SILVA FENNICA
Silva Fennica 44(3) research articles
www.metla.fi/silvafennica · ISSN 0037-5330
The Finnish Society of Forest Science · The Finnish Forest Research Institute

Effect of Soil Preparation Method on Economic Result of Norway Spruce Regeneration Chain

Karri Uotila, Juho Rantala, Timo Saksa and Pertti Harstela

Uotila, K., Rantala, J., Saksa, T. & Harstela, P. 2010. Effect of soil preparation method on economic result of Norway spruce regeneration chain. Silva Fennica 44(3): 511–524.

Economic result of forest regeneration chains, based either on spot mounding or on disc trenching and planting of Norway spruce (*Picea abies* [L.] Karst.) seedlings, were clarified and compared to each other. First, effects of soil preparation method on early development of Norway spruce stands were measured from field experiments. Second, the effects of soil preparation method on stand level management programs were modelled. The modelling was based on growth simulation and investment calculations. The soil preparation methods substantially affected early development of a stand. The density of the removed trees in early cleaning was 56% higher on the disc-trenched area compared to the spot-mounded area. The difference was especially high (120%), close by (<25 cm) the remained spruce seedlings. There was also a difference between the methods in the growth of crop spruces; at biological age of 8 years, the mean height of spruce was 110 cm on the spot-mounded area and 68 cm on the disc-trenched area. The differences led to divergent management programs between the areas. The disc-trenched area needed three young stand management operations whereas two was enough at the spot-mounded area. Although disc trenching is a less expensive method than spot mounding, the total management costs were higher in disc trenching than in spot mounding. Furthermore, incomes from the first commercial thinning were higher when regeneration based on spot mounding. At the interest rate of 3%, the investment in spot mounding had 329 € ha^{-1} higher net present value than the investment in disc trenching.

Keywords cleaning, disc trenching, forestry investment analysis, Picea abies, pre-commercial thinning, regeneration chain, soil preparation, spot mounding, sprouting
Addresses Finnish Forest Research Institute, Suonenjoki, Finland
E-mail karri.uotila@metla.fi
Received 15 October 2009 **Revised** 19 February 2010 **Accepted** 14 April 2010
Available at http://www.metla.fi/silvafennica/full/sf44/sf443511.pdf

1 Introduction

In general, investments in forest regeneration are economically rational if they are paid back as increased incomes or shortened rotation period (Hyytiäinen et al. 2006). Between a clear-cut and a first commercial thinning, forest management consists of several interrelated silvicultural operations, which compose a regeneration chain.

After clear-cutting, the first silvicultural treatment for the next tree generation is usually soil preparation. Soil preparation is an investment that increases survival and growth of the planted seedlings in Nordic boreal forests (Nordborg 2001). Unfortunately, soil preparation has also negative effects in terms of enhancing the development of unwanted tree species (Saksa et al. 1990). The unwanted trees are mostly hardwoods that disturb development of the coniferous crop trees. Hardwoods are unwanted especially at Norway spruce (*Picea abies* [L.] Karst.) sites, because they do not improve the quality of crop trees contrary to Scotch pine (*Pinus sylvestris* L.) sites (Nilsson and Gemmel 1993, Huuskonen 2008). However, effects of soil preparation on stand development vary a lot between different methods.

Disc trenching is a relatively light soil preparation method. The main idea in disc trenching is to expose mineral soil and to reduce competition between the crop trees and other vegetation (Nordborg 2001, Saksa et al. 2005). Mounding is a more intensive method and it has become more common especially in connection with spruce planting (Saksa et al. 2005). In addition to reduction of competition, intensive preparation accelerates nutrient release and enhances soil temperature more than disc trenching does (Örlander et al. 1990, Sutton 1993, Nordborg et al. 2006). On spot-mounded sites, a share of exposed mineral soil of the total area is 19%, when the corresponding share after disc trenching is 27% (Luoranen et al. 2007).

In Nordic growing conditions, effects of soil preparation on success of spruce seedlings are rather well known (Örlander et al. 1990, 1998, 2002, Hansson and Karlman 1997, Mäkitalo 1999, Nordborg 2001, Hallsby and Örlander 2004, Saksa et al. 2005). Survival of spruce is better and growth faster after an intensive soil preparation, such as spot mounding, compared with the lighter methods, such as disc trenching (Nordborg 2001, Örlander et al. 2002, Saksa et al. 2005, Nordborg et al. 2006). In addition to the observations made in the experimental studies above, Saksa and Kankaanhuhta (2007) reported similar results based on a large inventory data collected from young spruce plantations in Finland.

According to Saksa et al. (1990), mineral soil revealing increases establishment of unwanted birch seedlings (*Betula* sp.). High density of hardwoods, such as birch, decrease growth of coniferous crop trees (Folkesson and Bärring 1982, Pettersson 1992, Andersson 1993, Gobakken and Næsset 2002, Dehlin et al. 2004) by affecting water (Nilsson and Örlander 1995), nutrient (Jobidon 2000), and light (Jobidon 2000, Dehlin et al. 2004) conditions of growing site. In addition, risk of mechanical damages in crop trees increases as a function of density and size of unwanted trees (Walfridsson 1976, Laaksonen 2008). Because of the competition from hardwoods, spruce also develops thinner stem, which sensitizes it to wind, snow and ice damages (Jobidon 2000). Disadvantage caused by competition depends on the distance and height difference between the crop tree and the disturbing tree (Andersson 1993, Laaksonen 2008). Therefore, a properly timed pre-commercial thinning accelerates or at least sustains growth of crop trees (Folkesson and Bärring 1982, Pothier 2002, Fleming et al. 2005, Huuskonen and Hynynen 2006, Pitt and Lanteigne 2008).

However, optimal timing of young stand management operations is a multi-dimensional problem (Kaila et al. 2006, Kiljunen 2006). Costs of cleanings and pre-commercial thinning arise when density and stump diameter of the removed trees increase (Kaila et al. 2006, Metsäalan työehtosopimus 2008). On the other hand, the later a cleaning or a pre-commercial thinning is done, the taller the crop trees, and the weaker the development of new sprouts, will be (Johansson 1987, Dehlin et al. 2004). Sprouting can also create costs that come out as a need for pre-cleaning, a cleaning operation before the first commercial thinning (Kärhä et al. 2006).

Although the biological effects of different soil preparation methods on the development of a planted spruce stand are rather well known, there

Table 1. The main characteristics of the treatment areas and the silvicultural management history of the site.

Nearest town & Treatment	Location (WGS84) N	E	Site type	Soil texture	Particles < 0.06 mm, %	Thickness of humus layer, cm	Area, ha
Suonenjoki Spot-mounded	62°33	27°15	*Myrtillus*	Medium-coarse Sandy till	2.6 ± 0.54	4.6 ± 1.9	0.42
Suonenjoki Disc-trenched	62°33	27°15	*Myrtillus*	Medium-coarse Sandy till	3.9 ± 1.62	5.1 ± 1.7	0.53

	Clearcutting	Soil preparation	Planting	Early cleaning	Measurements
Management history, year	1999	2000	2000	2005	2007

is a lack of information about their effects on the whole regeneration chain in economic terms. The aim of the study was to find out and to compare the effects of spot mounding and disc trenching on early development of planted Norway spruce stands, and on stand level management programs, silvicultural costs, and incomes from the first commercial thinning.

2 Materials and Methods

Initial data was measured from an experimental site located in Suonenjoki in central Finland (Table 1). The site represented a typical Norway spruce planting site (Luoranen and Kiljunen 2006). The experiment site was initially established in 2000 to study effects of planting time on success of spruce seedlings. The experimental design is described in more detail in Luoranen et al. (2006) and the soil preparation methods, spot mounding and disc trenching, are described in Luoranen et al. (2007). This time, the site was measured just before the growth period of 2007, in April and May.

Effects of spot mounding and disc trenching on early development of planted spruce seedlings and naturally regenerated seedlings were measured seven growth periods after soil preparations when the biological age of the planted seedlings was 8 years. The treatment areas were cleaned a growth period before the measurements. Two kinds of circular sample plots were established to collect the data. *Grid plots* (r = 100 cm) were located systematically in lines at intervals of four metres. The distance between the lines was four metres as well. Every second line started four metres and the rest two metres from the border of a treatment area. A *spruce plot* (r = 100 cm) was connected to each grid plot so that the centre of the spruce plot was the nearest planted spruce from the centre of the grid plot. Both plot types were measured 255 and 246 times from the spot-mounded and disc-trenched treatment areas, respectively. Thickness of the humus layer was determined according to the previous measurements (Luoranen et al. 2006).

In each grid and spruce plot, stumps of the hardwoods (Ø>0.49 cm) removed in early cleaning and the hardwoods that presumably disturbed growth of crop trees at the time of early cleaning (but were not removed for some reason) were counted and classified into three diameter classes ((1) 0.50–0.99 cm; (2) 1.00–1.99 cm; (3) >1.99 cm) according to the stump diameter at the height of 10 cm. In addition, coniferous trees closer than 0.30 metres to the nearest crop spruce were counted and classified, because they were expected to cause costs in further silvicultural treatments. From every second grid plot, stump diameter and height of the nearest hardwood (culled or living) from the centre of the plot was measured.

In the spruce plots, stumps and trees were allocated into three rings according to their distance ((1) 0–25 cm; (2) 26–50 cm; (3) 51–100 cm) from the centre spruce. In data analyses, all stumps and trees (Ø>0.49 cm) inside the ring 1 were treated as disturbing trees, whereas inside the ring 2 trees and stumps from diameter classes 2 and 3, and inside the ring 3 only trees and stumps from diameter class 3 were treated as disturbing trees. If there was a disturbing tree inside any ring, a need for early cleaning was considered at that plot. Height of the spruce in the centre of each spruce plot was measured.

Descriptive statistics were calculated for heights of crop spruces, and for density in total and in different diameter classes of removed trees. Differences between the soil preparation methods (treatments) in total density and density in different diameter classes of removed trees (measured from grid plots) were tested by analysis of covariance (ANCOVA). The corresponding comparison was done for the total numbers and numbers in different diameter classes of removed trees located inside the rings (1–3) in the spruce plots. In ANCOVAs, the thickness of humus layer was used as a covariate. Although the densities of the trees between the plots were not normally distributed, ANCOVA was considered an applicable method because of the large sample size. Difference in the heights of crop spruces between the treatments was tested by t-test.

Stand development was simulated forward from early cleaning up to the first commercial thinning. The input data on height of spruces, and on removed and disturbing trees was based on results from the field experiments, whereas the input data on crop trees was taken from earlier studies. Planting density was assumed as 1800 seedlings per hectare. Mortality of planted trees before early cleaning was assumed as 13.3% in the spot-mounded area and 26.0% in the disc-trenched area (Kuitunen 2001, Luoranen and Kiljunen 2006 and Saksa and Kankaanhuhta 2007).

Density of complementary coniferous crop trees was assumed as 300 and 330 ha^{-1} on the spot-mounded and disc-trenched areas, respectively (Saksa and Kankaanhuhta 2007). Density of crop trees was assumed to remain constant after early cleaning. Thus, the estimated densities of coniferous crop trees were 1860 ha^{-1} on the spot-mounded area and 1662 ha^{-1} on the disc-trenched area at the stage of the first commercial thinning. Original dominant height was mean height of the 100 tallest crop spruces per hectare based on the densities above.

The developments of dominant heights of crop spruce on spot-mounded and disc-trenched areas were based on the models presented by Kaila et al. (2006) and Valkonen (1997), respectively. A typing error of the model presented by Kaila et al. (2006) was corrected, and the model was used in the form as it is presented in Eq. 1.

$$IH_{dom(adj)} = IH_{dom(unadj)} \times ((e^{0.80304 - 0.01687 T_1}) - 1) \quad (1)$$

where $IH_{dom(adj)}$ is adjusted dominant height growth based on the unadjusted dominant height growth $IH_{dom(unadj)}$ that is estimated with the single tree model of Valkonen (1997), T_1 is stand age at beginning of growth period.

Ahead from the height of eight metres, dominant height of crop spruces were assumed to develop according to Valkonen (1997) in both spot-mounded and disc-trenched areas to get the soil preparation methods in equal position, and thus comparable to each other. Estimation of the mean height of crop spruce was based on the single tree model presented by Valkonen (1997) on both areas. Height development of birch sprouts was based on the models presented by Björkdahl (1983) and Jokinen (1973); the same models were used with both soil preparation methods.

Sprouting intensity of hardwoods was determined according to Johansson (1992a) and Hakkila (1985); the number of sprouts per primary stump was assumed to be 3.5. In later treatments, a cluster of secondary sprouts was handled as a stump. Share of sprouting stumps depended on size of the removed trees and canopy coverage of the growing trees. Development of spruce canopy coverage was modelled based on branch length that was estimated according to Kantola and Mäkelä (2004). The estimated branch was assumed to grow at the distance of 90% of the tree height from the top of the tree. Self-thinning of hardwood sprouts was modelled based on Johansson (1992a). Density of hardwoods at the time of t was modelled according to Eq. 2

$$C_t = C_0 \times S_p \times A \times S_n \times t^{-0.4128} \quad (2)$$

where C_0 is density of hardwoods at the time of cleaning, S_p is proportion of sprouting stumps (Eq. 3), A is proportion of area free from spruce canopy competition, S_n is number of sprouts per sprouting stump and t is time from the previous cleaning treatment (growth periods). Proportion of sprouting stumps was modelled separately (Eq. 3) based on the surveys of Hakkila (1985) and Johansson (1992a):

$$S_p = 0.025 \frac{h}{x} + 0.595 \quad (3)$$

where S_p is proportion of sprouting stumps, h is height of hardwood (cm) and x is a parameter (89.61) for height to stump diameter ratio based on the field measurements. In connection with early cleaning, stump diameter based on the measured values instead of the height to diameter ratio.

In simulations, timing of cleaning and pre-commercial thinning operations were based on two criteria: 1) the mean height of birch overgrew the dominant height of spruce, or 2) after the operation, at least one metre height difference between the mean birch sprout and the mean crop spruce remains up to the first commercial thinning. The criteria were based on ideas of avoiding not only growth deceleration of crop spruces but also pre-cleaning before the first commercial thinning. On the other hand, the operations were done as immediately as it was possible without breaking the criteria. Incomes from the first commercial thinning were estimated with MOTTI-simulator software (Metla Metinfo… 2009). The assumed prices of spruce and birch pulpwood were 23 €/m^3 and 16 €/m^3, respectively. The first commercial thinning was done when the dominant height of crop spruce reached 14 metres.

Finally, the regeneration chains based on spot mounding and disc trenching were compared to each other by carrying out an investment analysis based on growth and stand management simulations. Sensitivity of obtained main results were analysed by varying sprouting intensity, price of birch pulpwood, and density of the crop spruces.

In the investment analysis, costs of different silvicultural operations were determined based on statistics and earlier studies. Soil preparation costs were 270 € ha^{-1} and 152 € ha^{-1}, respectively on the disc-trenched and the spot-mounded area (Juntunen and Herrala-Ylinen 2007). Direct costs of planting were calculated according to Metsäalan työehtosopimus (2008) and the cost difference caused by soil preparation method was estimated according to Saksa et al. (2002). Direct planting cost per seedling was 6.98 cents and 7.63 cents, respectively on the spot-mounded and disc-trenched areas. Price per seedling was assumed to be 19 cents, delivered to the site. Direct costs of cleanings and pre-commercial thinnings depended on density and diameter of removed trees and were calculated according to Metsäalan työehtosopimus (2008). Direct costs of plantings and young stand management operations were increased by 39.9% to cover pension and insurance costs, and social security tax, and costs of paid day offs (StatFin – Online… 2007, Työnantajan eläkemaksut… 2007). In addition, supervision and other costs were assumed to increase direct costs of planting and young stand management operations by 15%. Finally, travel expenses of 44 cents per kilometre (Taxpayers Association of Finland 2008) were added to planting and young stand management costs according to work productivity. Distance to the working site was 14 km (Rantala 2003).

3 Results

3.1 Field Experiments

Density of the trees removed in early cleaning was 56% higher in the disc-trenched area (22 570 ha^{-1}) compared to that of the spot-mounded area (14 490 ha^{-1}). The share of coniferous trees of the removed trees was 7% in the disc-trenched area and 3% in the spot-mounded area. Soil preparation method also affected diameter of the removed trees significantly. There was 134% more removed trees with stump diameter greater than 0.99 cm in the disc-trenched area compared to the spot-mounded area (Table 2).

Spatial allocation of removed trees in relation to crop spruces differed between the treatments (Table 3). On the average, there was 25% more removed trees near (<100 cm) crop spruces in the disc-trenched area (23 507 ha^{-1}) compared to the spot-mounded area (18 758 ha^{-1}). The difference was the greatest (121%) very close by (< 26 cm) crop spruces and became smaller when examined farther (26–100 cm) the crop spruces. The difference was especially high in bigger diameter classes. Disc trenching doubled the trees classified as disturbing ones compared to spot mounding (Table 3).

On the average, there were 5.9 removed trees (from which 1.4 were disturbing ones) per crop spruce in the spot-mounded area (Fig. 1). The corresponding figures on the disc-trenched area

Table 2. Densities of the trees removed in early cleaning on the spot-mounded and disc-trenched areas. In the corrected values, thickness of humus layer is standardized in order to eliminate the initial differences between the treatment areas.

	Spot-mounded		Disc-trenched		Difference to spot-mounded	
	Removed trees ha^{-1}	Proportion %	Removed trees ha^{-1}	Proportion %	%	p-value
Measured (mean ± SD)						
Hardwoods	13 806 ± 11 682	97	21 622 ± 19 457	93	57	
Coniferous	474 ± 1 389	3	1 617 ± 3 291	7	241	
Total	14 280 ± 11 812	100	23 239 ± 19 022	100	63	**0.001**
Corrected (mean ± SEM)						
Diameter class 1 (0.50–0.99 cm)	8 550 ± 504	59	8 696 ± 513	39	2	0.837
Diameter class 2 (1.00–1.99 cm)	4 701 ± 517	32	9 645 ± 528	43	105	**0.001**
Diameter class 3 (≥ 2.00 cm)	1 241 ± 259	9	4 230 ± 265	19	241	**0.001**
Total	14 490 ± 979	100	22 570 ± 1 001	100	56	**0.001**

Table 3. Densities and spatial allocation of the removed trees nearby crop spruces in the spot-mounded and disc-trenched areas. Gray background indicates disturbing trees.

	Ring 1 0–25 cm	Ring 2 26–50 cm	Ring 3 51–100 cm	Total 0–100 cm
Removed trees				
Diameter class 1 (0.50–0.99 cm)				
Spot-mounded, trees ha^{-1}	12 631	12 953	9 795	10 565
Disc-trenched, trees ha^{-1}	25 108	11 323	7 771	9 517
Difference, %	99	–13	–21	–10
p-value	**0.001**	0.299	**0.012**	0.175
Diameter class 2 (1.00–1.99 cm)				
Spot-mounded, trees ha^{-1}	7 385	7 572	5 976	6 366
Disc-trenched, trees ha^{-1}	18 080	12 834	8 501	9 912
Difference, %	145	70	42	56
p-value	**0.001**	**0.001**	**0.001**	**0.001**
Diameter class 3 (≥ 2.00 cm)				
Spot-mounded, trees ha^{-1}	1 986	3 158	1 477	1 827
Disc-trenched, trees ha^{-1}	5 602	4 261	3 900	4 074
Difference, %	182	35	164	123
p-value	**0.010**	0.181	**0.001**	**0.001**
Total removed trees				
Spot-mounded, trees ha^{-1}	22 053	23 699	17 252	18 758
Disc-trenched, trees ha^{-1}	48 791	28 419	20 172	23 507
Difference, %	121	20	17	25
p-value	**0.001**	0.102	**0.022**	**0.001**
Total disturbing trees				
Spot-mounded, trees ha^{-1}	22 053	10 729	1 477	4 498
Disc-trenched, trees ha^{-1}	48 791	17 095	3 900	9 180
Difference, %	121	59	164	104
p-value	**0.001**	**0.001**	**0.001**	**0.001**

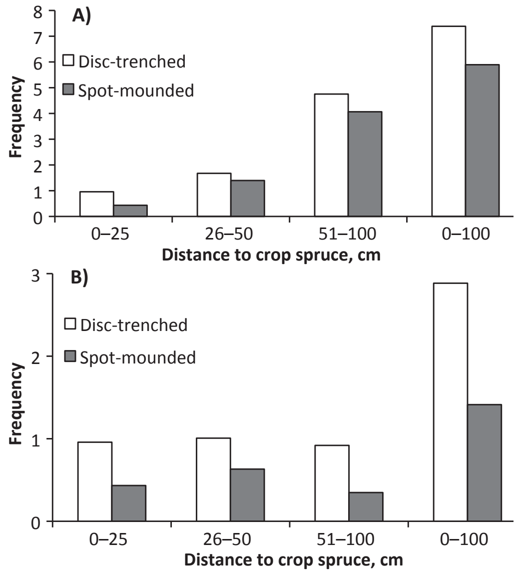

Fig. 1. Number of removed (A) and disturbing (B) trees per crop spruce in the spot-mounded and the disc-trenched area.

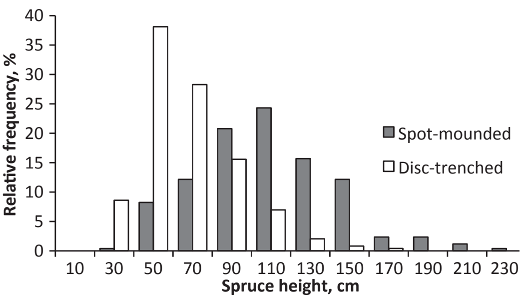

Fig. 2. Height distributions of crop spruces on the spot-mounded and the disc-trenched area.

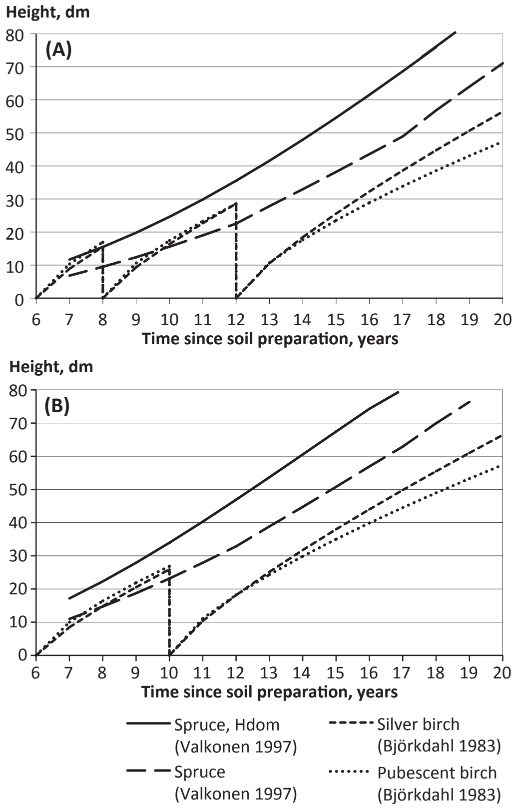

Fig. 3. Simulated growth of the stands on the disc-trenched (A) and the spot-mounded (B) area after early cleaning.

were 7.4 (2.9). At least one disturbing tree per crop spruce indicated a need for early cleaning. The shares of the crop trees needing early cleaning were 64% and 84% on the spot-mounded and disc-trenched areas, respectively.

Soil preparation method affected height development of crop spruce seedlings ($p < 0.001$). At the biological age of 8 years (7 growth periods after the soil preparation), the average crop spruce was 42 cm taller on the spot-mounded area (mean 110 cm; SD 36 cm) than on the disc-trenched area (mean 68 cm; SD 25 cm). For the purpose of further simulations, dominant heights of the stands were estimated based on the densities of crop spruces. At the time of early cleaning, the estimated densities of the crop spruces were 1860 ha^{-1} and 1662 ha^{-1} in the spot-mounded and disc-trenched areas, respectively. Based on these densities, the estimated dominant heights of the stands were 172 cm and 117 cm, respectively (Fig. 2).

3.2 Growth Simulations

In the spot-mounded area, the simulated average height of birch did not exceed the dominant height of crop spruce after early cleaning carried out six years after the soil preparation (Fig. 3). However, the height difference between birch sprouts and the mean crop spruce became less than 1 metre

Table 4. Costs of the regeneration chains and incomes from the first commercial thinnings in the spot-mounded and disc-trenched areas.

	Discount rate 0%	Discount rate 3%	Discount rate 5%	Time, years
SPOT-MOUNDED				
Costs, € ha^{-1}	1 278	1 175	1 122	
Soil preparation	270	270	270	0
Planting	549	549	549	0
Early cleaning	158	132	118	6
2. Cleaning / pre commercial thinning	301	224	185	10
3. Cleaning / pre commercial thinning	–	–	–	–
Incomes, € ha^{-1}				
First commercial thinning	1 304	605	367	26
Net present value € ha^{-1}	26	–571	–755	
DISC-TRENCHED				
Costs, € ha^{-1}	1 625	1 423	1 319	
Soil preparation	152	152	152	0
Planting	588	588	588	0
Early cleaning	230	193	172	6
2. Cleaning / pre commercial thinning	352	278	238	8
3. Cleaning / pre commercial thinning	303	213	169	12
Incomes, € ha^{-1}				
First commercial thinning	1198	524	306	28
Net present value € ha^{-1}	–427	–899	–1 013	

4 years after the early cleaning, and the stand was pre-commercially thinned 11 growth periods after the soil preparation (Criterion 2). In the disc-trenched area, the simulated average height of birch overtook the dominant height of the crop spruce two growth periods after the early cleaning and caused second cleaning (Criterion 1). The third treatment, pre-commercial thinning, of the disc-trenched area was 12 years after the soil preparation (Criterion 2).

Crop spruces reached the dominant height of 14 metres after 26 and 28 growth periods in the spot-mounded and disc-trenched areas, respectively. Thus, the incomes from the first commercial thinning were received two growth periods earlier from the spot-mounded area compared to the disc-trenched area. The exact stand characteristics, simulated by MOTTI, at the time of the first commercial thinning were: density 1859 trees ha^{-1}, stand dominant height 14.03 m, diameter at breast height 14.71 cm and quantity of pulpwood harvested 56.7 m^3 ha^{-1}. All of the wood harvested from the spot-mounded area was spruce, whereas 26.8% of the wood harvested from the disc-trenched area was birch. Complementary trees and mortality of the crop spruces were the reasons for the yield difference.

3.3 Investment Analysis

Although the cost of spot mounding was substantially higher than the cost of disc trenching, the total costs of the regeneration chain based on spot mounding were lower than those of the regeneration chain based on disc trenching. The difference was mainly caused by the disparity in the costs of young stand management operations; the total costs of cleanings and pre-commercial thinnings were over 90% higher with disc trenching compared to those with spot mounding. In addition to the smaller total costs, incomes from the first commercial thinning were higher with spot mounding than with disc trenching (Table 4).

Spot mounding investment had higher net present value (NPV) than disc trenching investment. Cash flow, including the first commercial thinning, was 26 € ha^{-1} positive in the case

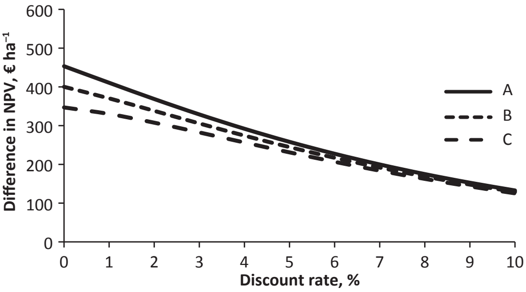

Fig. 4. Difference in net present value (NPV) between the investments in spot mounding and disc trenching at the time of the first commercial thinning. Density of crop spruces on the disc-trenched area at the age of the first commercial thinning in functions A, B and C is 1662 ha^{-1}, 1761 ha^{-1} and 1860 ha^{-1}, respectively.

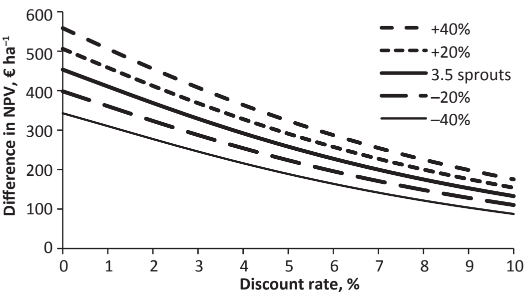

Fig. 5. Sensitivity analysis of the difference in NPV, between the investments in spot mounding and disc trenching, under variation of sprouting intensity (sprouts per stump).

of investment in spot mounding. In the case of disc trenching, corresponding cash flow was 427 € ha^{-1} negative. The difference in profitability between the investments in the different soil preparation methods became smaller when discount rate increased; when the discount rate of 5% was applied, for instance, the difference in net present value (NPV) was 258 € ha^{-1} (Fig. 4). Investment analysis did not include incomes from later cuttings nor value of the growing stock.

The difference in NPV decreased when the difference between the methods in stand crop spruce density were either reduced or removed. This effect was smaller with higher interest rates (Fig. 4). Effect of sprouting intensity on the difference in NPV between the investments in spot mounding and disc trenching was obvious; the higher the intensity, the bigger the difference (Fig. 5). Price of birch pulpwood had opposite effect; the higher the price the smaller the difference (Fig. 6). However, the investment in spot mounding produced substantially higher NPV than the investment in disc trenching in all calculations.

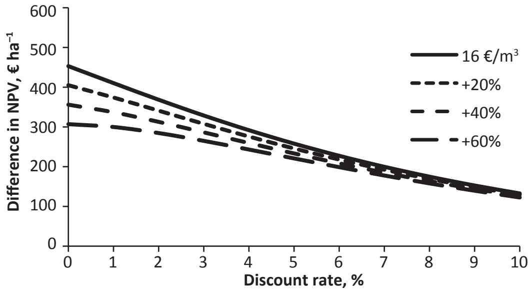

Fig. 6. Sensitivity analysis of the NPV difference, the investment in spot mounding compared to the investment in disc trenching, under variation of birch pulpwood price.

4 Discussion

This study addressed the effects of soil preparation methods on the development of young Norway spruce stands, and profitability of the investments in spot mounding and disc trenching over the whole regeneration chain. The experimental data was collected from the single site that was located in central Finland. Although the site represented a typical Finnish regeneration site for Norway spruce well, the lack of statistically valid blocks and geographical limitations must be taken into account when generalizing the results.

Total costs of the whole regeneration chain and especially the costs of silvicultural operations after soil preparation were lower when spot mounding was applied instead of disc trenching. Furthermore, investing in spot mounding was more profitable than investing in disc trenching. Reasons for better profitability of spot mounding were better survival and faster growth of the crop trees, and lower density and weaker growth of the competing hardwoods. Effects of faster growth and better survival of the crop trees to the incomes from the first commercial thinning based on simulations and preset criteria; optimization of maximum net present value or land value was not included in this study. However, it seems that the difference between the soil preparation methods would stay and even increase if the economic result of wood production was examined over the whole rotation period.

Biological impacts of soil preparation on the development of a stand, similar to the results of this study, have been widely described in earlier studies. According to Saksa et al. (1990), Agestam et al. (2003) and Lorenzetti et al. (2008), for instance, revealing mineral soil increases establishment of hardwoods. However, revealing mineral soil is not that important for growth of planted spruce seedlings. Actually, spruce seedlings grow better on a seedbed that contains humus (Hallsby 1994). Mounds contain plenty of humus, and according to Nordborg (2001), Örlander et al. (2002) and Saksa et al. (2005), planted trees seem to grow better on mounds than on bare mineral soil.

The difference in the density of hardwoods between the spot-mounded and disc-trenched areas was especially high nearby crop trees and in the biggest diameter class (Ø>1.99 cm). For the difference in the nearby trees, a possible explanation is better moisture conditions for seed germination after disc trenching than spot mounding (Latva-Karjanmaa et al. 2003). Especially good germination right after disc trenching might also explain the difference in the biggest diameter class. Disc trenching produces seedbed texture, which according to Lorenzetti et al. (2008), is especially good for early establishment and growth of birch (*Betula alleghaniensis*). However, emerging of birch stabilizes in few years to the level of unprepared soil (Lorenzetti et al. 2008).

Economic profitability of investments on silvicultural operations depends much on completion of interrelated operations. However, the interactions between the different silvicultural operations are difficult to take into account in economic analyses reaching over rotation periods. Thus, costs of pre-commercial thinnings, for instance, are often simplified and included in an analysis as independent variables that are not affected by other operations such as soil preparation (Vettenranta and Miina 1999, Hyytiäinen et al. 2005, Hyytiäinen et al. 2006). This study indicates that the interactions between a soil preparation method and later silvicultural operations are significant from the standpoint of economic profitability of the regeneration chain.

There were some factors causing uncertainty in accuracy of the simulation models. First, although competition for water, nutrient and light decrease growth of both coniferous crop trees and hardwood sprouts (Oker-Blom and Kellomäki 1982, Johansson 1987, Nilsson and Örlander 1995 and Jobidon 2000), it was not taken into account in height development models. Therefore, growth of the trees in understory position was possibly overestimated that again caused uncertainty and restricted the evaluation of alternative young stand management programs. However, it unlikely affects the differences between the methods, because the effects would be similar with both methods. Nevertheless, timing of operations could be closer to optimal, and thus achieving higher NPV might be possible.

Delaying the first pre-commercial thinning after early cleaning in terms to avoid the second pre-commercial thinning, for instance, could be a reasonable option in disc-trenched sites. However, delaying a young stand management operation increases an impending consumption of working time (Kaila et al. 2006) and decreases diameter growth of crop trees (Pothier 2002, Fleming et al. 2005, Pitt and Lanteigne 2008) and is in generally reasonable only if it enables to avoid some of later management operations. Anyhow, similar procedure could also be performed in spot-mounded site by delaying early cleaning.

Secondly, model predicting density development of coppice could be improved; it is rather well known that amount of sprouts after early cleaning depends on stump diameter, but variation in proportion of sprouting stumps and sprouts per stump is high (Hakkila 1985, Johansson 1987, 1992a, 1992c and Rossi and Rikala 1992). In addition, growing conditions and density of the stand affects to self-thinning and growth of the sprouts (Hakkila 1985, Johansson 1987, 1992a and 1992b and Dehlin et al. 2004). In this study, sprout density simulations were based on average values that were calculated on the basis of several independent studies. Thus, accuracy of the simulations could be improved by constructing more exact models for different conditions. The sprout development models created in this study (Eqs. 2 and 3) have been specified to the conditions of the study site, and therefore, should not be widely generalized.

In conclusion, there are strong economic interrelations between soil preparation and later young stand management operations in boreal Norway spruce stands. Depending on discount rate and a soil preparation method used, costs of the other operations in a regeneration chain might be 4–10 times higher than the soil preparation cost. Therefore, it is important to place extra attention to the costs of the whole regeneration chain when selecting a soil preparation method.

Acknowledgements

The research was partly funded by the Foundation for Research of Natural Resources in Finland. The authors thank the personnel of the Finnish Forest Research Institute at the Suonenjoki Research Unit for their valuable help and comments.

References

Agestam, E., Ekö, P.-M., Nilsson, U. & Welander, N.T. 2003. The effects of shelterwood density and site preparation on natural regeneration of Fagus sylvatica in southern Sweden. Forest Ecology and Management 176: 61–73.

Andersson, B. 1993. Lövträdens inverkan på små tallars (Pinus sylvestris) överlevnad, höjd och diameter. Abstarct: The influence of broad-leaved trees on survival, height and diameter of small Scots pine (Pinus sylvestris L.) trees. Sveriges lantbruksuniversitet, institution för skogsskötsel. Rapporter 36. 34 p. (In Swedish.)

Björkdahl, G. 1983. Höjdutveckling hos stubbskott av vårt- och glasbjörk samt tall och gran efter mekanisk röjning. [Height growth of Silver birch and Pubescent birch stump sprouts, and of Scots pine and Norway spruce after cleaning]. Sveriges Landsbruksuniversitet, Institution för skogsproduktion. Stencil 18. 54 p. (In Swedish.)

Dehlin, H., Nilsson, M-C., Wardle, D.A. & Shevtsova, A. 2004. Effects of shading and humus fertility on growth, competition, and ectomycorrhizal colonization of boreal forest tree seedlings. Canadian Journal of Forest Research. 34: 2573–2586.

Fleming, R.L., Mossa, D.S. & Marek, G.T. 2005. Upland black spruce development 17 years after cleaning and precommercial thinning. The forestry chronicle 81(1): 31–41.

Folkesson, B. & Bärring, U. 1982. Exempel på en riklig björkförekomst inverkan på utvecklingen av unga tall- och granbestånd i norra Sverige. Abstract: Some examples of the influence of an abundant occurrence of birch on the development of young Norway spruce and Scots pine stands in north Sweden. Sveriges lantbruksuniversitet, avdelning för skoglig herbologi. Rapport 1. 64 p. (In Swedish.)

Gobakken, T. & Næsset, E. 2002. Spruce diameter growth in young mixed stands of Norway spruce (Picea abies (L.) Karst.) and birch (Betula pendula Roth B. pubescens Ehrh.). Forest Ecology and Management 171: 297–308.

Hakkila, P. 1985. Metsäenergian mahdollisuudet Suomessa. PERA-projektin väliraportti. Abstract: The potential of forest energy in Finland. Interim report of PERA project. Folia Forestalia 624 :11–86. (In Finnish.)

Hallsby, G. 1994. The influence of different forest organic matter on the growth of one-year old planted Norway spruce seedlings in a greenhouse experiment. New Forests 8: 43–60.

— & Örlander, G. 2004. A comparison of mounding and inverting to establish Norway spruce on podzolic soils in Sweden. Forestry 77: 107–117.

Hansson, P. & Karlman, M. 1997. Survival, height and health status of 20-year-old pinus sylvestris and pinus contorta after different scarification treatments in a harsh boreal climate. Scandinavian Journal of Forest Research 12: 340–350.

Huuskonen, S. 2008. The development of young Scots pine stands – precommercial and first commercial thinning. Dissertationes Forestales 62. 61 p.

— & Hynynen, J. 2006. Timing and intensity of precommercial thinning and their effects on the first commercial thinning in Scots pine stands. Silva Fennica 40(4): 645–662.

Hyytiäinen, K., Tahvonen, O. & Valsta, L. 2005. Optimum juvenile density, harvesting and stand structure in even-aged Scots pine stands. Forest Science 51(2): 120–133.

— , Ilomäki, S., Mäkelä, M. & Kinnunen, K. 2006. Economic analysis of stand establishment for Scots pine. Canadian Journal of Forest Research 36: 1179–1189.

Jobidon, R. 2000. Density-dependent effects of northern hardwood competition on selected environmental resources and young White spruce (Picea glauca) plantation growth, mineral nutrition, and stand structural development – a 5-year study. Forest Ecology and Management 130: 77–97.

Johansson, T. 1987. Development of stump suckers by Betula pubescens at different light intensities. Swedish University of Agricultural Sciences, Department of Forest Yield Research. Scandinavian Journal of Forest Research 2: 77–83.

— 1992a. Sprouting of 2- to 5-year old birches (Betula pubescens Ehrh. and Betula pendula Roth) in stump height and felling time. Forest Ecology and Management 53: 263–281.

— 1992b. Sprouting of 10- to 50-year-old Betula pubescens in relation to felling time. Forest Ecology and Management 53: 283–296.

— 1992c. Stump heights and sprouting of European aspen, pubescent and silver birches, and damage to Norway spruce and Scots pine following mechanical and brush saw cleaning. Studia Forestalia Suecica 186. 15 p.

Jokinen, H. 1973. Luontaisesti syntyneiden koivuntaimien kehityksestä männyn viljelytaimistossa. [Growth of naturally established birch in artificially regenerated Scot pine stands] Metsänhoitotieteen laudaturtyö metsätutkintoa varten. 42 p. (In Finnish.)

Juntunen, M.-L. & Herrala-Ylinen, H. 2007. Metsänhoito- ja perusparannustyöt 2006. [Silvicultural and forest improvement work in 2006]. SVT Maa-, metsä- ja kalatalous 2007 (Metsätilastotiedote 872). 36 p. (In Finnish.)

Kaila, S., Kiljunen, N., Miettinen, A. & Valkonen, S. 2006. Effect of precommercial thinning on the consumption of working time in Picea abies stands in Finland. Scandinavian Journal of Forest Research 21: 496–504.

Kantola, A. & Mäkelä, A. 2004. Crown development in Norway spruce [Picea abies (L.) Karst.]. Trees 18: 408–421.

Kärhä, K., Keskinen, S., Kallio, T., Liikanen, R. & Lindroos, J. 2006. Ennakkoraivaus osana ensiharvennuspuun korjuuta. [Pre-cleaning – rationality of removing the trees impeding work productivity in the first commercial thinning beforehand]. Metsätehon raportti 187. 77 p. (In Finnish.)

Kiljunen, N. 2006. Creating value trough advanced silvicultural services. Dissertationes Forestales 17. 41 p.

Kuitunen, T. 2001. Laikkumätästettyjen kuusen istutustaimikoiden taimimäärän muutos 3–6 vuoden iässä UPM-Kymmenen Oyj:n metsissä. [Density development of spot-mounded Norway spruce plantations from the age of 3 to 6 years in UPM-Kymmene company's forests]. Pro gradu -tutkielma. Helsingin yliopisto. 48 p. (In Finnish.)

Laaksonen, M. 2008. Perkaamattomien kuusen istutustaimikoiden uudistamistulos 3 ja 7 vuoden iässä sekä lehtipuuston vaikutus kuusten pituuskasvuun ja mekaanisten vaurioiden syntyyn. [Success of regeneration in 3- and 7-year-old Norway spruce plantations and effect of hardwoods to height growth of spruce and mechanical damages in spruce]. Pro gradu -työ. 71 p. + appendices. (In Finnish.)

Latva-Karjanmaa, T., Suvanto, L., Leinonen, K. & Rita, H. 2003. Emergence and survival of Populus tremula seedlings under varying moisture conditions. Canadian Journal of Forest Research 33: 2081–2088.

Lorenzetti, F., Delagrange, S., Bouffard, D. & Nolet, P. 2008. Establishment, survivorship, and growth of yellow birch seedlings after site preparation treatments in large gaps. Forest Ecology and Management 254: 350–361.

Luoranen, J. & Kiljunen, N. 2006. Kuusen paakkutaimien viljelyopas. [Guide for forest regeneration with container-grown Norway spruce seedlings]. Metsäntutkimuslaitos, Suonenjoen toimintayksikkö. 108 p. (In Finnish.)

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

— , Saksa, T., Finér, L. & Tamminen, P. 2007. Metsämaan muokkausopas. [Guide for silvicultural soil preparation]. Metsäntutkimuslaitos, Suonenjoen toimintayksikkö. 75 p. (In Finnish.)

Mäkitalo, K. 1999. Effect of site preparation and reforestation method on survival and height growth of Scots pine. Scandinavian Journal of Forest Research 14: 512–525.

Metsäalan työehtosopimus 1.5.2008–31.5.2010. 2008.

[Collective labor agreement on forestry 2008]. Maaseudun Työnantajaliitto, Metsähallitus, Metsäteollisuus ry, Yksityismetsätalouden Työnantajat, Puu- ja erityisalojen liitto. 87 p. (In Finnish.)
Nilsson, U. & Gemmel, P. 1993. Changes in growth and allocation of growth in young Pinus sylvestris and Picea abies due to the competition. Scandinavian Journal of Forest Research 8: 213–222.
— & Örlander, G. 1995. Effects of regeneration methods on drought damage to newly planted Norway spruce seedlings. Canadian Journal of Forest Research 25(5): 790–802.
Nordborg, F. 2001. Effects of site preparation on soil properties and on growth, damage and nitrogen uptake in planted seedlings. Doctor's dissertation. 25 p.
— , Nilsson, U., Gemmel, P. & Örlander, G. 2006. Carbon and nitrogen stocks in soil, trees and field vegetation in conifer plantations 10 years after deep soil cultivation and patch scarification. Scandinavian Journal of Forest Research 21(5): 356–363.
Oker-Blom, P. & Kellomäki, S. 1982. Metsikön tiheyden vaikutus puun latvuksen sisäiseen valoilmastoon ja oksien kuolemiseen. Teoreettinen tutkimus. Abstract: Effect of stand density on the within-crown light regime and dying-off of branches. Theoretical study. Folia Forerstalia 509. 14 p. (In Finnish.)
Örlander, G., Gemmel, P. & Hunt, J. 1990. Site preparation: Swedish overview. FRDA Report 105. 61 p.
— , Hallsby, G., Gemmel, P. & Wilhelmsson, C. 1998. Inverting improves establishment of Pinus contorta and Picea abies – 10-year results from a site preparation trial in Northern Sweden. Scandinavian Journal of Forest Research 13(1): 160–168.
— , Nordborg, F. & Gemmel, P. 2002. Effects of complete deep-soil cultivation on initial forest stand development. Studia Forestalia Suecica 213. 20 p.
Pettersson, N. 1992. The effect on stand development of different spacing after planting and precommercial thinning in Norway spruce (Picea abies (L.) Karst.) and Scots pine (Pinus sylvestris L.) stands. Swedish University of Agricultural Sciences, Department of Forest Yield Research. Report 34. 17 p.
Pitt, D. & Lanteigne, L. 2008 Long-term outcome of precommercial thinning in northwestern New Brunswick growth and yield of balsam fir and red spruce. Canadian Journal of Forest Research 38: 592–610.
Pothier, D. 2002. Twenty-year results of precommercial thinning in a balsam fir stand. Forest Ecology and Management 168: 177–186.
Rantala, J. 2003. Organisaation toimintamallin vaikutus metsänistutustyön kustannustehokkuuteen. [Effect of an organization's operational model on cost-efficiency of forest planting]. Metsätieteen aikakauskirja 2/2003: 97–107. (In Finnish.)
Rossi, P. & Rikala, R. 1992. Lehtipuiden kantojen vesominen lannoituksen jälkeen. Abstract: Stump sprouting in an Alnus-Betula-Salix stand following fertilization. Metsäntutkimuslaitoksen tiedonantoja 425. 22 p. (In Finnish.)
Saksa, T. & Kankaanhuhta, V. 2007. Metsänuudistamisen laatu ja keskeisimmät kehityskohteet Etelä-Suomessa. Metsänuudistamisen laadun hallinta -hankkeen loppuraportti. [Success of forest regeneration in Southern Finland and the most essential matters to develop. Quality control in forest regeneration – final report of the project]. Metsäntutkimuslaitos, Suonenjoen yksikkö. 90 p. (In Finnish.)
— , Nerg, J. & Tuovinen, J. 1990. Havupuutaimikoiden tila 3–8 vuoden kuluttua istutuksesta tuoreilla kankailla Pohjois-Savossa [State of 3–8 years old Scots pine and Norway spruce plantations]. Folia Forestalia 753. 30 p. (In Finnish.)
— , Tervo, L. & Kautto, K. 2002. Hakkuutähde ja metsänuudistaminen. Abstract: Forest regeneration and slash. Metsäntutkimuslaitoksen tiedonantoja 851. 41 p. (In Finnish.)
— , Heiskanen, J., Miina, J., Tuomola, J. & Kolström, T. 2005. Multilevel modelling of height growth in young Norway spruce plantations in southern Finland. Silva Fennica 39(1): 143–153
Sutton, R.F. 1993. Mounding site preparation: a review of European and North-American experience. New Forests 7: 151–192.
Valkonen, S. 1997. Viljelykuusikoiden alkukehityksen malli. [Model for early development of Norway spruce plantations] Metsätieteen aikakauskirja – Folia Forestalia 3/1997: 321–347. (In Finnish.)
Vettenranta, J. & Miina, J. 1999. Optimizing thinnings and rotation of Scots pine and Norway spruce mixtures. Silva Fennica 33(1): 73–84.
Walfridsson, E. 1976. Lövets konkurrens i barrkulturen. [Competition from broadleaved trees in young conifer plantations]. Skogen 63: 631–633. (In Swedish.)

Internet references

Metla Metinfo – forest information services. 2009. [Internet service – software]. http://www.metla.fi/metinfo/motti/index-en.htm. [Cited 5 Mar 2009].

Taxpayer's Association of Finland. 2008. [Internet site]. Kilometrikorvaukset 2008. [Kilometer allowance in 2008]. Available at: http://www.veronmaksajat.fi/fi-FI/omatveroasiat/kilometrikorvaukset. [Cited 1 Oct 2008].

Työnantajan eläke- ja vakuutusmaksut. 2007. [Internet site]. [Employer's social security and pension contributions] Available at: http://www.vero.fi/default.asp?path=5,363&article=170&domain=VERO_MAIN&language=fin&index=. [Cited 15 Aug 2007].

StatFin – Online service. 2007. [Internet service – statistics]. Available at: http://statfin.stat.fi [Cited 15 Aug 2007].

Total of 60 references