# EFFECTS OF PLANTING QUALITY, DEPTH, AND MEDIUM ON GROWTH AND SURVIVAL OF LODGEPOLE PINE (*PINUS CONTORTA)* IN SOUTH CENTRAL BRITISH COLUMBIA

**By**

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**Abstract:** Tree-planting quality, depth, and medium can significantly affect seedling growth, vigour, and survival in the Very Dry, Cool Montane spruce Biogeoclimatic subsone (MSxk). In this study, lodgepole pine (*Pinus contorta*) seedlings were planted in seven different treatment units to test for difference in growth and mortality. Trees were planted in F-layer, mineral soil, and poor medium, with damaged plugs, J-rooted, deep, and shallow treatments to test for these differences. All trees were measured two growing seasons after planting for nursery year growth (year 1 growth), second year growth, third year growth, caliper and mortality. Trees planted in the F-layer and mineral soil had significantly greater caliper than shallow planted seedlings which correlated strongly with third year growth, and survival. Third year seedling growth was significantly greater in F-layer, mineral screefs, and deep treatments. Mortality was greatest in shallow, poor medium and damaged root treatments and was likely caused by moisture deficit and drought. Total height differences were not found to be significantly different between treatments.

**Keywords:** *tree-planting, planting quality, planting depth, planting medium, silviculture*

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## Introduction

Tree-planting is one of the most critical activities in the life of a stand. “The success of a whole rotation can depend on decisions made at planting time” (Smith, 1986, p. 305). Often, errors made at the time of planting can cause future problems that are not easily soluble (Smith, 1986). Unfortunately, it is not always known what these errors are or if they even have a significant impact on the future stand. Determining the effect of tree-planting quality, depth, and planting medium on growth and survival can be complicated. Silviculturalists face a large number of choices when determining the best planting prescription and tree-planting specifications for a given site. Aside from determining species, seed selection, stock size, and planting density, silviculturalists must choose optimal microsites, planting medium, depth, and quality standards. While there has been some research done on aspects of planting depth or medium (Black, et al., 1991; Schneider, et al., 1998; Shiver, et al., 1990; Simard, et al., 2003; Smith, 1986; South, 2000), they tended to study the effect of site preparation as opposed to forest floor or “F-layer planting”, and rarely studied the effects of planting quality, or depth. There has been little research done on the effects of planting quality and depth in F-layer. Blake & South (1991, p. 5), found…

> Because it is difficult to treat planting "quality" in a quantitative manner for all but a few traits, researchers tend to avoid the problem. As a result "planting quality", in practice, becomes an elusive personal or organization standard. However, […] careful planting technique makes a difference. Unfortunately, it is not known which "careful" techniques [lead] to the observed increases in survival.

The Ministry of Forests Silviculture Manual states “The specific factors that affect quality of planting will vary from site to site, and with species and stock type” (B.C. Ministry of Forests, Forest Practices Branch , 1999). However, no further guidance is given on what those specific factors are or how they impact growth and survival for a given site. Balisky, et al., (1995, p. 59) found in a study on F-layer planting that “current planting guidelines in British Columbia may inhibit optimal seedling function on numerous outplanting sites”. Other research done on planting quality tends to be site specific and not applicable to other areas.

It is critical for plantation success to implement a set of specific and measurable planting criteria that are appropriate for a given site. One study on loblolly pine (*Pinus taeda*) in the Georgia Piedmont found that poor planting and handling practices resulted in 0% - 30% seedling mortality (Shiver, et at., 1990). Another study on loblolly pine in Georgia found seedling mortality due to planter handling and planting varied from 25% - 95% (Rowan, 1987).

Proper planting guidelines and specifications are not only important for seedling success but also for economic reasons. A Canadian study found that "the cost on a national basis of planting trees that fail either to survive or to grow satisfactorily must amount to tens of millions of dollars annually" (Burdett, 1978, p. 133). It was not noted whether this estimate was strictly the cost of the seedlings or the future costs that may accrue due to unsatisfactorily stocked stands and the treatments necessary to remediate the problem. While seedling survival has increased dramatically since 1978, so has the number of seedlings that are planted. A US study found that "federal planting costs are often 50 – 100% greater than those of industry under similar site conditions. However, on comparable sites survival is usually no different, probably because the additional specifications or planting regulations rarely provide a marginal improvement in the conditions affecting seedling survival" (Blake & South, 1991, p. 8). It is therefore important to note that excessively restrictive planting specifications will both reduce planter productivity and cost the contract administrator more money. The challenge, then, is to determine what specifications are appropriate, site by site.

Given the lack of information on seedling growth and survival in F-layer planting or effects from poor planting quality in British Columbia, a significant challenge exists for silviculturalists to establish science-based criteria for tree-planting specifications. A second challenge is to transfer or extrapolate from the existing research and data on planting depth and medium to specific biogeoclimatic ecosystem classification (BEC) zones and sites. Thus, the goal of this paper is to answer the question, what effect does planting quality, depth, and medium have on growth and survival of lodgepole pine (*Pinus contorta*) in the MSxk and what recommendations can be made for future planting? This paper will also demonstrate a method for evaluating site specific planting specifications.

# Methods and materials

## Study area

The experiment is located in a cutblock in the Woods Creek drainage, 30 km southeast of Ashcroft on the Thompson Plateau in south-central British Columbia. The opening is approximately 72 hectares in size and located at 50°35’59”N, 121°06’26”W. The site is at 1680 m elevation and has a southwest aspect. The mesoslope position of the experiment plot is on the lower slope of a 2 – 15% slope. The site is mesic to subhygric moisture regime in the Very Dry Cool Montane Spruce Biogeoclimatic subzone (MSxk 01/07). The BEC zone and site series were determined using both the information from Tolko Industries Ltd. Site Plan for the cutblock as well as reconfirmed in the field using the slope position, soils and plant associations and *A Guide to Site Identification for the Kamloops Forest Region* (Lloyd, K., et al., 1990). The soils are moderate to poorly drained with low course fragments (<20%). The area also experiences a high water table despite indicators of dry soils. The soil is characteristic of a gleysol with a diagnostic gleyed layer (Bg) at 15-20 cm depth. The humus layer is approximately 2 – 10 cm deep.

The climate for this region is characterised by cold winters and moderate snowfall, and moderately short, warm summers. The average temperature in the MSxk is 3.1°C with an annual average snowfall of 206 cm. There is an average of 947 Growing Degree Days per year in the MSxk. The growing season is sufficiently warm that moisture deficits can occur. The average precipitation is 444 mm with 195 mm falling during the growing season; most precipitation falls as snow outside of the growing season. Frost is common during the growing seasons with an average of 55 frost free days. The site index for pine on this site is 13. (Lloyd, K., et al., 1990)

The cutblock was salvage harvested for Mountain Pine Beetle (*Dendroctonous ponderosae*) in July, 2008. Pre-harvest, the experiment site was composed of 90 year old lodgepole pine and Engelmann Spruce (*Picea engelmannii*) (60% and 40% respectively). The cutblock borders on the Very Dry Cold ESSF (ESSFxc) Biogeoclimatic subzone.

## Experimental design and treatments

Seven different tree-planting treatments with no replicates were planted in one area of the cutblocks to test the effect of planting quality, depth, and medium, on growth and survival in early June, 2010. Planting medium treatments consisted of F-layer planting, planting in mineral soil and planting in “inappropriate medium” (the litter layer). Depth treatments included shallow planting and deep planting treatments. Planting quality treatments consisted of planting seedlings with damaged roots, and planting J-roots. These seven treatments were tested as they are some of the most common depth, medium, and quality choices made when planting (see Fig. 1 - 7) Multiple replicates were not possible due to lack of time, labour resources and number of available seedlings. The selection of the treatment area was constrained to areas of the block close to the road (for logistical reasons), not planted by the licensee and left to naturally regenerate, and areas of consistent slope, aspect, and ground cover.

The total treatment area was roughly 15 × 60 m with each treatment unit roughly 9 × 15 m. Each treatment unit was planted with sixty, PSB 410 1 + 0 lodgepole pine seedlings. The seedlings were planted roughly 1.5 m apart in a semi-grid-shaped pattern. Seedlings were planted on a semi-grid-shaped pattern to allow for better micro-site selection when needed. There were no buffers between treatments as the trees would be measured before inter-tree competition affected growth. The treatment area was bordered on the north by a roughly 15 year old plantation which was buffered off by 5 m. The treatment area was bordered on the west by a small Non-Classified Drainage (NCD) and was buffered off by 5 m. The rest of the treatment area was bordered by unplanted cutblock that will regenerate from natural regen. Boundaries between treatment units were marked with spray paint on stumps and large wood, as well as spray painted sticks placed in the ground. Seedlings were planted with a shovel and all holes were closed by hand. All seedlings were planted by the author, an experienced tree planter with seven years of experience, to ensure the seedlings were planted according to treatment specifications.

**F-layer**

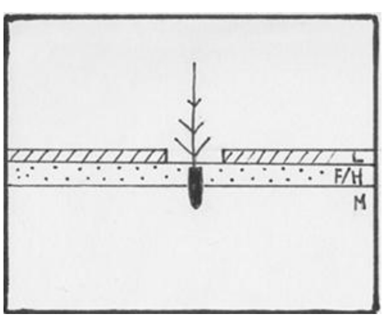


**Figure 1. F-layer planting**

In this treatment, F-layer seedlings were planted with the majority of the plug in the F and H (humus) layer after screefing the L-layer (litter layer). Where the F and H layer were less than the depth of the plug the bottom of the seedling was in mineral soil. The top of the plug was covered so that no plug was visible or exposed without covering any of the lower laterals

**Mineral screefs**

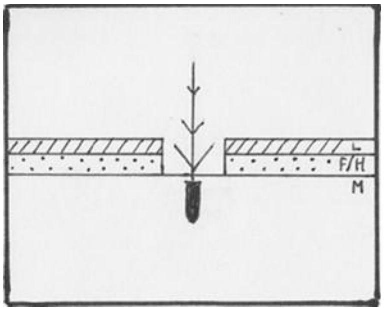


**Figure 2. Mineral screef planting**

In this treatment, L, F, and H layers were screefed. All plugs were planted in mineral soil to a depth that just covered the top of the plug without covering the lower laterals. In some spots, mineral soil was only 1-2 cm below the F and H layers. In other spots, the planter had to "screef" (remove) the F and H layers to a depth of up to 10 cm resulting in seedlings being planted in a small, localized depression.

**Poor medium**

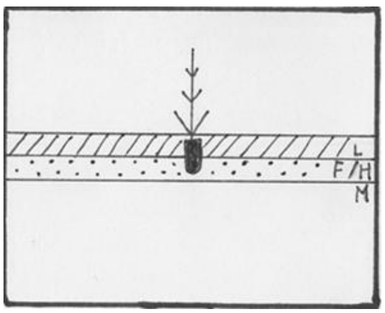


**Figure 3. Planting in poor medium**

In this treatment seedlings were planted in the L-layer with no screefing. These plugs were covered such that none of the plug was visible or exposed directly to the air, without covering the lower laterals. The litter layer consisted of small sticks (1 – 10 mm), non-decomposed wood, and needles. In some cases, the litter layer was less than the depth of the plug and the lower portion of the plug was in the F and H layer

**Shallow**

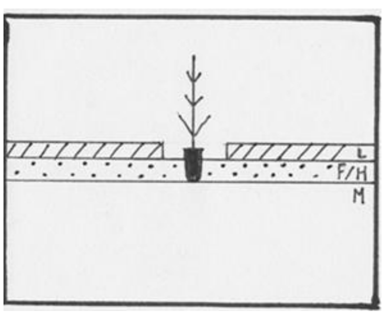


**Figure 4. Shallow seedling planting**

The shallow seedlings were planted in F-layer or mineral soil if on the surface, with 1 – 2 cm of the plug above the soil profile and exposed to the air. The litter layer was screefed away. The hole was closed around the plug of the seedling such that no air was freely circulating around the roots. The bottom of the seedling was usually in the F-layer with the bottom of the plug sometimes coming in contact with the mineral horizon.

**Deep**

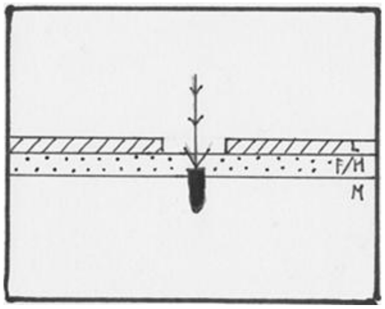


**Figure 5. Deep seedling planting**

The deep trees were planted in the F-layer, or mineral soil if on the surface, with the top of the plug 5 – 7 cm below the soil profile. The litter layer was screefed away. The lowest half to three quarters of the lower laterals were covered in F-layer or mineral soil with the bottom of the plug usually in mineral soil. At the time of planting there was a small amount of water seeping into some holes as they were opened.

**Damaged plugs**

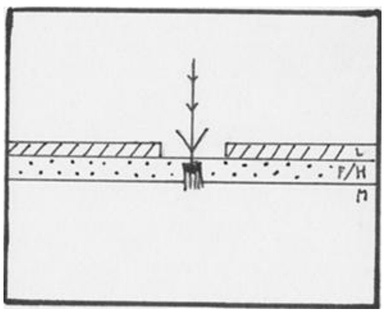


**Figure 6. Damaged roots planting**

The damaged plug treatment was used to assess the effects of improper seedling handling by planters. Planters may sometimes stand on plugs to remove excess water and lighten the load of the seedlings that must be carried. Excess dirt is sometimes shaken off for the same reason. If frozen bundles of trees are encountered, a planter may separate the individual plugs by striking them with their shovel or against a stump or log. South, (2000) found planters similarly damaged plugs by removing roots so they would better fit in shallow holes. In this treatment, seedlings were stood on to remove excess water and then hit on a stump to remove roughly 25 – 75% of the dirt in the plug. The remaining plugs were then planted in the F-layer or exposed mineral soil to a depth that just covered the plug without covering the lower laterals.

**J-roots**

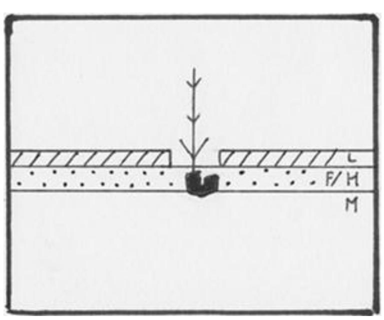


**Figure 7. J-root planting**

J-rooted trees are a common planting fault that results from planting a tree in a hole that is not deep enough, or due to improper root placement. It is more common with long slender plugs such as a PSB 415 than with smaller thicker plugs such as a PSB 512. The J-roots were planted in F-layer or exposed mineral soil to a depth that just covered the plug without covering the lower laterals. The bottom of the plug was curved underground such that it formed the shape of a J or U.

## Measurement of variables

The seedlings were planted June 7th, 2010 and all measurements were taken October 1st and 2nd, 2011. The measurements taken were stem caliper, total height, the length of the leader of the 2011 growing season (age 3), and the length of leader growth in the 2010 growing season (age 2). Mortality was also counted and notes were taken on the likely cause of mortality. First year nursery growth was calculated by subtracting second year and third year growth from total height. All measurements were taken by the author using a tape measure for height and steel vernier calipers for seedling caliper. Caliper was measured to an accuracy of 0.5 mm and height to an accuracy of 0.5 cm. Both caliper and height were measured at the base of the stem as close to the top of the plug as possible. Due to the difficulty in determining the bud scars from the 1st and 2nd year's growth, very few measurements were taken for them and therefore few inferences can be made based on these qualities . Heights were measured for all sixty trees in J-roots and F-layer treatments. It quickly became apparent that there was not enough time to measure every tree in all treatments. For the remainder of the treatments, forty heights and forty calipers were measured for each treatment. The author started at the western edge of each treatment block and measured eastward until forty trees were measured; the first forty trees measured were used for statistical analysis. Dead trees were included in the forty but not in the statistical analysis. For measurement of mortality, seedlings in this experiment were classified as dead or alive, with a dead tree being classified as anything greater than 75% drought or frost damage. There were a considerable number of seedlings that had 75 – 50% damage that may survive but were classified as dead. Determination of frost vs. drought was primarily based on a lack of signs of physical damage due to frost.

## Statistical analysis

Statistical analysis was performed with Minitab 16 Statistical Software and Microsoft Excel (version 2010) with Data Analysis add-on. Due to the experimental design and the confounding variables a three-way ANOVA was not possible; a one-way ANOVA was performed to test for treatment effects on both height and caliper. Where the ANOVA showed significant treatment effects ($p < .05$), means were separated using the Tukey range test. Other variables were analyzed in Excel using regression analysis. Seedling mortality was expressed as a percentage of seedlings in a treatment unit that died.

## Results

**Table 1. Means, 95% confidence intervals, *p* values for treatment effect, and % treatment unit level mortality for treatments. Planting treatments vary in planting medium, depth and quality.**

| | Planting Medium | | | Planting Depth | | Planting Quality | | |
|---|---|---|---|---|---|---|---|---|
| | F-Layer | Mineral Screefs | Poor Medium | Shallow | Deep | Damaged Roots | J-Roots | *P* |
| Caliper(mm) | 5.0 ± 0.4 | 5.0 ± 0.3 | 4.5 ± 0.4 | 4.3 ± 0.3 | 4.8 ± 0.3 | 4.4 ± 0.3 | 4.7 ± 0.3 | 0.006 |
| Leader year 1 (cm | 11.8 ± 0.9 | 11.6 ± 1.5 | 13.6 ± 1.2 | 14.4 ± 1.9 | 12.0 ± 2.4 | 13.6 ± 1.1 | 12.9 ± 1.1 | |
| Leader year 2 (cm | 8.3 ± 0.8 | 7.8 ± 1.0 | 7.8 ± 1.3 | 9.0 ± 1.1 | 8.7 ± 3.0 | 7.4 ± 0.7 | 8.0 ± 0.7 | |
| Leader year 3 (cm | 5.8 ± 0.8 | 7.2 ± 1.1 | 4.0 ± 0.8 | 3.6 ± 0.7 | 5.8 ± 0.6 | 4.2 ± 0.8 | 5.3 ± 0.9 | < 0.000 |
| Total Height (cm) | 25.8 ± 1.3 | 25.4 ± 1.8 | 24.3 ± 1.6 | 26.3 ± 1.2 | 23.2 ± 1.4 | 24.6 ± 1.7 | 26.2 ± 1.5 | 0.061 |
| % Dead | 6.9 | 7.5 | 37.5 | 17.5 | 5.0 | 15.0 | 12.0 | |

**Table 2. Tukey range test results comparing caliper between treatments. Means that do not share a letter are significantly different (α = .05)**

| Caliper (mm) | | | |
|---|---|---|---|
| | N | Mean | Grouping |
| Mineral Screefs | 38 | 5.0 | A |
| F-Layer | 31 | 5.0 | A |
| Deep | 38 | 4.8 | A B |
| J-Roots | 23 | 4.7 | A B |
| Poor Medium | 24 | 4.5 | A B |
| Damaged Roots | 34 | 4.4 | A B |
| Shallow | 33 | 4.3 | B |

**Table 3. Tukey range test comparing third year leader growth between treatments. Means that do not share a letter are different (α = .05)**

| Third Year Height Growth (cm) | | | |
|---|---|---|---|
| | N | Mean | Grouping |
| Mineral Screefs | 30 | 7.2 | A |
| Deep | 34 | 5.8 | A B |
| F-Layer | 54 | 5.8 | A B |
| J-Roots | 49 | 5.3 | B C |
| Damaged Roots | 32 | 4.2 | B C |
| Poor Medium | 21 | 4.0 | B C |
| Shallow | 22 | 3.6 | C |

### Planting medium

Caliper was found to be significantly different between treatments ($p = .006$). Tukeys range test showed this difference to be between the mineral and F-layer planted trees, and the shallow trees (see Table 2). Mineral screefs and F-layer planted trees had significantly larger caliper than shallow trees (5 mm, 5 mm, and 4.3 mm, respectively), however no difference in caliper was found between planting medium treatments (Fig. 8). No difference was found between any of the treatments total heights ($p = .061$) (Fig. 10). Third year leader growth was also found to be significantly different ($p < .001$) between treatments (Table 1). Tukey's range test showed the mineral screef treatment to be significantly larger than J-root, damaged roots, poor medium, and shallow treatments (see Table 3 and Fig. 9). While not statistically significant, there was a large difference in seedling mortality between planting mediums (Fig. 11). Seedling mortality for F-layer and mineral was 6.9% and 7.5%, respectively, while poor medium resulted in 37.5% mortality. Both the F-layer and mineral planting had the second and third lowest mortality, respectively and the largest calipers.

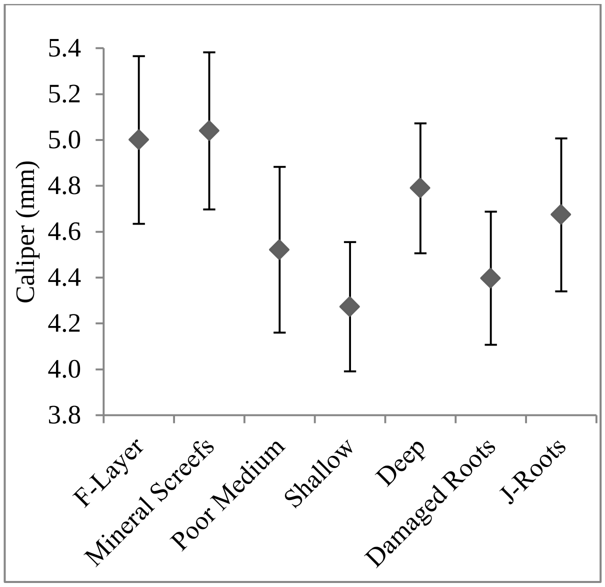


**Figure 8. Caliper in mm and 95% confidence intervals for different treatments**

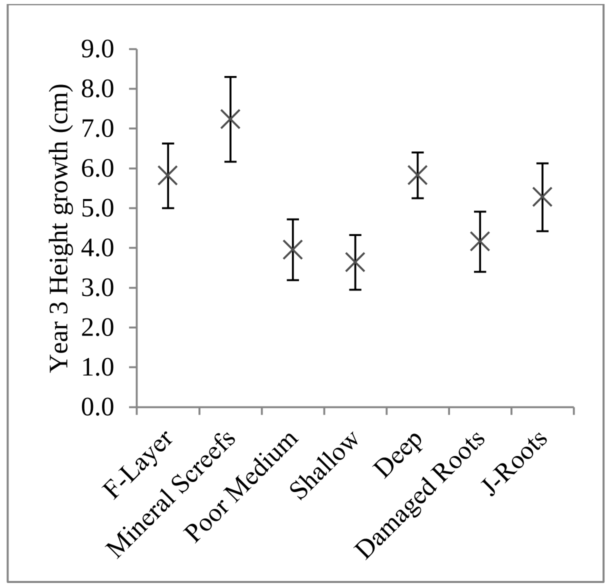


**Figure 9. Year three height growth and 95% confidence intervals for different treatments**

## Planting depth

Planting depth showed no significant difference in total height or caliper between shallow or deep trees. There was a significant difference in third year leader growth between deep and shallow trees (5.8 cm and 3.6 cm, respectively) (Table 3). Seedling mortality was notably different with shallow and deep seedling mortality of 17.5% and 5%, respectively (Fig. 11). Seedling mortality was lowest for deep trees compared to the other treatments while shallow trees had the second highest mortality and smallest caliper. Leader growth in year three was second highest for deep trees and shallow trees were lowest. (Table 4)

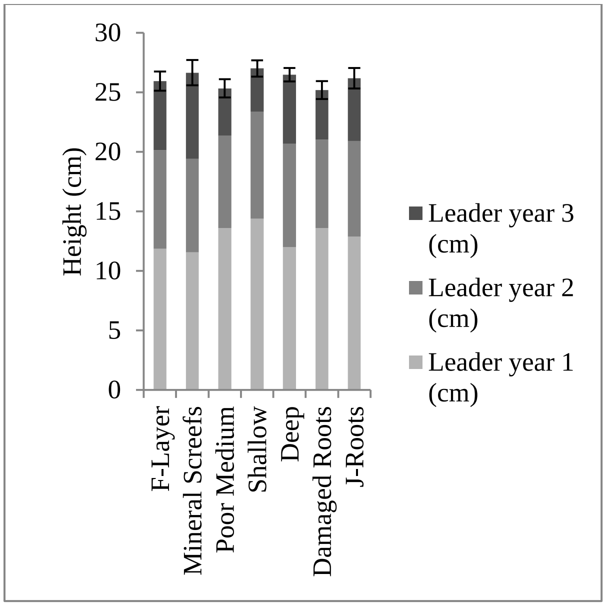


**Figure 10 Growth in cm of years 1, 2, and 3 and resulting total heights**

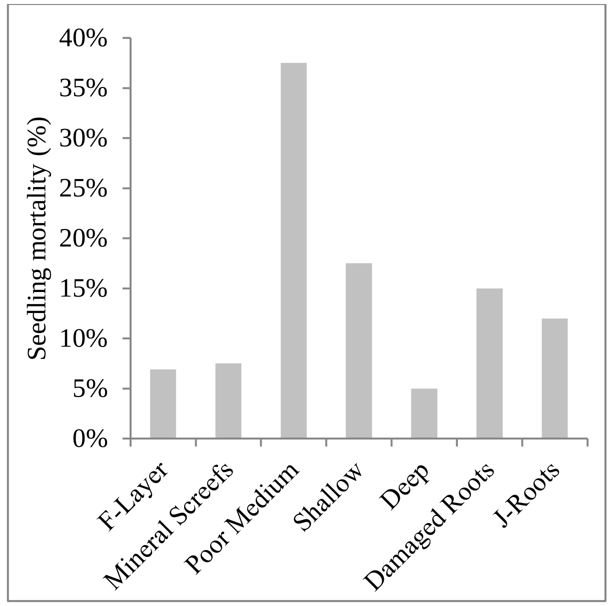


**Figure 11. % mortality of the different palnting treatments**

## Planting quality

Tree planting quality did not appear to have any significant difference on total height or caliper when compared to other treatments. Third year leader growth, however, was significantly different between the planting quality treatments and mineral screefs with mineral screefs being greater at 7.2 cm compared to 5.3 cm and 4.2 cm for J-roots and damaged plugs (Table 3). Damaged roots and J-roots have the second and third greatest mortality and performed poorly overall when ranking overall performance (Table 4).

**Table 4. The overall ranking of treatment effects with 1 being the best performance and 2 being the worst. When two treatments were equal they were given the same ranking.**

| | F-Layer | Mineral Screefs | Deep | J-Roots | Shallow | Damaged Roots | Random |
|---|---|---|---|---|---|---|---|
| Caliper(mm) | 1 | 1 | 2 | 3 | 6 | 5 | 4 |
| Leader year 3 (cm) | 2 | 1 | 2 | 3 | 6 | 4 | 5 |
| Total Height (cm) | 3 | 4 | 7 | 2 | 1 | 5 | 6 |
| % Dead | 2 | 3 | 1 | 4 | 6 | 5 | 7 |
| Total | **8** | **9** | **12** | **12** | **19** | **19** | **22** |

## Correlations

Regression analysis in Microsoft Excel with Data Analysis package was used to analyse correlations between variables across all treatments. Mean seedling height was not correlated with treatment unit level survival ($R^2$ = 26%) nor was seedling height correlated to seedling caliper ($R^2$ = 0%). Treatment unit mortality showed a strong negative correlation with caliper ($R^2$ = 81%); as caliper increased, mortality decreased. Caliper was also strongly positively correlated with year three leader growth; the larger the caliper the greater the leader growth in year 3. Interestingly, leader growth in year three was not correlated with the total height of the tree ($R^2$ = 10%).

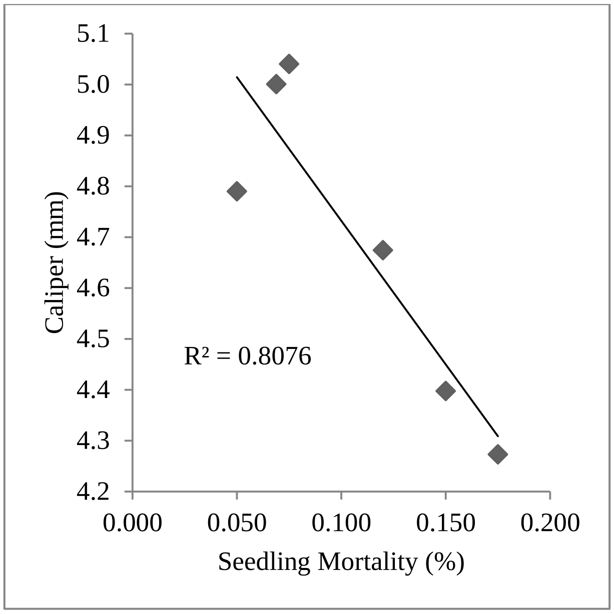


**Figure 12. The negative correleation between mean treatment unit caliper and treatment unit seedling mortality**

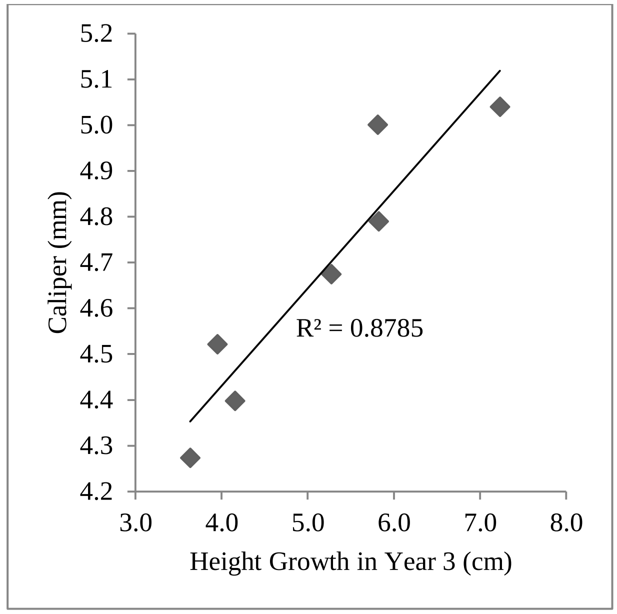


**Figure 13. The positive correlation between mean treatment unit caliper and mean gtreatment unit year 3 leader growth.**

# Discussion

## Seedling mortality

The high seedling mortality in the poor planting medium, shallow, and damaged plug treatments of 37.5%, 17.5%, and 15%, respectively, was likely a result of drought stress. This was evidenced by foliar symptoms and the likelihood of moisture deficits found on similar sites. Severe drought stress and resulting seedling mortality has been found on similar sites (Simard, et al., 2003, p. 1499) found for the IDFdk (an adjacent BEC subzone), that "early mortality was predominantly associated with summer frosts and summer drought, as indicated by foliar symptoms…" While some frost mortality was found on planted spruce (*Picea engalmani*) seedlings outside the treatment area, only minor frost damage was found on the pine in the seedling area. This finding is similar to that by Black, et al. (1991), that lodgepole pine is not susceptible to summer frost injury. Further investigation and better analysis would have been desired to separate the drought mortality from frost injury. While growing season frosts may have contributed to some of the mortality, direct signs of physical damage from frost could not be found to confirm this. Cold soils and a high seasonal water table found on the study site likely contributed to poor root egress which would have posed a significant problem when the moisture deficits became high later in the year. Simard, et al., (2003, p. 1506) found that "…cold soils increased resistance to water uptake, resulting in underutilization of available soil water by pine seedlings, especially soon after planting when root growth is inadequate". The low bulk density and poor moisture retaining capacity of the litter in poor planting medium treatments (Heineman 1998) would have exposed seedlings to greater moisture deficits for longer periods of time than other treatments resulting in the highest mortality. The shallow treatment would also have been more prone to drought for several reasons. First, the exposed plug would have increased evaporation of moisture from the plug compared to a covered plug. Second, the bottom of the plug would have been higher in the soil profile and further from the moist below ground water, as a result of being planted shallow. "A seedling planted half in the soil floor and half in mineral soil may be in contact with sufficient moisture for root development only at its lower tip" (Heineman, 1998, p. 7). Conversely, the deep and F-layer treatments likely had sufficient moisture and had lower mortality due to the F-layer acting as mulch to reduce moisture loss (Heineman, 1998). Reasonably high mortality in the damaged roots treatment likely resulted from loss of root tips and root mass as well as shorter roots resulting in less root material being in the higher moisture content lower soil profile.

While the differences in mortality between some treatments are noticeable, due to shortcomings in the experimental design, and time constraints at the time of measurement, no statistical conclusion is able to be drawn. Stratifying each treatment into four or more units would have allowed for statistics around mortality to be performed. Another factor that could be improved upon in future studies would be a more stringent guideline for classifying dead vs. dying seedlings as well as the amount of damage to a seedling. As mentioned, seedlings in this experiment were classified as dead or alive, with a dead tree being classified as anything greater than 75% drought or frost damage. There were a considerable number of seedlings that had 75 – 50% damage that may survive but were classified as dead. Further investigation and subsequent measurements would be necessary to determine the long term seedling mortality and to provide a more accurate classification. At least four plots per treatment unit would also help to allow for calculating statistics around mortality.

### Seedling growth

Caliper was significantly larger in F-layer and mineral screef treatments compared to the shallow treatment. Caliper was likely bigger in the F-layer and mineral treatments as a result of having the most favourable microsite growth conditions. While the deep treatment also had favourable growth condition and access to moisture, due to the seedling plug and stem being covered in soil up to 5 cm above the plug, the caliper was measured 5 cm above the plug resulting in a skewed measurement due to the stem taper. A recent paper that studied both short and long term effects of planting deep trees (up to 10 cm below the root collar) found no significant difference in height, diameter or mortality after 1 and 19 years post planting (Paquette, et al., 2011). As mentioned above, the most important factor for survival and early growth of planted seedlings is water uptake Orlander, et al., (n.d.). In combination with higher moisture, the mineral treatment, which had the highest caliper, also likely had warmer soil conditions due to removal of the F-layer that allowed better growth. Mineral soil has a higher heat capacity, thermal admittance and thermal diffusivity than F-layer resulting in warmer temperatures (Heineman, 1998). Due to the observed seasonally high water table, the F-layer treatment likely had sufficient moisture available to enough of the plug to prevent high mortality during droughty conditions that killed seedlings in other treatments, despite being in the F-layer. The F-layer treatment may also have had the second highest growth, despite being cooler in temperature, due to greater nutrients and mycorrhizal fungi (Harvey, et al., 1987). Harvey et al. (1987), found that the organic soil components supported virtually all the ectomycorrhizal root systems of naturally established seedlings. The humus layers are also the prime nutrient reservoirs of the forest ecosystem (Gessel & Balci, 1963).

Interestingly, survival and caliper were strongly correlated with an $R^2$ of 81%. This means that as caliper increased, so did survival. This result agrees with those found by South (2000) that found correlations in caliper and survival. Caliper was also strongly correlated with year 3 leader growth ($R^2$ = 88%). This shows that better microsites increase not only survival but 3^rd^ year leader growth. Caliper, however, was not associated with overall height ($R^2$ = 0%). It is likely that the first year of outplanting growth was focused on root and caliper growth and getting established, not on overall height. In the second year of outplanting growth, the trees in the most favorable microsites and treatments were then able to allocate enough resources to height growth. It is assumed that all trees in each treatment had similar variation in caliper before they were planted although it was not measured.

Total height was not found to be statistically different between treatments ($p < .05$). This is most likely due to the slow growing conditions of this high elevation site with cold soils and the relatively short duration (two years) of the study. This study could have been improved to better detect differences in height by choosing a more productive site at lower elevations and extending the study period. Despite this, the two tallest treatments were shallows and J-roots. The shallowest planted trees were likely tallest because they were the shallowest planted. Given the minimal growth across all treatments, they remained the tallest. Another explanation may be that the shallow trees that survived drought conditions were able to grow roots deep enough to access water. Having access to sufficient water as well as warm surface conditions may have given the surviving trees the resources to enhance growth beyond other treatments. Good growth was similarly found in a study by Blake & South, (1991), who noted that J-roots performed better than shallow trees, although no explanation was given The third and fourth greatest height was seen in the F-layer and mineral screefs and is likely due to the same favourable growing conditions that caused high caliper growth. The deep planting treatment was shortest due to the deep planting which negatively skewed the heights.

In regards to non-seedling effects, it was noted that there were differences in the amount of time and effort taken to plant the different treatments, depending on the planting specifications. Planting the mineral screef and F-layer seedlings took slightly more care, time, and effort than did the other treatments. Planting the deep seedlings required opening a larger hole which may have taken slightly more time and effort. While the amount of time taken was not actually measured, these differences are strictly anecdotal. This finding was also observed over the authors seven seasons of tree-planting experience and has anecdotally been confirmed by other planters. The observation and feeling among planters that more stringent quality standards and a greater number of planting specifications lead to lower productivity is ubiquitous. As mentioned, Blake & South (1991), hypothesized that not only can excessively restrictive planting specifications reduce productivity, but that they may have no marginal benefit to survival. It is therefore critical to ensure, through studies such as this, that planting specifications are appropriate and resoanable for a specific site. Planters may also be more likely to follow planting specifications if they know they are necessary to aid in seedling survival and improved growth on a given site.

While this site had a seasonally high water table, it also appeared to have significant moisture deficit as well as the dry site indicator common juniper (*Juniperus communis*). Recommendations on optimal planting for this site should not be extrapolated to permanently wet sites where other planting techniques and site ameliorating methods such as site preparation may be better suited. Neither are findings necessarily transferable to other species. Finally, recommendations from this study should not be extrapolated to sites with medium or high amounts of competing vegetation that may cause further moisture stress.

### Recommendations for planting in the MSxk and similar BEC subzones

Based on the observed results from this operational trial and ranking of overall performance (Table 4), several recommendations can be drawn to aid future planting in the MSxk and similar BEC subzones such as the ESSFxc, IDFdk3, and the SBPSmk.

- Plant seedlings in F-layer or mineral soil with the top of the plug covered to prevent drying of the plug to reduce mortality.
- Plant trees deep (5 – 7 cm) rather than shallow on dry sites, even if the laterals get covered, to reduce mortality.
- Plant trees in the F-layer where sufficient moisture is available throughout the growing season.
- Avoid damaging roots while handling and planting seedlings.
- Avoid planting in the litter layer or non-decomposed material such as sticks, needles, or wood.
- Eliminate planting specifications and regulations that do not provide a marginal benefit to seedling growth and survival.
- Cite or explain reasons to support planting recommendations when training new planters.

Further operation trials would be recommended in other zones before extrapolating these recommendations. Operational trails or studies can range from testing as few as two treatments to testing multiple treatments and replicates using advanced statistics to compare results. For operational trials implemented by licensees or consultants with limited time and resources, a trial could be as simple as planting, using several different methods and then visually observing the results for obvious trends. For those with more time and resources, measurement of the outcomes and comparing means could provide sufficient data to tailor planting practices to specific sites.

## Conclusion

This operational study found significant differences in some aspects of growth and vigour; however, it appears the environmental conditions of the site had a significant impact on seedling performance as well. While the death of a planted tree is frequently attributed to a single factor such as drought, animal damage, competition, poor planting, or, poor stock, planting performance is always the outcome of an interaction between the planted seedlings and its environment. Mortality rates between treatments analysed, varied between different planting treatments and provided sufficient information to allow for recommendations on future planting operations. While further study is desired to provide better statistical evidence, planting depth, quality and medium was found to significantly affect growth and survival of planting seedlings on this dry site. While many foresters and silviculturalists may be aware of the optimal planting specifications for given sites (from operational trials, observations, trial and error, knowledge from other practitioners, etc.), operational trials such as this can be a useful tool for new practitioners to a region where little data or information is available. Operational trials may also be useful for experienced silviculturalists to test or refine theories on optimal planting methods.

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