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# Soil preparation method affects outplanting success of Norway spruce container seedlings on till soils susceptible to frost heave

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## Abstract

Soil preparation is a common practice that precedes outplanting of Norway spruce (*Picea abies* (L.) Karst.) in Finland as it enhances the survival and early growth of seedlings. Mounding in particular has become more common with Norway spruce planting in recent years. However, on fine-grained soils, the postplanting performance of seedlings has been poorer than on coarser soils even with mounding. This study examined the effects of different soil preparation treatments (spot and ditch mounding with varying mound height, inverting, unprepared control with or without a herbicide) on the postplanting performance of Norway spruce container seedlings on till soil susceptible to frost heave in two outplanting forest sites in central Finland. The results indicate higher soil temperature and lower soil water content especially in the highest mounds. Mounds, however, subsided gradually during the study years. Seedling mortality was higher and the proportion of vigorous seedlings was lower in the unprepared treatments, mainly due to increased pine weevil (*Hylobius abietis* L.) damage. Frost heave was present mainly on ditch mounded and inverted spots. Glyphosate herbicide treatment showed no benefit compared to the untreated control in two years. Consequently, seedling damage and conditions in the planting spots were reflected in seedling growth which was enhanced in the mounded spots. However, varying mound height or thickness of mineral capping showed no clear difference in seedling growth. The results therefore suggest that ditch or spot mounding should be used on frost heave susceptible forest soils to promote plantation establishment. Inverting or having no soil preparation with or without herbicide is not recommended.

**Keywords** glyphosate; mounding; *Picea abies*; pine weevil; plantation establishment; reforestation; soil water content; vole

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## 1 Introduction

Norway spruce (*Picea abies* (L.) Karst.) is planted on more than 70% of the annual Finnish outplanting area (Finnish… 2011). Soil preparation commonly precedes outplanting of Norway spruce since it has been found to facilitate planting work and enhance the survival and early growth of planted seedlings (Ritari and Lähde 1978; Örlander et al. 1990; Sutton 1993; Hallsby and Örlander 2004). In Finland nowadays more than half of the annual soil-preparation area of about 120 000 ha is carried out by mounding (Finnish… 2011) as it has been found to enhance plantation establishment more than patch scarification or disc trenching (Hallsby and Örlander 2004; Saksa et al. 2005; Kankaanhuhta et al. 2009; Korhonen et al. 2010; Uotila et al. 2010; Saksa 2011).

Better postplanting seedling growth is considered to result from increased soil temperature and N availability from the buried humus layer, as well as decreased damage by surface vegetation and pine weevil (*Hylobius abietis* L.) after soil preparation (Örlander et al. 1998; Örlander and Nilsson 1999; Nordborg 2001; Nordborg et al. 2003; Heiskanen and Viiri 2005; Smolander and Heiskanen 2007). Effects of soil preparation on soil water status and on subsequent postplanting seedling growth have also been widely observed (Söderström et al. 1978; Örlander et al. 1990; Munson et al 1993; Grossnickle 2000; Knapp et al. 2008).

However, all the postmounding changes in soil or site properties and the reasons for improved seedling growth are not fully understood. For example, in recent Finnish forest plantation inventories, survival and growth of Norway spruce on fine-grained soils have been shown not to be as good as on coarser soils despite the use of preplanting mounding (Miina and Saksa 2006; Saksa and Kankaanhuhta 2007). Reasons for the poorer plantation success may derive from several reasons. Fine soil particles retain water and nutrients and can cause seedling injury from frost heave, especially when the soil is disturbed or mixed (Goulet 2005; de Chantal et al. 2006). Frost heave occurs mostly on water conducting silty soils in freezing climates, while it is limited on coarse and finest sorted (clay) soils owing to low hydraulic conductivity.

Furthermore, the previously used higher mounds, especially with ditch mounding, may have caused slower postplanting seedling performance owing to longer rooting distance down to the N-rich humus layer within the mound. Higher mounds also emerge usually earlier in springs from the snow cover than the lower positioned mounds or untreated planting spots. Therefore, winter desiccation damage (Grossnickle 2000; Langvall et al. 2001) to seedlings may occur when the transpiration begins but roots are still frozen. Furthermore, increased vegetation competition may reduce early seedling growth especially on finer fertile sites (Nilsson and Örlander 1999).

In general, on fertile fine-grained forest sites, high soil fine fraction content has been observed to decrease the rooting of seedlings into the soil (Repo and Valtanen 1994; Heiskanen and Saksa 2010) and overall growth potential of Norway spruce stands (Tamminen 1993; Johansson 1995). It has been found that the lower the dominant soil particle size and water content and the higher the bulk density, the higher is the mechanical resistance to root growth (Örlander et al. 1990; Sutton 1981; Jones 1983; Zou et al. 2001).

In Finnish forest inventory and management, mineral soils are classified by visual and tactile evaluation into three main categories according to the median particle size (Mälkönen 2003). In fine-grained soils, the median grain size is smaller than 0.06 mm containing silt and clay. Fine-grained soils that are Norway spruce dominated site types cover about 12% of the 14.6 million ha forested upland soil area in Finland (Finnish Forest Research Institute, 9th National Forest Inventory). In Finnish geological soil mapping by Geological Survey of Finland, fine-grained till soils should contain at least 30% of fine fractions (< 0.06 mm) and at least 5% clay (< 0.002 mm). Medium-grained soils are sandy (0.06–2 mm) and coarse soils gravelly (2–20 mm).

This study examines the effects of different mounding treatments on the postplanting performance of Norway spruce container seedlings on till soil susceptible to frost heave. Spot and ditch mounding with varying mound height as well as inverting together with an unprepared control with or without a glyphosate herbicide application were studied in two outplanting forest sites in central Finland. We hypothesized that a low mineral capping of the mound or low mound height could provide faster seedling rooting and plantation establishment. Vegetation control without soil preparation was also studied as it may reduce vegetation more effectively than mounding (Nilsson and Örlander 1999).

## 2 Materials and methods

### 2.1 Study sites and soil-preparation treatments

The study sites were located on a sloped terrain in Suonenjoki (latitude 62.65 N, longitude 27.10 E) and on flat, wetter terrain in Pieksämäki (62.38 N, 27.29 E) about 40 km apart from Suonenjoki in central Finland. Both sites were typical Norway spruce sites (mesic heath forest, Myrtillus type) (Cajander 1949) on silty, frost susceptible till soil. Soil texture, analysed by wet sieving and pipette method, was determined on samples from the eluvial layer (5 subsamples per site). Soil contained fine fractions slightly over 30%, but clay content was only 2.6%, i.e. too low to be qualified as a fine till according to the Finnish geological soil survey. Texture was similar on both sites but the organic layer was thicker in Pieksämäki (12.1 cm) than in Suonenjoki (6.2 cm). The weather in the studied growing seasons 2007–2011 was as warm as or warmer than average, with the exception of the 2008 season, which was cooler (Table 1). Seasons 2009 and 2010 were drier than average.

The study sites were soil prepared with an excavator in spring 2007 (Suonenjoki) and autumn 2008 (Pieksämäki) after clearcutting and slash removal during the previous winter. Spot mounding formed slight elevations consisting of a mineral soil layer on top of a double humus layer (Fig. 1). In ditch mounding, mineral soil from short ditches (not leading water away) was placed on the undisturbed single humus layer. In inverted spots, the dug up soil was inverted and then relaid onto the same pit with the mineral soil uppermost. The soil-preparation treatments resulted in almost 2000 planting spots ha$^{-1}$ in Suonenjoki and in slightly sparser spot positions in Pieksämäki. Descriptions about the soil treatments have also been given previously (Örlander at al. 1990; Sutton 1993; Heiskanen and Rikala 2006; Luoranen et al. 2007).

The experimental site in Suonenjoki was soil prepared with three different methods; i) ditch mounding (D) with short ditches, ii) spot mounding (S) and iii) inverting (Inv). Mounding treatments were carried out using three target thicknesses for the mineral soil on top of the double

**Table 1.** Temperature (threshold > +5 °C) and rainfall sums during May to September in the study years 2007 to 2011 in Suonenjoki, central Finland (Venäläinen et al 2005).

| Suonenjoki | Temperature, dd °C | Rainfall, mm |
|---|---|---|
| 2007 | 1220 | 372 |
| 2008 | 994 | 357 |
| 2009 | 1257 | 225 |
| 2010 | 1427 | 245 |
| 2011 | 1423 | 408 |
| 1970–2010 | 1167 | 297 |

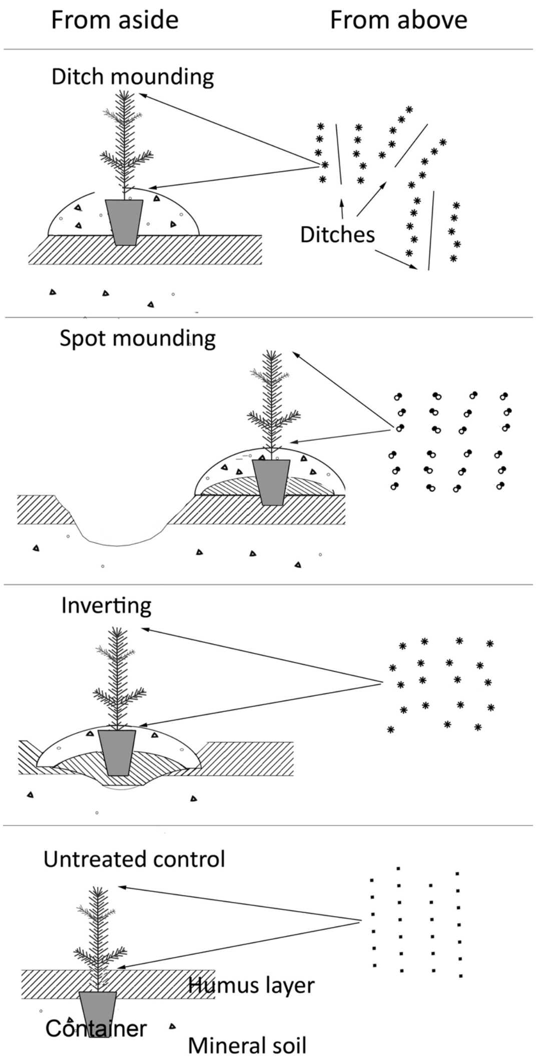

**Fig. 1.** Schematic illustration for the treatments of ditch and spot mounding, inverting and untreated control.

humus layer (5, 13 and 18 cm mineral capping for D_low, D_mid, D_high and S_low, S_mid, S_high, respectively), which were checked and modified using a hoe preceding planting. Between inverted spots, also unprepared control spots were left without (Ctrl) or with a glyphosate application (Herb). Glyphosate in 1.2% concentration (Glyfonova Bio, Cheminova A/S, Lemvig, Denmark) was sprayed 50 cm around the seedlings which were covered by an upside-down bucket during spraying in the second growing season (done 27th June 2008 in Suonenjoki).

The treatments in Suonenjoki were grouped according to the sloped terrain into four blocks. In each block, there was one quadrangle plot (about 640 $m^2$) for each soil preparation method, resulting in 12 plots in all (3 methods x 4 blocks). Each plot was treated with one of the three methods: i) ditch (D) or ii) spot (S) mounding with the three alternative mineral capping thicknesses or iii) inverting (Inv) and accompanied with the unprepared treatments (Herb and Ctrl). Within plots, the soil treatment spots were randomly positioned and the plots randomly assigned into each block (Fig. 2). There were 3 x 47 planting spots in each plot, with a total of 1692 spots. Total area of Suonenjoki experiment was 0.8 ha.

The soil in Pieksämäki was prepared similarly to that in Suonenjoki but there were two total target mound heights (mineral cappings were not recorded) used for ditch and spot mounding treat-

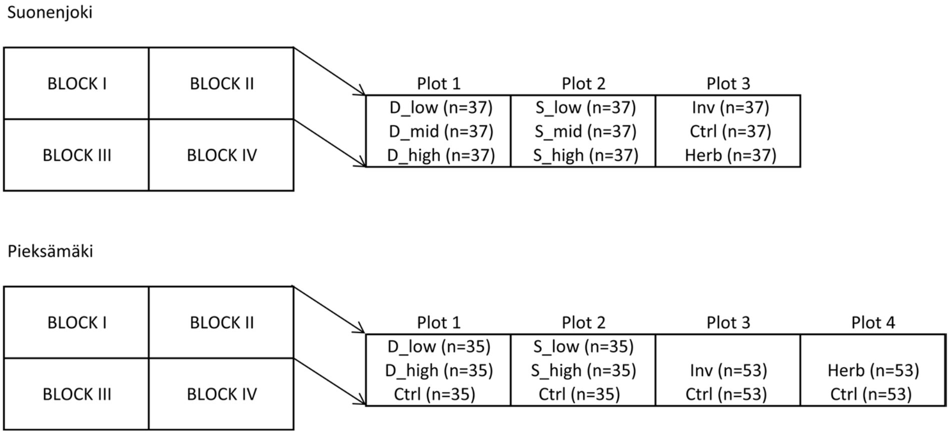

**Fig. 2.** Schematic graph of the experimental design. For treatment abbreviations, see text or legend for Table 3 (n refers to the number of planted seedlings).

ments (5–10 or 25–30 cm from the soil surface for D_low, D_high, S_low, S_high, respectively). The number of unprepared spots was also increased due to higher suspected seedling mortality rates. 16 plots (each 640 m$^2$) in four blocks (4 plots in each) were established (total area over 1 ha). Each plot included untreated Ctrl either with i) low and high mounding (D or S) treatments (each in 35 replications) or ii) Inv (in 53 replications) or iii) Herb treatment without soil preparation (in 53 replications). Thus there were eight plots with 3 x 35 planting spots and eight plots with 2 x 53 planting spots (1688 spots in all). Glyphosate was applied to the Herb treatment on 10 June 2010 likewise as in Suonenjoki.

## 2.2 Seedling and planting depth measurements

Two-year-old Norway spruce seedlings in Plantek 81F containers (Lannen Plant Systems, BCC Oy, Säkylä, Finland) were used for outplanting. The seedlings were grown from local seed using standard growing procedures in a forest nursery in Suonenjoki (62.65 N, 27.05 E). General seedling growing procedures have been described previously (Rikala 2002; Heiskanen and Rikala 2006; Heiskanen 2013). Before shipping and outplanting, seedling shoots were treated for pine weevil by submerging them into a 0.05% deltamethrin solution (Decis 25 EC; Bayer Crop Science AG, Manheim am Rhein, Germany) in the nursery.

The mean seedling height in Suonenjoki before planting in spring 2007 was 25.8 cm (sd 2.9 cm) and the root collar diameter was 3.3 mm (sd 0.5 mm). The mean seedling height in Pieksämäki before planting in spring 2009 was 24.1 cm (sd 2.3 cm) and root collar diameter 3.5 mm (sd 0.6 mm). The seedlings were planted with the Pottiputki planting tube (Lannen Plant Systems). The target planting depth was about 4–6 cm (distance between upper surface of plug and soil surface).

The actual planting depth, which was determined after the first growing season in Suonenjoki, varied slightly among the used treatments, being on average 3.3–5.1 cm. The actual distance between the root plug and the humus layer in mounds also varied according to the height of the mounds and the thickness of their mineral capping. After the first growing season, the thickness of the mineral soil layer was found to be 11 cm or less in the two shallowest mound categories (D_low, D_mid, S_low and S_mid), which indicates that, only in these mound types, the root plug reached (as the plug height is 7 cm and planting depth 3–5cm), on average, the humus layer in Suonenjoki.

In Pieksämäki, the mean mineral layer was 14–23 cm thick in the mounded or inverted spots. In Pieksämäki, the mean seedling height differed somewhat among treatments just after planting although there was no difference in seedling height prior to planting. This resulted partly from the slightly differing planting depths, which tended to be deepest in ditch mounding (4.8 cm in D_low and 4.5 cm in D_high) and shallowest in spot mounding (4.1 cm in S_low and S_high).

Seedlings were measured for height (mm) and vigour in autumn after outplanting for four years in Suonenjoki (2007–2010) and three years in Pieksämäki (2009–2011). Seedling vigour was rated in categories according to growth and visually determined needle colour as follows; 1 high vigour, 2 slightly weakened (some chlorosis), 3 weakened (chlorotic needles), 4 very weak (very chlorotic or brown needles) and 5 dead. Any seedling in vigour categories 1 or 2 was counted as vigorous. Clear visual damage by frost heave, pine weevil (*Hylobius abietis* L.) and voles (mainly *Microtus agrestis* L.) as well as damage by other causes were determined for each seedling and recorded as percentages.

In addition, after the first growing season, four randomly chosen vigorous planted seedlings were lifted from each treatment within each plot in Suonenjoki (in all 144 seedlings). In Pieksämäki, four seedlings were also lifted each treatment except one from each Ctrl treatment within plots (in all 112 seedlings). The dry masses (mg) of the roots and shoots were determined after two days of drying at 60 °C. Roots that had grown out from the root plug into the surrounding soil were specified separately as well as the longest outgrown root length (mm).

Samples for analysing foliar nutrients were collected after the second growing season from new (current) lateral side shoots of four to five randomly chosen seedlings which were combined to one sample for each treatment within each plot (in all 36 samples in Suonenjoki and 40 samples in Pieksämäki). The nitrogen (N) concentration was analysed using a CHN-1000 analyzer (Leco Corp., St. Joseph, MI, USA). Other foliar nutrients were determined using dry ashing. The ash was dissolved in hydrochloric acid (HCl), and the analyte concentrations were determined by means of an inductively coupled plasma atomic emission spectrometer (TJA Iris Advantage, Thermo Jarrell Ash Corporation, Franklin, MA, USA).

## 2.3 Soil measurements

Soil temperature in the growing season was measured using one Hobo logger (type H08-008-04, Onset Computer Corp., MA, USA) with four temperature sensors (type Hobo TMC20-HD) at both study sites (measuring depths 6–12 cm below soil surface in Ctrl, Inv, Spot and/or Ditch treatments). Air temperature and relative humidity were also measured using a thermometer screen in the middle of the study site at a height of 15 cm using a Hobo data logger (type H08-032-08).

Volumetric soil water content was measured downwards (about 6 cm) from the mound surfaces and from the unprepared Ctrl soil beneath the humus layer. Readings were taken four to five times per summer following two to three rainless days using a hand-held soil moisture meter (ThetaProbe, ML2, Delta-T Devices, Cambridge, UK). At each measurement time, there were 16 measurements for each treatment (i.e. $n=4$ within blocks). The readings were calibrated in the laboratory against a typical mineral soil from the sites.

In Suonenjoki, the heights of the planting spots from the soil surface were measured after the first growing season. To follow the subsidence of mounds in more detail, mound heights in relation to unprepared soil surface were determined from a random sample of 100 mounds (five from each mound height category within each plot) in spring and autumn in Pieksämäki. Ditch mounding yielded the tallest mounds (maximum nearly 50 cm) and the inverted spots were at about the soil surface level (Fig. 3). The subsidence of mounds was gradual over years. The mean depression was about 10 cm in the highest mounds over the three years. The mean base area of mounds was about 0.41 and 0.48 $m^2$ after the first and second growing season, respectively, in Pieksämäki.

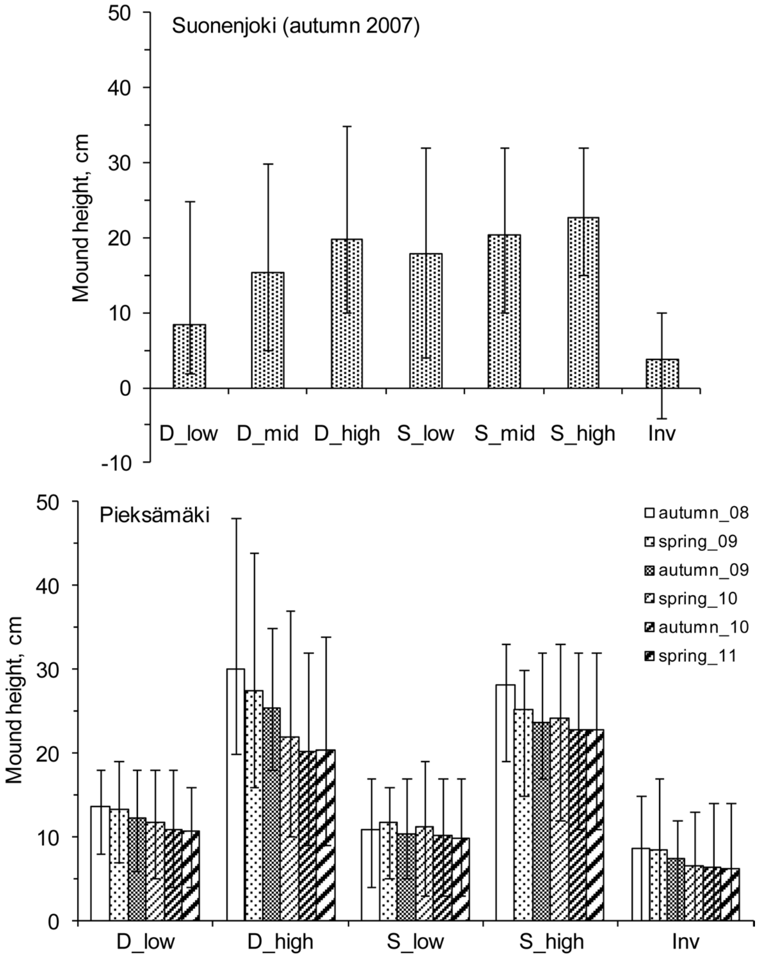

**Fig. 3.** Arithmetic means for the mound heights in the different mounding treatments in Suonenjoki (measured only after the first growing season) and Pieksämäki (n = 15–20). Vertical lines on bars show the range of variation (i.e. max-min). For treatment abbreviations, see text or legend for Table 3.

## 2.4 Data analysis

The studied soil-preparation treatments were in a modified form of split-plot design. Each of the four blocks on both sites included one plot for each treatment (i.e. mainplot treatment) with or without unprepared control spots (Fig. 2). Mounds within the mounding (D and S) plots were handled as categories (i.e. subplot treatments) according to the height of the mineral capping (three categories in Suonenjoki) or total height of the mound (two categories in Pieksämäki).

The differences in means of the studied variables (seedling attributes, soil water content) between the different treatments (9 in Suonenjoki and 7 in Pieksämäki) were tested using a mixed model analysis of variance with seedling planting height as a covariate for the seedling variables. The model used was therefore of the form $Y_{ijkl} = \mu + \mathrm{treatment}_{ij} + \beta_{ij} * X_{ijkl} + \mathrm{block}_k + \mathrm{plot}_{ik} + \varepsilon_{ijkl}$ , where $\mathrm{treatment}_{ij}$ is a fixed treatment effect, $\beta_{ij}$ is a fixed regression coefficient, $X_{ijkl}$ is the value of a covariate, $\mathrm{block}_k$ is a random block effect, $\mathrm{plot}_{ik}$ is a random plot effect and $\varepsilon_{ijkl}$ is a residual term. In subindexes, $i = 1–3$ (mainplot treatments), $j = 1–3$ (subplot treatments), $k = 1–4$ (blocks), $l = 1\text{-}n_{ijk}$ where $n_{ijk}$ refers to the number of replicates of treatment ij on block k.

Corresponding model dimensions resulted in i) F tests of fixed effects (intercept, treatment, covariate, treatment*covariate), ii) an univariate F-test of covariate adjusted effects of the treatment as well as iii) estimates of covariance parameters for random effects (residual, block, plot). Since the subplot treatments were not the same in all the mainplot treatments, the usual tests of main effects and interaction are not reported but the univariate F-test for the treatment effect and the corresponding pairwise comparisons for the effects of the used treatment combinations. Presented pairwise comparisons are always based on estimated marginal means from the used mixed model and are tested with LSD or contrasts at a significance level of $p<0.05$. Treatment means are presented as estimated marginal means but plain arithmetic means are shown for percentage values for mortality, proportions of vigorous seedlings and those gnawed by pine weevil or voles and heaved by frost (x) because they were statistically tested after arcsine($x^{0.5}$) transformation.

## 3 Results

Soil temperature during the growing season until September was on average lowest under the organic layer in the unprepared planting spots and highest in the mounded spots (data not shown). Later in the autumn, the situation was reversed. Temperature sums (threshold > +5 °C) obtained for both study sites in the different measurement spots were highest in spot and ditch mounds (Table 2). Suonenjoki site had overall a greater temperature sum than Pieksämäki. Soil water content tended to be highest under the organic layer in the unprepared planting spots and next highest in inverted spots (Fig. 4, Table 3). The highest ditch mounds tended to be driest especially in dry summers. The average water content among the treatments was within 10–35 vol. %, which corresponds to matric potentials –100…–10 kPa (data not shown). Despite a higher water table, the average water content in Ctrl spots in Pieksämäki was only slightly higher (33%) than in Suonenjoki (30%). The driest mounds contained about 25% water in Pieksämäki and 20% in Suonenjoki on average.

After the first growing season, above- and below-ground seedling masses (data not shown) varied only slightly among the treatments (F-test $p>0.05$). Estimated marginal means in the treatments were within 3.8 and 5.0 g (DM) for above ground and 2.1–3.8 g (DM) for below ground biomasses, respectively. Root egress from the root plug (measured as dry mass) varied also little among the treatments ($p>0.05$), but tended to be lower in the unprepared planting spots especially in Pieksämäki and was overall lower in Pieksämäki (0.6 g DM) than in Suonenjoki (1.3 g DM). In Suonenjoki, longest root was significantly lower in Herb (25 cm) than in D_low treatment (35 cm).

**Table 2.** Temperature sums (threshold > +5 °C) for the soil preparation treatments in 2009 (29th April to 30th September) in Suonenjoki and Pieksämäki (one sensor in each treatment). The numbers within brackets indicates the distance in cm from the soil surface. Treatment abbreviations: Ctrl – untreated soil, Inv – inverting, S_low, S_mid – low or mid height spot mounding and D_low – low ditch mounding.

| Suonenjoki | dd, °C | Pieksämäki | dd, °C |
|---|---|---|---|
| Air (+15 cm) | 1284 | Air (+15 cm) | 1169 |
| Ctrl (–11 cm) | 1062 | Ctrl (–12 cm) | 807 |
| Inv (–5 cm) | 1322 | Inv (–6 cm) | 1238 |
| S_mid (–5 cm) | 1446 | S_low (–6 cm) | 1282 |
| S_mid (–8 cm) | 1463 | D_low (–6 cm) | 1186 |

**Table 3.** Soil water content (vol.%) in the different soil preparation treatments in Suonenjoki and in Pieksämäki. Estimated marginal means denoted by the same letter within years show non-significant differences according to LSD pairwise comparisons at $p > 0.05$. *p*-value shows the significance of the difference in means within sites and years (F-test, block means as observations i.e. $n = 4$). Treatment abbreviations: Ctrl – untreated soil, Inv – inverting, S_low, S_mid, S_high – low, mid or high height spot mounding and D_low, D_mid, D_high – low, mid or high height ditch mounding.

Suonenjoki

| Treatment | 2007 | 2008 | 2009 |
|---|---|---|---|
| D_low | 20.4 a | 17.2 a | 21.9 a |
| D_mid | 20.4 a | 20.6 b | 23.1 ab |
| D_high | 21.1 a | 22.4 b | 23.7 ab |
| S_low | 23.3 a | 22.6 b | 24.3 b |
| S_mid | 23.8 a | 22.7 b | 22.5 a |
| S_high | 22.8 a | 22.0 b | 23.5 ab |
| Inv | 29.1 b | 28.4 c | 27.7 c |
| Ctrl | 31.4 b | 29.3 c | 29.6 c |
| *p* | *<0.0005* | *<0.0005* | *<0.0005* |

Pieksämäki

| Treatment | 2009 | 2010 | 2011 |
|---|---|---|---|
| D_low | 30.5 ab | 27.7 ab | 31.3 abc |
| D_high | 28.4 a | 24.3 a | 27.9 a |
| S_low | 32.2 bcd | 28.2 ab | 31.7 bc |
| S_high | 30.7 abc | 27.4 ab | 30.5 ab |
| Inv | 33.0 cd | 30.6 bc | 32.9 bc |
| Ctrl | 33.3 d | 31.8 c | 33.4 c |
| *p* | *<0.0005* | *<0.0005* | *<0.0005* |

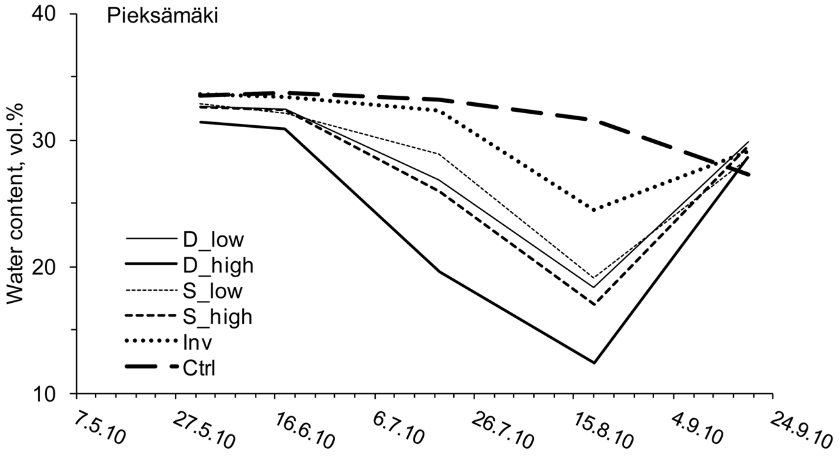

**Fig. 4.** Example of the mean course of soil water content during the dryish summer of 2010 in Pieksämäki ($n = 16$). For treatment abbreviations, see text or legend for Table 3. Date presented as day/month/year.

Foliar nutrients, that were determined after the second growing season, differed slightly according to treatments (Table 4). On prepared spots seedlings tended to have higher foliar Al than on unprepared spots, and higher foliar Ca on ditch mounded spots than on spot mounded spots. Mean foliar boron was lower in Suonenjoki (5.7 mg kg$^{-1}$) than in Pieksämäki (9.3 mg kg$^{-1}$). Foliar N was fairly even at about 2.5% in Suonenjoki and 2% in Pieksämäki although it tended to be highest in the Herb treatment.

The proportion of seedlings with visual pine weevil damage was significantly higher in Herb and Ctrl treatments than in the other treatments after the first growing season in Suonenjoki (Table 5). In the following seasons, the situation was alleviated and was similar in all treatments. The majority of seedlings were gnawed by voles in winter 2008–2009 (Table 5) but slightly less in ditch mounds. Seedlings were heaved by frost especially in ditch mounds and inverted spots but not at all in the Herb and Ctrl treatments (Table 5).

In Pieksämäki, the proportion of seedlings with pine weevil damage was also significantly higher in Herb and Ctrl treatments than in the other treatments after the first growing season (Table 5). In the following autumn, the situation was alleviated but still worse in Herb and Ctrl than in the other treatments. Seedlings were only slightly heaved by frost (<6%) but almost not at all in the Herb and Ctrl treatments (Table 5). Little vole damage was observed.

Annual seedling mortality was below 5% in the soil prepared spots but could be up to 20% in the unprepared spots (Table 6). Seedling mortality was higher and the proportion of vigorous seedlings lower in the unprepared treatments mainly due to the pine weevil damage. In inverted spots, the seedling vigour also tended to be weaker compared to mounded spots. In Suonenjoki, vole damage after the winter of 2008–2009 decreased seedling vigour in general (Table 6). In Pieksä-

**Table 4.** Current-year foliar nutrients of vigorous seedlings in the different soil preparation treatments after the second growing season 2008 in Suonenjoki and 2010 in Pieksämäki. Estimated marginal means denoted by the same letter show non-significant differences according to LSD pairwise comparisons at $p > 0.05$ ($n = 4$ within treatments). *p*-value shows the significance of the difference in means (F-test). For treatment abbreviations, see text or legend for Table 3.

| Treatment | N, % | P, mg kg$^{-1}$ | Ca, mg kg$^{-1}$ | Al, mg kg$^{-1}$ | Fe, mg kg$^{-1}$ | B mg kg$^{-1}$ |
|---|---|---|---|---|---|---|
| Suonenjoki 2008 | | | | | | |
| D_low | 2.5 abc | 1990 a | 3995 a | 116 bc | 61 b | 6.7 a |
| D_mid | 2.4 ab | 1975 a | 3500 b | 138 ab | 82 a | 5.0 b |
| D_high | 2.4 ab | 1958 ab | 3540 b | 148 a | 82 a | 5.0 b |
| S_low | 2.7 cd | 1748 d | 2778 c | 92 c | 54 bcd | 6.0 ab |
| S_mid | 2.5 ab | 1828 cd | 2773 c | 114 bc | 56 bcd | 5.3 ab |
| S_high | 2.6 bcd | 1840 bcd | 2430 d | 144 a | 49 abc | 5.1 b |
| Inv | 2.4 a | 1913 abc | 2638 cd | 157 a | 44 bcd | 5.7 ab |
| Herb | 2.7 d | 1798 d | 3370 b | 47 d | 34 d | 6.4 ab |
| Ctrl | 2.5 ab | 1815 cd | 3295 b | 45 d | 38 cd | 6.4 ab |
| *p* | *0.007* | *0.016* | *<0.0005* | *<0.0005* | *0.010* | *0.078* |
| Pieksämäki 2010 | | | | | | |
| D_low | 2.0 abc | 1756 ab | 4636 ab | 119 a | 44 a | 9.0 ab |
| D_high | 2.1 abc | 1794 ab | 5043 b | 145 a | 68 a | 6.3 a |
| S_low | 1.9 ab | 1742 a | 3336 a | 105 a | 43 a | 12.3 b |
| S_high | 2.3 bc | 1792 ab | 3571 ab | 140 a | 61 a | 9.5 ab |
| Inv | 1.8 ab | 1683 a | 3351 a | 115 a | 41 a | 8.0 ab |
| Herb | 2.4 c | 2084 b | 3949 ab | 40 b | 92 a | 9.7 ab |
| Ctrl | 1.8 a | 1901 ab | 3444 a | 32 b | 36 a | 9.9 ab |
| *p* | *<0.0005* | *0.012* | *0.002* | *<0.0005* | *0.153* | *0.023* |

**Table 5.** Percentage of seedlings gnawed by pine weevil and voles and heaved by frost in Suonenjoki and Pieksämäki. Arithmetic means denoted by the same letter show non-significant differences within years according to LSD pairwise comparisons at p > 0.05 (n = 4 i.e. block means as observations). *p*-value shows the significance of the difference in means (F-test). For treatment abbreviations, see text or legend for Table 3.

| Treatment | Frost heave | Frost heave | Vole | Pine weevil | Pine weevil |
|---|---|---|---|---|---|
| Suonenjoki | 2008 spring | 2009 spring | 2009 spring | 2007 autumn | 2008 autumn |
| D_low | 16.9 ab | 19.7 ab | 62.0 a | 1.1 a | 5.3 a |
| D_mid | 18.1 ab | 23.3 ab | 56.5 ab | 0.5 a | 6.7 a |
| D_high | 12.5 abc | 17.0 abc | 52.0 b | 0.0 a | 7.8 a |
| S_low | 1.8 bcd | 3.7 bcd | 81.8 d | 0.5 a | 10.4 a |
| S_mid | 4.8 abd | 9.1 abcd | 78.8 cd | 0.0 a | 7.3 a |
| S_high | 2.7 abd | 10.9 abcd | 77.8 cd | 0.0 a | 7.9 a |
| Inv | 18.4 a | 18.5 a | 73.4 a | 0.0 a | 11.8 a |
| Herb | 0.0 cd | 0.0 cd | 79.0 cd | 37.7 b | 15.4 a |
| Ctrl | 0.0 d | 0.0 d | 72.5 ac | 31.0 b | 10.4 a |
| *p* | *0.001* | *0.001* | *<0.0005* | *<0.0005* | *0.648* |
| Pieksämäki | 2010 spring | 2011 spring | 2009 autumn | 2009 autumn | 2010 autumn |
| D_low | 4.0 ab | 0.8 ab | 2.9 a | 7.1 a | 1.6 abc |
| D_high | 1.7 bc | 0.8 ab | 0.7 a | 2.9 a | 2.5 abc |
| S_low | 5.7 ab | 2.4 ab | 0.0 a | 7.9 a | 4.8 b |
| S_high | 2.4 abc | 1.6 ab | 0.0 a | 5.0 a | 0.0 c |
| Inv | 5.7 a | 3.1 a | 0.5 a | 8.0 a | 3.6 abc |
| Herb | 0.0 c | 0.0 b | 2.8 a | 67.2 b | 33.4 d |
| Ctrl | 0.1 c | 0.0 b | 1.6 a | 55.6 b | 13.0 b |
| *p* | *0.016* | *0.206* | *0.603* | *<0.0005* | *0.001* |

**Table 6.** Percentage of mortality and vigorous seedlings (class 1 and 2) in different years in Suonenjoki and Pieksämäki. Seedlings that died in previous years are not counted in the values for the current year. Arithmetic means denoted by the same letter show non-significant differences within years according to LSD pairwise comparisons at p > 0.05. *p*-value shows the significance of the difference in means (F-test). For treatment abbreviations, see text or legend for Table 3.

| Treatment | Mortality | | | | Vigorous seedlings | | | |
|---|---|---|---|---|---|---|---|---|
| Suonenjoki | 2007 | 2008 | 2009 | 2010 | 2007 | 2008 | 2009 | 2010 |
| D_low | 0.6 a | 0.0 | 4.1 ab | 1.8 a | 96.8 a | 98.3 a | 66.5 ab | 82.5 a |
| D_mid | 2.1 a | 0.0 | 2.4 a | 1.8 a | 97.9 a | 98.3 a | 70.3 ab | 79.0 ab |
| D_high | 0.6 a | 0.0 | 4.1 a | 1.3 a | 98.9 a | 98.3 a | 80.3 c | 84.0 a |
| S_low | 0.0 a | 0.0 | 4.8 ab | 1.3 a | 98.9 a | 98.8 a | 64.0 ab | 79.8 a |
| S_mid | 0.0 a | 0.0 | 2.9 a | 1.8 a | 99.5 a | 97.8 a | 64.0 ab | 70.5 b |
| S_high | 0.0 a | 0.0 | 3.9 | 3.0 a | 99.5 a | 100.0 a | 66.5 abc | 75.5 ab |
| Inv | 1.0 a | 0.0 | 4.9 abc | 2.8 a | 98.5 a | 93.3 a | 63.0 b | 62.3 c |
| Herb | 19.2 b | 0.0 | 11.6 bc | 2.1 a | 71.1 b | 97.8 a | 48.8 a | 66.5 bc |
| Ctrl | 27.5 c | 0.0 | 11.1 c | 0.8 a | 63.9 b | 96.5 a | 59.3 ab | 66.3 bc |
| *p* | *<0.0005* | - | *0.047* | *0.781* | *<0.0005* | *0.428* | *0.041* | *0.037* |
| Pieksämäki | 2009 | 2010 | 2011 | | 2009 | 2010 | 2011 | |
| D_low | 1.4 a | 0.8 a | 0.8 ab | | 90.8 a | 89.4 ab | 95.9 ab | |
| D_high | 0.7 a | 2.5 a | 0.0 a | | 95.0 a | 92.7 ab | 96.7 a | |
| S_low | 0.7 a | 4.8 a | 0.8 a | | 97.8 a | 89.4 bc | 96.0 abc | |
| S_high | 0.7 a | 0.0 a | 0.0 a | | 99.3 a | 97.6 a | 98.4 ab | |
| Inv | 0.5 a | 2.1 a | 0.5 a | | 89.6 a | 81.4 bc | 84.8 bcd | |
| Herb | 13.3 b | 20.1 b | 2.6 ab | | 64.5 b | 48.4 d | 74.0 d | |
| Ctrl | 8.5 b | 7.2 a | 6.3 b | | 75.9 b | 71.3 cd | 85.3 cd | |
| *p* | *0.002* | *0.010* | *0.065* | | *<0.0005* | *<0.0005* | *0.009* | |

**Table 7.** Seedling height (cm) development in the different soil preparation treatments in Suonenjoki and in Pieksämäki. Estimated marginal means denoted by the same letter show non-significant differences according to LSD pairwise comparisons at $p > 0.05$. *p*-value shows the significance of the difference in means (F-test). In each treatment within each of the four blocks initial $n = 47$ in Suonenjoki and $= 35$ or 53 in Pieksämäki. Pairwise comparisons for the mainplot treatments (D, S, Inv, Herb, Ctrl) are deriving from contrast tests. For treatment abbreviations, see text or legend for Table 3.

| Treatment | 2007 Planting | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|---|
| Suonenjoki | | | | | |
| D_low | 23.4 a | 27.2 a | 40.8 abc | 47.1 ab | 67.8 abc |
| D_mid | 23.2 a | 27.7 abc | 40.0 ab | 46.3 b | 67.5 abc |
| D_high | 22.9 a | 27.6 ab | 39.8 a | 49.4 a | 70.7 a |
| S_low | 22.9 a | 28.4 bcd | 43.0 c | 45.5 ab | 66.5 ab |
| S_mid | 22.8 a | 28.7 de | 42.2 bc | 42.9 b | 61.7 c |
| S_high | 22.7 a | 28.9 de | 42.5 c | 45.1 ab | 64.5 abc |
| Inv | 22.5 a | 29.6 e | 41.0 abc | 44.1 ab | 60.2 c |
| Herb | 22.7 a | 28.5 cd | 42.2 abc | 43.4 ab | 61.6 c |
| Ctrl | 22.7 a | 28.8 d | 42.2 abc | 44.0 ab | 60.9 c |
| *p* | *0.712* | *0.003* | *0.083* | *0.278* | *0.138* |
| D | 23.2 a | 27.5 a | 40.2 a | 47.6 a | 68.6 a |
| S | 22.8 a | 28.7 b | 42.6 b | 44.5 a | 64.2 ab |
| Inv | 22.5 a | 29.6 c | 41.0 ab | 44.1 a | 60.2 b |
| Herb | 22.7 a | 28.5 b | 42.2 ab | 43.4 a | 61.6 ab |
| Ctrl | 22.7 a | 28.8 b | 42.2 ab | 44.0 a | 60.9 ab |
| *p* | *0.633* | *0.002* | *0.065* | *0.628* | *0.285* |
| Pieksämäki | 2009 Planting | 2009 | 2010 | 2011 | |
| D_low | 19.6 ab | 24.6 ab | 33.3 ab | 50.2 ab | |
| D_high | 19.7 ab | 24.9 ab | 34.3 ab | 51.5 a | |
| S_low | 20.1 a | 25.4 a | 34.5 ab | 49.2 abc | |
| S_high | 19.9 ab | 24.7 ab | 35.3 a | 51.5 a | |
| Inv | 19.3 b | 25.4 a | 34.1 ab | 47.4 b | |
| Herb | 20.0 ab | 22.8 c | 31.8 b | 45.7 c | |
| Ctrl | 19.9 a | 24.1 b | 32.8 b | 48.2 b | |
| *p* | *0.32* | *0.001* | *0.070* | *0.057* | |
| D | 19.6 ab | 24.7 ab | 33.8 ab | 50.8 a | |
| S | 20.0 a | 25.1 b | 34.9 b | 50.4 a | |
| Inv | 19.3 b | 25.4 b | 34.1 ab | 47.4 ab | |
| Herb | 20.0 ab | 22.8 c | 31.8 a | 45.7 b | |
| Ctrl | 19.9 a | 24.1 a | 32.8 a | 48.2 ab | |
| *p* | *0.181* | *0.001* | *0.039* | *0.047* | |

mäki, on the other hand, the glyphosate treatment (Herb) in the second growing season decreased seedling vigour.

Seedling height development differed a little among the treatments as absolutely measured but was affected by seedling damage and conditions in the planting spot (Table 7). Although vole damage disturbed height development in Suonenjoki, the general trend was that height increment tended to be better in mounds than in unprepared and inverted spots after the third growing season on both sites. Root collar diameter did not differ among treatments and was on average 3.2 mm after planting and 9.9 mm after the third growing season in Suonenjoki. In Pieksämäki, the root collar diameter was similar, on average 2.9 mm after planting and 9.9 mm after the third growing season.

## 4 Discussion

### 4.1 Soil preparation for Norway spruce planting on frost heave susceptible soils

The observed seedling height development on the studied frost-heave susceptible forest soils was found to be similar or somewhat weaker than that found previously in soil-preparation studies in similar conditions but on coarser soils with about 5 cm taller seedlings at planting (Heiskanen and Viiri 2005; Heiskanen et al. 2009). For example, during the second growing season after planting, height growth was about 10–12 cm in the present study whereas it was 11–15 cm in the previous studies. In a plantation inventory in southern Finland, mean seedling height after the third growing season has been found to be 55–60 cm on varying soil textures and lowest on fine-grained soils (Saksa and Kankaanhuhta 2007). This is in line with the results of the present study since the mean height on the mounding treatments was 52–56 cm in Pieksämäki (below 50 cm in Suonenjoki due to vole damage).

Above-ground seedling biomass after the first growing season was, however, slightly greater in this study than in a previous study on a similar but coarser forest soil with few cm taller seedlings at planting (Heiskanen and Rikala 2006) and within the values found on an another coarser soil (Heiskanen et al. 2009). Compared to these previous studies, root egress from the root plug into the soil was similar in this study as was the benefit from mounding to seedling growth and vigour.

Soil preparation uncovering an open mineral soil commonly reduces pine-weevil damage on planted seedlings even if seedling pre-treatment with insecticides is used (Örlander and Nilsson 1999; Heiskanen and Viiri 2005). Thus the mounding treatments in the present study also showed significantly less damage by the pine weevil, which obviously contributed to the better seedling growth compared to the unprepared treatments. Lower temperature and wetness of the soil may also have contributed somewhat to the decreased seedling performance in unprepared spots. Vole damage to seedlings (in Suonenjoki) tended to be lower in ditch mounds possibly due to their more difficult accessibility to voles as the mound surface is somewhat looser than in spot mounds. In general, voles occur variably over years and regions, but during high winter time population of voles, the amount of vegetation at the site increases the risk of vole damage to seedlings (Teivainen et al. 1986).

Differences in seedling attributes between the study sites were also contributed by the site (hydrology) and year (weather, damage). About one-half lower root egress in Pieksämäki than in Suonenjoki implies that soil wetness had decreased rooting into the soil. Frost heave was mainly present on the ditch mounded and inverted spots in Suonenjoki. In ditch mounds, the soil was presupposedly taken deeper from the soil, which was observed to be finer and containing less humus. This may have promoted frost heave as also has the higher water content in the inverted spots. Lower frost heave occurrence in Pieksämäki probably resulted from more stable thermal conditions due to wetness, which therefore could not yield enough freezing and thawing cycles for frost heave.

Preplanting seedling water status can have a marked impact on postplanting rooting into the soil, early survival and height growth although water availability from the soil also has an impact on seedling performance (Heiskanen and Rikala 2000; Helenius et al. 2005). In this study, seedlings were sufficiently watered prior to outplanting. In addition, the soil in the planting spots was also on average relatively moist in the mounds (matric potential –10…–100 kPa), although the soil water content dropped close to 10 vol.% in the highest mounds during the driest spell (in mid-August 2010). Thus the seedling performance cannot be seen to have suffered greatly from the pre- or postplanting drought. Instead, higher soil temperature and lower soil water content especially in the highest mounds obviously enhanced seedling growth. Mounding and other soil preparation treatments can improve postplanting seedling development by decreasing drought risk or excessive soil wetness (Söderström et al. 1978; Örlander et al. 1990; Munson et al 1993; Grossnickle 2000; Knapp et al. 2008).

Decreasing surface vegetation around seedlings tends to decrease seedling mortality and improve seedling growth at least a few years after planting (Munson et al. 1993; Nilsson and Örlander 1999; Örlander and Nilsson 1999; Knapp et al. 2008). During the present study period, however, the surface vegetation was still rather scant. The increased seedling mortality after the herbicide treatment in the second growing season (in Pieksämäki) suggests that seedlings have even suffered from the herbicide. A similar effect has also been found previously (Heiskanen and Viiri 2005), which could happen through root contact in the active growth stage of seedlings at the time when the herbicide was applied and surface vegetation was still minimal.

Foliar N was relatively uniform among the treatments (about 2.5% in Suonenjoki and 2% in Pieksämäki), although it tended to be higher in the herbicide treatment. Decreased vegetation competition and subsequent decomposition of died vegetation by the herbicide treatment may have increased N mineralization and availability to seedlings (Nordborg 2001; Smolander and Heiskanen 2007). Usually foliar N concentration of Norway spruce seedlings increases after mounding on medium coarse soils, and even so that foliar boron may dilute to a level of deficiency in Nordic forest sites (Heiskanen and Rikala 2006). In this study, boron was probably not a limiting growth factor although it was just slightly above the deficit limit (Braekke 1994) in Suonenjoki (mean 5.7 mg kg$^{-1}$). In Pieksämäki, foliar boron was a bit higher (9.3 mg kg$^{-1}$). A higher foliar Al in mounded spots and a slightly higher foliar Ca in ditch mounds indicates differences in the nutrients of soil that has been excavated from varying depths.

Seedling height development was found to be, on average, better in the mounded treatments than in the unprepared and inverted treatments after the third growing season on both study sites. The benefits of mounding have also been found in several previous studies (e.g. Örlander et al. 1990; Sutton 1993; Nordborg 2001; Nordborg et al. 2003; Heiskanen and Viiri 2005; Knapp et al. 2008).Variations in mound height or thickness of mineral capping did not show a clear difference in the seedling growth on the studied soils and years. Nevertheless, the highest mounds in this study can potentially decrease available water (and possibly nutrients) to seedlings especially in dry growing seasons.

Inverting has been previously observed to yield less (visual) soil disturbance and enhance seedling planting survival and height development similarly in comparison with spot mounding. However, on the studied sites, inverting showed a poorer postplanting seedling performance than previously found in Sweden and Finland (Örlander et al. 1998; Hallsby and Örlander 2004; Heiskanen and Viiri 2005; Heiskanen and Rikala 2006). This seems to derive from the frost heave susceptible soils on the studied sites, which can not provide good conditions for seedling growth owing to soil wetness and coolness in the low-positioned inverted spots.

### 4.2 Conclusions

The results suggest that seedling damage, thermal conditions and the availability of water and nutrients in the different planting spots were reflected in the seedling development which was enhanced in mounds. The used soil preparation treatments had a greater effect on seedling vigour than on seedling growth as absolutely measured. Therefore, ditch and spot mounding should be used on frost heave susceptible soils to promote plantation establishment. However, the formation of overly high mounds and excavating ditch mounds from too deep in the soil should be avoided owing to frost heave risk. Inverting or having no soil preparation with or without herbicide treatment is not recommended due to subsequent wetness, coolness and/or pine weevil damage.

Seedling growth was found to be similar or slightly lower than that found previously on similar but coarser mounded forest soils nearby, and on fine-grained soils in southern Finland. Varying mound height or thickness of mineral capping did not yield a clear difference in the seedling growth on the studied soils. It is therefore possible that even a good soil preparation cannot fully alleviate the inherent effects of the compactness of frost heave susceptible soils on root and shoot growth of outplanted seedlings to the growth levels found on coarser and looser soils. However, the effects of a shallower mounding on seedling performance on sorted fine-grained silty and clayey soils are still not well known. Further studies may be also needed on very fine, sludgy soils, that are difficult to mound and plant, in order to find out whether planting in unprepared organic surface layer can ease reforestation if pine weevil damage is avoided and vegetation controlled.

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