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Machine Planting of Norway Spruce by Bracke and Ecoplanter: An Evaluation of Soil Preparation, Planting Method and Seedling Performance

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We evaluated the effects of planting date and planting machine (Bracke: three machines, 69 regeneration areas in three years; Ecoplanter: six areas, two years) on the quality and field performance one and three years after planting of Norway spruce (*Picea abies* (L.) Karst.) seedlings in central Finland. Both machine types planted on average 1800 seedlings per hectare, and after three years approximately 1600 (Bracke) and 1200 (Ecoplanter) were still alive. This study suggests that planting with a Bracke machine can achieve better regeneration rates than those observed in privately-owned Finnish forests. We characterized the quality of mounding and planting with the Bracke machine as excellent and that of the Ecoplanter as good. The soil preparation method of the Ecoplanter produced humus-rich mounds where seedlings were susceptible to pine weevils and consequently suffered higher mortality. Different machines were used in different regional areas and each machine was operated by different driver/s which may have influenced the results. No negative effects of planting date were observed. Seedling growth decreased if they were tall in relation to their root plug volume, grown too densely in the nursery, and if stored in the field for several months prior to planting. We conclude that mechanized planting is successful when the soil preparation method produces mounds covered by purely mineral soil. Planting from May to the end of September is suitable for seedlings intended for use during this period.

Keywords height growth, machine planting, mechanized forestry, mounding, *Picea abies*, quality of planting, survival
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1 Introduction

Although it accounts for less than 5% of new seedlings (Rantala et al. 2009), the use of planting machinery is increasing in Nordic forests. Previously, planting machines such as Silva Nova (Sweden) and Serlachius (Finland) that disc trench and plant simultaneously, were suitable for use only in large regeneration areas and were relatively expensive compared to manual methods (Hallonborg 1997, von Hofsten 2003). In order to be cost-effective, a planting machine should complete both soil preparation and planting in a single operation and be highly utilized (Rantala and Saarinen 2006; Rantala et al. 2009).

Beginning in the 1990s, new planting machines were developed that combined soil preparation with planting and, ten years later, two such machines were used commercially in Finland. The Bracke planting machine (Bracke Forest, Bräcke, Sweden) is mounted to an excavator and, with a mounding blade and a planting head, forms and compacts a mound while simultaneously planting the seedling. The Ecoplanter planting machine (Partek Forest Oy Ab, Finland) is mounted on a harvester and equipped with two rotovator wheels and two planting heads but does not compact the mound after planting.

Quality of planting is just as important as cost of planting. Effective planting machines prepare the soil to enhance seedling survival and performance after planting. The quality of soil preparation can be measured as the number and structure of prepared mounds per hectare. The ideal mound is a core of humus covered by a 10 cm layer of pure mineral soil. The outer layer of mineral soil prevents damage from pine weevils (*Hylobius abietis* (L.) Col., Curculionidae) (Nordlander et al. 2005, Örlander and Nordlander 1998, Petersson and Örlander 2003, Petersson et al. 2005) and the humus core promotes the healthy growth of planted seedlings (Hallsby 1994, Smolander and Heiskanen 2007). Mounds may be spoiled by stones or logging residues that increase the risk of drying. Decomposition of logging residues may also immobilize nutrients and reduce the growth of seedlings after planting (Hallsby 1995).

Quality of planting depends on several factors. First and foremost, the planting machine must not damage the seedlings in the process. Second, the seedling must be planted at the correct depth and in an upright position. To avoid drying, the planting hole should be filled with and covered by at least 2–3 cm of soil after receiving a seedling root plug (Högberg 1987, Örlander et al. 1990). The aim is to insert root plugs into the double humus layer (Örlander et al. 1990) and if the mineral soil layer is too thick, there is a risk of incorrect planting depth. Nordlander et al. (2005) observed that deep planting can increase seedling susceptibility to pine weevils, and according to Huuri (1972) more than half of the shoot height should be left above the soil surface to avoid impaired field performance.

The performance of Ecoplanter and Bracke planting machines has been compared previously in Finland (Arnkil and Hämäläinen 1995, Härkönen 2008, Saarinen 2006) and Ireland (Keane 2006, Nieuwenhuis and Egan 2002) but data at the practical scale are lacking. In Ireland, Nieuwenhuis and Egan (2002) showed that planting quality and first-year survival of seedlings planted with the Bracke machine were inferior to those that were manually planted, but their growth rates were similar. Keane (2006) studied seedlings planted by Bracke and Ecoplanter and found that seedling survival and growth were both good two years after planting.

In order to ensure high utilization of machines, the planting season should be as long as possible. Results in field experiments have shown that planting Norway spruce container seedlings from May to the end of September is possible without any negative effects on performance (Luoranen et al. 2005, 2006). However, a comprehensive assessment of the risks associated with summer and autumn plantings requires practical-scale trials as well as carefully controlled experiments.

The aims of the study were to clarify the quality of two planting machines by assessing the i) quality of soil preparation and planting and ii) the field performance of machine-planted seedlings in regeneration areas one and three years after planting.

2 Material and Methods

2.1 Planting Sites and Material

Our survey was conducted in Central Finland between 2000 and 2005 and included two types of machines; Bracke (3: A, B, and C) and Ecoplanter (1). Bracke machines worked in three different areas of Central Finland (Fig. 1): Bracke A within a 100 km radius of Kuopio, Bracke B within a 100 km radius of Iisalmi and Bracke C around Pihtipudas and Viitasaari. The Ecoplanter planted seedlings around Suonenjoki and Pieksämäki (Fig. 1). Logging residues or stumps were not removed from any of the regeneration areas prior to soil preparation and planting.

Planting material contained one or two year-old container seedlings grown in different nurseries of Central Finland. Seedlings were packed in plastic trays and almost all transported to the planting site where they were stored for a maximum of three weeks prior to planting. Bracke C was an exception; some of the seedlings were transported to the field storage site the previous autumn and most of those seedlings were planted in May and June but in 2000 seedlings were transported the previous autumn and planted during and after July. Seedlings stored at the planting site were watered regularly but not fertilized. Prior to transportation, all seedlings were treated with insecticide.

2.2 100-Seedling Plots

Between 2000 and 2002, seedlings were marked immediately after planting by the Bracke machines in a regeneration area. Every second week, one area planted by each of Bracke A, B and C in 2001 and 2002, and one area once a week for Bracke C in 2000, was selected to yield a total of 69 areas planted by a Bracke machine. For the Ecoplanter, two areas in 2001 and four areas in 2002 were selected from different times of the planting season. Selected areas were sampled throughout the planting season from early May to mid November. The distribution of regeneration areas for machines, years, site type, soil type, and planting dates are presented in Table 1. In each selected area, 100 adjacent seedlings were marked with untagged plastic poles in a more or

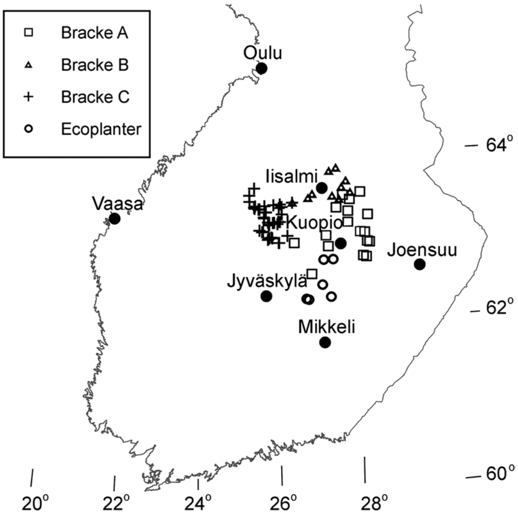

Fig. 1. The location of regeneration areas included in this study.

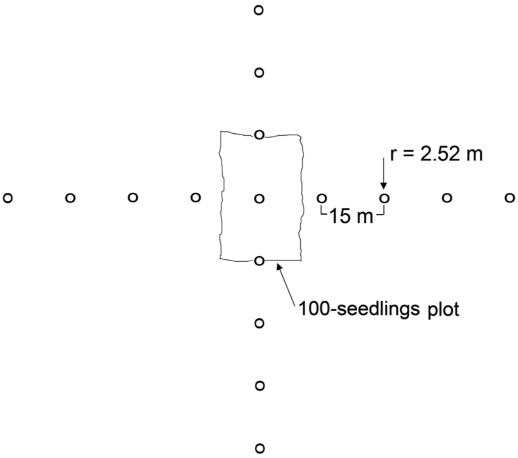

Fig. 2. Illustration of sampling. In each regeneration area, 100 seedlings were systematically marked on the day of planting forming rectangular 100-seedling plot and measured one and three years after that. Around the marked but untagged seedlings, 17 circular plots were systematically sampled one and three years after planting. The first circular plot was in the approximate centre of the 100-seedling plot.

Table 1. Description of the regeneration areas planted by each of three Bracke or one Ecoplanter machines included in the survey. Figures present the number of regeneration areas planted by a machine in each year.

Variable	Planting machine							
	Bracke A		Bracke B	Bracke C			Ecoplanter	
Planting years	2000	2001	2001	2000	2001	2002	2001	2002
Planted regeneration areas	7	10	10	22	11	9	2	4
Site types								
Rich (*Oxalis-Myrtillus* type)	3	3	3	7	3			1
Damp (*Myrtillus* type)	3	7	6	14	7	3	2	2
Sub-dry (*Vaccinium* type)	1		1	2	3	6		1
Soil types								
Coarse mineral soil				1	1			
Medium coarse mineral soil	6	8	9	10	6	8	1	4
Fine mineral soil	1	1		10	2		1	
Peat		1	1	2	2	1		
Stoniness								
Stone-free	1	2	1	7	5	6	1	1
Stony	2	5	3	13	5	3	1	3
Very stony	5	3	6	2	1			
Planting dates								
Spring (1 May–31 May)		2	1	3	1	1		2
Early summer (1 June–24 June)	2	1	1	2	2			1
Summer (25 June–15 August)	4	4	3	5	4	4		
Autumn (16 August–30 Sept.)	1	2	3	6	3	3		1
Late autumn (1 Oct.–23 Nov.)		1	2	7	1	1	2	

less rectangular plot (hereafter 100-seedling plot; see Fig. 2).

2.3 Quality Measurements

In the first inventory one year after planting, the quality of soil preparation and planting was evaluated within each 100-seedling plot. The floor of each mound was scored according to the following categories: 0 = normal forest soil, 1 = stone, 2 = logging residue and 3 = other (stumps, wet hollow, rock, etc). The amount of logging residue below or in the mound was classified according to three categories: 1 = no logging residues; 2 = little, some branches or roots below the mounds with little or no effect on the quality of planting; 3 = abundant branches and roots have prevented proper planting. The inclination of each seedling was classified according to three categories: 1 = < 15°; 2 = > 15°; 3 = prone. The planting depth was scored as one of three classes: correct depth, too deep (3–4 cm shoot above ground), too shallow (root plug showing) or the planting hole was not filled with soil. Finally, the stoniness of each plot was determined by pushing a 10 mm steel rod into the soil to a maximum depth of 30 cm 10 times and recording the penetration depth as far as a stone or boulder was hit and the index was calculated by using the formula described by Viro (1952).

The dominant soil cover around a seedling in the 2001- and 2002-plantings was determined from each mound in a 100-seedling plot by classifying them in one of five categories: 1 = mineral soil, 2 = mineral-humus soil (> 50% mineral soil), 3 = humus-mineral soil (> 50% humus), 4 = humus, 5 = litter and twigs. Categories 2 and 3 were combined for further analysis as a mixture of humus and mineral soil and categories 4 and 5 to new one later called humus. Since seedlings were not tagged individually within a 100-seedling plot, the effects of soil cover on each seedling could only be analyzed for the first inventory.

The dimensions of 10 randomly-selected mounds were recorded to ±1 cm. The height of each mound was measured as the vertical distance from the surface of the surrounding unprepared soil to the top of the mound. Patch depth, from which soil was removed to form the mound, was measured from the bottom of the patch to the top of the mound. Mound size was estimated as the distance from the seedling to the mound edge in four directions and the length and width of the mound was calculated by summing the two distances. Planting depth was measured from all plots (except three planted by Bracke A in 2001) by splitting a mound crosswise a few centimeters away from the seedling so that the root plug came into sight and was then measured as the vertical distance between the upper surface of the mound and the top of the root plug. In addition, thicknesses of the upper mineral soil and the double humus layers were measured as well as the distance the root plug was from the undisturbed mineral soil layer. In total, the mound survey included 15 plots planted by Bracke C in 2000, and 46 Bracke plots and 6 Ecoplanter plots planted in 2001.

2.4 Field Performance

On the 100-seedling plots, height and growth (±0.5 cm) of the current and previous years as well as condition (healthy, weakened, dead) and reasons for deterioration or mortality (pine weevil, black spruce beetle, frost, drought, field vegetation, etc.) of each marked seedling was assessed in August and September one (first inventory) and three or four (second inventory) years after planting.

In order to study the effects of planting date on field performance, the planting season was divided into five arbitrary periods: spring (1–31 May), early summer (1–24 June), summer (25 June–15 August), autumn (16 August–30 September), and late autumn (1 October–23 November). The number of regeneration areas per planting date for each machine and year are presented in Table 1.

2.5 Density

One and three (or four for plantings in 2000) years after planting, systematic plot sampling was used in all the selected regeneration areas to determine the mound and planted seedling densities (in the first measurement) and survival (in the second measurement) using the method of Kankaanhuhta et al. (2009) with following modifications. A total of 17 temporary circular plots (20 m^2, radius 2.52 m) per regeneration area were sampled systematically. One sample plot was located at the centre of each 100-seedling plot, and the remaining 16 radiated at 15 m intervals along four arms of a cross drawn through the centre (Fig. 2).

From each circular plot, the number of mounds and planted seedlings (both live and dead) were counted, soil/humus layer thicknesses were measured, and the forest site, soil type and reasons for poor quality or low number of mounds if fewer than four seedlings within a circular plot were found (e.g., stones, logging residues, stumps, some other material such as wet hollow or rock). Site types were classified as very rich, rich, damp, sub-dry, dry and barren. Soil types were classified as coarse, medium and fine mineral soil or as peat when the peat layer exceeded 20 cm. The area was defined as peatland with a thick layer of peat if the peat layer was > 30 cm, otherwise it was defined as peatland with a thin layer of peat.

2.6 Weather Conditions in Study Years

Monthly mean and minimum temperatures and precipitation in 2000–2002 in Viitasaari, Iisalmi, Kuopio and Suonenjoki were obtained from the Finnish Meteorological Institute (Venäläinen et al. 2005). Weather data in Viitasaari is presented in Table 2. Differences among sites within a year were minor, but weather conditions varied among years. As a whole, the temperatures of years 2000 and 2001 were near the long-term average, but 2002 was clearly warmer and also drier in late summer and autumn. However, monthly variation in mean temperatures and especially in precipitation was large.

The minimum temperature in May was –2 °C or lower in all years and places. In June, the temperature also dropped below 0 °C in 2000 and 2001 in

Table 2. Monthly mean (T_{mean}) and minimum (T_{min}) air temperature (°C) and precipitation (P, mm) as well as the temperature sum (T_{sum}) of each growing season in Viitasaari for planting years 2000–2002 and the long-term average of T_{mean} and P. Calculated from data provided by the Finnish Meteorological Institute described by Venäläinen et al. (2005). T_{sum} is the sum of temperatures >+5 °C during a growing season calculated from the beginning of May. P_{sum} is the sum of precipitation from the beginning of May to the end of September.

Month	2000			2001			2002			1971–2000	
	T_{mean}	T_{min}	P	T_{mean}	T_{min}	P	T_{mean}	T_{min}	P	T_{mean}	P
May	9.7	–3.9	28	7.3	–2.7	56	10.8	–3.7	51	8.4	32
June	13.4	–0.6	46	13.9	–0.3	64	15.3	4.5	60	13.5	57
July	16.1	5.4	84	17.7	3.6	45	17.8	7.2	90	15.5	65
Aug.	13.3	2.8	65	13.9	4.0	49	17.1	4.4	41	13.1	65
Sept.	8.1	–2.2	15	10.0	–2.7	75	8.3	–4.4	31	8.0	53
Oct.	7.1	–7.3	43	5.5	–7.7	62	–1.5	–15.8	11	3.0	46
Nov.	2.3	–10.3	80	–2.5	–13.1	17	–6.4	–22.2	46	–2.3	43
T_{sum} and P_{sum}	1198		238	1241		289	1388		273	1084	269

all places. In September, minimum temperatures were especially low (–5 °C) in Iisalmi in 2001 and in Suonenjoki in 2001 and 2002 but night frosts (<0 °C) were also experienced in Kuopio and Viitasaari in 2000 and 2001. In October, minimum temperatures were lower than –5 °C in all years and occasionally dropped below –10 °C in all regions (2002). In November, minimum temperatures were below –10 °C and even below –20 °C in 2002.

2.7 Statistical Analysis

Differences in mounding and planting quality, survival and cause of weakening or growth between planting machines, years and planting dates and other explanatory variables were analyzed in PASW SAS 9.1.3. for Windows. Following McCulloch et al. (2008), we employed generalized linear mixed models (GLIMMIX procedure) or mixed models (MIXED procedure) when the dependent variable was binary or continuous, respectively. Planting machine (M), year (Y), soil type (S), stoniness (K), seedling soil cover (D) and planting date (P) were used as fixed effects and regeneration area as a random effect. Interactions among fixed effects were also analyzed but only statistically significant interactions are presented. A normal distribution was used in the case of a continuous dependent variable. Otherwise, we employed a binomial distribution with logit-link function. Characteristics measured from mounds, damage and other multinomials were analyzed as separate binomial variables. Only healthy seedlings were included in the height and height growth analyses. Tables 4–6 present probabilities (LS-means; GLIMMIX) or marginal means (MIXED) of fixed effects over a balanced population. Only statistically significant fixed effects are presented although all effects were analyzed. The machine effect is confounded with effects caused by driver, regional (e.g., weather conditions, vegetation zone) factors and planting material (e.g., seedlings produced in different nurseries, transportation).

3 Results

3.1 Mound and Seedling Densities

On average, 1806 mounds and 1778 planted (live + dead) seedlings per ha were found one year after planting without statistically significant differences among machines (Fig. 3, $p = 0.641$ for mounds and $p = 0.554$ for seedlings). After three years, the average number of living seedlings differed among machines ($p = 0.001$); on average

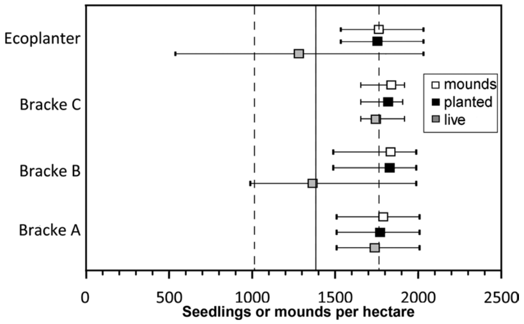

Fig. 3. Average mounding (mound) and planting density (planted) of three Bracke and one Ecoplanter planting machines operating in Central Finland and the number of live seedlings measured three years after planting, respectively. Horizontal bars indicate 25% quartiles. The vertical solid line indicates the average number of live seedlings and the vertical dashed lines the standard deviation of it three years after planting in privately-owned forests of southern Finland (from Kankaanhuhta et al. 2009).

1578 seedlings per ha were alive when planted by Bracke, fewer after planting by Bracke B than A or C (Fig. 3). In contrast, 45% of seedlings planted by Ecoplanter had died within three years of planting (a mean of 1240 seedlings per ha).

The density of mounds was reduced by the large amount of logging residues (probability 0.16), stones (0.07), stumps (0.12) or other factors (0.07). Secondly, the quality of mounds was weakened by logging residues (0.02), stones (0.05) and stumps (0.005). No statistically significant differences among machines were found.

3.2 Quality of Soil Preparation

All Bracke machines planted seedlings to a depth of 6 cm and the Ecoplanter to 7 cm (Table 3, Fig. 4). Mound dimensions varied between machine types (Fig. 4) and to some extent among Bracke machines (Table 3). The patches, from which soil was taken to form the mound, were shallower for the Ecoplanter than Bracke (Fig. 4). In mineral soils, the mineral soil layer on the mound was quite often so thick that the root plug did not reach the humus layer (Table 3). Only in a few cases were the root plugs planted so deep that their bottom reached the mineral soil below the double humus layer, although these cases were not dependent on machine (Table 3).

The base of mounds varied among years (Y: $p<0.001$) and the probability that mounds lay on stones (0.03–0.10%) increased when the stoniness (K: $p<0.001$; Y×K $p=0.599$) of an area increased, but no differences among machines were found. In 2002 (0.13), more mounds were found on logging residues than in other years

Table 3. Planting depth (least square mean±standard error) and mound characteristics (probabilities) of each planting machine. Different letters indicate statistically significant differences among machines according to Tukey's test ($p<0.05$). P-values of fixed effects are also presented.

Variable	Planting machine				
	Bracke A	Bracke B	Bracke C	Ecoplanter	p-value
Planting depth, cm	6±0.6	6±0.5	6±0.3	7±0.7	0.709
Mound dimensions (calculated for all sites)					
Length, cm	79±3a	66±3a	71±2a	60±3b	0.0002
Width, cm	86±3a	83±3a	73±1b	64±4b	<0.001
Height, cm	17±1ab	18±1a	16±0.5b	8±1c	<0.001
Patch depth, cm	39±1ab	42±1a	36±1b	26±2c	<0.001
Quality of mounds in sites with mineral soil					
Thickness of mineral soil layer, cm	8±1a	10±1a	7±1a	3±1b	<0.001
Thickness of humus layer, cm	15±2	13±2	12±1	11±2	0.530
Surface of mound was humus	0.55±0.13a	0.15±0.07b	0.12±0.04b	0.64±0.15	0.0007
Plug in upper mineral soil	0.30±0.09ab	0.56±0.09a	0.24±0.04b	0.09±0.05b	0.002
Plug through the humus	0.11±0.07	0.04±0.03	0.13±0.05	0.24±0.11	0.340

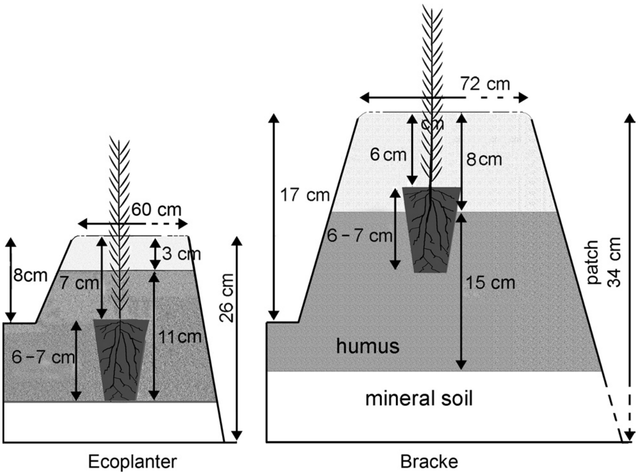

Fig. 4. Average structure of mounds made by Ecoplanter or Bracke machines. Planting depth, thickness of mineral soil and humus layers, mound dimensions and patch depth are described in the figure.

Table 4. Probability of mounds with no, few or many logging residues below the mound and survival one and three years after planting according to planting machine (M) in 2000–2002 (year = Y). Different letters after the probabilities indicate statistically significant differences between machines or years according to Tukey's test (p < 0.05). P-values of fixed effects are presented in the last three columns.

Variable	Planting machine and planting year										
	Bracke A		Bracke B	Bracke C			Ecoplanter		p-value		
	2000	2001	2001	2000	2001	2002	2001	2002	M	Y	M×Y
Amount of logging residues below the mound											
No residues	0.71a	0.61ab	0.51bd	0.29c	0.36bcd	0.49b	0.4abcd	0.38abd	0.002	0.597	0.170
Few branches or roots	0.29a	0.39ad	0.49bd	0.68c	0.64c	0.44ab	0.42abc	0.49abc	<0.001	0.451	0.112
Many residues	0.01ab	0.003b	0abc	0.01a	0.002b	0.05c	0.14c	0.12c	<0.001	0.061	0.056
Survival											
1 year	0.99a	0.97ab	0.98ab	0.97ab	0.94bc	0.92ce	0.93de	0.84e	0.182	0.033	0.828
3 years	0.92a	0.91a	0.92a	0.88ab	0.78bd	0.93a	0.24c	0.67d	<0.001	0.012	0.567

(probability < 0.01; p < 0.001). Ecoplanter (0.03) mounds were also found more often on stumps, rocks or some other material than Bracke mounds (< 0.01; p < 0.001).

The amount of logging residues below the mounds varied among machines and planting years. Bracke A left less residue below the mounds than other machines in both years (Table 4). In Bracke C, differences were also found between years. Ecoplanter mounds contained a lot of branches or roots (Table 4).

Machine and soil type (all mineral soil types were combined and peatlands were classified as having a thin or thick layer of peat) affected the probability of dominant soil cover around seedlings (p < 0.001 for S in all cover types, M: p = 0.002, p = 0.325 and p < 0.001 for mineral soil, mixture of mineral soil and humus, and humus, respectively). In mineral soils, Bracke machines formed mounds covered with mineral soil or a mixture of mineral soil and humus (Fig. 5). Differences among Bracke machines were small.

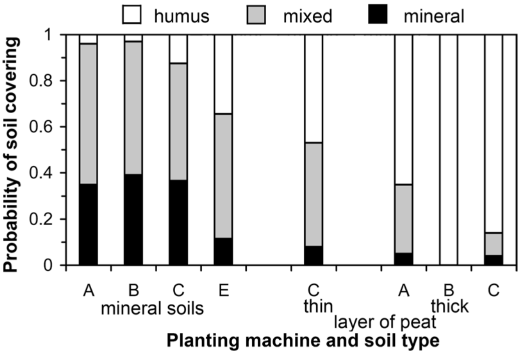

Fig. 5. Probability (least squares means of fixed effects) of mounds with different soil coverings according to planting machine and soil type and peat layer thickness. A–C are different Bracke-machines and E is the Ecoplanter.

Ecoplanter, on the other hand, made mounds that were covered mainly with humus and a mixture of mineral soil and humus (Fig. 5). In peatlands, although the probability of peat-covered mounds was naturally greater than in mineral soils, Bracke A and C made some mounds covered by mineral soil or mineral soil and humus (Fig. 5).

3.3 Planting Quality

The planting quality was good with all machines, although slightly better ($p<0.001$) in Bracke A (probability of good planting 1.0) and B (1.0) than in Bracke C (0.99) and Ecoplanter (0.91). Only a few seedlings were planted too deeply (probability 0.01 in 2002 and 0.001–0.002 in other years) or prone (0.001 when planted by Bracke and 0.01 when planted by Ecoplanter; M: $p=0.008$). Planting holes were filled with soil when planted by Bracke (probability of unfilled holes <0.01) but there was a 0.07 (M: $p<0.001$) probability that holes made by the Ecoplanter were unfilled a year after planting. In addition, the probability of an unfilled planting hole was greater in fine soil (0.03) compared to other soil types (0–0.01; S: $p<0.001$). Seedlings planted in 2001 were more often inclined (0.07) than in other years (0.01; $Y<0.001$) and more seedlings planted by the Ecoplanter (0.05) were inclined than those planted by Bracke (0.01–0.02; $M=0.006$).

3.4 Survival

Survival of seedlings varied among regeneration areas, planting years, machines and planting dates (Fig. 6). In the first inventory, no differences in survival among machines were found but in 2002 mortality was higher than in the other two planting years (Table 4). In the second inventory, however, the survival probability of seedlings planted by the Ecoplanter was lower (0.52) compared to Bracke (0.89; Table 3). Survival of seedlings varied also among planting years and was better in 2000 and 2001 than in 2002.

In the first inventory, the dominant soil cover

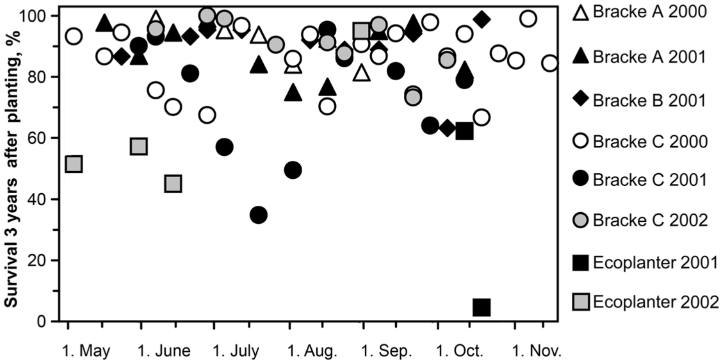

Fig. 6. Survival of machine-planted Norway spruce seedlings three years after planting and according to each sample plot and planting machine (three Bracke, one Ecoplanter) in 2000–2002.

Table 5. Probability of survival and pine weevil damage one year after planting in relation to seedling cover (D) of bare mineral soil, humus, or a mixture of mineral soil and humus and planting machine (M). Different letters after the probabilities indicate statistically significant differences between machines or seedling cover according to Tukey's test ($p < 0.05$). P-values of fixed effects are presented in the last three rows.

Planting machine	Dominant soil cover	Probability of survival	Probability of pine weevil damage (1st yr)
Bracke A	Mineral	0.99a	0ac
	Mixed	0.97abce	0.005a
	Humus	0.93bgcdf	0.02a
Bracke B	Mineral	0.98agce	0a
	Mixed	0.98ag	0a
	Humus	0.95abcdf	0.04a
Bracke C	Mineral	0.95agce	0.005a
	Mixed	0.93ceh	0.02bc
	Humus	0.90dh	0.01ab
Ecoplanter	Mineral	0.93abcd	0.01ab
	Mixed	0.91de	0.02ab
	Humus	0.91fh	0.09c
p-values	M	0.105	0.655
	D	0.002	1.000
	M×D	0.691	0.069

Table 6. Probability of frost damage in the second (3^{rd} year) inventory in different soil types (S; for 3^{rd} year) in planting years (Y) 2000–2002. Different letters after the probabilities indicate statistically significant differences between years and soil types according to Tukey's test ($p < 0.05$). P-values of fixed effects are presented in the last three rows.

Planting year	Soil type	Probability of frost damage 3rd year
2000	Coarse	0
	Medium-coarse	0.01a
	Fine	0.02ab
	Peat	0.01ab
2001	Coarse	0.01ad
	Medium-coarse	0.01a
	Fine	0.01ab
	Peat	0.07cd
2002	Coarse	
	Medium-coarse	0.03bd
	Fine	
	Peat	0.49c
p-values	Y	0.003
	S	0.008
	Y×S	0.323

around the seedlings affected the probability of survival but no differences among machines were found (Table 5). Survival was lower in mounds covered by humus than in mounds covered by pure mineral soil or when mixed with humus, regardless of planting machine. Since survival in Ecoplanter plots was low, these data were analysed with respect to damage caused by the pine weevil and black spruce beetle. Only the Bracke data were used for analysing differences among planting periods and other variables.

3.5 Damage

In the first inventory, 10, 2, 2 and 3% of seedlings were damaged or killed by frost, pine weevil, mammals (voles or hares) and defects in seedling material, respectively. In the second inventory field vegetation (10%), pine weevil (5%), frost (3%), drought (3%), black spruce beetle (2%) and mammals (2%) damaged the seedlings.

In the first inventory, frost damage ($p < 0.001$) was more common in seedlings planted in 2001 (0.18) than in 2000 (0.02) and 2002 (0.02). In the second inventory, the probability for frost damage was greater in sites planted in 2002 than in other years and when the soil type was peat (Table 6).

In the first inventory, pine weevils had damaged seedlings planted by the Ecoplanter more often than seedlings planted by Bracke machines (Table 5). When we analyzed only the Bracke data, the probability for pine weevil damage was greater ($p = 0.024$) in peatlands, coarse and medium-coarse soils (0.01–0.04) than in fine soils (0.002). In 2001–2002, pine weevils had damaged more seedlings per year after planting in mounds covered by humus than in mounds covered by pure or mixed mineral soil, especially when they had been planted by Ecoplanter (Table 5). In the second inventory, the probability of pine weevil damage varied from 0.02 (Bracke A) to 0.11 (Ecoplanter) and from 0.02 (fine soils) to 0.26 (course soils) without statistically significant differences among machines ($p=0.213$) or soil types ($p=0.116$).

In the first inventory ($p<0.001$), damage caused by black spruce beetles was more probable in regeneration areas planted by Bracke C (0.01) and Ecoplanter (0.03) than in areas planted by Bracke A (0.003) or B (0.006). In the second inventory ($p=0.059$), beetle damage was more probable in plantings by Ecoplanter (0.04) than by Bracke A (<0.01). Mammal damage was more probable in seedlings planted in 2002 (0.10) than in other planting years (<0.01; $p<0.001$).

In the first inventory, damage caused by drying was affected by the soil cover around the seedling ($p=0.002$) and by planting year ($p=0.003$; interaction $p=0.697$; data not shown). Wilting was more probable in seedlings planted under a humus-dominated surface (0.02 and 0.09 in 2001 and 2002) than other soil coverings (0.003–0.04 in 2001 and 2002). In the second inventory, drought damage was less probable in nearly stone-free sites (<0.01; stoniness K: $p<0.001$) than in stony (0.005–0.05) and very stony sites (0.01–0.08) and more probable in seedlings planted in 2001 than other years (Y: $p<0.001$, $Y\times K$: $p=0.006$; data not shown). Stoniness ($p=0.019$) also affected the probability of planting failures in the second inventory. In the first inventory, vegetation did not affect seedlings but in the second inventory its negative effects were more likely in rich sites (0.04–0.34 among machines) than in other site types (0–0.13; $p<0.001$) and more probable for seedlings planted by Bracke A (0.13–0.15 in different site types) than Bracke C (0.02–0.34; $p=0.009$; $M\times S$: $p<0.001$).

Frost heave lifted some seedlings during the first year and was more common in peat than in other soil types in 2001 (0.06 vs. 0.01–0.03). In 2000, seedlings planted in mineral soils were more likely to be lifted in fine (0.05) than in coarse (0.01) or medium-coarse (0.01) soils, although the differences were not statistically significant (Y: $p=0.987$; S: $p=0.742$; $Y\times S$: $p=0.417$). Planting date did not affect the probability of frost heave ($p=0.068$).

3.6 Height Growth

The first height measurement was made one year after planting. Height growth since planting was not possible to calculate by subtracting annual shoot growth since some seedlings were already growing when planted. However, at the end of the planting year and the year following, seedlings were of a similar size regardless of planting machine (Table 7, Fig. 7). The growth of seedlings planted by Bracke A was better and seedlings were taller at the end of the second and third growing seasons after planting than those planted by other machines.

At the end of the planting season, differences in seedling height among planting periods were found only in Bracke C during 2000 and 2002 (Fig. 7, Table 7). In 2002, seedlings planted by Bracke C earlier in the growing season were taller at the end of the planting season and seedlings planted in autumn grew less during the three first

Table 7. Statistical significance of estimated fixed effects and their interactions (excluded from final model if non-significant) with respect to growth measured a year and three years after planting. H0 = height at the end of the planting year, H1–H3 and G1–G3 = end-of-year height and growth after planting.

Fixed effect	H0	H1	H2	H3	G1	G2	G3
Machine (M)	0.045	0.401	0.030	0.001	0.054	<0.001	<0.001
Planting year (Y)	0.003	<0.001	0.401	0.072	0.449	<0.001	<0.001
Planting date (P)	0.018	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
M×Y				0.008		0.008	
M×P						0.021	0.013
Y×P	0.036	0.018				<0.001	0.008
M×Y×P	0.039	0.119	0.047	0.069	0.601	0.022	0.168

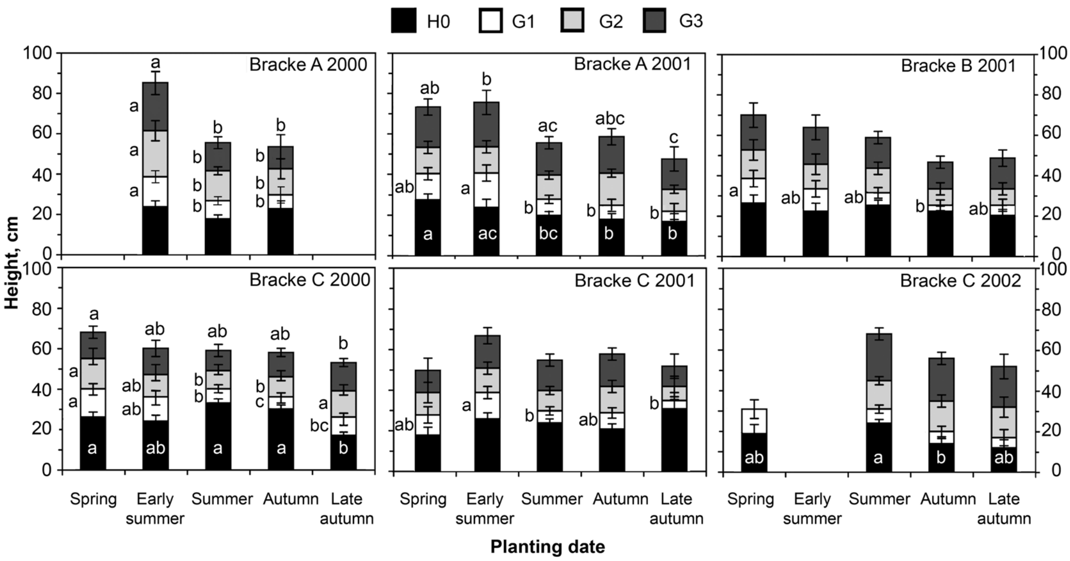

Fig. 7. Height growth (cm) of seedlings planted on different dates by three Bracke machines between 2000 and 2002. H0 = height at the end of the planting season. G1–G3 = height growth of seedlings from first to third growing season after planting. Vertical bars indicate the standard errors of the means. Different letters inside (height at the end of planting season), above (final height at the end of third season) or left side of the bar (growth) indicate statistically significant differences between planting dates at the ends of growing seasons and separately for each year.

seasons after planting than spring and summer seedlings (Fig. 7). For Bracke C in 2000, differences in growth between summer- and autumn-planted seedlings were significant but a reverse trend applied; seedlings planted in late autumn grew better. For all machines, the height growth of autumn-planted seedlings in 2001 was weaker (although not statistically significant) than those planted in summer.

4 Discussion

4.1 Seedling Densities

The average mounding and planting densities of both Ecoplanter and Bracke were about the recommended mounding and planting densities (1800 seedlings per ha) for commercial forests (Ruuska 2001). In Ireland, both Ecoplanter and Bracke were capable of planting as many as 2500 seedlings per ha (Keane 2006). Regardless of machine type, the main reasons for fewer mounds formed were logging residues and stumps. In the future, increased recovery of these materials (e.g., for bioenergy programs) will likely improve the quality of mounding and seedling survival.

Surviving seedling density was higher and variability lower for Bracke (mean of 1578 seedlings/ha) than Ecoplanter (mean of 1240 seedlings/ha). During the same time period, three years after planting Ecoplanter seedling densities were lower and Bracke seedling densities were higher than those measured in manually-planted private forests of southern Finland (1388 seedlings/ha; Kankaanhuhta et al. 2009) (Fig. 3).

4.2 Structure of Mounds

Ecoplanter and Bracke use different methods of soil preparation that account for differences in mound structure. Bracke makes mounds by a blade bringing deeper soil to the surface. Ecoplanter uses a rotovator wheel to form mounds that are flatter and narrower and the soil preparation patches are smaller and shallower than those made by Bracke. In an earlier study, Arnkil and Hämäläinen (1995) measured the height of mounds and the thickness of the mineral soil layer after Bracke planting. Compared to their results, average Bracke mounds in our survey were a few centimeters taller and the mineral soil layer was the same or thicker.

Ecoplanter planting resulted in more logging residues below the mounds than were present after Bracke planting. Being mounted to a harvester, the Ecoplanter machine may have greater difficulty removing logging residues than the Bracke machine which has a mounding blade mounted to an excavator. During the soil preparation step, it is important to leave as few twigs and other logging residues inside the mounds as possible. Logging residues inside the mound can cause drying and bind nutrients, especially nitrogen, which can then negatively affect seedling growth (Hallsby 1994, 1995).

4.3 Quality of Planting

The quality of Bracke planting was good and superior to that of Ecoplanter, in which more than 20% of seedlings failed within three years of planting. Our study found better performance for both Bracke and Ecoplanter than Arnkil and Hämäläinen (1995), who reported failure for approximately 45% of seedlings planted by Bracke. One of the main differences between planting quality was an increased incidence of unfilled holes made by Ecoplanter. The reason likely involved the failure of the Ecoplanter to compact the soil after planting. In unfilled holes, seedlings have a loose root-soil contact and may suffer water stress and consequently reduced survival and growth (Beyler 1996).

Ecoplanter results are not as reliable as those for Bracke machines due to few (n=6) study sites. In addition, the Ecoplanter contractor (same driver for all sites) was inexperienced. However, experimental results both in the same year and with same contractor and in another year with another contractor also indicated poor performance of Ecoplanter-planted seedlings (Luoranen, unpublished).

Although our study included few very stony sites, seedling failures were more common and ran a greater risk of being damaged due to drying than in less stony sites. Arnkil and Hämäläinen (1995) and Härkönen (2008) have shown that planting quality is impaired when stoniness increases, and machine productivity is also known to diminish on such ground (Rantala et al. 2009).

Between one and nine percent of seedlings were inclined or prone. We did not find differences among site, soil types or stoniness on seedling inclination, but Ecoplanter seedlings were more often inclined than Bracke seedlings. Previously, Saarinen (unpublished results) observed more inclined seedlings after mechanized planting than after manual planting in very stony sites. However, most inclined Norway spruce seedlings straighten during the first growing season (Huuri 1972).

4.4 Effects of Mound Cover Material

The soil preparation method also affected mound quality. The Ecoplanter made mounds dominated by a covering of humus, as found by Saarinen (2006). Arnkil and Hämäläinen (1995) found more than 87% of Bracke mounds were covered by mineral soil while in our study this proportion was only 37%. According to our results, the risk for damage due to drying also increased in humus-covered mounds. Organic matter without a covering of mineral soil dries out rapidly and increases the risk of seedling wilt. Similarly, if seedlings are planted too shallow, the root plug is partly or completely in the upper mineral soil layer and at risk of desiccation (Örlander et al. 1990).

Similar to Petersson and Örlander (2003) and Petersson et al. (2005), we observed that the mineral soil layer around Bracke seedlings provided protection against pine weevil damage. Petersson et al. (2005) also observed that a mixture of humus and mineral soil can reduce pine weevil damage, which agrees with our results. The main reason for poor regeneration results after Ecoplanter planting was pine weevil damage, which was independent of cover material although most mounds had a covering of mainly humus. Ecoplanter did not compact the mounds, resulting in a looser structure and an increased vulnerability to pine weevils was clear when they were flatter than typical Bracke mounds. Humus-dominated, flat mounds provide shelter for weevils and increase the vulnerability of the seedling to this pest (Björklund et al. 2003, Nordlander et al. 2005, Petersson et al. 2005).

In peatlands, humus and peat covered most of the Bracke mounds. Bracke A and C were able to cover some mounds with a humus-mineral soil mix even when the peat layer was thick. Although we did not find differences in pine weevil damage between peatlands and mineral soils, we recommend that in order to decrease the risk of pine weevil damage and increase seedling survival in peatlands, mounds should be covered with mineral soil whenever possible.

4.5 Planting Depth

Both machine types planted seedlings deeper than manual planting (1–2 cm) in Finland. Previous studies have shown that Norway spruce and white spruce (*P. glauca* (Moench) Voss) seedlings planted at least 10 cm deep can grow better than shallow-planted seedlings without any negative effects on survival (Sutton 1967, Macadam and Bedford 1998). However, Beyeler (1996) obtained contradictory results where deep planting reduced the survival of container-grown black spruce (*P. mariana* (Mill.) B.S.P.) whereas it did not affect seedling growth. Deep planting can be beneficial if seedlings are planted into the inverted humus layer, lessening the risk of desiccation or frost heave (Örlander et al. 1990). Nordlander et al. (2005) observed that pine weevils prefer to feed underground if no above ground shelter is available. In mechanized planting, deep-planted seedlings should be covered by mineral soil in order to reduce the risk of insect damage.

4.6 Effect of Soil and Site Type

Different soil types had only a little effect on risk factors. The risk for frost heave and frost damage was slightly higher in peatlands than mineral soils. Both frost heave and frost damage depend on temperature and soil moisture content in spring and autumn and a large variation between years is common. In peatlands, Moilanen et al. (1995) found that over 20% of Norway spruce container seedlings in mounds were lifted by frost heave. Night frosts are more common in peatlands than other forest sites, which might also explain the increased risks observed in our study. We did not find any effect of planting date on frost heave, which agrees with the results of Sahlén and Goulet (2002).

In mineral soils, frost heave was more common in fine textured soils than in other soil types, which is also widely reported in similar studies (de Chantal et al. 2006, reviews by Goulet 1995, Örlander et al. 1990). Depending on weather conditions, frost heave can also occur in more coarsely textured soil (Örlander et al. 1990), as was the case in our study. According to Örlander et al. (1990), the risk of frost heave and desiccation can be reduced by planting seedlings deep into the inverted humus as it is usually the case in machine planting. Thus, it is important that the mineral soil layer covering the mound is not so thick as to prevent the root plug penetration during planting. In our study, over half of the mounds made by Bracke B had root plugs fully within a thick layer of mineral soil (Table 3).

While site type was involved in seedling deterioration via competition with other plants, especially in rich sites and those planted by Bracke A, it did not affect survival. This was not caused by real differences among machines but differences in growing conditions. The region in which Bracke A worked (around Kuopio, see Fig. 1) is warmer and sites are more fertile than in other regions.

4.7 Planting Date

Year-to-year variation in survival and damage were partly caused by weather conditions.

Planting date did not affect the risk of damage either of inventories. Night frosts occurred during June 2000 and 2001, which probably accounts for the frost damage observed in 2001. Otherwise it seems safe to plant seedlings from spring to autumn when the seedlings used are grown specifically for the intended planting date. Although we did not find any differences between planting dates and frost heave, we recommend planting fine texture soils in spring or early summer to ensure that seedlings have the time to grow roots and become established (Örlander et al. 1990).

We observed that seedlings of a suitable size in relation to growing density and root plug volume (Rikala 2006) and stored in the field for less than a few weeks grew well after planting. However, when seedlings were stored for longer time periods (e.g., up to a year) without fertilization or other care, they were oversized at planting and growth in subsequent years was diminished, especially Bracke C seedlings planted in 2000. Luoranen et al. (2005) observed that if seedlings grown for spring planting were planted after mid-June, their growth was reduced compared to seedlings planted earlier in the summer that were shorter at the time of planting. Weather conditions at the time of planting can affect the growth of seedlings, as seen in 2001 when July and August were drier than average and probably caused the poor growth of seedlings planted that summer.

We did not find differences in pine weevil damage among planting dates, which agrees with the results of earlier experimental studies (Luoranen et al. 2005, 2006). Örlander and Nilsson (1999) showed that pine weevil damage reduced when seedlings were planted in mid-June instead of early-May in regeneration areas that had been clear-cut at least three years earlier. In our survey, the time between clear-cutting and planting was shorter than that and could account for the failure to detect a relationship between planting date and incidence of pine weevil damage.

5 Conclusions

Quality of soil preparation was the most important factor affecting the performance of machine planted seedlings. The risk of damage to seedlings was small if a machine-formed mineral soil layer mainly covered them. From the machines included this study, the Bracke planting machine produced good mounds containing well-planted seedlings. Average seedling densities three years after planting were superior even to those of manually planted privately-owned Finnish forests indicating that quality of machine planting is at least as good as that of manual planting. In contrast, seedlings planted by the Ecoplanter machine performed poorly, most likely due to an inferior soil preparation method that increased the amount of humus covering mounds that consequently increased risk of drying or insect damage. However, operator error (one driver) and few sites (six) may have influenced the Ecoplanter results. Planting machines are least effective in very stony areas due to an increased risk of planting failure and drought damage; forest managers should consider manual planting methods in such situations. Bracke and other planting machines that can make mounds covered by mineral soil can be used safely from spring to autumn provided that fine textured soils and peatlands are planted in spring or early summer to reduce the risk of frost heave, and that seedlings are grown specifically for the intended planting date.

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References

Arnkil, R. & Hämäläinen, J. 1995. Bräcke Planter and Ilves tree planting machines. Metsäteho Review 1/1995. (In Finnish with English summary).

Beyeler, J. 1996. Effect of planting methods on field performance of black spruce five years after planting. Forest Planning and Research Section, Forestry Division, Nova Scotia Department of Natural Resources, Forest Research Report 62.

Björklund, N., Nordlander, G. & Bylund, H. 2003. Host-plant acceptance on mineral soil and humus by the pine weevil *Hylobius abietis* (L.). Agricultural and Forest Entomology 5: 61–65.

de Chantal, M., Rita, H., Bergsten, U., Ottoson Löfvenius, M. & Grip, H. 2006. Effect of soil properties and soil disturbance on frost heaving of mineral soil: a laboratory experiment. Canadian Journal of Forest Research 36: 2885–2893.

Goulet, F. 1995. Frost heaving of forest tree seedlings: a review. New Forests 9: 67–94.

Hallonborg, U. 1997. Aspects of mechanized tree planting. Doctoral thesis. Swedish University of Agricultural Sciences, Uppsala. Silvestria 29.

Hallsby, G. 1994. The influence of different forest organic matter on the growth of one-year old planted Norway spruce seedlings in a greenhouse experiment. New Forests 8: 41–60.

— 1995. Field performance of ouplanted Norway spruce: effects of organic matter amendments and site preparation. Canadian Journal of Forest Research 25: 1356–1367.

Härkönen, M. 2008. Work quality of M-Planter and Bräcke forest planting machines. M. (Sc.) thesis. University of Joensuu, Faculty of Forest Science, Joensuu. (In Finnish).

von Hofsten, H. 2003. Machine planting – history or present day? Plantaktuellt 2003/2: 6–7. (In Swedish).

Högberg, K.-A. 1987. Needle conductance and root egress of containerized Scots pine and Norway spruce seedlings after surface and deep planting. Canadian Journal of Forest Research 17(8): 783–786.

Huuri, O. 1972. The effect of deviating planting techniques on initial development of seedlings of Scots pine and Norway spruce. Communicationes Instituti Forestalia Fennica 75(6). (In Finnish with English summary).

Kankaanhuhta, V., Saksa, T. & Smolander, H. 2009. Variation in the results of Norway spruce planting and Scots pine direct seeding in privately-owned forests in southern Finland. Silva Fennica 43(1): 51–70.

Keane, M. 2006. Container plants and mechanised planting – the way forward? In: MacLennan, L. & Fennessy, J. (eds.). Plant quality – a key to success in forest establishment. Proceedings of the COFORD conference, 20–21 September 2005. Mount Wolseley Hotel, Tullow, Co Carlow. COFORD, Dublin. p. 67–71.

Luoranen, J., Rikala, R., Konttinen, K. & Smolander, H. 2005. Extending the planting period of dormant and growing Norway spruce container seedlings to early summer. Silva Fennica 39(4): 481–496.

— , Rikala, R., Konttinen, K. & Smolander, H. 2006. Summer planting of Picea abies container-grown seedlings: Effects of planting date on survival, height growth and root egress. Forest Ecology and Management 237(1–3): 534–544.

Macadam, A. & Bedford, L. 1998. Mounding in the sub-boreal spruce zone of west-central British Columbia: 8-year results. The Forestry Chronicle 74(3): 421–427.

McCulloch, C.E., Searle S.R. & Neuhaus J.M. 2008. Generalized, linear, and mixed models. 2nd edition. Wiley, New York.

Moilanen, M., Ferm, A. & Issakainen, J. 1995. [Early development of Norway spruce and silver birch seedlings in spruce swamp regeneration areas]. Folia Forestalia – Metsätieteen aikakauskirja 1995(2): 115–130. (In Finnish).

Nieuwenhuis, M. & Egan, D. 2002. An evaluation and comparison of mechanized and manual tree planting on afforestation and reforestation sites in Ireland. International Journal of Forest Engineering 13(2): 11–23.

Nordlander, G., Bylund, H. & Björklund, N. 2005. Soil type and microtopography influencing feeding above and below ground by the pine weevil Hylobius abietis. Agricultural and Forest Entomology 7: 107–113.

Örlander, G. & Nilsson, U. 1999. Effect of reforestation methods on pine weevil (Hylobius abietis) damage and seedling survival. Scandinavian Journal of Forest Research 14: 341–354.

— & Nordlander, G. 1998. Shelterwood, soil preparation and other silvicultural operations – can they decrease pine weevil damage? Kungliga Skogs- och Lantbruksakademiens Tidskrift 137(15): 59–69. (In Swedish).

— , Gemmel, P. & Hunt, J. 1990. Site preparation: a Swedish overview. FRDA Rep. 105. British Columbia Ministry of Forests, Victoria, B.C. 60 p.

Petersson, M. & Örlander, G. 2003. Effectiveness of combinations of shelterwood, scarification, and feeding barriers to reduce pine weevil damage. Canadian Journal of Forest Research 33: 64–73.

— , Örlander, G. & Nordlander, G. 2005. Soil features affecting damage to conifer seedlings by the pine weevil Hylobius abietis. Forestry 78(1): 83–92.

Rantala, J. & Saarinen, V.-M. 2006. Economic evaluation of investing in three planting device – machine contractor’s viewpoint. Metsätieteen aikakauskirja 3/2006, 343–352. (In Finnish).

— , Harstela, P., Saarinen, V.-M. & Tervo, L. 2009. A techno-economic evaluation of Bracke and M-Planter tree planting machines. Silva Fennica 43(3): 659–667.

Rikala, R. 2006. Metsätaimiopas. 2nd edition. Metsäntutkimuslaitoksen tiedonantoja 881. (In Finnish).

Ruuska, J. 2001. Taimikon tiheyssuosituksia organisaatioittain. In: Valkonen, S., Ruuska, J., Kolström, T., Kubin, E. & Saarinen, M. (eds.). Onnistunut metsänuudistaminen. Kustannusosakeyhtiö Metsälehti.p. 14–15. (In Finnish).

Saarinen, V.-M., 2006. The effects of slash and stump removal on productivity and quality of forest regeneration operations – preliminary results. Biomass and Bioenergy 30: 349–356.

Sahlén, K. & Goulet, F. 2002. Reduction of frost heaving of Norway spruce and Scots pine seedlings by planting in mounds or in humus. New Forestry 24 (3): 175–182.

Smolander, A. & Heiskanen, J. 2007. Soil N and C transformations in two forest clear-cuts during three years after mounding and inverting. Canadian Journal of Soil Science 87: 251–258.

Sutton, R.F. 1967. Influence of planting depth on early growth of conifers. Commonwealth forestry review 46(4): 282–295.

Venäläinen, A., Tuomenvirta, H. & Drebs, A. 2005. A basic Finnish climate data set 1961–2000 – description and illustrations. Finnish Meteorological Institute, Reports 2005: 5.

Viro, R.J. 1952. On the determination of stoniness. Communicationes Instituti Forestalis Fenniae 40(3). 23 p. (In Finnish with English summary).

Total of 36 references