ABSTRACT

JOHANSSON, KARIN MARGARETA. Interactions between site preparation, seedling type and genetics on the establishment of Norway spruce.

Effects of site preparation methods on establishment and growth of different seedling types and clones of Norway spruce were examined in this project. Two studies were established in the southern parts of Sweden. The first study aimed at investigating the effects of mulch and scarification on growth of six clones of Norway spruce in the form of rooted cuttings. In the second study, interactions between scarification treatments, including non scarified control, mounding and soil inversion, and seedling types of Norway spruce were examined at two different locations. The three different seedling types used in the experiment were a 10 weeks old containerized seedling referred to as mini seedling, a 2 year-old containerized seedling and a 2 year-old hybrid seedling (grown both as a containerized- and a bare root seedling).

Mulch and scarification reduced amount of competing vegetation. Bud break occurred earlier for cuttings planted in scarification compared to control and mulch. Gas exchange and the number of new roots were higher in planting spots covered with mulch. Mulch and scarification affected survival and growth of the cuttings after the second growing season positively. Height growth was 32 mm greater and biomass increment 6 g higher in plots treated with both scarification and mulch compared to the control. Clonal differences regarding gas exchange and growth were significant. Clone 1100 had poor biomass growth, height growth and gas exchange and the lowest amount of new roots. Clone 2136 achieved

the highest biomass and height growth after two years. This clone had high gas exchange values and a large number of new roots compared to clone 1100. In this study, clonal effects on growth were greater than site preparation effects.

Scarification increased survival of the mini seedlings. Differences in growth between the control and scarification treatments were relatively greater for the mini seedling than for the two larger seedling types. Interactions between seedling type and scarification method for growth indicates that the mini seedlings were able to establish faster in the soil inversion treatments compared to the larger seedling types. Comparing growth rates at the same seedling age, biomass and height growth of the mini seedlings were higher or similar as for the containerized and the hybrid seedling in all scarification treatments. At the age of 3 years in the soil inversion treatment, height of the mini seedlings was 600 mm and for the hybrid seedlings the height was 400 mm. Results from this study show that mini seedlings can grow as well as or even better than larger seedlings if they are successfully established. However, mini seedlings are more sensitive to their planting environment and proper handling is critical. Problems with frost heaving and competing vegetation can be a problem and has to be taken into consideration when choosing site preparation method.

INTERACTIONS BETWEEN SITE PREPARATION, SEEDLING TYPE AND GENETICS ON THE ESTABLISHMENT OF NORWAY SPRUCE

by

KARIN MARGARETA JOHANSSON

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APPROVED BY:

H. Lee Allen Chair of Advisory Committee	Phillip M. Dougherty
Steven E. McKeand	Urban Nilsson

To Tobias

BIOGRAPHY

Karin Margareta Johansson was born in Katrineholm, Sweden, on April 15, 1977. She grew up with her two parents Mårten and Margareta Johansson and her younger brother Carl. After graduating from high school in 1996, she moved to Umeå and began her undergraduate studies in forestry at SLU, the Swedish University of Agricultural Sciences. During her time as an undergraduate student she took classes at SLU in both Umeå, Uppsala and Alnarp. In 2000 she decided that she wanted to live in the southern parts of Sweden and moved down to Malmö to do her Master thesis in forestry at SLU in Alnarp. With an interest in research, she decided to continue her studies. In January 2001 she received the Gunnar and Lilian Nicholson Graduate Fellowship and moved to Raleigh to pursue a Doctoral degree at North Carolina State University.

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TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER 1

CHAPTER 2

LIST OF TABLES

CHAPTER 1.

CHAPTER 2.

CHAPTER 1

EFFECTS OF SCARIFICATION AND MULCH ON ESTABLISHMENT AND GROWTH OF SIX DIFFERENT CLONES OF NORWAY SPRUCE

INTRODUCTION

In southern Sweden, rotation length for Norway spruce forests are around 70 years. By using rooted cuttings selected for high growth, the rotation length may be reduced significantly (Ritchie 1991). In comparison with seedlings, rooted cuttings have also shown a higher survival rate and improved resistance to pine weevil damage and frost (Gemmel et al. 1991; Hannerz et al. 2002). However, the use of rooted cuttings in Swedish forestry is not common, partly because of legal restrictions and partly because of the lack of knowledge about the performance of rooted cuttings. According to the law, not more than 5 % of a forest land holding can be planted with vegetative propagated material, or, if it is a small property, the planted area shall not exceed 20 hectares (SKSFS 2002:3). The costs of cuttings are also considerably greater than for seedlings. Of the 172,000,000 Norway spruce seedlings planted in 2002, only a few hundred thousands were rooted cuttings in clonal mixes (www.svo.se 2003).

As for all seedlings, establishment is the most critical phase concerning survival and future growth of the newly planted rooted cuttings. To be able to acquire soil resources, the roots of the seedling need to be in contact with surrounding soil (Burdett 1990; Margolis and Brand 1990). The development of new roots is required to achieve root-soil contact and depends upon the planting environment. For rooted cuttings, new root development can be slower than for ordinary seedlings, which makes the planting environment even more important (Folk et al. 1995). Site preparation can make the rooting environment more favorable by manipulating several soil characteristics. For example, scarification may increase soil temperature, decrease bulk density and improve water holding capacity of the soil (Flint and

Childs 1987; Örlander et al. 1998). Wood chips used as a mulch on planting spots can conserve soil water by acting as an isolation layer preventing surface evaporation (Bulmer 2000; Koshi and Stephenson 1962) and also discourage weed growth (Jacobs 1959).

Physiological traits differ greatly within species and affect seedling performance in the field (Cregg 1994; Larsen and Wellendorf 1990; Pelkonen and Luukkanen 1974). Norway spruce seedlings of different genetic origin have shown significant genetic variation in nutrient utilization, growth traits, survival rates and drought tolerance (Mari et al. 2003; Sonesson and Eriksson 2003). Successful seedling establishment can be achieved by using genetic material adapted to the field environment together with a proper site preparation method.

Water stress under moist soil conditions is usually a sign of poor seedling establishment. Measurement of stomatal conductance can be used to analyze seedling establishment and soil–root contact (Grossnickle and Blake 1987). When the stomatal pore width increases, the diffusion of gases through stomata increases. Soil water availability, air temperature, CO_2, light and daily changes in vapor pressure deficit (VPD) are environmental factors influencing g_{wv} and net photosynthesis, A (Ludlow and Jarvis 1971). Seedlings under water stress close their stomata to maintain a desirable water potential in the shoot, which causes a decrease in g_{wv} and the photosynthetic activity (Cregg 1994; Ni and Pallardy 1992). The ability of a seedling to control water loss through stomata is important for initial survival and establishment (Margolis and Brand 1990).

Drought stress at transplanting may cause mortality and reduce growth of Norway spruce seedlings in southern Sweden (Nilsson and Örlander 1995). New root growth improves seedling water balance (Grossnickle and Blake 1987) and is very important for growth and survival of the newly planted seedlings (Ritchie and Dunlap 1980). Factors such as improper storage and handling of the seedlings, seedling quality, low soil temperature, soil moisture characteristics and soil compaction may reduce new root growth (Ritchie and Dunlap 1980).

The objectives of this study were to investigate the influence of genetics and site preparation on the establishment of Norway spruce (*Picea abies* L. Karst). Variation in planting and growth environments were created using site preparation methods such as scarification and wood chip mulch. The hypothesis was that cuttings planted in scarified plots and plots covered with mulch would be under less water stress and would exhibit higher stomatal conductance, photosynthetic activity and new root growth compared to untreated plots, as well as higher growth and survival. We hypothesized that gas exchange and new root growth measurements could be used as measures of cutting establishment and that cuttings with high gas exchange and many new roots should have a greater growth and survival after one and two seasons respectively. We also hypothesized that there would be differences in gas exchange and growth amongst clones grown in different site preparation treatments due to interactions between genotype and environment .

MATERIALS AND METHODS

Plant material

Six clones of Norway spruce (*Picea abies* L. Karst.) adapted to different growth zones (zone 5 and 6) in Sweden were chosen (table 1). Zone 5 includes northern Götaland and Svealand, zone 6 includes Svealand and the coastal line of southern Norrland. The clones had shown better performance than other clones in field trials (Sonesson and Hannerz 2002). All seedlings were one year old rooted cuttings and container grown at the StoraEnso's nursery Sjögränd.

Table 1. Clones used in the experiment. Category Full means that the clone is selected from a full sibling family. Half stands for half sibling family with mother known and father unknown. Mother/father shows the number of the parent trees, S, E and W originates from Sweden while PL originates from Poland. The numbers 5 and 6 show which seed orchard zone the clone is selected for. Height at 6 years is the height of the genotype after six years in field compared to other clones in the same trial where 100 was the mean.

Clone number	Category	Mother	Father	Height at 6 years (relative values)
1100	Full 6	S3227	S3127	107.5
1199	Full 5	S3312	E075	126.6
2136	Full 5	S3355	PL7068	129.8
1509	Full 5	S6276	PL7073	120.0
1269	Half 6	W3025	Unknown	119.8
72	Half 6	S6316	Unknown	115.4

Study design

The study site was located in south-western Sweden at Tönnersjöheden's Experimental Forest (56˚40'N, 13˚08'E) on a one-year old clear cut with site index G32 (G stands for spruce and the number stands for height at 100 years). The soil texture was classified as a sandy loam using the ISSS classification system. Gravel and rocks were frequent in the soil and the topography varied. Mean precipitation for the area was around 1150 mm and evenly distributed within a year. The ground vegetation was composed mainly of grass (*Deschampsia flexuosa*). Norway spruce (*Picea abies* L. Karst.) was the dominant tree species in the original stand.

Four site preparation treatments were applied to the site: (1) no soil preparation (control), (2) no soil preparation covered wood chips, (3) scarification (the humus layer was removed using a harrow), and (4) scarification covered with wood chips. Due to variation in topography the site was divided into four blocks of 12x30 m. Each block was divided into eight rows 1.5 m apart. Scarification was performed in four randomly selected rows leaving a 40 cm wide row of bare mineral soil. The remaining rows where left untreated. Prior to site preparation, all slash was removed from the blocks.

In the middle of May 2002, rooted cuttings were planted to a depth of approximately 10 cm at a spacing around 1 m. Clones were randomly distributed within the scarification treatments. All cuttings were treated with permethrin (1% active ingredient) to reduce damage by pine weevil. Fifteen cuttings per clone were brought back to a lab and put in a freezer for later determination of biomass before planting.

Mulch in the form of wood chips was applied randomly on half of the planting spots for each clone and scarification treatment one week after planting. Twenty liters of wood chips were distributed around each cutting creating a mound with a diameter of 30 cm and a depth of 6 cm. Since the cuttings were small (average height was 130 mm), care was taken to not cover the cutting. A total of 960 cuttings (4 block x 2 scarification x 2 mulch x 6 clones x 10 cuttings per treatment) were used.

Cutting growth

Height and diameter of the cuttings were measured immediately after planting and at the end of each growing season. Any damage caused by insects or animals found on the seedlings was recorded. Since some of the seedlings had plagiotropic growth and no current leader, height was sometimes difficult to determine. In this case, the tallest branch was measured for length and was used for height.

In the lab, height and diameter of the cuttings were determined. They were then carefully washed and dried at 70º C for 48 hours and needle, stem and root dry weights were recorded. Pooled samples of needles, stems and roots from each clone were ground to use in a nitrogen content analysis. For the analysis, 7-10 mg of ground tissue was weighed and total N analysis was made by combustion on a NC 2100 Soil Analyzer (CE Instruments, Milan , Italy).

At the end of the first and the second growing season, one ramet per clone, treatment and block (a total of 96 cuttings) was harvested to determine shoot and root biomass. The harvested cuttings were treated in the same way as the initial cuttings. Nitrogen determinations were made on a pooled sample from each clone, treatment and block. Regressions were developed to predict shoot and root biomass from diameter and height from the harvested cuttings. These regressions were used to determine shoot and root weight for all cuttings. One regression per clone and variable (total-, needle-, stem- and root weight) was made including all site preparation treatments, since site preparation did not affect biomass allocation patterns. Following regressions were obtained:

$$\text{Total weight} = ß_0 + ß_1 * d^2h \qquad (1)$$

where total weight is the sum of needle weight, stem weight and root weight, $ß_0$ is the intercept, $ß_1$ the parameter coefficient and d^2h is the diameter squared times the height. To calculate needle weight, stem weight and root weight of individual seedlings, new regressions were made using total weight as the independent variable:

$$\text{Needle weight} = ß_0 + ß_1 * \text{Total weight} \qquad (2)$$

$$\text{Stem weight} = ß_0 + ß_1 * \text{Total weight} \qquad (3)$$

$$\text{Root weight} = ß_0 + ß_1 * \text{Total weight} \qquad (4)$$

The Krutzch index was applied to each cutting to determine the effect of bud break on shoot development (Krutzch 1973). Krutzch index is a scale numbered from 1-8, giving an indication of how far bud development has progressed. Measurements were made weekly during the first growing season until all cuttings had broken their buds and achieved a Krutzch index of 8.

Gas exchange

Gas exchange measurements were made the first growing season using a portable computerized open system IRGA (LI-6400, Li-Cor, Lincoln, NE, USA). The measurements included net photosynthesis (A) and stomatal conductance (g). Measurements were performed during the second week of August (Julian days 216-219) when the sky was clear and temperatures were around 25° C.

Cuttings from one block per day were measured between 9.30 and 16.00. One randomly selected cutting per clone, treatment and block was used, for a total of 96 cuttings. Approximately 14 one-year-old needles were collected from each cutting. The bases of the needles were placed on a piece of tape and attached across the short dimension of a 2x3 cm leaf chamber. In the chamber the CO_2 concentration was set to 360 µmol m^{-2} s^{-1} and light was provided by an LED light source (Li-Cor 6400-02B) set to 1500 µmol m^{-2} s^{-1}. The CO_2 concentration was controlled by the LI-6400 CO_2 injection system. Relative humidity was not adjusted and represented ambient levels from the surrounding environment. The temperature was set to near ambient temperature, which varied between 23-25° C. When values for the different variables measured had stabilized after approximately 5 minutes, they were recorded. No changes in stomatal conductance or net photosynthesis was observed within 10 minutes following needle detachment (data not shown). Control values using an empty chamber were taken after approximately every eight measurements to calibrate the equipment.

The needles from each cutting were placed in a small plastic bag and frozen at -20° C. Projected leaf area was measured in a lab using WinDIAS color image analysis system (Delta-T Devices, Cambridge, UK).

All cuttings used in the gas exchange study were excavated and destructively sampled following gas exchange measurements. The cuttings were carefully washed and separated into new and old roots, stems and needles. The number of new white root tips was recorded. In this study, only the new, white root tips were counted. All plant parts were stored in a freezer (-20° C) until dry weight measurements were made.

Soil temperature

Thermistors inserted into small brass cylinders were placed 7 cm below the soil surface and connected to a datalogger (Campbell CR 10, Campbell Scientific Inc., USA) to record soil temperature. Measurements were reported as hourly mean temperatures by the logger, including minimum and maximum temperatures for the specific hour. Only three out of four blocks were used for the temperature measurements due to limitations in wire lengths. A total of 24 thermistors were used, two per treatment (scarification and/or mulch) and block. Temperature was measured from May (the same week as planting) until the beginning of September during the first growing season in 2002. The datalogger was down for several weeks in July (Julian days 190-220) and data were estimated using a regression model based on measurements taken from a nearby experimental site (data not shown).

Soil moisture and precipitation

Soil moisture content was measured as percent water by volume using a TDR, Time Domain Reflectometer (Moisture Point, E.S.I. Environmental Sensors Inc., Canada). Metal probes with a length of 15 cm were installed at two randomly selected spots per treatment (scarification and/or mulch) and block, giving a total of 32 permanent probes. Additionally, soil moisture content was measured manually in 32 other randomly selected spots, two per treatment (scarification and/or mulch) and block. The probes were placed as close to the cutting as possible without damaging the root system. Measurements started in the end of May and continued until the end of September during the first and second growing seasons.

Equipment for measuring precipitation was connected to the same datalogger as the temperature measurements. Total precipitation was recorded daily.

Nitrogen mineralization

Nitrogen mineralization was determined using the buried bags method (Binkley and Hart 1989) during the first two growing seasons. In late June, 2.8 cm diameter soil cores were taken from the top 5 cm mineral soil, adjacent to the spots where the TDR measurements were made. The cores were placed in small polyethylene bags, tied shut and put back into their original holes. In treatments without scarification, soil cores incubated the humus layer and therefore the size of the cores varied with depth of the humus layer, but the mineral soil portion was always 5 cm. At the same time as the incubations were initiated, soil cores to use as initial values were collected and placed in a cooler. In the non-scarified treatments the humus layer was separated from the mineral soil. After approximately 2 months, the buried bags were removed from the soil. All samples were stored in a freezer until NH_4^+ and NO_3^- extraction with 2M KCl could be made. Net N-mineralization was calculated as the sum of NH_4^+ and NO_3^- in the extract, minus the amounts present before incubation.

Vegetation

The percentage of the area within a radius of 5 cm and 40 cm around each seedling, which was covered by competing vegetation, was ocularly determined in August the first and the second growing season, respectively. The average vegetation height was also measured.

Statistical analyses

The experiment was analyzed as a split-plot design with soil preparation as the main plot and mulch and clones as subplots. Analysis of variance was performed using PROC GLM (SAS Institute, Cary, NC, USA) with block as a random factor. The following model was used when analyzing cutting data to test for effects of scarification, mulch and clone on Krutzch index, height, biomass, survival, root growth and gas exchange:

$$Y_{ijkl} = \mu_{....} + \rho_{i(j)} + \alpha_j + ß_k + (\alpha_j ß_k) + \gamma_l + (\alpha_j \gamma_l) + (ß_k \gamma_l) + (\alpha j ß k \gamma_l) + \varepsilon_{ijkl} \qquad (5)$$

where Y_{ijkl} is the dependent variable, $\mu_{....}$ is the overall mean, $\rho_{i(j)}$ is the block main effect, α_j (scarification) $ß_k$ (mulch) and γ_l (clone) are factor main effects, $(\alpha_j ß_k)$, $(\alpha_j \gamma_l)$ and $(\alpha j ß k \gamma_l)$ are interaction effects and ε_{ijkl} the error. The error for block and scarification was block x scarification and for mulch and clone MSE. Where significant differences were found, means were separated by overall pair wise comparisons using Tukey's test. For all tests, a significance level of $\alpha = 0.05$ was used. Since the data for photosynthesis and conductance showed unequal error variances in PROC UNIVARIATE, a logarithmic (ln) transformations were used.

When analyzing for treatment effects on soil temperature, soil moisture and vegetation data the ANOVA-model was:

$$Y_{ijk} = \mu\ldots + \rho_{i(j)} + \alpha_j + \beta_k + (\alpha_j\beta_k) + \varepsilon_{ijk} \qquad (6)$$

The error term for block and scarification was block x scarification and for mulch the error was MSE. Analyses were made on each measurement, but since no differences were shown between treatments at any occasion regarding soil moisture or temperature, total sums from the growing seasons were used and presented in ANOVA-tables in the results section.

To examine relationships between root growth versus gas exchange and other growth parameters, regression analyses were made in PROC REG using the following model:

$$Y_i = \beta_0 + \beta_1 X_i + \varepsilon_i \qquad (7)$$

where β_0 is the intercept, β_1 the parameter coefficient, X_i is the independent variable and ε_i is the error.

Results

Soil moisture and temperature

Soil moisture and soil temperature were not significantly affected by scarification or mulch at significance level 0.05 (table 2). However, at significance level 0.10, scarification without mulch had lower soil moisture content throughout the growing seasons and a higher soil temperature (fig. 1). Soil moisture was relatively high throughout the growing season, in this type of soil the permanent wilting point is around 10%. In early May when measurements started, soil temperature was around 11° C. The temperature increased over time and peaked in the middle of August (21° C). During the first two growing seasons, rainfall as well as soil moisture were higher in the first half of the growth period with a peak in the end of June (early May to late June).

Table 2. Results of ANOVA of soil temperature, soil moisture and net N-mineralization.

	p-value			
	Soil temperature	Soil moisture	N_{min}	
	2002	2002	2002	2003
Scarification	0.1010	0.0974	0.060	0.670
Mulch	0.5974	0.3502	0.161	0.855
Scarification*Mulch	0.4696	0.4356	0.548	0.686

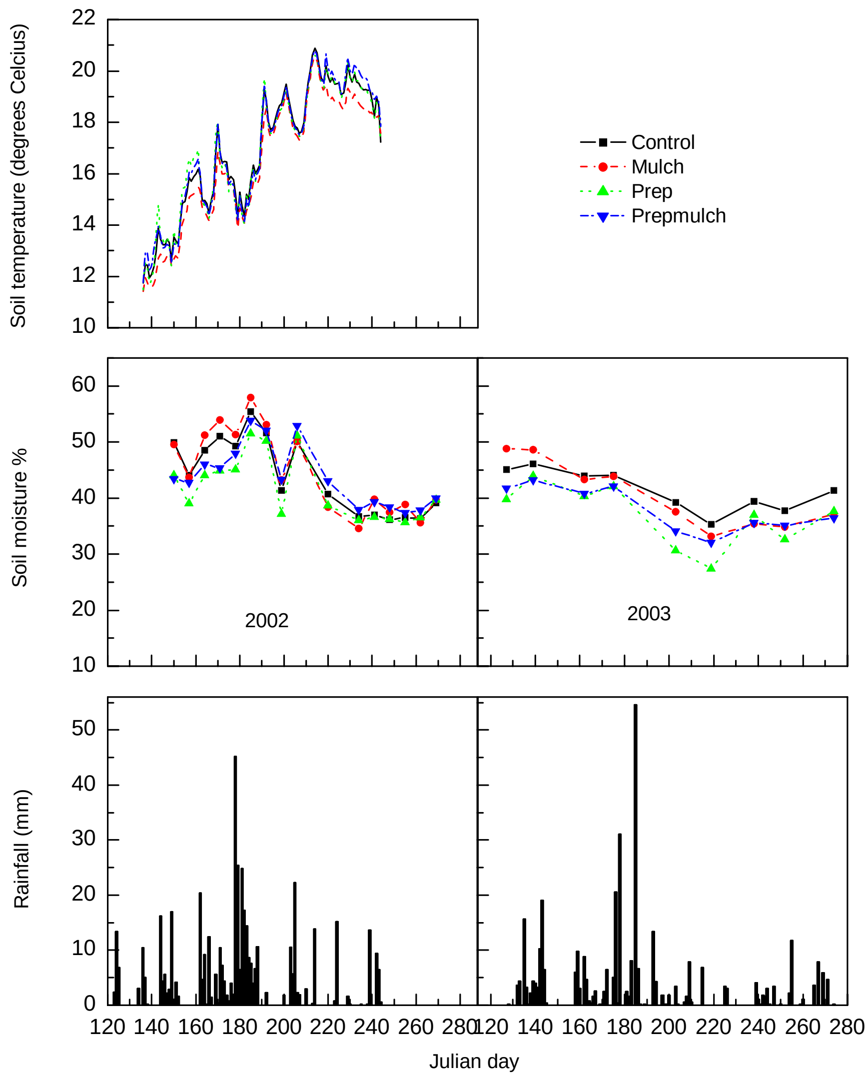

Fig. 1. Soil temperature and soil moisture in percent water by volume in the different site preparation treatments during year 2002 and 2003. Precipitation during the first growing season is also presented in the figure.

Nitrogen mineralization

Nitrogen mineralization did not differ significantly between the site preparation treatments at significance level 0.05, partly due to the large variation among the samples (table 2). During the first growing season, scarification and mulch had a lower net N-mineralization compared to the control at significance level 0.10. Scarification in combination with mulch had the lowest values in both 2002 and 2003 (table 3).

Table 3. Net N-mineralization in the different treatments. Values with different letters are significantly different (p<0,05).

	N_{min}	
Treatment	2002	2003
Control	9.14 a	4.76 a
Mulch	3.08 a	2.90 a
Scarification	4.13 a	5.93 a
Scarification + mulch	0.74 a	2.45 a

Vegetation

Height and percent cover of competing vegetation were significantly reduced by scarification during both growing seasons (tables 4 and 5). Percent cover was also reduced by mulching. Interactions between scarification and mulch were significant. The interaction indicated that mulch in combination with scarification reduced percent cover but the effect was less than additive. In 2003, the effect of mulch on percent cover within a diameter of 10 cm was greater than the effect of scarification. During the second year 2003 the percentage cover was much greater and mulch was the only treatment that reduced vegetation cover within the larger diameter 80 cm. The lower height but greater cover of competing vegetation in scarified treatments compared to non scarified plots was due to the different species occupying the areas. Hairy grass (*Deschampsia* ssp.) dominated the non scarified plots and shorter grass (*Carex* ssp.) occupied the scarified area .

Table 4. Results of ANOVA of height and percent cover of competing vegetation.

	p-value					
	Height		Cover ø 80 cm		Cover ø 10 cm	
	2002	2003	2002	2003	2002	2003
Scarification	0.008	0.001	0.009	0.066	0.006	0.016
Mulch	0.724	0.729	0.032	0.005	0.001	0.001
Scarification*Mulch	0.678	0.866	0.224	0.279	0.001	0.038

Table 5. Height (mm) and percentage cover of competing vegetation year 2002 and 2003. Values with different letters are significantly different (p<0,05).

	Height (mm)		% cover ø 80 cm		% cover ø 10 cm	
Treatment	2002	2003	2002	2003	2002	2003
Control	311 a	270 a	27 a	79 a	21 a	82 ab
Mulch	324 a	280 a	22 a	64 b	2 b	53 c
Scarification	122 b	160 b	5 b	87 a	3 b	90 a
Scarification + mulch	121 b	160 b	3 b	78 a	0 b	76 b

Cutting growth

The time of bud break during the first growing season was similar for all clones except 1269 and 1100, which broke bud significantly later than the other clones (fig. 2 and table 6). Bud break occurred earlier in scarified plots, while cuttings grown in mulch had a significantly later bud break. The results are based on Krutzch index and at each measurement occasion the same pattern was found until shoot elongation was completed in the middle of July.

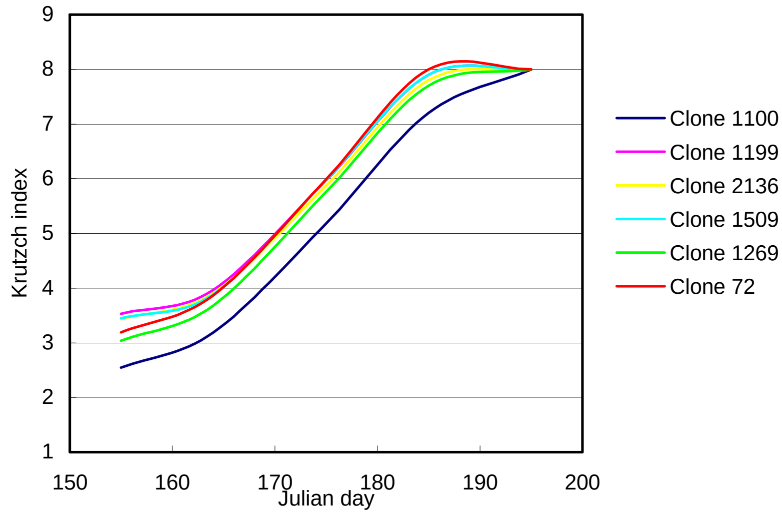

Fig. 2. Time of bud break defined as Krutzch index on Julian day.

Table 6. Results of ANOVA of Krutzch index are shown for three occasions with approximately 10 days between each occasion.

	p-value		
	Krutzch 1	Krutzch 2	Krutzch 3
Scarification	0.014	0.088	0.040
Mulch	0.045	0.027	0.974
Scarification*Mulch	0.040	0.008	0.486
Clone	<.001	<.001	<.001
Scarification*Clone	0.800	0.501	0.056
Mulch*Clone	0.115	0.068	0.837
Scarification*Mulch*Clone	0.599	0.715	0.982

Cutting biomass, height growth and root weight were negatively affected by mulch at the end of the first growing season 2002 (tables 7 and 8). In contrast with the results from the first year, mulching increased height growth by 12 mm compared to the control during the second year 2003. Cuttings grown in a combination of mulch and scarification had the greatest biomass and height growth in 2003. In comparison with the control, the increase in biomass was 6 g and height 32 mm. Survival was positively affected by scarification but not by mulch.

Table 7. Results of ANOVA of height and biomass growth and survival year 2002 and 2003 and root weight 2002.

	p-value						
	Height		Biomass		Survival		Root weight
	2002	2003	2002	2003	2002	2003	2002
Scarification	0.271	0.147	0.047	0.154	0.048	0.037	0.107
Mulch	<.001	0.002	0.023	0.132	0.310	0.995	0.038
Scarification*Mulch	0.065	0.733	0.166	0.128	0.776	0.565	0.088
Clone	<.001	<.001	0.006	<.001	0.027	0.499	<.001
Scarification*Clone	0.336	0.165	0.726	0.202	0.155	0.282	0.418
Mulch*Clone	0.382	0.817	0.986	0.974	0.411	0.455	0.947
Scarification*Mulch*Clone	0.500	0.014	0.317	0.106	0.352	0.729	0.295

Table 8. Biomass development, height growth and survival after one and two growing seasons and root weight after one growing season in the different site preparation treatments. Values with different letters are significantly different (p<0.05).

	Biomass growth (g)		Height growth (mm)		Survival (%)		Root weight (g)
Treatment	2002	2003	2002	2003	2002	2003	2002
Control	3.1 a	13.7 a	55.5 a	76.5 a	88 a	80 a	1.64 a
Mulch	2.1 b	13.1 a	35.0 b	88.6 b	86 a	82 a	1.30 b
Scarification	3.2 a	15.2 a	45.8 c	90.9 b	95 b	93 b	1.58 a
Scarification + mulch	3.0 a	19.9 b	36.5 b	109.0 c	94 b	92 b	1.55 a

Clonal differences in growth were significant after the first and second growing season (tables 7 and 9). Height growth ranged from 20 mm for clone 1100 to 70 mm for clone 1509 the first year and from 44 mm for clone 1100 to 134 mm for clone 2136 the second year. Clone 1100 had the poorest height and biomass growth overall. The other clones had similar growth rates during the first year. After the second growing season, both biomass growth and height growth of clone 2136 was significantly greater than for the other clones. Survival for clone 1100 was lower (85 %) in year 2002 compared with the other clones, which all had a survival greater than 90 %. However, in 2003 no differences in survival were found between the clones. Root weight in clone 1100 was only 0.83 g, while it was more than twice as high in the best clones 1509 and 2136. No significant interactions for growth or survival were found between clones and mulch or scarification.

Table 9. Biomass growth, height growth and survival for each clone after one and two growing seasons and root weight for 2002. Values with different letters are significantly different (p<0.05).

	Biomass growth (g)		Height growth (mm)		Survival (%)		Root weight (g)
Clone number	2002	2003	2002	2003	2002	2003	2002
1100	1.9 a	4.6 a	20 a	44 a	85 a	84 a	0.83 a
1199	2.5 ab	18.5 c	40 b	103 c	90 ab	86 a	1.38 b
2136	3.3 b	26.0 d	37 b	134 d	91 ab	87 a	1.84 cd
1509	3.4 b	16.4 bc	70 c	95 c	95 b	91 a	1.89 d
1269	2.5 ab	11.2 b	49 b	71 b	90 ab	86 a	1.40 bc
72	3.2 b	16.0 bc	40 b	98 c	92 ab	87 a	1.78 bcd

Nitrogen concentration differed between clones (table 10). The concentration was lower in clone 1100 (1.43 %) and 1509 (1.38%) compared to the other clones (table 11). Nitrogen content of the cuttings were similar in all clones and varied between 0.08-0.10 g per seedling, except for clone 1100 where the N-content was 0.04 g. Mulch and scarification did not affect nitrogen concentration of the cuttings, but nitrogen content for cuttings grown in scarification were significantly higher. Without mulch, the mean N-concentration was 1.63 % and with mulch 1.65 %, while the N-content was 0.07 g and 0.08 g respectively. Scarification increased the concentration from 1.60 % to 1.68 % and content from 0.07 g to 0.08 g. No measurements were made after the second growing season 2003.

Table 10. Results of ANOVA of nitrogen concentration and content in cuttings. Pooled samples for measuring concentration changes the model and values for interactions are not available.

	N-concentration	N-content
Scarification	0.108	0.026
Mulch	0.600	0.057
Scarification*Mulch		0.068
Clone	0.001	0.001
Scarification*Clone		0.881
Mulch*Clone		0.878
Scarification*Mulch*Clone		0.708

Table 11. Nitrogen concentration and content of the different clones.

Clone	Nitrogen concentration (%)	Nitrogen content (g)
1100	1.43 ab	0.04 a
1199	1.89 c	0.08 b
2136	1.76 c	0.10 b
1509	1.38 b	0.08 b
1269	1.71 c	0.08 b
72	1.67 bc	0.09 b

Root growth

The number of new root tips of cuttings growing with mulch was significantly greater than for cuttings growing without mulch (tables 12 and 13). With mulch, the number of new root tips varied from 43 to 49, while it was only 25 in the scarified plots (table 14). Clonal differences in root growth were also found. Clone 1100 had fewest new root tips (21) and clone 1509 most (54). No correlations were found between the amount of new root tips and various dependent variables (table 15).

Table 12. Results of ANOVA of new root growth, g and A.

	p-value		
	Number of new roots	Stomatal conductance	Photosynthesis
Scarification	0.231	0.594	0.203
Mulch	0.002	0.001	0.003
Scarification*Mulch	0.593	0.654	0.712
Clone	0.001	0.009	0.076
Scarification*Clone	0.278	0.048	0.005
Mulch*Clone	0.459	0.886	0.609
Scarification*Mulch*Clone	0.119	0.847	0.549

Table 13. Differences between treatments regarding number of new roots, g and A. Values with different letters are significantly different ($p<0.05$).

Treatment	Number of new roots	Stomatal conductance (mmol m^{-2} s^{-1})	Photosynthesis (µmol m^{-2} s^{-1})
Control	35 ab	54 a	2.58 a
Mulch	49 b	72 b	4.16 a
Scarification	25 a	55 a	3.18 a
Scarification + mulch	43 b	82 b	5.62 b

Table 14. Mean values of stomatal conductance g and net photosynthesis A for each clone. The table also shows the average number of new roots for each clone. Zone indicates for which growth zone the clone is chosen. Values with different letters are significantly different ($p<0.05$).

Clone number	Zone	Number of new roots	Stomatal conductance (mmol m^{-2} s^{-1})	Photosynthesis (µmol m^{-2} s^{-1})
1100	6	21 a	47 a	2.5 a
1199	6	50 bc	63 ab	3.7 a
2136	5	46 bc	74 ab	4.7 a
1509	5	54 c	52 ab	2.7 a
1269	5	30 abc	74 ab	4.4 a
72	6	27 ab	85 a	5.2 a

Table 15. Correlation between several dependent variables and the amount of new root tips.

Dependent variable	p-value	R^2
A	0.022	0.09
G	0.150	0.04
Height	0.530	0.01
Biomass	0.426	0.01
N-content	0.330	0.02
N-concentration	0.273	0.02

Gas exchange

Significant effects of mulch were found on gas exchange of cuttings (table 12). Cuttings with mulch had higher g (72 mmol m^{-2} s^{-1} only mulch and 82 mmol m^{-2} s^{-1} with mulch and scarification) compared to cuttings planted without mulch (54 mmol m^{-2} s^{-1} in control and 54 mmol m^{-2} s^{-1} in scarification). The average A for cuttings planted with mulch was also significantly higher. No significant effects of scarification were found. No significant relationships were found among A and the number of new roots (table 14, fig. 3).

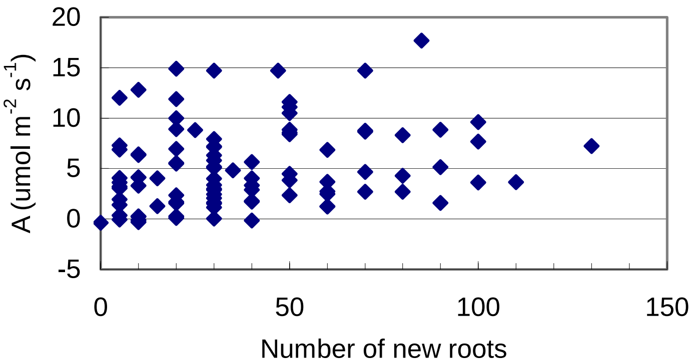

Fig. 3. No correlation was found between the amount of new roots and net photosynthesis, A. The coefficient of determination $r^2 = 0.09$.

Clonal differences in g were detected (table 11). Clones 72 and 1100 were significantly different with two extreme values 85 mmol m^{-2} s^{-1} and 47 mmol m^{-2} s^{-1}, while remaining clones had similar values. No significant differences were found between clones for A. Interactions between scarification and clone showed that the response in A to scarification differed between clones (fig. 4). Clone 2136 responded more strongly to scarification than the other clones, while A of clone 1509 and 1269 was negatively affected by scarification.

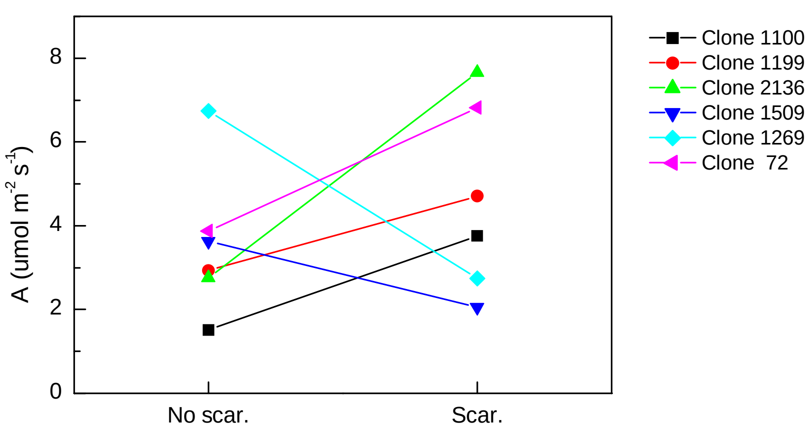

Fig. 4. The response in A of the clones growing in non scarified and scarified plots.

DISCUSSION

Gas exchange and new root growth of cuttings were increased by mulching, but biomass and height growth was negatively affected by mulch during the first year. During the second growing season mulch and scarification affected growth of cuttings positively, indicating improved site conditions associated with the scarified and mulched plots. Growth of seedlings of Norway spruce are partly dependent on environmental circumstances during the previous year for growth since the number of cells are developed when the seedling sets bud (Grossnickle 2000). The increased root growth and gas exchange in mulch may have been an indicator of higher growth the following year. The lack of a first year growth response to cultural treatments is common in boreal forests (Löf 2000), and after two or three years significant effects appear (Örlander et al. 1996). The lack of first year effects may also be explained by the condition of the seedlings at planting (Bulmer 2000). The first two years of growth for the cuttings was poor compared to other studies with Norway spruce seedlings in similar treatments (Hallsby 1995; Nordborg and Nilsson 2003), which may indicate that the cuttings were in a poor condition. Usually, rooted cuttings of Norway spruce need two years in the nursery to reduce problems with plagiotropic growth and poor root development (Sonesson and Hannerz 2002). The rooted cuttings used in this study were only one-year-old. It is possible that our cuttings were under stress during the first year and could therefore not benefit from the site preparation treatments. Although the positive effect of mulch on seedling growth was significant after two years, better cuttings may have responded earlier and more strongly.

Clone 1100 had low height and biomass increment during both growing seasons as well as a low nitrogen content and concentration. Clone 1509 had slightly greater height and biomass growth compared to the other clones during the first year but after the second growing season, clone 2136 achieved the highest biomass and height increment. These two clones had the highest root weight the first growing season. Comparing the ranking of the clones in this study in year two (table 6) regarding height growth with the ranking from earlier field tests (table 1), clone 1100 had the poorest height growth after six years and was selected for growth zone 6 while clone 2136 had the largest height growth and was selected for growth zone 5 (Sonesson and Hannerz 2002), and was therefore more adapted to the site in our study. The clones that had a later bud break (1100 and 1269) also had a lower height growth compared with clones with an earlier bud break. Usually, northern provenances of Norway spruce break buds earlier than southern provenances (Hannerz 1993; Werner and Karlsson 1982). Bud break occurred earlier in scarified plots. Even though the higher soil temperature in the scarified plots was only significant at the 0.10 level in this study, it may still have been important for the cuttings. An increase in soil temperature leads to earlier bud break in Norway spruce (Lopushinsky and Max 1990; Söderström 1974).

Clone 1100 had a small number of new roots and the poorest height growth, indicating that initial root growth may be important for shoot growth and development. Clone 1100 also had lower stomatal conductance compared with the other clones. Clone 1509 had the greatest number of new roots and was also the clone with the highest growth and survival rate during the first year. Interestingly, clone 1509 did not stand out from other clones in terms of the gas exchange. Gas exchange measurements did not correlate with new root development or any other growth variable (table 14). Similar lack of correlations between new root growth, transpiration rates and photosynthesis has been found in Norway spruce seedlings (Thompson and Puttonen 1992) and in Douglas fir seedlings (van den Driessche 1987). One explanation for the poor correlations could be that the cuttings were more dependent upon having new roots rather than on the actual number of new roots. Similar conclusions were drawn when Norway spruce seedlings with root growth capacity (RGC) values of up to three times as much as the lowest value did not survive or grow any better than other seedlings (Mattsson 1991). Clones with higher gas exchange rates were in the upper ranking regarding height growth the second growing season. For example, clone 2136, which was superior in growth during the second year, also exhibited high stomatal conductance and photosynthesis, although it did not differ significantly compared to the other clones. Higher gas exchange may have indicated lower stress for the specific clone and generated higher growth following year. The results from this study suggest that a single gas exchange measurement was not enough to determine new root growth and cutting establishment. Measuring gas exchange is both time consuming and expensive and therefore not a practical way of determining seedling establishment.

Scarification reduces competing vegetation, especially on clearcuts older than two years where a vegetation cover is abundant (Örlander et al. 1996). However, the scarification effect only lasts for a few years and on older clearcuts the effect of mulch on seedling growth may be more important due to its ability to reduce competing vegetation for a longer time. In this study the scarified area was already covered with grass after one year, while the mulched plots had significantly less competing vegetation (table 2). The fact that mulch in the form of wood chips reduces the amount of competing vegetation and therefore had a positive effect on seedling growth has been observed (Clemens and Starr 1985). Mulch may also have a positive effect on future growth by an increase of nutrients around the seedling. Slash and wood residues left on a clear-cut improved site nutrition due to an increased mineralization (Fahey et al. 1991). However, the total amount of wood chips applied on our site was rather small so we suspect little long term mulching effect.

Site preparation increased survival and growth of the cuttings. Mulch in combination with scarification generated the highest growth rate, although the effect was not additive. Mulch in the form of sawdust has earlier shown to increase seedling growth (Bulmer 2000). No interactions between clone and site preparation were found, except for gas exchange and scarification where clone 1509 and 1269 were negatively affected by scarification while the remaining clones were positively affected by scarification and there was a change in rank between the clones. In the long run, a few centimeters in advance on scarified and mulched plots may not be important, however this difference may be important in terms of damage by browsing animals. In addition, an increase of a few millimeters in diameter can reduce damage by pine weevil significantly (Hannerz et al. 2002). Improved site conditions due to scarification and mulch increased the nutrient status and the vitality of the cuttings and may have made them more resistant to damages in the future. However, in this study the clonal effect on growth was higher than the site preparation effect. A regeneration site with high survival and a low frequency of damage by animals, frosts and insects will create a more homogeneous stand with high quality trees at the end of the rotation. Mortality creates gaps in the stand and replacement planting may be needed, which increases variation in tree size (Gemmel 1988).

Conclusions

Planting rooted cuttings can increase growth and quality of a stand. The planting material best adapted to the specific site can be chosen if the performance of the clones are known. Due to their larger diameter, rooted cuttings are less susceptible to pine weevil damage and late flushing clones can be planted on frost prone sites. A reduced variation in the performance of the cuttings compared with ordinary seedling material will create a more homogenous stand in the future. But to be able to use rooted cuttings in practical forestry and benefit from the improved genetics, better plant material is needed. Currently, rooted cuttings are more expensive than regular seedlings and therefore the plant quality of the rooted cuttings must be high to make the planting economically feasible.

Mulch reduces vegetation and may therefore also improve seedling growth. Today, mulching is not used in practice in Sweden. If vegetation control with mulch is desirable on a regeneration site, wood chips can be processed using wood residues on the site at the time of harvest or taken from a sawmill nearby. Future research is needed to understand the interactions between mulching and seedling establishment as well as the long term effects of mulching on tree growth.

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CHAPTER 2

INTERACTIONS BETWEEN SOIL SCARIFICATION TREATMENTS AND SEEDLING TYPES OF NORWAY SPRUCE

Introduction

One of the main problems during the establishment of planted seedlings is that they do not have access to site resources because of undeveloped root systems and poor root-soil contact. Root development is a major factor controlling survival and first-year growth of planted seedlings (Ritchie and Dunlap 1980). When seedlings are newly planted, their access to soil water is restricted because of a poor root-soil contact, which can lead to water stress (Grossnickle and Blake 1987). Important soil factors influencing root growth are moisture availability, mechanical strength, aeration and temperature (Gregory 1987). Soil temperature is probably the main factor controlling root growth and development in northern latitudes (Landhäusser et al. 2001). Low soil temperatures can limit water permeability, reduce root growth and therefore increase seedling water stress (Lopushinsky and Max 1990).

Site preparation changes and improves soil physical properties and may therefore improve seedling establishment. Soil treatments involving exposure of the mineral soil and/or elevated planting spots may improve micro climate, soil temperature and ameliorate water supply and nutrients for seedling establishment (Nilsson and Örlander 1995; Nilsson and Örlander 1999). Often, a higher intensity of site preparation results in increased growth, which may be explained by higher availability of soil moisture, light and nutrients partly due to less competing vegetation (Allen and Wentworth 1993; Nilsson and Allen 2003; Nordborg and Nilsson 2003). Common soil preparation methods in Sweden are disc trenching, patch scarification and mounding. Soil inversion is a new soil preparation method, which has been tested in experiments with good results (Örlander et al. 1998). Soil inversion combines bare mineral soil with retention of the humus layer, which may be positive since humus has a positive effect on seedling growth compared with pure mineral soil (Hallsby 1995).

When regenerating forests with Norway spruce (*Picea abies* L. Karst.) in southern Sweden, large 2 or 3 year old bare rooted or containerized seedlings are often used. They are thought to be less affected by competition from vegetation, have a greater resistance to pine weevil damage and a shorter establishment phase due to the size of their root systems. However, if site preparation improves soil characteristics, reduces competition from vegetation and damage by pine weevil, the establishment of small seedlings may be as good as for larger seedlings. Small seedlings are less expensive since they require less space and time in the nursery and the planting costs are lower. Therefore, it may be financially attractive if planting spots could be prepared in a way that provides for successful establishment of small seedlings.

The main objective of this study was to investigate possible interactions between seedling size and site preparation method. The hypothesis to be tested was that small seedlings require more intensive site preparation than larger seedlings to achieve a satisfactory establishment and growth since they are more sensitive to unfavorable environments.

MATERIALS AND METHODS

Study design

The experiment was established on two sites, one site was located at Asa experimental forest (57˚10'N, 14˚47'E) and the other at Skogaby (56˚33'N, 13˚13'E). Both sites were relatively fertile with site index (meters at 100 years) T26 at Skogaby and G28 at Asa (T=pine and G=spruce). Precipitation was relatively high at Skogaby (1145 mm) and evenly distributed throughout the year. At Asa (800 mm) there were occasional dry periods during the vegetation period. Summer frosts were more common at Asa than at Skogaby. On both sites, Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*) dominated the sites prior to cutting, and the ground vegetation on the clearcuts was dominated by grass.

The one-year-old clearcuts were fenced to reduce browsing by deer and moose. Each location was divided into four blocks with a size of 15x30 m. The blocks were divided into two main plots with and without fertilization (Hydro NPK 20-3-5 Svavel Bor). Fertilizer was first applied in July 2000, one year before planting, and included a broadcast application of 150 kg /ha of N, of which 80 kg was NH_4-N and 70 kg NO_3-N, 22.5 kg/ha of P and 37.5 kg/ha of K. The fertilizer also contained sulfur and boron. In 2001 and 2002, fertilizer with the same formulation was applied in both June and August using 75 kg/ha of N, 11.25 kg/ha of P and 18.75 kg/ha of K each time. No fertilizer was added during 2003.

Three soil scarification treatments; 1) control, 2) mound and 3) soil inversion, were randomly applied in rows in each main plot and considered as subplots. Each treatment was represented by two randomly selected rows per main plot. Both soil scarification treatments were made with a small excavator. Mounds, consisting of 20 liters of soil, were placed on a patch of bare mineral soil, 30 x 30 cm in size. Soil inversion was a 30 x 30 cm patch of inverted humus layer covered with about 5 cm of mineral soil, placed on the patch of mineral soil from which it was taken. The control was not scarified. Each row consisted of 12 planting spots at a spacing of 1.25 m. Three different seedling types were planted in May 2001 (Skogaby) and June 2001 (Asa). Two seedlings were planted per planting spot to have enough material to measure and harvest . The seedling types were: 1) mini, a small, 10 weeks old, containerized seedling grown at 1000 per m^2, 2) containerized, an ordinary 2 year-old containerized seedling grown at 400 per m^2, and 3) hybrid, a 2 year-old combination between a containerized seedling and a bare root seedling. All seedlings were of the Belarusian provenance from natural stands. The mini seedlings were actively growing at the time of planting while the other two seedling types were dormant. All seedlings were treated with permethrin (1% active ingredient) to minimize damage by the pine weevil. To facilitate planting and future measurements, the seedlings were planted in a repeating pattern of mini, containerized and hybrid in each row. A total of 1152 seedlings were planted on each site. At the end of the first growing season, in the planting spots where there was still two seedlings, one of seedlings were cut.

Seedling growth

Seedling height and root collar diameter were measured directly after planting. After the first, second and third growing season, seedling height, length of current leader and root collar diameter were recorded.

Seedlings were harvested at three dates during the first growing season, at the end of June, in the beginning of August and when the seedlings had stopped their growth in November. At each date, two seedlings per seedling type, scarification treatment, fertilization treatment and block were harvested (144 seedlings per location). All seedlings were stored in a freezer (-20^{o} C) until they were processed in the lab. In the lab, the root systems were carefully washed and the seedlings were oven dried for 48 hours in 70˚ C. Thereafter, the seedlings were divided into stems, needles and roots and all parts were weighed and ground. One pooled sample per seedling type, scarification and fertilization treatment was used for N concentration determination. For the N analysis, 7-10 mg of ground tissue was weighed and total N analysis was made by combustion on a NC 2100 Soil Analyzer (CE Instruments, Milan , Italy). After the second growing season, analyses of K and P were made. The ground plant tissue was digest with nitric acid and analyzed with an ICP spectrometer (Westerman 1990).

At Skogaby, seedlings were also harvested after the second and third growing season. After the second growing season, the shoots of one seedling per type, scarification treatment and fertilization treatment from two blocks were harvested (36 seedlings). The roots of nine of these seedlings were also excavated, one per seedling type and treatment. After the third growing season only the mini and hybrid seedlings grown in both fertilized and non fertilized control and soil inversion were harvested. Eight seedlings per treatment combination, for a total of 64 seedlings, were harvested including the root systems. These four treatments were chosen for sampling because they included the range of site preparation intensity found in the experiment. Seedlings from all harvests were treated in the same way in the lab.

Biomass of all seedlings in the field were estimated at the time of planting and after each growing season using regression functions. One regression per seedling type and treatment was estimated to capture differences in allocation patterns between seedling types and site preparation treatments. The following regressions were used:

$$\text{Total biomass or above ground biomass} = \beta_0 + \beta_1 * d^2h \quad (1)$$

where total biomass (g) is the sum of needle weight, stem weight and root weight of the harvested seedlings, while above ground biomass (g) is the sum of needle weight and stem weight. β_0 is the intercept, β_1 the parameter coefficient and d^2h is the squared diameter multiplied by height. The above-ground biomass was used when regressions were made for the second growing season where not enough roots were excavated to fit a proper model. To calculate needle weight, stem weight and root weight of individual seedlings, new regressions were made using total biomass as the explanatory variable:

$$\text{Needle weight} = \beta_0 + \beta_1 * \text{Total biomass} \quad (2)$$

$$\text{Stem weight} = \beta_0 + \beta_1 * \text{Total biomass} \quad (3)$$

$$\text{Root weight} = \beta_0 + \beta_1 * \text{Total biomass} \quad (4)$$

To make regressions for needle-, stem- and root weight after two and three growing seasons, the above-ground weight instead of the total weight was used in the models because more seedlings were available with above-ground weight.

As a measure of productivity, a growth efficiency index was developed for each seedling type using the following equation:

$$\text{Growth efficiency} = \text{Yearly production} / (\text{Old needles} + \text{Current needles}/2) \qquad (5)$$

where the yearly production was based on the increase in total biomass (g) during the specific growing season, old needles was the sum of the needle weight (g) from the time of planting until the specific year and the current needles was the weight of the needles developed during the year used in the calculation. Current needle weight was divided by two since the needles do not contribute to growth until the last half part of the growing season due to low photosynthetic activity (Ludlow and Jarvis 1971).

In a similar way, nitrogen use was calculated:

$$\text{Nitrogen use} = \text{Yearly production} / \text{Nitrogen content} \qquad (6)$$

Nitrogen content (g) was calculated by multiplying the nitrogen concentration in the seedling by its total biomass. Values of nitrogen content from fall of the same year were used in the calculations.

Soil water

Soil water contents at Asa were measured gravimetrically in the different soil preparation treatments directly after planting, at the end of June and at the end of July during the first growing season. Soil cores were collected to a 10 cm depth, five per treatment and block. In the control plots, samples were taken both in the humus layer and in the mineral soil. All samples from one treatment and block were put together as a pooled sample. After weighing, the samples were dried for 24 hours in 105º C and weighed again. In Skogaby, soil moisture content was measured using gypsum blocks (Soil Moisture Inc., USA) during the first growing season. One gypsum block per scarification and fertilization treatment was installed 10 cm below the soil surface and measurements were taken approximately every other week during the growing season; once in June and twice in July and August.

Competing vegetation

At Skogaby, the amount of competing vegetation was estimated by destructive harvest in the middle of August every year. In each main plot, i.e. fertilization treatment, five randomly chosen circular spots (0.5 m^2) on untreated ground were harvested. All the above ground biomass sampled from each block and fertilization treatment was treated as a bulk sample, and the vegetation was divided into herbaceous species and woody species. Samples were dried in 70 °C for 48 hours and dry weight recorded. After the third growing season below ground biomass of vegetation was also harvested. A soil core with a radius of 10 cm and a depth of 20 cm was collected from each block, fertilization and scarification treatment. Each soil core were then sieved to separate the roots from the soil. All the roots from one core were then dried at 70 °C for 48 hours and dry weight recorded.

Statistical analyses

All analysis were made using the SAS software (SAS Institute, Cary, NC, USA). The experiment was treated as a split-split-plot design with fertilizer as main plot, scarification treatment as sub-plot and seedling type as sub-sub-plot. Analysis of variance was performed using PROC GLM with block as a random factor. The error term for block and fertilization was block * fertilization, for scarification it was block * fertilization * scarification and MSE was the error for seedling type. The seedling types were treated as being randomly distributed, although to facilitate planting they were planted using a specific pattern. However, by giving each seedling a number showing its position in each row, and by using this position as a concominant variable in a covariance model, seedling growth was not affected by planting position (data not shown) and the assumption of randomly distributed seedlings could be accepted. Where significant treatment differences were indicated, means were separated by overall pair wise comparisons using Tukey's test. For all tests, an α-value of 0.05 was used to show significance. When analyzing soil moisture data at Skogaby, sums for the growing season were used.

Coefficients of variation (CV) for height, i.e. the standard deviation over the mean, were calculated for each seedling type and scarification treatment.

Economical calculations

Net present values for the different treatment combinations were calculated. The calculations were based on regeneration costs and survival rates obtained in the study. No effects of future stand quality and development were taken into account.

RESULTS

Soil water

No significant differences were found for soil moisture at Skogaby (table 1). At Asa, the highest soil water content was found in the control followed by the mound and the soil inversion had the lowest value (fig. 1). At Asa, only scarification treatment means were compared and they differed significantly at the 0.05 level.

Table 1. Results of ANOVA of soil moisture at Skogaby.

	Soil moisture
	2001
Fertilization	0.1583
Scarification	0.8761
Fertilization*Scarification	0.0917

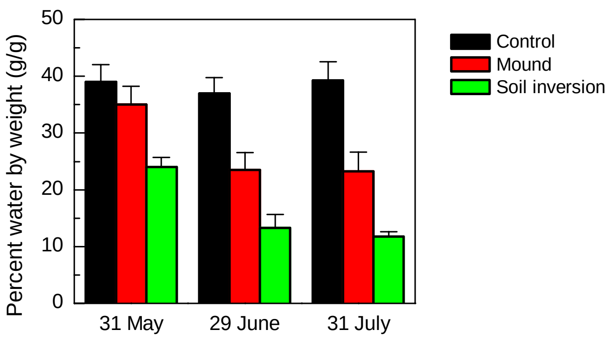

Fig. 1. Percent water by weight in the different scarification treatments at Asa.

Vegetation

Not surprisingly, grass and herbaceous vegetation was significantly increased by fertilization at Skogaby (fig. 2). In 2002, biomass of grass species grown totaled 2.61 tons/ha on control plots compared with 4.32 tons/ha on the fertilized plots. In 2003 the means were 3.64 tons/ha (no fertilization) and 3.22 tons/ha (fertilization). Biomass of woody species averaged 1.0 tons/ha and was not affected by fertilization in 2002. In 2003, woody biomass increased to 6.41 tons/ha on fertilized plots and 1.43 tons/ha on non fertilized plots.

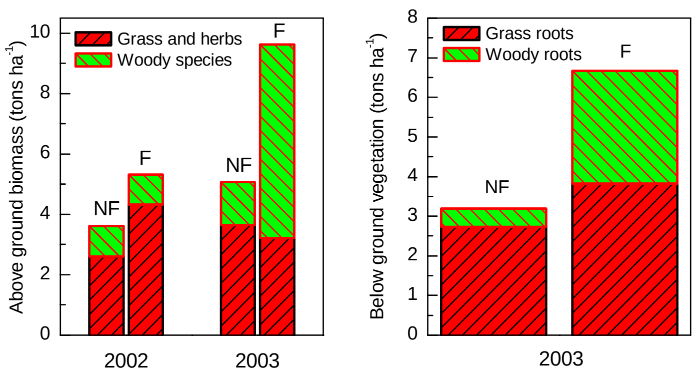

Fig. 2. Above-ground and below-ground vegetation at Skogaby divided into grass and woody species in tons per hectare in the two fertilization treatments (NF = no fertilization and F = fertilization).

The below-ground vegetation harvested in fall 2003 also showed tendencies towards a higher biomass in the fertilized plots (fig. 2). For grass roots, a significantly higher amount was found in the fertilized plots, 3.82 tons/ha (to a depth of 20 cm), compared to 2.73 tons/ha in unfertilized plots. There were 2.85 tons/ha (fertilization) and 0.46 tons/ha (no fertilization) of woody roots, however these differences were not significant due to large variation. No effects of soil scarification were found.

Seedling survival

Results differed for the two locations (table 2). At Skogaby, survival was higher than at Asa, especially for the mini seedling (table 3). During the first growing season 2001, only 51 % of the mini seedlings survived in the control treatment at Asa. However, in all other treatments survival was relatively high. Several mini seedlings (38 %) were frost heaved in the mound treatment during winter and spring of 2001-2002, which caused an increase in mortality the following growing season 2002 at Asa. Some frost heaving also occurred in the soil inversion treatment and for the containerized seedlings grown on the mounds. Overall, survival at Skogaby was high and damage caused by frost heaving was low (table 2). In the mound treatment, some frost heaving was detected in spring 2002 among the mini seedlings (11 %), but it was not as severe as at Asa and without any mortality the following year.

Table 2. Results of ANOVA of survival and frost heaving at Asa and Skogaby.

	Asa				Skogaby			
	Survival			Frostheaved	Survival			Frostheaved
	2001	2002	2003	2002	2001	2002	2003	2002
Fertilization	0.287	0.731	1.00	0.360	0.480	0.700	0.747	0.015
Scarification	<.001	<.001	<.001	0.001	0.075	0.010	0.010	<.001
Fertilization*Scarification	0.983	0.472	0.682	0.326	0.581	0.700	0.743	0.002
Seedling type	<.001	<.001	<.001	<.001	0.017	<.001	<.001	<.001
Fertilization*Seedling type	0.376	0.992	0.864	0.673	0.430	0.212	0.090	<.001
Scarification*Seedling type	<.001	<.001	<.001	<.001	0.014	<.001	<.001	<.001
Fertilization*Scarification*Seedling type	0.901	0.601	0.816	0.978	0.171	0.048	0.027	<.001

Table 3. Treatment effects on survival and frostheaving of the three different seedling types of Norway spruce at Asa and Skogaby after the growing seasons in year 2001, 2002 and 2003. Frostheaving only occurred during the first winter and spring 2002. Numbers followed by different letters are statistically significant at $\alpha = 0.05$.

		Asa				Skogaby			
		Survival (%)			Frostheaved (%)	Survival (%)			Frostheaved (%)
Treatment	Seedling Type	2001	2002	2003	2002	2001	2002	2003	2002
Control	Mini	51 a	46 a	42 a	0 a	90 a	85 a	83 a	0 a
	Containerized	93 b	91 bc	89 b	0 a	95 b	93 b	93 b	0 a
	Hybrid	100 b	98 b	95 bc	0 a	100 c	98 c	98 c	0 a
Mound	Mini	94 b	78 c	75 d	38 b	99 c	99 c	99 c	11 b
	Containerized	99 b	99 b	99 c	7 c	99 c	99 c	99 c	1 a
	Hybrid	100 b	98 b	98 c	3 ac	100 c	100 c	99 c	0 a
Inversion	Mini	94 b	87 bc	86 b	15 c	100 c	99 c	98 c	2 a
	Containerized	98 b	98 b	98 c	5 ac	100 c	100 c	99 c	0 a
	Hybrid	99 b	98 b	98 c	0 a	100 c	100 c	99 c	0 a

Seedling growth

Biomass and height increment differed between seedling types and treatments (table 4). Where no interactions between seedling type and scarification were found, soil inversion resulted in the greatest height and biomass at both Skogaby and Asa. Significant interactions showed that biomass increment and height growth of the mini seedling were positively affected by soil inversion at Skogaby. Biomass of the mini seedling was almost four times greater in the soil inversion (64 g) than in the control (17 g) in 2003. For the two larger seedling types there were no statistical differences in growth between the mounding and soil inversion (fig. 3). At Asa, interactions were caused by the large increase in growth for the hybrid and mini seedlings planted on mounding and in soil inversion compared to the control. Even at Asa, the increase in biomass was four times higher in the soil inversion (19 g) compared to the control (4 g). No effects of scarification were found for the containerized seedling. Height growth at Skogaby was significantly greater in fertilized plots for all seedling types in 2001 and 2002.

Table 4. Results of ANOVA of biomass and height growth at Asa 2001, 2002 and 2003 (only height) and at Skogaby 2001, 2002 and 2003.

	Biomass					Height					
	Asa		Skogaby			Asa			Skogaby		
	2001	2002	2001	2002	2003	2001	2002	2003	2001	2002	2003
Fertilization	0.374	0.387	0.734	0.262	0.616	0.732	0.494	0.114	0.001	0.006	0.454
Scarification	0.002	<.001	<.001	<.001	0.003	0.139	0.001	0.035	0.003	<.001	0.001
Fertilization*Scarification	0.820	0.335	0.008	0.928	0.656	0.850	0.172	0.601	0.207	0.218	0.446
Seedling type	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	0.001	<.001
Fertilization*Seedling type	0.434	0.277	0.490	0.378	0.806	0.575	0.981	0.441	0.017	0.237	0.579
Scarification*Seedling type	0.018	<.001	0.017	<.001	0.150	0.128	0.007	0.250	0.004	0.574	0.698
Fertilization*Scarification* Seedling type	0.418	0.189	0.138	0.779	0.885	0.688	0.085	0.084	0.024	0.120	0.474

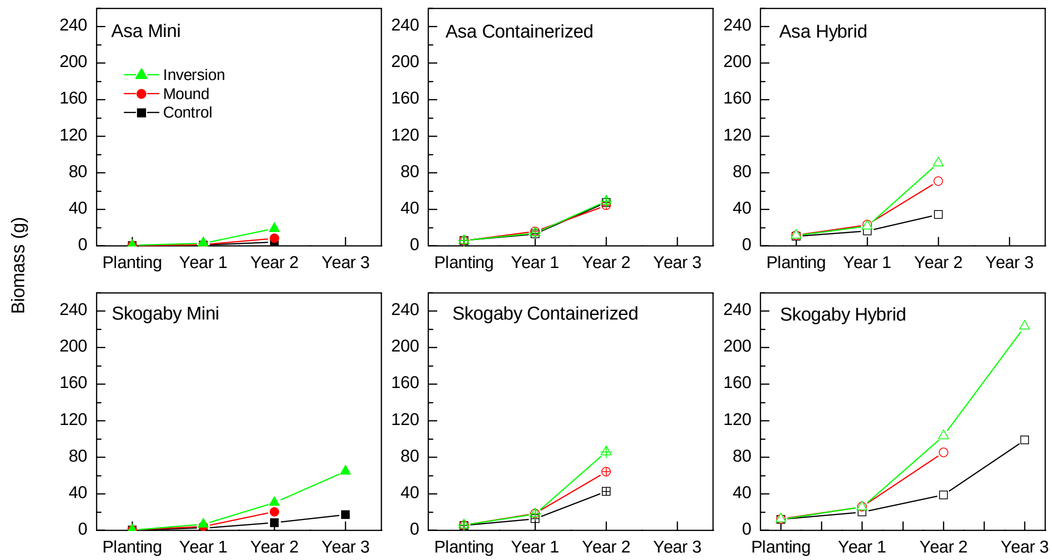

Fig. 3. Biomass (total weight in gram) of each seedling type in respective site preparation treatment grown at Asa (above) and Skogaby (below). Data from Asa and the mound treatment and the containerized seedling at Skogaby from the 3rd year are not shown in the figure. Filled symbols represents mini seedlings, crossed containerized seedling and open hybrid seedlings.

Comparing growth rates at the same seedling age up through 40 months, the mini seedling at Skogaby had a greater height and biomass growth than the other two seedling types in the soil inversion (fig. 4). At the age of 40 months, both the mini, containerized and hybrid seedling had a biomass around 60 g and the mini seedling had a height around 700 mm while the height for the two other seedling types were around 500 mm. When the small seedlings were older than 40 months, their height increments were still greater in comparison with other treatment combinations, while their biomass increments had slowed down. At Asa height growth rates were lower for the mini seedling but the biomass growth in the soil inversion was similar in comparison with the containerized and the hybrid seedling. At Skogaby all the seedling types had similar values of height and biomass in the control treatment at the same age, but at Asa the mini seedling had the lowest growth in the control.

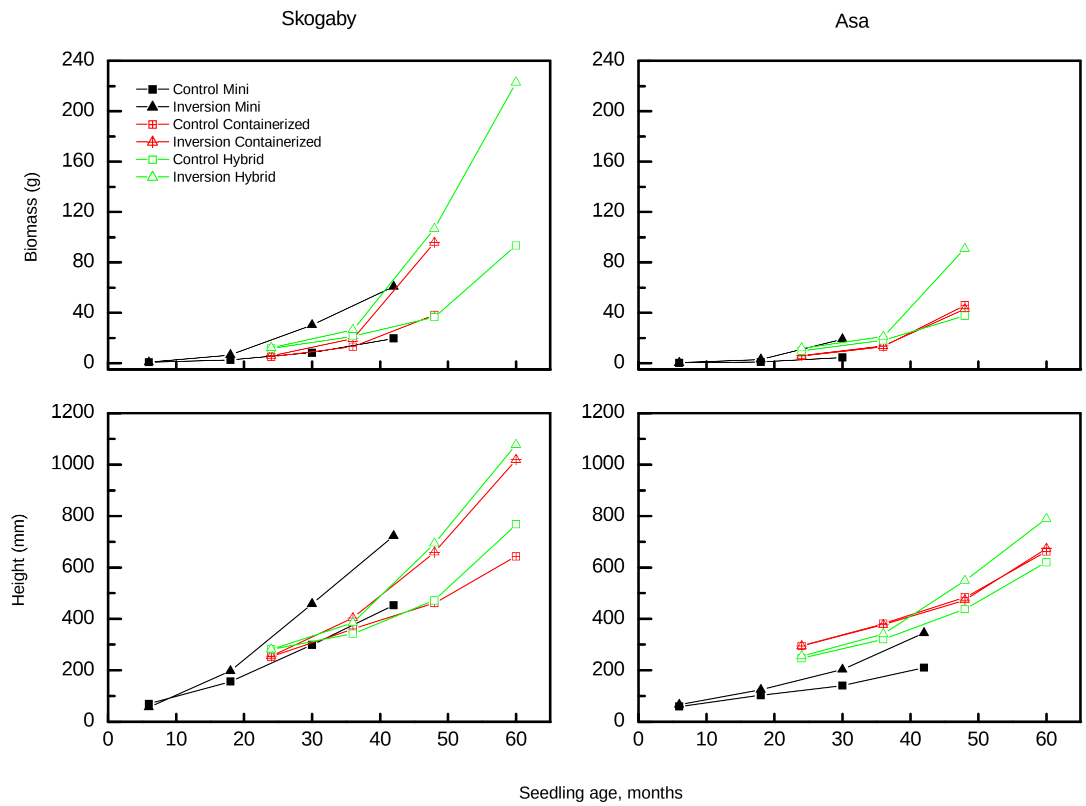

Fig. 4. Biomass and height development for the three different seedling types at Skogaby (left) and Asa (right) in relation to the age of the seedlings. Biomass development at Asa after the 3rd growing season is not shown in the graph. Notice the different scales on the Y-axes.

The variation in height was different for the seedling types. The height distribution of hybrid seedlings in fall 2002 grown was compared with the height distribution of mini seedlings in fall 2003. Results showed that the mini seedlings had a greater variation in height in the soil inversion treatment compared with the hybrid (fig. 4). The coefficient of variation for height was 31% for the mini seedling and 23% for the hybrid seedling. Coefficients of variation were also calculated for the control and mound treatment. For the mini seedling CV was 29% (control) and 39% (mound) and for the hybrid 26% (control) and 23%(mound).

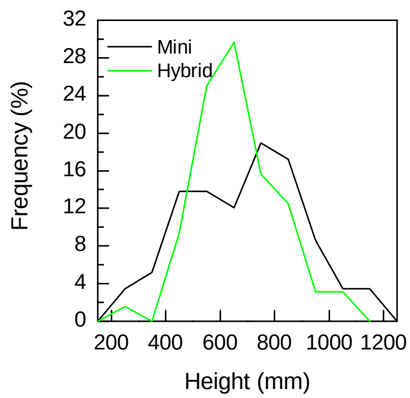

Fig. 5. Frequency distribution of height for mini (fall 2003) and hybrid (fall 2002) seedlings grown in soil inversion.

Stem, needle and root weight followed the same pattern as total biomass (fig. 6), and were significantly affected by seedling type, scarification and their interactions (table 5). Soil inversion had greatest effect on stem, needle and root weights of the mini seedling compared to other treatment combinations. No significant differences between soil inversion and mounding were found for the containerized or the hybrid seedling. Root weight of the mini seedlings was 3 g in the control and 18 g in the soil inversion at the end of 2003, and 11 g and 45 g for the hybrid seedlings, respectively.

Table 5. Results of ANOVA of stem-, needle- and root biomass at Skogaby 2001, 2002 and 2003.

	Stem			Needle			Root		
	2001	2002	2003	2001	2002	2003	2001	2002	2003
Fertilization	0.832	0.266	0.864	0.734	0.259	0.848	0.822	0.252	0.895
Scarification	<.001	<.001	0.001	<.001	<.001	0.001	<.001	<.001	0.001
Fertilization*Scarification	0.143	0.888	0.767	0.019	0.912	0.778	0.059	0.865	0.822
Seedling type	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001
Fertilization*Seedling type	0.467	0.324	0.717	0.515	0.261	0.720	0.365	0.408	0.808
Scarification*Seedling type	0.392	<.001	0.027	0.107	0.001	0.024	0.009	0.001	0.014
Fertilization*Scarification*Seedling type	0.725	0.881	0.894	0.707	0.864	0.901	0.846	0.737	0.915

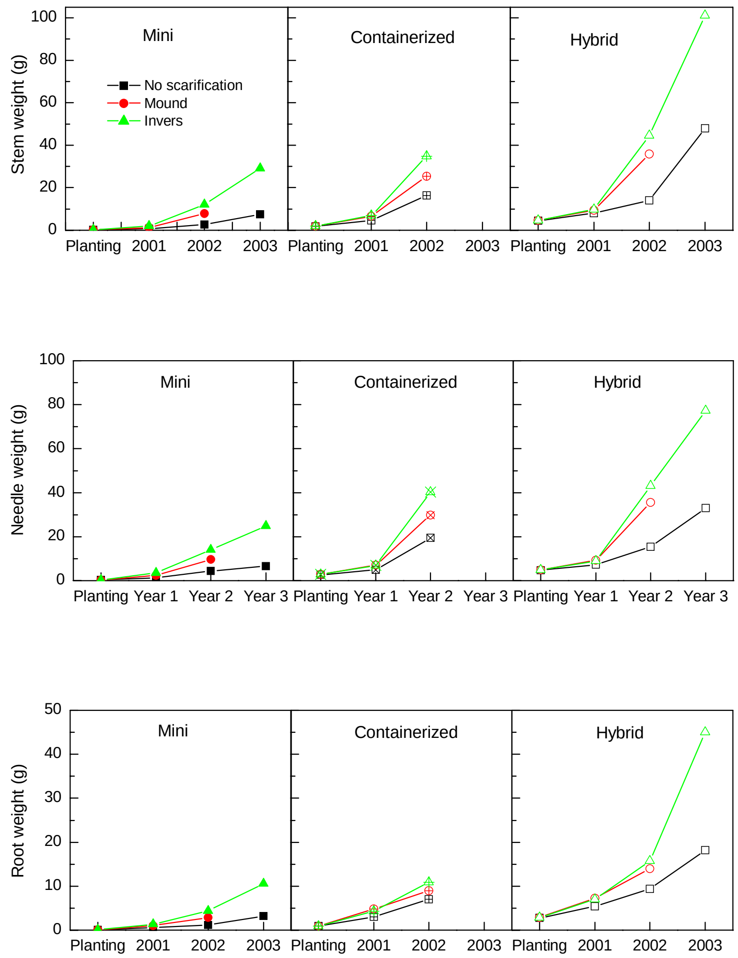

Fig. 6. Stem-, needle- and root biomass for the three different seedling types and scarification treatments at Skogaby. Data for the containerized seedling is only shown for year 2001 and 2002. Filled symbols represents mini seedlings, crossed containerized seedling and open hybrid seedlings.

Relative needle biomass decreased in favor of stem biomass as the total biomass increased and the allocation patterns were similar for both scarification and seedling type at Skogaby (fig. 7). The only tendency was that the mini seedlings grown in the soil inversion allocated more to needles than to roots compared to the control. These differences seemed to diminish as the total biomass of the seedling increased. In general, around 45 % of the total biomass was allocated to the stem, 35 % to the needles and 20 % to the roots.

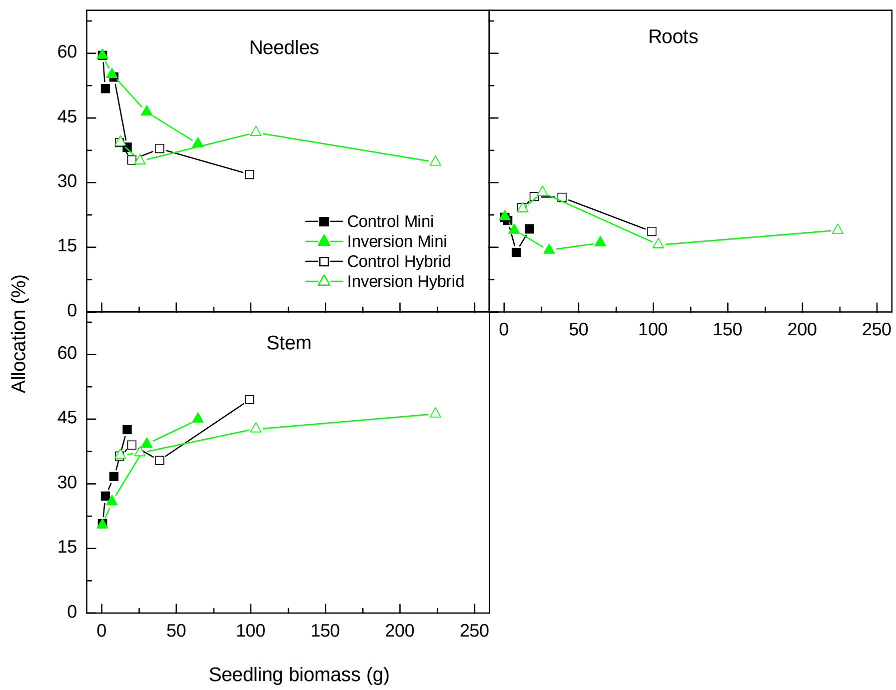

Fig. 7. Allocation to needles, stem and roots calculated as percentage of total biomass for the two seedling types mini and hybrid grown in the control and soil inversion treatment.

Growth efficiency varied over the years and among seedling types (fig. 8). Both differences between scarification method and seedling types were detected (table 6). For the mini seedlings, a decrease in growth efficiency with time was found in all treatments. During the first year (2001), the mini seedling had a higher growth efficiency compared to the two other seedling types, while it was lower compared to the other seedling types during the following two years (2002 and 2003). Soil inversion and mound increased growth efficiency in 2001 and 2002 compared with the control. However, no treatment effects were significant in 2003 and values for the soil inversion equaled the control.

Table 6. Results of ANOVA of growth efficiency in year 2001, 2002 and 2003.

	Growth efficiency		
	2001	2002	2003
Fertilization	0.821	0.153	0.133
Scarification	<.001	<.001	0.258
Fertilization*Scarification	0.006	0.857	0.962
Seedling type	<.001	0.001	0.001
Fertilization*Seedling type	0.985	0.279	0.333
Scarification*Seedling type	0.086	<0.001	0.074
Fertilization*Scarification*Seedling type	0.290	0.011	0.254

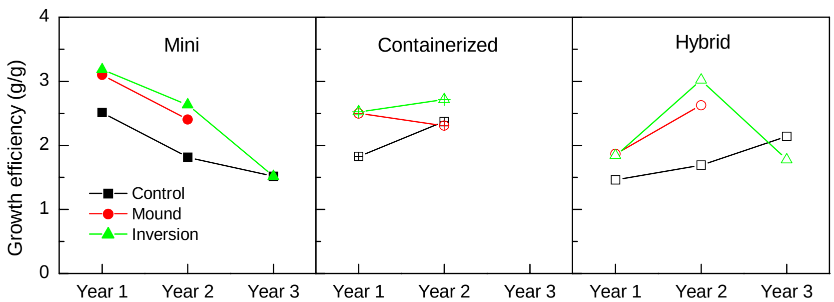

Fig. 8. Growth efficiency as produced biomass per needle biomass (g/g) for the three different seedling types grown in control, mound and inversion. Data from year 3 including mound and the containerized seedling was not available. Filled symbols represents mini seedlings, crossed containerized seedling and open hybrid seedlings.

Seedling nutrition

Nitrogen concentration differed significantly between scarification treatment and seedling type in year 2001 (table 7), and the nitrogen concentration was higher in the mini seedling and in soil inversion (table 8). Nitrogen concentration of the mini seedling was 1.84 % compared with 1.51 % for the hybrid seedling. Seedlings grown in the soil inversion had an average nitrogen concentration of 1.76 % in comparison with 1.50 % for seedlings grown in the control. Fertilization increased nitrogen concentration 0.05 %, but this difference was not significant. In 2002, no significant differences in nitrogen concentrations were found. In the fertilization treatment there was a tendency towards a lower nitrogen concentration (1.08 %) of the seedlings in comparison with non fertilized plots (1.23 %).

Table 7. Results of ANOVA of nitrogen concentration year 2001 and 2002, and for K/N-ratio and P/N-ratio year 2002. No interaction effects with fertilization are shown due to pooled samples.

	Nitrogen concentration		K/N	P/N
	2001	2002	2001	2001
Fertilization	0.532	0.100	0.030	0.050
Scarification	0.047	0.576	0.224	0.224
Seedling type	0.020	0.696	0.406	0.012
Scarification*Seedling type	0.406	0.341	0.450	0.060

Table 8. Nitrogen concentration (%) of the seedlings in the different treatments year 2001 and 2002. Numbers followed by different letters are significantly different (p<0.05).

	Nitrogen concentration (%)							
	Seedling type			Scarification			Fertilization	
Year	Mini	Containerized	Hybrid	Control	Mound	Soil inversion	Non fertilized	Fertilized
2001	1.84 a	1.63 ab	1.51 b	1.50 a	1.72 ab	1.76 b	1.63 a	1.68 a
2002	1.11 a	1.14 a	1.20 a	1.12 a	1.21 a	1.12 a	1.23 a	1.08 a

The ratio between nitrogen and the two other nutrient elements K and P differed between fertilization treatments and seedling type (only P) (table 7). Both the ratios for K:N and P:N were higher in the non fertilized treatment and the P:N ratio was higher in mini seedlings compared to hybrid seedlings (table 9). Among all treatment combinations, the K:N ratio varied between 32-38 % and the P:N ratio between 10-13 %.

Table 9. Ratios between N and K and P.

	Nutrient ratios (%)							
	Seedling type			Scarification			Fertilization	
	Mini	Containerized	Hybrid	Control	Mound	Soil inversion	Non fertilized	Fertilized
K:N	37 a	34 a	34 a	34 a	33 a	38 a	38 a	32 b
P:N	13 a	12 ab	10 b	11 a	12 a	13 a	12 a	11 b

Nitrogen content was significantly affected by scarification, seedling type, fertilization and their interactions (table 10). As for biomass and height growth, the larger seedlings were not as strongly affected by scarification treatment as the mini seedling regarding nitrogen content during the first year (fig. 9). Fertilization increased nitrogen content in all seedling types during the second year and the effect of fertilization was greater than the effect of scarification. The nitrogen content in seedlings grown in mound with fertilization were higher or similar than seedlings grown in soil inversion without fertilization. In comparison with the control without fertilization, nitrogen content of all seedling types was three times higher in fertilized soil inversion.

Table 10. Results of ANOVA of nitrogen content year 2001 and 2002.

	Nitrogen content	
	2001	2002
Fertilization	0.157	0.041
Scarification	<.001	<.001
Fertilization*Scarification	0.010	0.131
Seedling type	<.001	<.001
Fertilization*Seedling type	0.090	0.006
Scarification*Seedling type	0.001	<.001
Fertilization*Scarification*Seedling type	0.564	0.122

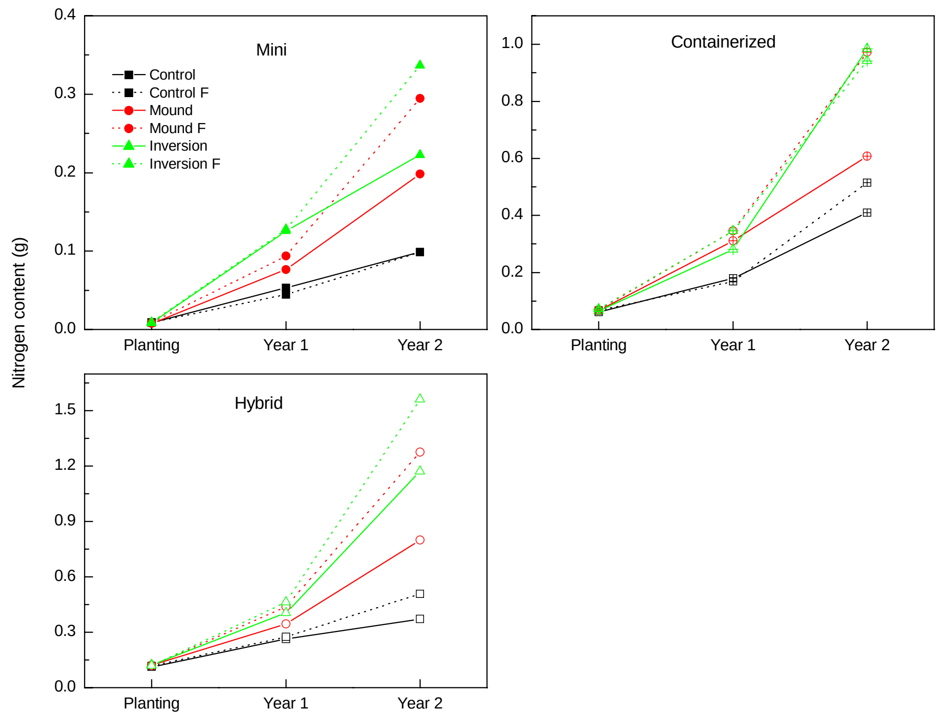

Fig. 9. Nitrogen content (g) in the three different seedling types during two years. Values for both fertilized and unfertilized treatments are shown. Filled symbols represents mini seedlings, crossed containerized seedling and open hybrid seedlings.

Nitrogen use differed significantly between fertilization, scarification and seedling type and their interactions (table 11). Soil inversion increased nitrogen use and the mini seedling grown in soil inversion had the greatest value (fig. 10). For the mini seedling, the ranking of the scarification treatments were stable and the soil inversion had the highest value. Among the two other seedling types, the ranking of the scarification treatments was not that obvious. The hybrid seedling had the lowest nitrogen use overall. Fertilization caused a decrease in nitrogen use compared to non fertilized plots.

Table 11. Results of ANOVA of nitrogen use in 2001 and 2002.

	Nitrogen use	
	2001	2002
Fertilization	0.141	0.044
Scarification	0.033	<.001
Fertilization*Scarification	0.308	0.022
Seedling type	<.001	<.001
Fertilization*Seedling type	<.001	<.001
Scarification*Seedling type	<.001	<.001
Fertilization*Scarification*Seedling type	<.001	<.001

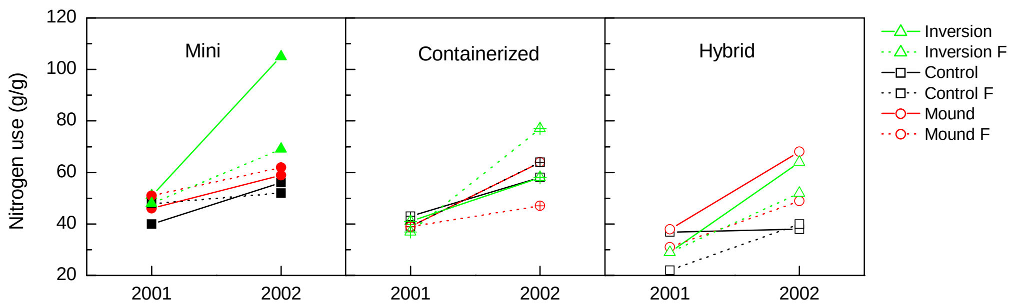

Fig. 10. Nitrogen use for the three different seedling types in scarification treatments with and without fertilization. Filled symbols represents mini seedlings, crossed containerized seedling and open hybrid seedlings.

DISCUSSION

The hypothesis that the smaller seedlings are more dependent on the site preparation intensity than larger seedlings was supported by results from this study. Differences in growth between the control and scarification treatments was relatively greater for the mini seedling than for the two larger seedling types (fig. 1). The interactions between seedling type and scarification method for growth indicated that the mini seedlings were able to establish faster in the soil inversion treatments compared to other treatments and compared to larger seedlings. Site preparation is known to increase growth of planted seedlings (Allen and Wentworth 1993; Brand 1990; Hallsby 1995; Nilsson and Allen 2003), and this was also true for this experiment. In the soil inversion the mini seedling allocated more biomass to the needles and less to the roots when compared to the control and had therefore a greater photosynthetic capacity. A higher allocation to the roots in the control may indicate soil water and nutrient deficits. Water stress is common at establishment and a high moisture supply is important (Dougherty 1996). Larger seedlings may experience greater water stress than smaller seedlings, which could be caused by a lower root growth capacity and a more suberized root system compared to smaller seedlings (Lamhamedi et al. 1996). Bare-root seedlings have shown a reduction in growth and an increase in mortality under conditions of drought compared to smaller containerized seedlings (Nilsson and Örlander 1995). In this study, the poor growth of the larger seedlings in relation to the smaller seedlings during the first two growing seasons may be explained by the root functioning. Visual observations confirmed that the larger seedling types had a less branched root system and a higher amount of suberized roots than the mini seedlings and were more susceptible to root deformations. With a greater number of active roots in relation to its leaf area, the mini seedling might have had an advantage. The characteristics of the root system can also affect future growth of the trees. Deformed and poorly developed root systems of the seedlings can result in crooked stems and the formation of compression wood when the trees get older (Lindström and Rune 1999).

The high mortality among the mini seedlings in Asa (table 2), may have been caused by an unfavorable planting environment and the fact that the small seedlings were not dormant during transport and storage. The same seedling material was used at both locations, but the seedlings were planted a couple of weeks later in Asa than in Skogaby. New root growth is dependent on current photosynthates, but when the planting conditions become less favorable the importance of stored reserves increases (van den Driessche 1987). During storage, the mini seedlings may have experienced a major reduction of their stored reserves, which complicated their establishment. The poor seedling growth at Asa compared to Skogaby may in part be due to frost damage as well as the poor establishment. Asa is a frost prone site and frost causes needle damage, which will decrease the amount of photosynthetically active leaf area and the photosynthetic efficiency (Lundmark and Hällgren 1987). Scarification reduces the frequency of frost injury due to a higher heat transfer capacity between soil and air compared to non scarified sites (Langvall et al. 2001). Langvall et al. (2001) also showed that containerized seedlings were more susceptible to frost damage than bare-root seedlings because of earlier flushing. The mini seedlings were growing when planting, which made them more susceptible to frost.

Frost heaving was the major factor causing seedling mortality in the soil scarification treatments. The higher percentage of frost heaved seedlings in the mounds compared to the soil inversion can be explained by soil water characteristics in the two treatments. With soil inversion, the capillarity flow of water was broken by the buried humus layer, while the mound of pure mineral soil did not break the capillarity flow. At cold temperatures, ice lenses were created, which pushed up the seedlings (Goulet 1995). Frost heaving was less severe in Skogaby, where it was only observed as a problem for the mini seedling in the mound treatment. Seedlings grown in Skogaby were less affected by frost heaving in part due to better establishment and root system development and partly due to more favorable weather conditions at Skogaby. The importance of proper establishment for mini seedlings to avoid damage caused by frost heaving or competition has been shown in another experiment (Lindström 2003). However, the variation in height was large in the mound, the coefficient of variation was 39 %, which was higher than in both soil inversion and control. Damaged seedlings probably had a lower height growth and therefore the variation increased.

During the third growing season the biomass growth of the smaller seedlings was less than the two larger seedling types at the same age, but the height growth was still higher (fig. 2). The morphology of the seedlings types differed and the shoots of the mini seedling were long and slender while the other seedling types had more branches, which increased seedling biomass. In a study where containerized seedlings had a greater growth compared to bare-root seedlings during the first two growing seasons but not the third, the differences during the third season were assumed to be caused by a larger biomass of bare-root seedlings (Nilsson and Örlander 1999). Interestingly, the growth efficiency of the mini seedlings decreased with time. A decrease in growth efficiency could be a sign of physiological stress. The high nitrogen use of the mini seedling could also be a stress symptom since biomass did not increase even if the nitrogen content was high. Other nutrients or water may have been limited, but the ratios between nitrogen, potassium and phosphorus did not show any sign of nutrient imbalances according to recommended values (K:N 35 % and P:N 10%) (Linder 1995). After three years, competition for soil resources and light from competing vegetation was significant. In comparison with the larger seedling types, the amount of competing vegetation on the site was less at this specific time then for the smaller seedlings of the same age and size. An earlier study has shown that competition from ground vegetation is only a problem during the establishment phase (Nilsson and Örlander 1999). However, the results from this study suggests that competing vegetation may be a problem even after the establishment phase for mini seedlings. If this holds true, the amount of competing vegetation will need to be controlled for a number of years to be able to benefit from the high growth potential of the mini seedlings. Usually, positive site preparation effects on field vegetation are only found during the first one or two growing seasons (Nordborg and Nilsson 2003), and this was also true for this study where no effects of scarification were found on below ground vegetation biomass after three growing seasons.

Fertilization did not affect seedling biomass. Similar results have been reported by (Nordborg and Nilsson 2003), where fertilization had no effect on biomass of Norway spruce seedlings, and (Brand 1990) for White spruce. In some cases, there was a tendency towards a negative fertilization effect, which can be explained by an increase of competing vegetation on fertilized plots. Height growth was positively affected by fertilization. This observation may be explained if the seedlings grown on fertilized plots experienced a competition for light from surrounding vegetation and responded with longer shoots. Even before shading by neighbouring plants occurs, the seedlings may respond to a change in the red:far-red ratio (Casal and Smith 1989). A study on growth of Pinus radiata seedlings showed that light quality affected height growth and fascicle density but not dry weight or diameter (Morgan et al. 1983). In this study the fertilizer was broadcasted on the site to create a more fertile growth environment. If an increase in seedling growth is desirable, a banded application in the scarified rows may be better. When broadcasting, surrounding vegetation is also fertilized and competition on the site is increased.

The greater variation in height for the mini seedling may create more heterogeneous stands. Small seedlings with a low height increment will continue to be suppressed while the larger ones become strong competitors with heavy branches and there is a risk of poor quality in the stand (Gemmel 1988). Site preparation increases survival and reduces variation in the mature stands (Nilsson and Allen 2003). Homogeneous stands are preferred to get high quality and from a management perspective.

Net present values for the different combinations of seedling types and site preparation treatments used in this study were calculated (appendix 1). No effects of future stand development and quality were taken into account and the calculations were only based on differences in regeneration cost. Therefore, the control treatment generated the largest NPV since planting costs are highly reduced. On a fresh clear-cut, planting without scarification is possible, but several factors can cause a decrease in NPV. Without scarification pine weevil damages can be as high as 80 % (Peterson and Örlander 2003), seedling vigour may be reduced (Bergquist et al. 2003), heterogeneity of the stand increases and the planting process is more complicated than with scarification. All these factors reduces quality of the future stand and therefore also cause a decrease in net present value.

Conclusions

This study shows that small seedlings can establish quickly and grow even better than larger seedlings when planted in a favorable environment. Comparing the growth rate of the different seedling types at the same age, transplanted young seedlings into the field may grow at a higher growth rate than in the nursery, which in practice will save both time and money. However, small seedlings are more sensitive to the planting environment and proper handling before planting is critical. They are also more susceptible to frost heaving and competition, which has to be considered when choosing site preparation method. The use of mini seedlings in Sweden can become a problem if the use of herbicides will be needed. Planting on a fresh clear cut can be a way to avoid competing vegetation, but instead severe damage by the pine weevil may cause a failure of the plantation. A positive effect of planting mini seedlings may be a higher quality of future stands due to less root deformations, but this assumption has to be further investigated. More research is needed to understand the establishment of seedlings and why the growth is higher in the mini seedlings in the beginning. The advantage in growth among the mini seedlings should be transferred to the larger seedling types to be able to achieve optimal growth in young Norway spruce plantations in southern Sweden.

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appendix 1

NET PRESENT VALUE FOR DIFFERENT REGENERATION METHODS

Regeneration costs

Seedling type (per seedling)

Mini	0:60 SEK
Containerized	2:00 SEK
Hybrid	2:50 SEK

Site preparation (per hectare)

Mound	3,000:00 SEK
Soil inversion	5,000:00 SEK

Planting costs (per hectare)

Mini	4,000:00 SEK
Containerized	5,000:00 SEK
Hybrid	6,000:00 SEK

Calculations

The goal was to have 2000 seedlings per hectare after three years. Based on this, the number of seedlings planted were calculated using the survival rates at Asa and Skogaby after three years. The mini seedling was assumed to be two years behind the larger seedling types through the whole rotation. Pre-commercial thinning was performed at a cost of 3,000:00

SEK and the stand was thinned three times during the rotation, after 30, 40 and 50 years. The stand was harvested after 63 years (containerized, hybrid) and 65 years (mini). The interest rate was set to 3%.

Differences in growth, damages and future variation in the stand depending on the seedling type used are not taken into account. Quality of the seedlings and site characteristics are other factors that may influence the net present value.

		Seedlings/ha	Regeneration (SEK)	Net Present Value (SEK)
Mini	No preparation	2750	5,650	22,699
	Mound	2260	8,356	19,993
	Soil inversion	2160	10,296	18,053
Containerized	No preparation	2180	9,360	20,716
	Mound	2020	12,040	18,036
	Soil inversion	2030	14,060	16,016
Hybrid	No preparation	2070	11,175	18,900
	Mound	2030	14,075	16,000
	Soil inversion	2030	16,075	14,000