised microsites for planting was a benefit of forest floor planting. This concept is relative, however. For example, a raised microsite in undisturbed forest floor materials will be warmer and drier than mineral soil at the bottom of a deep screef, but because of the different physical properties of organic and mineral materials, it is likely to be less warm than the mineral cap of a mechanically prepared mound of equivalent size.

Physical Characteristics of Forest Floor Materials and the Seedling Environment

Forest floor materials have different structure and properties from each other and from mineral soil, which affects the environment they provide for planted seedlings. Most questionnaire respondents considered the F-layer, H-layer, and well-decomposed wood to be acceptable planting substrates, and these broad classes of materials are discussed below. Although there is great variability within these categories of forest floor materials, as documented by Green *et al.* (1993), it is beyond the scope of this paper and beyond the results of available research to address these differences in relation to forest floor planting. Physical characteristics of the F- and H-layers are compared to those of sand and clay in Table 1.

Structure and aeration

Forest floor materials have low bulk density and are well aerated, making them good media for root egress under conditions of adequate, but not excessive, moisture and warmth.

The structure of forest floor materials is dependent, in part, on characteristics of the original litter materials, their state of decomposition, and what the decomposing agents are. The F-horizon, where the majority of soil flora and fauna are found, is made up of partially decomposed materials, and has a loose structure with many large pore spaces. H-horizon material is decomposed to a state where individual particles of litter are no longer discernable, and it has smaller pore spaces than the F-horizon. The structure of rotten wood depends on its state of decomposition and the size of individual particles, which may range from large chunks to a fine powder that likely has similar characteristics to the H-horizon. All three of these materials have low bulk density and high porosity in comparison with mineral soil (Table 1), which, depending largely on texture and pore size, may or may not be a substrate that is conducive to root egress.

Moisture

The F-horizon drains rapidly and has less available water storage capacity than either the H-horizon or most mineral soils. When dry, both F- and H-layers conduct moisture poorly in comparison to mineral soil.

There has been comparatively little research on the hydrological properties of specific forest floor materials. However, available information is sufficient to provide a general description of the characteristics as they relate to the availability of moisture for the establishment and growth of planted seedlings. The terminology presented in the shaded box is commonly used to discuss moisture availability in the seedling microenvironment, and is relevant to forest floor materials as well as mineral soil.

Table 1. Physical characteristics of organic and mineral materials

	F-layer	H-layer	Sand	Clay
Structure				
Bulk density (kg m^{-3})	100–130	150–300	1000–1600	
Porosity (m^{3} m^{-3})	0.8		0.4–0.6	0.4
Moisture characteristics				
AWSC (%)	8	14–20	13	16
Thermal characteristics[a]				
Volumetric heat capacity ($\times 10^{6}$)(Jm^{-3} K^{-1})	0.58		1.28	1.42
Thermal conductivity (W m^{-1} K^{-1})	0.06		0.30	0.25
Thermal diffusivity ($\times 10^{-6}$)(m^{2} s^{-1})	0.10		0.24	0.25
Thermal admittance ($\times 10^{3}$ (J m^{-2} K^{-1} s$^{-1/2}$)	0.35		0.62	0.60

[a] Units: J = joule; K = °Kelvin; W = watt = J s^{-1}

A suitable range of values in B.C. for bulk density, AWSC, and volumetric water content at FC were obtained from D. Spittlehouse (pers. comm.) and R. Trowbridge (pers. comm.). Porosity and temperature characteristics (recalculated in SI units) are from van Wijk and de Vries (1966).

Soil Moisture Terminology

Water content is the amount of water present within a soil. It may be expressed volumetrically, or as a percent of the dry weight.

Water potential is the tension by which water is held in pore spaces within a material. It is expressed in units of negative pressure (-1 MPa= -1000 KPa= -10 bars). Water moves from areas of high water potential to those of lower (more negative) water potential, so that as a soil dries and its water potential becomes more negative, moisture is less available for uptake by plants. Materials having different structures have different water potentials at the same water content.

Field capacity (FC) is the water potential at which the free water has drained out of the soil profile. This generally occurs at -0.01 to -0.03 MPa, regardless of material, as long as the soil profile is free-draining.

Permanent wilting point (PWP) is the lowest water potential from which plants can recover. For conifer seedlings this value is commonly considered to be -2.5 MPa. Seedling growth may be affected at much less negative water potentials than the PWP.

Available water storage capacity (AWSC) is the water available for plant uptake between field capacity and the permanent wilting point.

Hydraulic conductivity is the ability of a soil material to conduct water, and it varies with both the structure of the material and its water content.

Definitions based on Spittlehouse and Stathers (1990).

The F-horizon has many large, irregular pore spaces that contain a large volume of water under saturated conditions, but which drain quickly under unsaturated conditions. Rainfall moves rapidly downward through the F-horizon, and at field capacity the volumetric water content of this material is only about 20%. The hydraulic conductivity of F-material is also relatively low under unsaturated conditions because the large air-filled pores interfere with the continuity of water flow. The H-horizon, because of its smaller pore size, drains less rapidly under unsaturated conditions than the F-layer, and its volumetric moisture content at field capacity is greater (about 45%). The unsaturated hydraulic conductivity of the H-layer is higher than for the F-layer, but is still lower than for mineral soil (Örlander *et al.* 1990). The moisture characteristics of rotten wood are not well documented, but in a decomposed state it appears to be similar to the H-horizon. When less decomposed (fibrous or chunky) it is likely to exhibit low water retention and low hydraulic conductivity because of structural discontinuities.

As shown by Figure 1, the AWSC of the F-layer is only about 8%, and unless moisture is regularly replenished, this material will soon dry down to the permanent wilting point. Also, because of its low hydraulic conductivity, even when the water potential of F-material is in the AWSC range, movement of water to the seedling root zone may be restricted. The H-horizon has better moisture characteristics than the

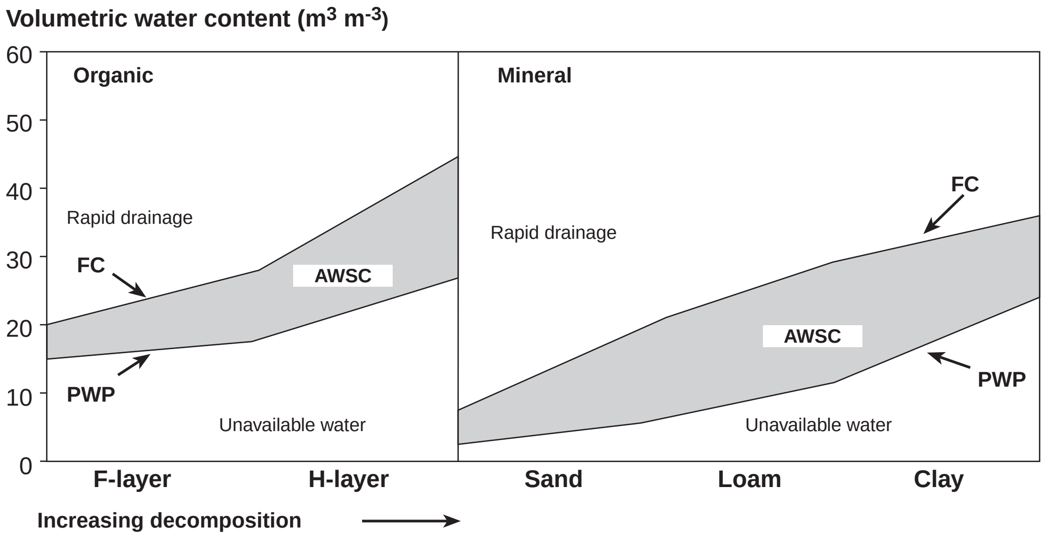

Figure 1. Available water storage capacity in organic and mineral materials (based on values from Plamondon *et al.* (1972) and D. Spittlehouse (pers. comm.)).

AWSC is the amount of water available to seedlings between field capacity (-0.01 to -0.03 MPa) and the permanent wilting point (-2.5 MPa). AWSC increases with the level of decomposition of organic materials, and it varies with the texture of mineral soils.

F-horizon, and well-decomposed material with small pores has similar AWSC to mineral soil. However, well-developed H-layers tend to develop in wetter ecosystems where the availability of moisture is not a limiting factor. Depending on thickness, the H-layer may also dry to the permanent wilting point relatively quickly unless moisture is replenished. A dry F-horizon will slightly retard loss of moisture from the H-horizon, but as drying continues, the low hydraulic conductivity of both materials will restrict movement of moisture upwards from mineral horizons.

The availability of moisture within the root zone of seedlings planted in forest floor materials will vary with the total thickness of the forest floor, with the relative proportions of F and H, and with the characteristics of underlying mineral horizons.

As an example, Figure 2 shows the availability of water within a 20 cm root zone for three hypothetical forest floor situations. Available water in a 20 cm deep F-layer was depleted several days sooner than when the 20 cm forest floor consisted of a 10 cm F-layer over 10 cm of H. When the 20 cm depth consisted of only a 5 cm thick forest floor over 15 cm silty clay mineral soil, water was available longer still within the 20 cm root zone.

During the first weeks after planting, availability of moisture to the seedling root plug is critical. Spittlehouse and Goldstein (1989) consider a

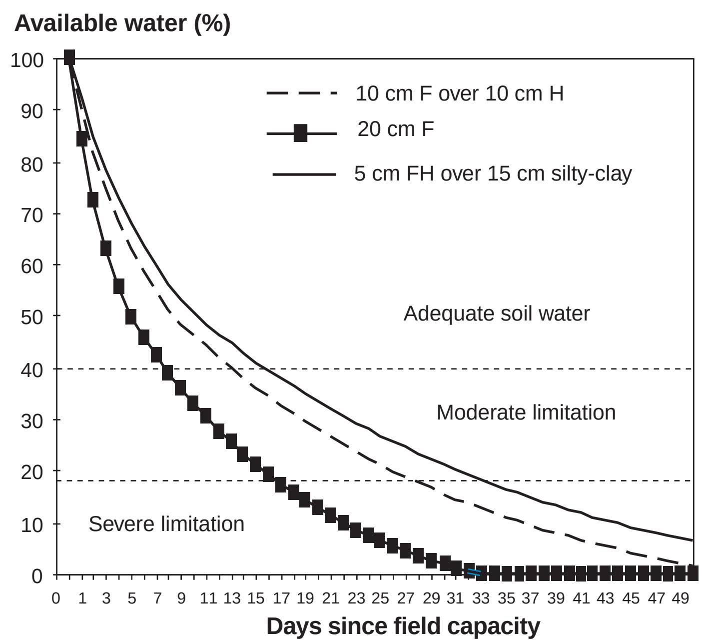

Figure 2. The depletion over time of available water within a 20 cm root zone for three hypothetical forest floor situations: 20 cm F-layer; 10 cm F-layer + 10 cm H-layer; 5 cm F and H over 15 cm silty-clay mineral soil (generated from a seedling root zone water model by D. Spittlehouse, MOF).

Available moisture decreases rapidly in F-material, particularly in the first days after field capacity. H-material and silty-clay mineral soil have smaller pore spaces, allowing those materials to retain moisture for longer periods.

reasonable planting window to be a period of four weeks following planting where water potentials do not drop below -0.1 MPa in the seedling root plug zone. On some sites, adequate moisture is always available in forest floor materials, either because of regular rainfall events, or because water is stored in underlying mineral horizons. For example, Heineman (1991) measured summer water contents for the F and H layers on a hygric site in the ICHmc1, and found these materials were rarely below field capacity. At the other extreme, however, the availability of moisture in the 5 cm thick forest floor on a high elevation site along the Idaho–Montana border would have been extremely limiting to seedling growth four days after it was at field capacity. Water potentials on that site were -1.5 MPa in early July and -100 MPa by late August (Potts 1985).

Temperature

The physical properties of forest floor materials make them less able to retain and conduct heat than mineral soil. On undisturbed sites, however, F- and H-layers occupy a physically superior position in the microtopography and prevent underlying mineral soil from warming. Seedlings planted in forest floor materials may therefore experience a warmer rooting environment than those planted in mineral soil at the bottom of deep screefs. This is particularly true on sites with a high soil moisture content.

Consideration of soil temperature is particularly important in British Columbia where cold soils are a widespread limitation to seedling growth. Terminology in the adjacent shaded box is used to describe soil temperature characteristics as they relate to seedling microenvironment, and applies to both mineral and organic materials. These properties, as they relate to soil moisture content, are illustrated in Figure 3. Typical values for the thermal characteristics of mineral and organic materials are provided in Table 1.

Figure 3 shows that dry mineral soil has a greater ability to retain heat than dry forest floor materials because it has a higher heat capacity, and also that it is better able to conduct heat because it has higher thermal conductivity. In addition, mineral soil warms more readily at depth than organic material because of its higher thermal diffusivity. Figure 3 also shows how water content affects the thermal characteristics of both mineral and organic substrates. Based on a one-to-one comparison of the thermal characteristics of mineral versus organic materials, mineral soil is better able to provide a warm root environment for seedlings than forest floor materials. However, on undisturbed sites, factors such as the relative position of these substrates in the microtopography, the rates at which they drain, and their water content at field capacity play a large role in determining how much they will warm. Forest floor layers insulate the lower mineral horizons from warming, and on moist sites this problem is compounded by high soil moisture content. Undisturbed forest floor materials, even though they have poorer thermal characteristics than mineral soil, will generally provide a warmer root environment than the underlying mineral soil. Seedlings planted on undisturbed sites have traditionally been placed on microsites screefed to mineral soil, which, depending on regional climate and soil drainage, were often too cold and too wet to be a good environment for root growth.

The low thermal admittance of forest floor materials makes them more likely to reach high surface temperatures than mineral soil. However, materials would have to be in firm contact with the seedling root collar, and rise above 54°C (Cleary *et al.* 1978) to be damaging to the seedling.

Soil Thermal Characteristics

Volumetric heat capacity (C) is the amount of heat required to raise the temperature of a given volume of soil material by 1°C. Dry mineral soil has a volumetric heat capacity two to four times that of dry organic material (Figure 3a).

Thermal conductivity (λ) is a measure of how well a material is able to move heat. Dry mineral soil conducts heat four to five times better than dry organic (Figure 3b).

Thermal diffusivity (λ/C) is a measure of how rapidly a material will be warmed at depth. Soils with high diffusivity allow changes in surface temperature to penetrate rapidly into the profile (Figure 3c).

Thermal admittance ($(\lambda C)^{1/2}$) is an index of the amplitude of surface temperature changes when heat is added or removed. A soil with low thermal admittance has large fluctuations in surface temperature (Figure 3d).

Definitions based on Stathers and Spittlehouse (1990).

Nutrient status and biological activity

Forest floor materials are rich in nutrients and they also harbour organisms essential for converting nitrogen in particular, into forms available for plant uptake. Mycorrhizal fungi are also common in the forest floor.

Most respondents to the questionnaire rated seedling nutrition high among the expected benefits of forest floor planting. Forest floor materials contain significant amounts of nutrients, athough they may be in forms

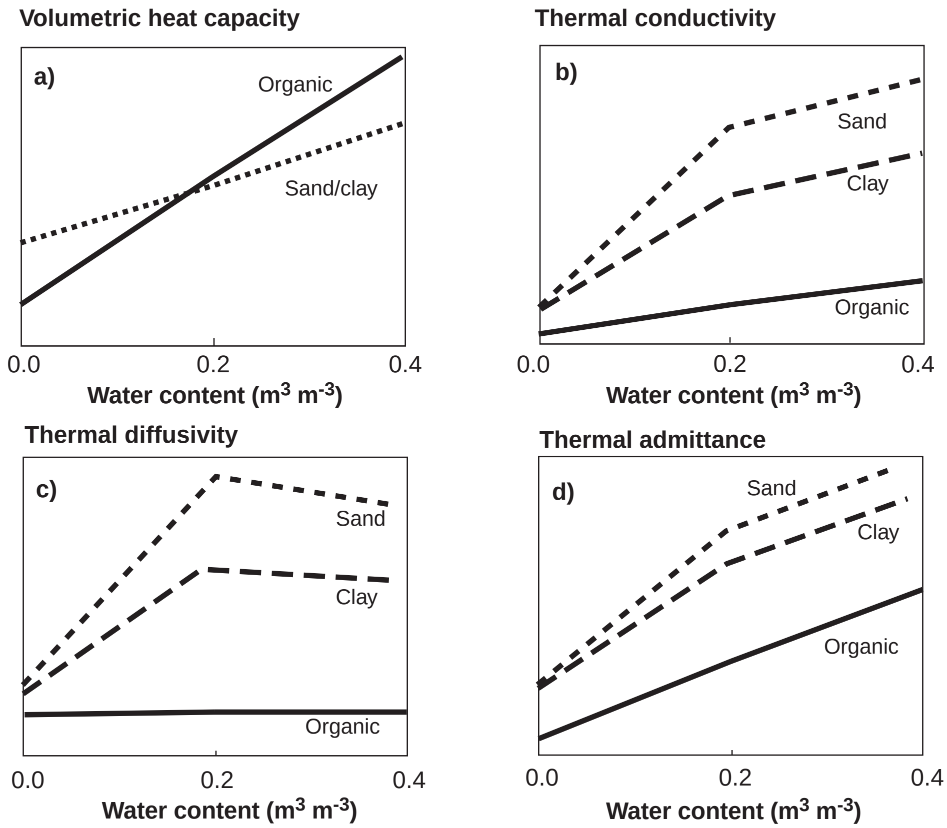

Figure 3. Thermal characteristics of mineral and organic materials: a) volumetric heat capacity; b) thermal conductivity; c) thermal diffusivity; and d) thermal admittance (based on van Wijk and de Vries (1966)).

that are unavailable for plant uptake. However, organisms that moderate the conversion of nutrients such as nitrogen and sulfur into usable forms are also found in the forest floor. Diverse populations of mycorrhizal fungi exist in forest floor materials, and colonization of seedling roots is enhanced when forest floor materials are undisturbed by site preparation (Jones *et al.* 1996). Mycorrhizae are well known to enhance the ability of seedlings to take up nutrients (particularly phosphorous) and water. Well-decomposed humus also contributes significantly to the cation exchange capacity (CEC) of a site, so that positively charged ions of minerals such as potassium and calcium, as well as ammonium ions, remain available for plant uptake rather than being leached out (Kimmins 1987).

Sources of information regarding the nutritional characteristics of individual forest floor materials were limited, but one study suggested that nutrient status varied with the stage of decomposition. Levels of available nitrogen were similar in well-decomposed rotten wood, undisturbed duff (likely F-layer), and mineral soil, but were lower in less-decomposed wood (>2 mm chunks) (Sidle and Shaw 1983).

Considering Forest Floor Planting in Relation to Site Limiting Factors

As with all aspects of a silviculture prescription, decisions regarding site preparation (including no site preparation), screefing, and acceptable planting substrates involve consideration of site limiting factors and existing constraints. Forest floor materials have many positive attributes, but their appropriateness, particularly with regard to the ability to provide adequate moisture to newly planted seedlings, must be considered on a site-by-site basis. Planting in undisturbed forest floor materials is most likely to be suitable for sites having slight to moderate growth limiting factors, rather than for sites where conditions are extremely limiting to seedling survival and growth. On sites with pronounced limiting factors, applying some form of site preparation to ameliorate the undesirable conditions may provide the best chance for successful plantation establishment. Site preparation has been observed to have less effect on the amount of time to free growing and green-up on sites with modest limiting factors than on sites with severe limiting factors (L. Bedford, pers. comm.). For some sites with severe growth limitations, however, MSP may not be an option because of factors such as steep terrain or concerns about site degradation.

Low soil temperature

Low soil temperature, compounded by high soil moisture content, is the most common limitation to seedling growth in north and north-central B.C., and it is also a common problem in many high elevation ecosystems across the province. Practitioners must assess the severity of the cold soil problem, and decide whether some form of site preparation is warranted. On many low to medium elevation sites where the growing season is not excessively short, nor the environment excessively cold, and where lack of soil moisture is not a limiting factor, good survival and growth have been observed for pine and spruce seedlings planted on natural raised microsites in the undisturbed forest floor. These observations apply particularly to various SBS subzones in the Prince George and Prince Rupert forest regions. Screefing to mineral soil would have traditionally been prescribed for many of these sites.

For sites where soils scarcely warm above 10°C in the growing season, studies have demonstrated that mechanical site preparation increases temperature in the seedling root zone (Macadam 1988) and improves seedling performance (e.g., Dobbs and McMinn 1977; Bedford *et al.* 1998). Most questionnaire respondents in the Prince George Forest Region were satisfied, so far, with the results of forest floor planting in the ESSF. However, a cautious approach is recommended for this zone. Limiting factors, particularly cold soils, are severe in the ESSF, and the growing season is short. In his report on regeneration in the ESSF, Farnden (1994) recommends that particular attention be paid to the management of thermal regimes, and he notes that soil temperature can be considerably improved by site preparation. He acknowledges, however, that options for site preparation are often limited by terrain and site conditions.

Cold, moist, fine-textured mineral soils are also a severe limitation to seedling performance in the BWBS zone of northeastern B.C. Many of these sites are unsuitable for MSP because of high water tables and lack of summer access, making forest floor planting the more desirable option. Soils with high clay contents are often so dense that root egress is physically restricted, and on mechanically prepared sites, soils may dry and harden during summer months, magnifying the problem.

Dry/hot sites

On dry sites, where stored moisture is depleted early in the growing season and precipitation events are irregular, planting in undisturbed forest floor horizons should be approached with caution.

Although no directly related research is available, examination of the hydrological characteristics of organic substrates suggests that seedlings planted with a large proportion of the root plug in the forest floor are likely to experience substantial moisture stress during the growing season, especially when competing vegetation is present. The forest floor is generally thin on dry sites, so the total amount of water stored in the F and H horizons, even at field capacity, is small. As forest floor materials dry, hydraulic conductivity decreases and they act as a mulch restricting the movement of water upward from mineral horizons. A seedling root plug that is planted half in the forest floor and half in mineral soil may be in contact with sufficient moisture for root development only at its lower tip. On the other hand, if the majority of the plug is situated in mineral horizons, and forest floor materials are retained as a mulch, moisture loss from the root zone will be reduced. However, because of the low thermal admittance of organic substrates, there is also a concern that the surface of the forest floor on hot, dry southern aspects may reach temperatures that are damaging to the stems of young seedlings.

Competing vegetation is examined as a separate issue in this report. However, since pinegrass is so common on dry sites in the Cariboo and southern interior, its compounding effect on drought is discussed in this section. Pinegrass is an extremely effective competitor for moisture because it grows rapidly in the spring, depleting available moisture (Nicholson 1989), and because its roots form a dense mat at the soil surface. A modelling study in the IDFdk suggests that in the presence of pinegrass, the top 20 cm of soil may soon dry to water potentials limiting to seedling growth, whereas in the absence of pinegrass, the dry surface mineral soil acts as a mulch restricting water loss from lower portions of the root zone (Spittlehouse and Goldstein 1989). On pinegrass dominated sites, manual scalp and screef at a minimum, or site preparation is recommended.

While concerns about drought and forest floor planting are valid in many areas of B.C., it is difficult to define parameters for sites at risk. A possible solution would be to examine long-term climate data for different subzones and determine the probability that moisture will be limiting. For example, Nicholson (1989) found long-term climate records for the IDFdk near Williams Lake indicated early spring conditions were unsuitable for seedling growth 80% of the time. Similarly, Spittlehouse and Childs (1990) examined 57 years of records for a site in the CWHds1, and found conditions were too dry for seedling establishment 17% of the time, and marginal 50% of the time.

Excess soil moisture

Excess moisture is a common problem on sites across B.C., particularly in lower slope portions of cutblocks and depressions where there is a high water table, as well as in areas with persistent, shallow seepage throughout the year. There is no easy solution to meeting stocking requirements on these sites, many of which have historically supported stands with low basal area. Although excess moisture is a severe growth limiting factor, there may be no advantage to MSP, since observations suggest that seedling roots have difficulty leaving mounds in high water table areas. Planting multiple seedlings high in organic material around stumps may be as viable an option, and it is considerably less costly.

Competing vegetation

The implications of forest floor planting on competing vegetation depend on the type of vegetation complex that is expected to be dominant. The occurence of vegetation species that benefit from disturbance of the forest floor, either because they bank seed, or because they germinate in exposed mineral soil, will be less on sites where the forest floor is left intact. On the other hand, species that respond vigorously to increased light levels following harvesting are likely to be more problematic on undisturbed sites than where some form of site preparation is applied. Pinegrass, which was discussed earlier as a serious competitor for moisture, falls into this second category.

Prompt planting after harvesting is often a key factor to successful seedling establishment on sites prone to vegetation competition. Forest floor planting is not recommended for backlog sites with a well developed vegetation community.

Summer frost injury

On sites that have little vegetation cover and are subject to severe summer frosts, seedlings planted in the undisturbed forest floor are at a higher risk of summer frost injury than seedlings planted in exposed mineral soil. Black *et al.* (1991) found that frost injury of Douglas-fir and Engelmann spruce in the southern interior could be reduced by scalping and ripping treatments that exposed large patches of mineral soil. The exposed mineral soil warmed during the day and released heat during the night, offsetting the effects of frost. Undisturbed grass and organic material were noted to limit both the amount of heat conducted into the soil during the day and the amount of heat released during the night. In order to reduce summer frost injury, patches of exposed mineral soil must be a minimum of 0.5 m × 0.5 m (D. Spittlehouse, pers. comm.), which may increase the risk of frost heaving.

Snow creep and press

On high elevation sites that receive a considerable amount of snow, particularly in the ESSF of north-central B.C., the risk of physical damage from snow creep and snow press may be a greater limiting factor than cold soils. On those sites, regardless of whether or not seedlings are planted in the forest floor, microsites should be selected primarily for the presence of obstacles that protect the seedlings, and secondarily for position in the microtopography (A. Eastham, pers. comm.).

Shallow soils

On sites where mineral soils are either shallow or have a shallow restricting layer, forest floor materials are particularly important as rooting substrates. Seedlings on some sites in north-central B.C. experience both extremes of moisture availability during the growing season because they are exposed to a perched water table in early spring, followed by moisture stress later in the season because their roots are unable to exploit mineral material below the shallow impervious layer (P. Sanborn, pers. comm.). On these sites, H-layer material and well-decomposed wood may provide a more suitable and stable moisture environment than other substrates for roots of planted seedlings.

Frost heaving

In areas that have a high risk of frost heaving, retention of forest floor materials serves to insulate surface mineral horizons against freezing. Frost heaving requires repeated freeze / thaw cycles in the fall and early spring, when there is no snow cover. Reducing the number of times ice forms in the upper mineral horizons will reduce the extent of heaving. Frost heaving has also been associated with depressions created by screefing, particularly when mineral soil is exposed in the depression (Bowden *et al.* 1994).

Insects and disease

Certain insects and diseases are associated with forest floor materials in British Columbia, but they are not a major consideration in the decision about whether or not to plant in these materials. For instance, Warren's root collar weevil, which is common throughout the interior of B.C., is known to increase in abundance as forest floor depth increases, but it is not known whether seedlings planted in the forest floor are at greater risk than seedlings planted in mineral soil.

Root rots are associated with forest floor materials only to the extent that old infected roots from the harvested stand are present in that substrate. Young seedlings only become infected when they come into direct contact with old infected root systems. In the case of *Armillaria*, rhizomorphs which can occur some distance from the stump, can be a factor in determining rates of infection. In order to lower the probability of innoculation, provincial root disease management guidelines suggest that seedlings be planted at least 50 cm away from stumps on *Armillaria* infested sites, and 5 m away on *Phellinus* and *Tomentosus* infested sites.

Planting Specifications for Forest Floor Materials

Questionnaire responses indicated only a few specifications were particular to planting in forest floor materials. Others, such as planting date were a matter of location and opinion, and applied equally to all types of planting.

Acceptable substrates and screefing

It is now general opinion that mineral soil is not the only acceptable planting substrate, and that the suitability of a material must be assessed in terms of its ability to meet seedling establishment and growth requirements. The majority of respondents thought F-layer, H-layer, and well decomposed rotten wood were acceptable planting substrates, but that totally undecomposed litter and slash must be avoided. Many recommended a shallow screef to get rid of loose material and confirm substrate suitability. It was also noted that live moss on newly harvested sites, except in hypermaritime coastal areas, is an unacceptable substrate because it tends to dry up and disappear within a year, leaving plugs exposed.

In order to avoid the perception that forest floor planting equals ‘drop and run’, it is important that planters have a good understanding of the concepts of microsite and substrate selection.

Seedling tightness

A number of respondents recommended that seedlings should be considered ‘tightly planted’ as long as one or two top needles could be grasped and plucked off the seedling without dislodging it. This would eliminate the necessity for planters to kick seedlings in to ensure tightness, thereby creating depressions around seedlings and destroying the structural integrity of the forest floor materials. Planters sometimes reported difficulty securing shorter plug sizes in loose forest floor materials. Under these conditions, provincial guidelines recommend larger stocktypes (e.g., 415B, 412A) be used (Scagel *et al.* 1998).

Planting next to stumps

Most respondents thought planting next to stumps was desirable because of the elevated microsite position, and also because the stumps served as obstacles to offset snowpress, snow creep, and cattle trampling. However, one respondent recommended that seedlings be planted at least 30–60 cm from the stumps in order to avoid air pockets. This suggestion is supported by a toppling study in the Vancouver Forest Region, in which unstable trees were observed in proximity to stumps, particularly on burned sites (Bancroft and Nelson 1992). Another study found that asymmetrical root systems developed when seedlings were planted next to stumps, and recommends planting at least 70 cm from stumps on sites with a high windthrow hazard (Quine *et al.* 1991). As noted above, distance from the stump is also related to rates of infection by root rots.

Depth of planting

Questionnaire responses were variable with regard to planting depth, and ranged from placing the surface of the plug even with the forest floor to placing the plug two fingers (about 5 cm) below the surface. It was also noted, however, that the forest floor decreases in thickness gradually as organic material mineralizes, and root plugs planted even with the forest floor surface are likely to become exposed. Appropriate planting depth depends on local site conditions, and as Sutton (1967) points out, the most important consideration is to place roots where they can best exploit the resources of moisture and nutrients at the planting site.

Conclusions

On unprepared sites, seedlings have traditionally been planted in screefs that extend down to mineral soil, but good seedling performance has recently been reported, particularly in north and north-central B.C., for seedlings planted in forest floor materials. Forest floor substrates have many qualities that make them good media for root growth, particularly good aeration, low bulk density, and availability of nutrients. However, their characteristics with regard to moisture availability during the few weeks after planting are also very important, and may be limiting in dry regions of the province.

Planting in forest floor materials is one of many options available to silviculturists, but like other options, its suitability in addressing site limiting factors must be considered. The severity of the limiting factor is important, and forest floor planting should not be considered to the exclusion of MSP for sites with harsh growing conditions. Drought is a valid concern in many areas of the province, such as the Cariboo and southern interior, but it should be emphasized that many other types of ecosystems are present in these geographic areas, for which forest floor planting may be a suitable option.

Specific recommendations on forest floor planting in various subzones have not been made in this report because insufficient information is available to do so. Questionnaire responses were helpful for defining issues, but were anecdotal rather than research related. Very few studies have been carried out that are directly related to forest floor planting. However, the general discussion about forest floor properties and site limiting factors should serve to clarify some of the issues involved in appropriately prescribing this technique.

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