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Extension Note

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Opportunities for Improvements to Reforestation Success

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Abstract

Various issues pertaining to artificial reforestation using coniferous planting stock are presented in the question/answer format. The discussed topics include: planting into organic soil substrates, microsite selection, planting depth, and closing the planting hole. These topics are viewed in the context of different site-related or climate-associated factors that may limit the successful establishment and growth of planted seedlings. A brief discussion of the literature on basic requirements for seedling growth and survival is also presented.

Introduction

Current Ministry of Forests planting standards in British Columbia (effective since February, 1997) include several requirements considered to be crucial to the successful establishment and appropriate growth of planted seedlings. Practitioners accept most of these requirements without controversy but a few have been questioned. Some of the topics for consideration are as follows:

1) planting into organic soil substrates
2) microsite selection
3) planting depth
4) closing the planting hole

The ongoing discussion and the expression of views and recommendations contrary to those outlined in the current standards have caused some confusion in reforestation operations. Some planters and planting supervisors rigidly adhere to the existing standards. Others are willing to try new alternatives but are uncertain how broadly these innovations can be implemented. Planters may face penalties for diverging from the accepted contract standards. This extension note is not intended to replace the existing contractual planting standards but to provide background for possible future amendments to these standards and for improvements to planting practices. Still, the sole base for evaluation of planting crew performance should be their adherence to the conditions mutually agreed upon by the contractor and the employer prior to undertaking the work.

A major reason for differences in opinions as to what can or cannot be seen as acceptable planting methods is the diversity of site conditions in the province. Factors that are limiting to successful plantation establishment in one part of the province may be of little relevance somewhere else. In this extension note, we will discuss the subjects of controversy and relate them to the major limiting factors that commonly occur on forest sites in British

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Columbia. Literature relevant to these subjects is presented, where available.

Planting into organic soil substrates

Current planting standards consider that the removal of all humus by screefing is not always desirable or warranted, but planting into duff, rotten wood, stumps, and other organic material subject to drying out is listed as unacceptable. This implies that humus is not considered "duff." Judging by answers to the questionnaire used in the preparation of Silvicultural Note 16 (Heineman 1998), the meaning of the term "duff" is ambiguous, and the term "duff planting" can have different meanings, depending on the meaning of "duff." Schedule C of the planting contract allows the definition of acceptable microsites according to site-specific requirements.

The removal of some or all organic materials from the planting spot determines the placement of roots in particular soil substrates. According to the current standards, screefing depth and scalping width, if applicable, must be specified in the planting contract.

How have we developed the impression that mineral soil is a better rooting medium than organic substrates?

Experiences with natural regeneration have shown better establishment of seedlings on mineral substrates than on organic substrates. This is mainly because mineral soils usually dry less rapidly than do organic substrates. Mineral soils heat up more slowly than do many organic substrates but also stay warm longer.

M. Krasowski: Natural regeneration is often more successful on exposed mineral soils than on undisturbed forest floor. Although seed germination occurs on almost any forest floor substrate (Harvey 1982), the subsequent establishment success or failure depends on the mortality among germinants. Inadequate moisture, excessive heat, and fungal pathogens are among the most common reasons for this mortality (Vaartaja 1954). Thus, poor moisture retention properties and undesirable thermal characteristics of organic substrates (see Heineman 1998) contribute to high mortality of germinants growing on these substrates.

R. Elder: Caution must be exercised when referring to the poor moisture-retention properties or the undesirable thermal characteristics of organic substrates. Not all organic materials exhibit the same characteristics. Litter, for example, may have poor moisture retention that could result in excessive drying, whereas the humic layer may have great moisture retention, which, under certain site conditions, may result in storing excess moisture.

Can we extrapolate to planted seedlings from observations made on natural regeneration?

Only partly. Large transplants would be expected to be more stress resistant than succulent germinants. On the other hand, established naturals could be less prone to stress than newly planted seedlings that need some time to expand their root systems and develop good contact between their roots and the soil. Thus, it is important to understand the development and requirements of tree seedlings so that their handling and timing of planting place seedlings in harmony with their post-planting environment.

What sites are good candidates for planting into undisturbed organic soil substrates?

Sites with adequate soil moisture throughout the growing season or even with periodically excessive soil moisture (provided that mechanical site preparation is unnecessary) can be planted without disturbing the organic matter. Sites with low or moderate competing vegetation can be considered for planting into undisturbed forest floor.

Many sites in British Columbia may be suitable for planting into undisturbed organic substrates. Sites where severe summer drought is unlikely are good candidates. Successful planting into organic substrates, referred to as duff, has been reported for Sitka spruce planted on clearcuts in southeastern Alaska (Sidle and Shaw 1987; Loopstra et al. 1988). Duff planting resulted in very good height growth reported in these studies. Balisky et al. (1993, 1995) recommended planting into undisturbed organic soils in some ecosystems of British Columbia. They reasoned that the shallow rooting characteristics of naturally established seedlings in boreal and sub-boreal zones imply that there is adequate moisture in the shallow soil to sustain seedling growth. They also cited the work of Heineman (1991), which demonstrated that moisture availability did not limit seedling survival and growth in the moist, cool ICH. The type and the aggressiveness of competing vegetation should be assessed before a decision is made to plant into the undisturbed forest floor.

Are sites with aggressive competing vegetation suitable for planting into undisturbed forest floor?

When competing vegetation is mainly herbaceous, planting without disturbing the forest floor also leaves this vegetation undisturbed. This can limit regeneration success. Vegetation control or mechanical site preparation are better options than raw planting for such sites. Grassy sites are especially unsuitable for planting into undisturbed forest floor.

The decision whether to plant raw or not depends on the type and aggressiveness of competing vegetation. Vegetation not only reduces the light available to seedlings but it also competes for soil moisture and nutrients. Studies on cool, moist, higher-elevation SBS sites in the Prince George Forest Region showed that competition from herbaceous vegetation on raw-planted sites severely reduced growth and survival of planted spruce. All types of site preparation applied on these sites (scalping, mounding, and prescribed fire) showed much better growth and survival after 10 years than planting without site preparation, and so did vegetation control by herbiciding (Hawkins et al. 1995). The controls were planted after screefing the microsite but it is doubtful if planting without any disturbance would yield better results, because vegetation was the most important limiting factor on these sites. Mullin (1966) concluded that when competing vegetation was the most important factor affecting the growth of white spruce seedlings, its negative effect could not be surpassed by the choice of planting techniques or planting depths. Vegetation also improves habitat for voles and mice, which can have a detrimental impact on seedlings.

Roots of competing vegetation deplete the soil of water and nutrients. Placing seedling roots in the same rooting zone as that occupied by roots of competing vegetation makes little sense, especially on sites where moisture availability is limited. In a critical drought, treatments that best control vegetation retain the highest soil moisture content and result in the best survival of planted conifer seedlings. Larson and Shubert (1969) examined the growth of ponderosa pine in competition with various grasses, finding the best growth of conifer seedlings on cleared plots. Grass roots began to grow earlier than roots of pine seedlings. They severely depleted soil moisture and reduced colonization of pine roots by mycorrhizal fungi. Some vegetation (e.g., bluejoint reedgrass [*Calamagrostis canadensis* L.]) forms a thick insulating layer on the ground and can delay soil thawing by a month, compared to mowed plots (Hogg and Lieffers 1991), thus shortening the growing season. Bluejoint reedgrass is also a fierce competitor and a contributor to problems with vegetation press and snowpress. The occurrence of this grass can be reduced by broadcast burning using hot fire (Dyrness and Norum 1983). Generally, site preparation treatments and/or vegetation control should be used rather than raw planting (whether into mineral or organic substrates) on sites where competition from vegetation is growth limiting.

Is planting into undisturbed organic substrates suitable for hot, dry sites?

Ensuring root access to soil moisture should be the most important objective while planting on hot, dry sites. Planting into screefed microsites places most or all of the root system into the mineral soil that stores and conducts moisture to the roots better than do organic substrates. Leaving a shallow humus layer on top of the mineral soil may be considered. It would insulate the mineral soil and slow down its drying. Longer root plugs would allow access to moisture deeper in the soil when the ground surface dries out. Generally, planting into undisturbed organic substrates on hot, dry sites is risky and it is not recommended.

Excessive heating and drying of organic substrates may cause severe stress and mortality among seedlings whose roots are mainly in organic substrates. Potts (1985) analyzed moisture characteristics of different organic materials he considered as "duff." The study was conducted in the northern Rocky Mountains of the United States and the duff depth on the study site averaged 8.5 cm (5 cm of upper duff—the fermenting layer, and 3.5 cm of deeper duff—decomposed humus). His calculations showed that these materials could provide only a 4-day water supply for evapotranspiration in mid-summer. He concluded that on such sites, even in summers with normal precipitation, seedlings rooted only in duff would be severely stressed or dead by mid-summer. Dry substrates passively compete with roots for moisture, and on some sites duff competition for moisture can account for up to 100% of growing-season precipitation in most years (Potts 1985). Potts (1985) stated that temperature extremes between 40 and 50°C at the duff surface were not uncommon in the study area. He cited DeByle (1981) who observed duff surface temperatures in western Montana reaching 79°C. Hot, dry ecosystems often have shallow organic layers, and the opportunity to plant solely into organic layers, without root contact with underlying mineral soil, may be limited. Maximizing root contact with mineral soil is recommended.

Personal observations (R. Elder) from several sites planted in the Chilcotin Plateau, in the southern Okanagan, and on the east side of the Coast Range in Washington and Oregon: Where container-grown stock was used, planting into organic substrates did not result in mortality rates greater than planting into mineral soil, providing that excessive disturbance of the planting medium was minimized. "Excessive disturbance" can be described as any practice that significantly alters the original integrity of the planting medium profile, as can happen in the case of mechanical site preparation or "enthusiastic" planting-hole preparation. Many early studies involving planting into organic substrates, particularly in the United States, were carried out utilizing bare-root or plug-transplant stock. Root form and structure were significantly different from those of plug stock, and excessive drying has been reported (Cleary et al. 1978). When planting into potentially dry sites, it is critically important to choose a planting window that allows initial root development to occur prior to the onset of the dry season. Riverside Forest Products Ltd., Williams Lake, has reported that planting on the Chilcotin Plateau in central British Columbia in the last 2 weeks of June and the first week of July has consistently yielded good seedling survival and growth, when well-conditioned container-grown seedlings were used.

Is planting into undisturbed organic materials acceptable on sites with excessive moisture?

Yes, if there are enough high, dry microsites. Screefing and creating deep depressions must be avoided. Vegetation control may be necessary.

Planting into organic substrates may be the only way to plant wet sites without site preparation. Raw planting of wet sites makes sense only if there are enough high, dry microsites. Otherwise, it is necessary to prepare the site mechanically. Excessive moisture results from shallow water tables, poor drainage through the mineral soil, or both. Thus, screefing removes the driest surface layer of the soil and causes root placement close to the water table and/or into the poorly drained mineral soil. Poor aeration usually occurs with excessive moisture. These problems are often encountered on sites with fine-textured soils. Peatlands that are difficult to regenerate can be treated by combining site mounding with deciduous nurse crops (Multamaki 1942; Johansson 1987).

The highest and driest microsites, either natural or artificially prepared, should be chosen when planting on sites with excessive moisture. However, planting microsites that have been created from thick humus, fine-textured silts, or clays may place roots in poorly aerated environments, yielding unacceptable survival and growth (R. Elder, personal observations).

Do most roots of naturally regenerated trees occur in organic soil substrates?

Naturally regenerated seedlings develop their roots first in the substrate in which they germinated. As they grow, most fine roots typically develop in the interface between organic and mineral soil. Further development of the root system depends on the species habits. Many structural roots develop in the mineral soil to provide anchorage.

It is often said that most roots and most root activity occur in the surface soil, and that this soil has the greatest importance to site productivity (Kimmins and Hawkes 1978; Little and Shainsky 1992). The "surface soil" is an imprecise term that may imply that most roots occur in the organic soil. Balisky et al. (1993, 1995) cited studies that showed that most fine roots develop in the interface between organic and mineral soil. They also presented a drawing that showed that most seedling roots were positioned just under that interface, in the uppermost mineral soil. One benefit of planting into undisturbed forest floor is the positioning of the root system such that most of the new root growth can occur in the interface between organic and mineral soil. Planting a large portion of the root system deep in the mineral soil may be counterproductive to that purpose.

Which organic substrates are acceptable planting media and which ones are not?

Some substrates should always be avoided. Logging slash and fresh wood chips are not a good place for roots. The suitability of other organic substrates for root development depends on site conditions, and individual substrates should be assessed in the context of site-limiting factors. Are they likely to dry out or become very hot? Are they too fine textured to provide good aeration? Fine-textured, moist, decomposed humus, when too thick, may not be a good rooting medium. Usually, the fermenting organic layer is suitable for root growth.

Many organic substrates (even if classified as the same type of substrate) vary in their properties depending on the original material from which they were formed, their state of decomposition, their depth, and their interaction with other site characteristics (aspect, depth to water table, type of underlying mineral soil). These characteristics, together with precipitation and evapotranspiration (from soil surface and through vegetation on the site), confound seedling growth responses in relation to soil organic matter (Jurgensen et al. 1997). On sites where soil moisture is not a problem, most decomposing or decomposed organic substrates appear to be acceptable planting media. When utilizing organic material as a planting medium, the disturbance to the material should be minimized. Excessive disturbance will disrupt the integrity of the profiles, which in some cases can lead to increased drying (R. Elder, personal observation).

On the other hand, manual mixing of mineral and organic substrates while preparing microsites has produced very good results on Acadian mixedwood sites (Salonius et al. 1996). Although it is costly, this method may be appropriate and beneficial for planting steep slopes characterized by aggressive competing vegetation, partially harvested sites such as shelterwoods, and sites that require some site preparation treatment but are subject to restrictions of soil disturbance at the same time.

Is decayed wood an appropriate rooting medium?

Not necessarily. On hot, dry sites decayed wood can hold moisture longer than other organic substrates but, with declining moisture, it passively competes with roots for water (absorbing and binding water, making it unavailable to the roots). On cold, moist sites, decaying wood is typically cooler than other organic matter usually referred to as "duff." Planting into decayed wood on hot, dry sites and on cold, moist sites is not recommended. Since little information is available on the effects of decaying wood on seedling growth, avoid planting into this substrate.

Loopstra et al. (1988) reported that height growth of Sitka spruce seedlings planted into rotten wood was, after 4 years, poorer than growth of seedlings planted into mineral soil and of those planted in undisturbed duff. Shaw et al. (1987) also found that the growth of Sitka spruce seedlings planted in rotten wood was significantly slower than the growth of seedlings planted into undisturbed duff. This research was conducted on sites where the soil was cool and moist. Woody material is often wetter and cooler than the rest of the forest floor (Reinhardt et al. 1991), and, on cold, moist sites, rotten wood may be detrimental to root growth (Loopstra 1988). On warm sites, soil wood retains moisture better than does the forest floor (Loopstra 1988) but on hot, dry sites it may become excessively dry. The discussion on woody residues by Jurgensen et al. (1997) cites various studies showing that decaying wood is a good source of nutrients but that decomposition and mineralization of organic compounds depend on the microclimate and species of fungi that colonized that wood. Wood of different tree species decays differently and has different value as a rooting medium. White-rotted wood of conifer species rapidly looses its structural integrity but better supports non-symbiotic nitrogen fixation and has more rapid nutrient fluxes than brown rotten wood (see Jurgensen et al. 1997). Little information is available on the value of different types of rotten wood as root growth media, especially in relation to various limiting site conditions. An article in a recent issue of the Forest Science Department Newsletter (University of British Columbia) discussed the nutritional significance of coarse woody debris, based on work by Dr. Cindy Prescott. Coarse woody debris of lodgepole pine, Engelmann spruce, and subalpine fir was not considered a significant source of nitrogen and phosphorus in these forests. During wood decomposition, the decomposing microbes can actually compete with the seedling for growth-limiting nutrients.

Considering the incomplete state of current knowledge on the effects of decaying wood on seedling growth, it is better to be cautious about using such wood as a planting medium. Where other acceptable planting sites are available, avoid decaying wood as a plantable microsite. It may be better to plant the seedling just off the edge of the decaying wood rather than immediately into it, providing that the adjacent spot does not place the root system into moisture-laden zones. In some coastal environments or cool, moist ecosystems, there may be many sites with a high proportion of decaying-wood microsites. If planting into decaying wood is necessary, only material that can be easily penetrated with a planting tool should be considered and its disturbance minimized to prevent its drying (R. Elder, personal observation).

What are the benefits and disadvantages of boot screefing?

The decision whether to screef or not should be based on the assessment of site-limiting conditions and the effects of screefing on these conditions.

Hot, dry sites: *Although both screefing and not screefing have certain potential benefits, it may be safer to screef such sites and expose the mineral soil than to leave the organic layer and plant a portion of the root system in the organic substrates.*

Screefing to the mineral soil moderates temperature extremes at the soil surface and reduces the possibility of soil-surface drying, compared to organic surfaces. A small depression at the microsite (organic layers are usually shallow on such sites) promotes the accumulation of water at the microsite, which is desirable on these sites. Not screefing will leave an insulating layer of organic substrates at the surface and reduce the heating and drying of the underlying mineral soil. This can be beneficial. However, the organic layer can become very hot and dry, and it is uncertain if it can sustain any root growth. If not screefing, the logical solution would be to plant the root collar flush with the underlying mineral soil so root growth from the upper part of the root system would not be impeded by the hot, dry organic layer. The insulating properties of the organic layer will also slow down the warming of the mineral soil early in the growing season, which may be detrimental to root growth during the time when soil moisture may not be growth-limiting (most root growth typically occurs in the spring and fall).

Moderately warm sites without soil drought or drainage problems: *Such sites are good candidates for planting into the forest floor without screefing. If competing vegetation poses a significant threat, boot screefing cannot be viewed as* *an effective method of controlling competing vegetation, and other measures must be undertaken.*

See preceding discussion about the suitability of sites for planting into undisturbed forest floor.

Cold sites and sites with excessive moisture: *Screefing is generally not recommended, because it places microsites into depressions that are colder and wetter than other microsites. Planting high microsites is recommended, because it improves soil temperature in the root zone and decreases the possibility of excess moisture conditions, improving soil aeration at the same time.*

See discussion of related topics in this text.

Microsite selection

Current planting standards recognize that proper microsite selection is critical to plantation success. Common planting faults related to microsite selection include planting on dry mounds (natural mounds) or into loose gravel (considered too dry), and planting in a depression or creek bed where the conditions are likely to be too wet. Planting under overhead obstacles is listed as faulty, but side shading may be desirable when a reduction of seedling exposure to full sunlight and to the sky at night (related to frost hazard) is desired. Planting contracts should instruct planters how to secure proper shading. Improper shading (usually planting on the wrong side of a potentially shading object) is considered a fault. Planting into shallow soil, as over a buried rock, is also considered improper. These specifications, together with the definition of acceptable spacing, provide a reasonable guideline. Nevertheless, microsite selection criteria should be clearly defined in the planting contract and discussed with planters before the planting begins.

What are the benefits of planting elevated microsites?

Elevated microsites are warmer (air and soil temperatures) and drier than the adjacent flat terrain and ground depressions. Benefits of soil warming to seedling growth have been consistently reported for many sites in British Columbia. On sites with excess moisture, elevated microsites are less prone to develop problems with poor soil aeration than are adjacent, lower microsites. High microsites may provide seedlings with better access to light (less impact of brush competition) than lower microsites.

Depending on the type and height of competing vegetation, seedlings on elevated microsites may be above at least some of that vegetation. On sites with variable topography, less frost, greater survival, and better growth of seedlings occurs on higher microsites and on the upper part of the slope than at its bottom and on low microsites (Raitio 1987). Andersson (1976) found that Norway spruce seedlings planted in depressions had a lower survival rate than those planted elsewhere. Benefits from planting on elevated sites are likely to be most evident on sites characterized by low soil temperatures and/or excessive moisture. Low soil temperature was found to limit root growth and rooting depth in many boreal forest soils (Sutton 1969; Lopushinsky and Max 1990). Balisky and Burton (1995) suggested low soil temperature as the main cause of poor rooting at high-elevation sites in British Columbia. Therefore, planting on elevated microsites is strongly recommended for sites where increasing soil temperature and decreasing soil moisture is expected to improve seedling survival and growth performance. Many sites in British Columbia fall into this category.

When should planting not occur on elevated microsites?

Elevated microsites increase seedling exposure to direct sunlight. On hot, dry sites, planting elevated microsites may be risky, unless the microsites are sheltered by objects present on the site. On sites with fine-textured soils and typically shallow snowpacks, high microsites increase the risk of freeze desiccation, especially if the site is raw planted. Planting in depressions could improve survival on hot, dry sites and on sites prone to problems with freeze desiccation. Plant in depressions on such sites only if significant seedling mortality is otherwise expected on raised sites.

Elevated microsites may increase drought and heat injury hazard on sites prone to this type of problem. Soil temperature extremes may be limiting to root growth in different geographic locales in different ways. Sutton (1991) cited Bilan (1968) who had shown that high soil temperature in Texas resulted in virtual absence of lateral roots in the uppermost 5 cm of the soil. Obviously, the climate of the southern United States is different from that of British Columbia, but there are sites in the southern interior of our province where heat and drought are a significant problem.

Natural humps covered with organic material are different from mechanically prepared mounds. These natural humps would likely develop greater temperature extremes at the surface but less rapid temperature changes at depth, compared to excavator mounds. They may also become drier than excavator mounds, especially at the surface. Natural humps are also prone to be drier and to have greater temperature extremes than non-elevated ground. Thus, natural elevated microsites should not be selected for planting on sites where drought and heat are serious problems, unless some kind of sheltering is available. Sheltering seedlings by planting behind stumps or stones, or even by planting into depressions (provided there is little frost hazard), may improve survival. Potts (1985) considered depressions beneficial to the establishment of natural regeneration on hot, dry sites. However, on many sites, soil temperatures in depressions may not be optimal for root growth in the spring. Plant into positions where soil temperatures suitable for root growth occur early in the season. Hot, dry sites, especially sites where late frosts are uncommon, should be planted early in the spring when soils are still moist.

High-planted seedlings can also be susceptible to freeze-desiccation injury (Krasowski et al. 1995, 1996) and photoinjury (injury caused by intense sunlight during subfreezing air temperatures) (Christersson and von Fricks 1988). All methods that reduce seedling exposure to direct sunlight during winter and early spring may reduce the danger of freeze desiccation and photoinjury. Sheltering sites prone to freeze desiccation may be a better method of alleviating hazardous conditions than planting into depressions. Shelterwood has proven to be an effective method of moderating environmental extremes in temperate regions (Windell 1992). In early spring when snow is gone, promoting early ground thawing and protecting seedlings from intense sunlight will reduce the danger of freeze desiccation. This may be achieved by planting near stumps, especially on their eastern sides. Microsites around stumps are typically free of snow earlier, and thaw and warm earlier, than microsites on flats or in depressions (Brett and Klinka 1998[1]; R. Elder, personal observations). Planting sites prone to freeze desiccation without site preparation is risky, and all measures that reduce ground-insulating vegetation and hasten soil thawing are recommended (Bärring 1967; Krasowski 1996). Nevertheless, retaining some well-spaced, narrow rows of brushy vegetation is encouraged, to reduce snow sweeping by wind from clearcut sites, to promote snow retention, and to protect seedlings against freeze desiccation and photoinjury.

Does planting elevated microsites and planting into organic substrates of the forest floor increase or decrease the risk of injury from growing-season frost?

Seedlings on elevated microsites are at lower risk of injury by growing-season frost than those planted on lower microsites. Growing-season frost occurs more often just above the ground covered with organic substrates than above the exposed mineral soil. Planting high microsites in frost-prone areas is strongly recommended, regardless of the type of ground cover.

Selection of the highest microsites will alleviate some of the risk of growing-season frost damage (Raitio 1987). Cold air typically flows from higher to lower locations, and night air temperatures will be lower in low than in high microsites. Cold air tends to pond in depressions and on cleared flats with less than 3° slope (Washburn 1978). Flat clearcuts and those with few elevated microsites may need to be mechanically prepared if frost hazard is serious. It is very important to correctly predict the pathways of air movement downslope, and to design cutblock boundaries, windrows, and other potential barriers to air movement such that they do not obstruct that movement of cold air. New cutblocks can alter the air drainage on the landscape. Creating new openings that redirect cold air towards young plantations should be delayed until the average height of trees on the plantation at risk is greater than 1 m. Trees taller than 1 m are above the coldest air and usually escape serious injury from growing-season frosts (Cannell and Smith 1984).

A reduced risk of growing-season frost on various mechanically prepared and/or herbicided sites is well documented in the literature (e.g., Hadders and Karlsson 1962; Brække et al. 1986; Balneaves 1988; Kubin 1990; Sutton 1991, 1993; Kubin and Kemppainen 1994; Lindström and Troeng 1995). Minimum air temperatures at night just above exposed mineral soil are higher than above vegetation-covered ground (Brække 1972; Washburn 1977, 1978; Bjor and Sandvik 1984; Kubin and Kemppainen 1994). Perhaps the most convincing example of the effect of mineral soil exposure on the occurrence of growing-season frost comes from New Zealand's agroforestry. The bare-earth policy (complete site preparation and cultivation with removal of all ground vegetation for 2 years after the establishment of fast-growing conifers) resulted in successful establishment of these species on sites previously notorious for frost hazard (Washburn 1978; Menzies and Chavasse 1982). Clearcuts with high frost hazard should not be raw planted. Boot screefing the microsite exposes too little mineral soil to significantly reduce frost hazard. On such sites, the only alternatives to mechanical site preparation are planting only the hardiest species, or sheltering frost-sensitive species using shelterwoods or nurse crops. Utilizing naturally occurring high planting spots, particularly adjacent to stumps, improves protection against growing-season frosts, as seen in the Lake

1 R.B. Brett and K. Klinka. A comparison of natural regeneration patterns in old-growth stands and clearcuts in the Mountain Hemlock zone of southern British Columbia. Presentation at the workshop on findings from recent research on the effects of converting old-growth forests to managed forests. Feb. 17–19, 1998. Victoria, B.C. Unpublished.

Williston area as well as on the Chilcotin Plateau for spring- and summer-planted lodgepole pine and white spruce (R. Elder, personal observation).

Does mineral soil exposure increase the chance of frost heaving?

Yes, especially on moist, fine-textured soils.

Goulet (1995) recommended the following methods of ameliorating the risk of frost heaving: 1) retaining a portion of natural plant cover and minimizing the exposure of mineral soil, 2) using large planting stock, 3) adhering to proper time of planting (to allow for root growth and good anchorage), 4) fertilizing (to enhance shoot and root growth), 5) draining sites with excessive moisture, 6) shading the site, and 7) mulching to reduce freezing and thawing of mineral soil. Thus, planting into undisturbed forest floor on sites prone to frost can reduce the risk of frost heaving. Screefing microsites may increase the risk of frost heaving (Bowden et al. 1994). There are situations where multiple risk factors occur on the same site. For example, a site can have a high risk of growing-season frost and of frost heaving. Raw planting would increase the risk of growing season-frost but decrease the risk of frost heaving. To resolve this, it is necessary to assess which of the hazardous factors is likely to pose more serious danger. Some choices of methods for ameliorating these hazards have been outlined, so a silviculturalist can choose a method or combine methods that address both problems at the same time. For the example given above, planting under shelterwood would be the most effective means of addressing both problems at the same time.

When and how should planted seedlings be shaded?

Objects that naturally occur on forest sites such as stumps, stones, and logs, can provide shade to planted seedlings. Alternative methods of shading are partial harvesting that leaves residual trees on a site or specially introduced nurse crops planted or sown prior to the introduction of crop species. Shading reduces seedling exposure to environmental extremes and may moderate the rate of change in environmental conditions. When using natural obstacles, seedlings should be planted close to the shading object (relative to its size) and on its eastern or northern side to benefit from shading during the hours of most intense sunlight. Shading reduces the hazard of injuries resulting from exposure: heat injury, winter desiccation injury, drought injury, and frost injury.

Planting depth

Current planting standards deal with the subject of planting depth in relation to instructions given at the Pre-Work Conference. Thus, whether planting is considered as too deep or too shallow depends on what was specified prior to starting the work. This implies that planting standards allow for some flexibility in defining the desirable planting depth and leave it to the supervisor to determine what planting depth they see as appropriate in a particular situation. However, exposed roots are listed as unacceptable. Root systems of container-grown stock form a compact plug; therefore, root exposure usually means the exposure of the upper part of the plug.

What planting depth is most appropriate?

Unless there is a specific reason to plant deeper than to the root collar, planting to that depth is recommended, because it follows the natural separation between roots and the above-ground seedling portion as it developed in the nursery. Planting so that part of the root system is exposed above the ground is not recommended.

Planting deeper than to the root collar may be considered: 1) if soil erosion or ground settling after planting is expected, 2) to reduce seedling exposure and reduce transpirational loss of water, and 3) in dry soils to increase the access of roots to moisture deep in the mineral soil. Soil settling is more likely to happen on mechanically prepared sites than after planting without disturbing the substrates of the forest floor. Örlander et al. (1990) and Macadam and Bedford (1998) recommended that seedlings should be planted deeper than to the root collar on excavator-made mounds. Points 2) and 3) pertain to very harsh sites, and reports showing better survival of deep-planted seedlings originated from research in warm and dry parts of the world (e.g., Donald 1970; Strothmann 1971). In Ontario, Stroempl (1990) recommended deep planting of conifer bareroot stock so that the root collar would be protected. This was based on the assumption that the root collar was one of the most sensitive parts of the plant, but there are more morphological and anatomical reasons to contradict rather than to support this assumption. Good planting behaviour should expect that, in most situations, seedlings should be planted with the root collar flush with the surface of the soil profile, regardless of the type of material that constitutes that surface. The exceptions are listed above. When planting hot, dry sites without screefing (to benefit from the insulating properties of shallow organic material), the root collar should be flush with the surface of the underlying mineral soil rather than with the surface of the organic material.

Could some species benefit from planting deeper than to the root collar?

Species that produce adventitious roots can develop such roots from the buried portion of the stem. This can be an advantage if the original (seminal) roots are in cold soil and grow poorly. But this is correcting an error that could be avoided. In cold soils, plant seedlings with short plugs (at least three or four types of short-plug planting stock can be currently ordered) and pruned roots, encouraging root proliferation from the upper part of the root system into the warmest soil (near its surface).

The advantage of deep planting of species that form adventitious roots is the formation of these roots that supplement the pre-existing root system. Sutton (1967) reported excellent growth of deep-planted white spruce but remarked that the superior shoot elongation during the first 2 post-planting years did not make up for the decrease in height caused by deep planting; however, the seedlings in that study were planted as deep as 10 cm from the root collar. The formation of adventitious roots may be especially important for seedlings planted into cold soils where their seminal (not adventitious) roots are placed deep in the cold, wet mineral soil. Thus, the need to plant deep in such soils to stimulate adventitious root formation may be unnecessary if shorter plugs are used and if the upper part of the root system is planted into warmer, organic substrates of the forest floor, provided that this does not result in poor anchorage. Sutton (1995) stated that the importance of deeply planted roots to the stability of planted seedlings should not be overlooked, because these roots initially anchor the seedling in the ground and allow new roots to form; thus, they fulfill an important purpose. However, seedling anchorage is dependent upon the plant's ability to grow roots into the surrounding soil profiles. Rapid development of new roots for the purpose of anchorage, nutrient uptake, and moisture uptake can only occur where optimal rooting-zone temperatures and adequate oxygen levels are present. Both of these conditions are frequently compromised when roots are planted too deep (R. Elder, personal observations). Deep planting in soils with excessive moisture is not recommended. Sutton (1995) discussed studies by Armstrong (1953, 1957) performed in Ontario in which black spruce planted deeply into poorly drained organic soil had only a 36% survival rate, obviously due to anaerobic soil conditions. Poor growth of roots positioned deep in some well-drained mineral soils may result from poor fertility of these soils (Yeatman 1955; Pittman 1991). For species that do not form adventitious roots, such as many pines, there is no advantage to deep planting under moderately warm and temperate climates (Carvell 1964; Hermann 1965). In red pine, deep planting increased survival but decreased height growth (Mullin 1964). Current trials with lodgepole pine near Prince George indicate that this species tends to form multiple stems when deep planted (M. Krasowski, unpublished observations). Therefore, unless there is a strong and valid reason to plant deeply, planting depth should be to the root collar.

Should shallow planting (exposing the uppermost part of the root system) be acceptable?

If the soil is too shallow to accommodate the whole root system without bending it, shorter plugs should be used. Nursery producers offer a wide range of stock types, thus there is no reason to accept planting that exposes a portion of the root system above the ground.

Shallow planting is as unnatural as deep planting, but, while sometimes there are reasons to plant deep, there are hardly any reasons to plant shallow. Smith (1976) concluded that shallow planting of longleaf pine should be avoided. Slocum and Make (1956) reported significantly greater mortality of several pines planted with 25% of the root system above the ground, compared to root collar or deeper planting. If a shallow water table is a problem, a better solution is to plant short-plug seedlings to the root collar on elevated microsites than to shallow-plant seedlings with longer plugs. If moisture is a problem even for short-plug seedlings, the site is likely unsuitable for raw planting. If the soil is too shallow to accommodate the whole length of the root system, it is far better to use shorter plugs, to J-root, or to compress the plug.

A frequently observed problem resulting in shallow planting of plugs is the improper creation of the planting hole. The planting hole must be made to an adequate depth to accommodate the entire length of the plug, with no obstructions such as constrictions, roots, or stones. For plug planting, the planting tool (typically a shovel) should be 50% longer than the plug. The planting hole should be made by inserting the shovel all the way, creating an unobstructed, minimally disturbed hole, positioning the seedling, and gently closing the hole.

Closing the planting hole

Current planting standards consider that air pockets (any air channel that reaches the root zone) are not acceptable. Seedlings planted too loosely are also unacceptable. Methods of evaluating the firmness of planting vary, but many checkers pull up on a seedling while holding it by a couple of needles (for conifer species). It is expected that the needles will tear off rather than the seedling be removed from the ground. Backfilling a planting hole with litter, snow, and duff is listed as unacceptable. Positioning the roots obliquely in the planting hole, creating "J" and "U" (bent) roots, and having the aboveground portion of a seedling not straight are all listed as poor-quality planting.

How firmly should a planting hole be closed?

The planting hole should be closed firmly enough to securely anchor a seedling in an upright position (seedlings should not wiggle in the ground). Excessive pressure (kicking the soil or hard pressing the backcut against the roots) should be avoided because it compacts the soil.

Compacted soils impede root growth (Greacen 1986; Bennie 1991). Gentle pressure with a shovel, a foot, or the hands should be applied to ensure firm planting. Some planters use a backcut with the shovel to close the hole; some supervisors accept this, while others do not. Backcuts should not be left open because this dries the soil near the roots and creates a large space through which roots cannot grow. When closing the backcut, apply only gentle pressure with the shovel.

Is it acceptable to seal only the uppermost part of the planting hole and allow air pockets at the bottom?

It is very important to maximize the contact between the soil and the roots. Air pockets reduce this contact and should be avoided on all sites, especially dry sites.

M. Krasowski: It is critical to establish an effective interface between the soil and the roots of planted seedlings in order to access soil water and nutrients (Sutton 1995). Thus, creating air pockets by merely sealing the top of the planting hole may not be sufficient to create such an interface. Air gaps at root surfaces create a very high resistance to the flow of water (Oertli 1991). Even if the air in the soil is saturated with water vapour, the vapour is not a substitute for liquid-state water. Moreshet and Huck (1991) write: "Contact between root epidermis (including contiguous root hairs) and water films surrounding adjacent soil particles seems essential for liquid-phase flow from soil storage into the root system." Mineral nutrients can be absorbed by roots in the dissolved state only and contact between root surface and soil nutrients is prerequisite for nutrient uptake (Jungk 1991). Thus, roots that have no contact with the soil and that remain suspended in air pockets have no function in either water uptake or nutrient uptake. This situation is not comparable to aeroponic culture of plants in which roots suspended in the air are frequently or constantly misted with an aqueous nutrient solution, which delivers water and nutrients onto root surfaces. Water vapour does not carry any nutrients. Moist air can delay drying and death of the suspended roots. These roots can even elongate somewhat but if contact with the soil is not established these roots will be air pruned. More importantly, the functionality of a portion of the root system in the air pocket is eliminated during the important period shortly after planting, and this may compromise seedling survival. Moist sites may be more forgiving to air pockets than dry sites. If only the upper part of the root system is in good contact with the soil, it is adhering to the very soil that is most likely to dry out, especially if it is the organic soil of the forest floor.

R. Elder: Care in closing the planting hole is important. It is not to be suggested that "air pockets" or "oxygen chambers" should intentionally be created. Nor should unacceptable planting procedures be promoted. It should be noted that there are fewer growth problems observed when planting holes are gently closed compared with the use of excess force. The dilemma with specifying that air pockets are unacceptable results in the practice of more force being used to close the hole to guarantee that any possibility of such a fault is eliminated. It is, after all, extremely difficult to evaluate if air pockets exist, particularly when planting into well-aerated, organic or organic/mineral soil profiles. When planting into such materials, the closing of the planting hole throughout the length of the plug is easily achieved using little force. When planting into fine-textured soil, closing the hole can be more difficult and may result in more force being used than necessary to ensure meeting the required standard.

Discussion

The basic requirements for seedling growth

The main goal of any planting program should be to achieve acceptable survival and optimal growth of planted seedlings. A basic understanding of seedling requirements and accurate evaluation of site-limiting factors is essential for accomplishing these goals. To grow well, seedlings require optimal air and soil temperatures, adequate air and moisture supply to the roots, sufficient nutrients, and adequate light. These are all basic demands that should be kept in mind when selecting planting locations, planting spots, planting media, and planting techniques. Even when all these requirements are satisfied, seedlings may succumb to pests, pathogens, and the adverse effects of abiotic (not caused by living organisms) factors.

Soil temperature has a profound effect on root growth. Root initiation, branching, elongation, diameter growth, direction of growth, senescence, suberization, and turnover are all influenced by soil temperature (Kaspar and Bland 1992). Soil temperatures optimal for root development vary among species but are usually between 12 and 25° C (Oosting 1956; Cleary and Waring 1969). Stone and Shubert (1959) reported the most dramatic increase in proliferation and length of roots of ponderosa pine when soil temperature increased from 10 to 15° C. In radiata pine, this temperature ranged between 11 and 14° C (Nambiar 1980). Thus, planting spot selection that provides these ranges, especially early in the growing season, should be sought. Low and high soil temperatures can diminish or even stop root growth (Lopushinsky and Max 1990; Sutton 1991). Prompt establishment of a well-functioning root system after planting is essential for sufficient water and nutrient uptake by seedlings and for their strong anchorage in the soil.

Soil water status influences the plant by changing its growth rates and/or developmental patterns. It also influences the physical and mechanical soil properties such as nutrient availability, aeration, mechanical impedance, and temperature (see pertinent reviews in Waisel et al. 1991). Root systems play a decisive role in plant adaptation to moisture deficit (Vartanian 1981). Both inadequate and excessive soil moisture is harmful to seedlings and compromises their growth and survival. Drought stress reduces growth rates and may result in a plant's death. Shoot growth is usually restricted more by soil drying than is root growth. Root growth can even be stimulated by moderate drought (Sharp and Davies 1979; Jupp and Newman 1987; Sharp 1990; Krasowski and Owens 1991; Sword and Brissette 1993). Permanently saturated soils are inhospitable to roots of most tree species (Sutton 1991) but even transient flooding and waterlogging can result in severe damage to root systems or to the whole plant in most boreal and temperate conifers. This is caused by a reduction in oxygen availability to the roots, which slows their respiration and reduces or stops growth (Lopez-Saez et al. 1969; Jackson and Drew 1984). Soil oxygen is rapidly depleted by respiration of roots and soil microorganisms (Drew and Stolzy 1991). Not only a plant, but also the soil, responds to oxygen limitation. Accumulation of reduced compounds in the soil increases with the duration of flooding and with increasing soil temperature reaching levels that can be toxic to plants (Drew and Lynch 1980; Drew and Stolzy 1991). Some species are capable of adaptations to low soil oxygen (Jackson and Drew 1984; Drew 1988; Drew and Stolzy 1991). The development of cortical air spaces—aerenchyma (Drew et al. 1979; Sutton and Tinus 1983)—allows for longitudinal air transport in the roots of such species (e.g., black spruce and slash pine growing on permanently saturated soils [Sutton 1991]).

Soil nutrients originate from the solid organic and inorganic materials of the soil. The importance of nutrients to plant growth has been well recognized (Brix and van den Driessche 1974; Binkley 1986). Balisky et al. (1995) criticized the type of planting stock produced and planting practices applied in British Columbia for neglecting the forest floor. In their opinion, reforestation practices in British Columbia favoured root establishment in the mineral soil and denied planted seedlings the access to the nutrient-rich organic soil. Organic soils contain many nutrients, especially nitrogen originating from organic matter turnover (McColl and Powers 1984). Assimilation of nitrogen is viewed as the second most important process (after photosynthesis) for plant growth and development (Vance 1991). However, organic matter must be mineralized to make nutrients available for uptake by roots; thus, not all elements present in the organic soil are readily accessible to the plant. Nutrients are often leached from the organic soil to the mineral soil. Competition for nutrients in the soil may severely limit root growth.

Light is essential for the process of photosynthesis. Air temperature affects photosynthesis; thus, it is a factor important to shoot and root growth and development through its effects on the availability of photosynthate for the growth (Torrey 1986; Coutts 1987; van den Driessche 1987). The importance of photosynthesis to the growth of new roots in conifer seedlings has also been well-documented (van den Driessche 1978, 1987, 1991; Abod et al. 1979). Planting seedlings on elevated microsites usually improves seedlings' access to light. However, there may be situations where the exposure of seedlings to intense sunlight could cause more harm than a reduction in the availability of light. Foresters should evaluate the importance of potential damaging factors and adjust planting practices such that the most hazardous factors are addressed first.

Many foresters believe that organic soil substrates are the primary supporters of various beneficial soil organisms, especially of mycorrhizal fungi. Microbial populations in the rhizosphere thrive especially in organic substances at the root/soil interface (Sutton 1991). However, soil microorganisms also occur in mineral soils. Positive effects of associations between roots and soil microorganisms include nitrogen fixation (in some plant species), mycorrhizae, biocontrol of harmful organisms, release of growth stimulators, and improvements to the availability of nutrients (Bowen and Rovira 1991). Soil substrates that support favourable organisms often support harmful organisms as well (Jurgensen et al. 1997). Free-living soil organisms (those not directly associated with roots) can improve soil structure and porosity (Jenny 1980). Seedling roots must cope with the presence of other plants' roots in the soil. Exudations and leaching from neighbouring roots can affect a plant positively or negatively (Curl and Truelove 1986). Little is known about resource sharing by roots of different species in different soil types, or at different times of the year (Sutton 1991).

No single factor affecting a plant should be viewed as the most critical one to the plant's well-being. What is most limiting to a plant's growth or threatening to its survival in a particular situation is the most important factor in that situation. The importance of different factors affecting seedling survival and growth may vary during different times of the year (e.g., drought in summer, excessive moisture in spring and fall, frost in winter). Accurate identification of a factor or factors most limiting to the establishment of seedlings on a specific site is the critical, indispensable step toward choosing an effective method of reforestation of that site. In addition to the factors discussed above, seedling establishment and growth can be significantly influenced by planting practices (Mullin 1974).

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