Examensarbeten **2009:14**
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Sveriges Lantbruksuniversitet Skogligt magisterprogram/Jägmästarprogrammet
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I denna rapport redovisas ett examensarbete utfört vid Institutionen för skogens ekologi och skötsel, Skogsvetenskapliga fakulteten, SLU. Arbetet har handletts och granskats av handledaren, och godkänts av examinator. För rapportens slutliga innehåll är dock författaren ensam ansvarig.

This report presents an MSc/BSc thesis at the Department of Forest Ecology and Management, Faculty of Forest Sciences, SLU. The work has been supervised and reviewed by the supervisor, and been approved by the examinator. However, the author is the sole responsible for the content.

Abstract
In order to evaluate different afforestation methods for exposed heath lands a field experiment was established in Mosfell on southern Iceland in 1989. The trial comprised six different site preparation methods (control, herbicide application, tree shelters, patch scarification, TTS trenching and mounding). In total 960 container seedlings (1+0) and 960 Nisula roll transplants (2+1) of lodgepole pine were planted. Various planting positions (furrow, hinge, no site preparation (control) and on top of mounds) were tested within the site preparation treatments. This study involves renewed measurements and analyses of the trial.
After 19 years the overall survival was 51,7 %. Patch scarification and herbicide application resulted in the highest survival (58 %) while tree shelters obtained the poorest survival (36%). Nisula rolls showed a significantly higher survival and stem form quality compared to container seedlings. Choice of planting stock had no effect on average height. Trees on control and mounded areas displayed the lowest (132 cm) respectively the highest (252 cm) mean height. Furrow planting generally affected survival and mean height in a negative way while hinge planting improved survival and mean height.
In conclusion, scarification had a low impact on survival but enhanced height growth. Herbicide treatment increased mean height and mean diameter compared to control and is therefore an alternative to scarification. The use of tree shelters is not a sufficient site preparation method. The results of this study indicate that hinge planting offers an environment where seedlings are protected from wind, frost heaving and erosion while they at the same time are offered an adequate water and nutrient supply. Choice of planting spot was found to be crucial after mounding. A low planting position should be avoided regardless of site preparation method.
Key words: *afforestation; lodgepole pine; scarification*

Sammanfattning
I syfte att utvärdera olika beskogningsmetoder för exponerade hedar upprättades 1989 ett fältförsök i Mosfell på södra Island. I försöket ingick sex olika behandlingar (kontroll, herbicidbehandling, trädskydd, fläckmarkberedning, TTS-harvning och högläggning). 960 täckrots- (1+0) och 960 s.k. Nisula roll (2+1) plantor av contortatall planterades. Fyra olika planteringspunkter (fåra, gångjärn, ingen behandling (kontroll) och topp av hög) testades inom de olika behandlingarna. Den här studien omfattar förnyade mätningar och analyser av försöket.
Efter 19 år var överlevnaden för försöket som helhet 51,7 %. Fläckmarkberedning och herbicidbehandling resulterade i den högsta överlevnaden (58 %) och trädskydd i den lägsta (36 %). Nisula rolls uppvisade en signifikant högre överlevnad och kvalitet jämfört med täckrot. Planttyp hade däremot ingen inverkan på medelhöjd. Träden på kontrollytorna och högläggningsytorna hade lägst (132 cm) respektive högst (252 cm) medelhöjd. Vad gällde planteringspunkterna hade plantering i fåra generellt en negativ inverkan medan gångjärnsplantering hade en positiv inverkan på överlevnad och medelhöjd.
Sammanfattningsvis hade markberedning en liten effekt på överlevnad men påverkade medelhöjd positivt. Herbicidbehandling gav ökad medelhöjd och medeldiameter jämfört med kontroll och är därför ett alternativ till markberedning. Att använda trädskydd är inte en tillräcklig behandling. Resultaten från den här studien indikerar att gångjärnsplantering erbjuder en miljö där plantor är skyddade från vind, uppfrysning och erosion samtidigt som de får tillräckligt med vatten och näring. Val av planteringspunkt var särskilt viktigt efter högläggning. En låg planteringspunkt skall undvikas oavsett av markberedningsmetod.
Nyckelord: *beskogning; contortatall; markberedning*

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1. Introduction

Pollen analysis of vegetation cover on Iceland show that dwarf shrub and shrub heaths first appeared around 9200 BP. Before that time continuous vegetation cover could not develop, mainly due to deglaciation. Later the heaths were followed by juniper (which is the only native conifer tree species) and birch (*Betula pubescens*) groves (8500- 8100 BP). About 7200 years ago birch woodland had established on more favorable places and the birch cover reached its peak 7200-6000 BP (Hallsdóttir 1995). Birch is the only species considered to form natural woodland areas in Iceland (Blöndal 1987, Bragason 1995, Hallsdóttir 1995). 6000 years ago the climate became more humid, the birch woodlands declined, and a more open landscape with peat land and heaths developed. Rowan (*Sorbus aucuparia*) pollen first appeared in sediments around 5500 years BP which might indicate that the species immigrated around that time. Around 2800 years BP an eruption of mount Hekla caused the second large expansion of birch woodlands. The tephra layer from the eruption dried large areas of peat land and made them favorable for birch once more (Hallsdóttir 1995).

When Iceland was settled 1100 years ago about 60 % of the land area was covered with vegetation. The main species, birch, then covered 30 % of the land area (Blöndal 1987) (Figure 1). When the settlers arrived they cleared large areas for grazing, hayfields, lumber, charcoal and fuel (Arnalds 1987, Kristinsson 1995). After consuming all wood in densely populated areas, the settlers had to go to more remote non settled areas in the country for wood supplies. Non-restricted grazing (mainly by sheep) stopped the natural regeneration which probably would have taken place otherwise (Kristinsson 1995). Deforestation and overgrazing has contributed to the loss of 95 % of the pre-settlement forest cover (Figure 1). Today Iceland has the smallest forest area in Europe and an expansion, in order to increase social and economic values, is of great interest (Pétursson & Sigurgeirsson 2004).

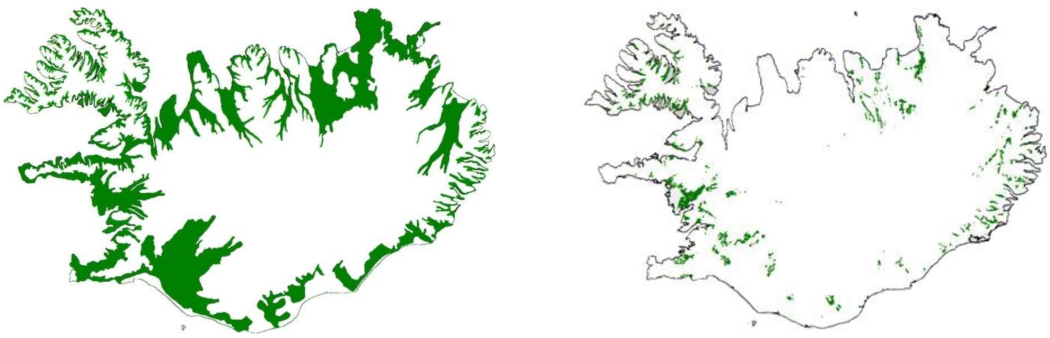

Figure 1. Estimated birch cover at the time of settlement (to the left) and nowadays (to the right) in Iceland (Arnalds 2005).

1.1 Climate and soils

Iceland is an island of 100 000 km^2 situated across the Mid-Atlantic Ridge. In average volcanic eruptions occur once every five years (Arnalds 2004). The climate in Iceland is strongly influenced by the Gulf Stream. This results in mild, windy winters with an average January temperature close to 0ºC. Summers are cool and moist, average temperature in July is 10-11ºC. The growing season (days with average temperature above 7.5ºC) is between 70 and 120 days long (Óskarsson & Sigurgeirsson 2001). The climate could support a much more diverse vegetation composition but due to the isolated location of the country few species have managed to immigrate (Blöndal 1987). The flora of today is mainly a result of the geographic isolation combined with a high pressure from grazing animals and volcanic activity. This has caused a vegetation degradation and therefore also problems with erosion (Arnalds 1987). The total area of woodlands is 150 000 hectares (FAO 2005). About 80 % of the forest area is classified as shrub (average height less than 2 meters). The upper limits for trees are about 300-600 meters above sea level. Birch can in the most continental sites reach 600 meters. In more oceanic regions in northern and north-eastern parts of Iceland, where strong winds are prevailing, the tree line is about 300 meters a.s.l. (Bragason 1995). In coastal regions where heavy storms are common, birch forms only low shrubs (1-2 meters). At inland sites birch can reach a height of 10-13 meters (Bragason 1995, Kristinsson 1995).

Volcanic activity has strongly affected the structure and composition of the Icelandic soils. The volcanic belt running from the southwest to the northeastern parts of the country is characterized by soils containing thick layers of tephra (Arnalds 2004). The widespread and alkaline tephra explains the moderate soil acidity (pH 5.4-6.5 is normal (Óskarsson & Sigurgeirsson 2001)) and the high mineral content of Icelandic top soils (Arnalds 1987). Outside the volcanic belt poorly drained peat lands dominate (Arnalds 2004). Due to wind carried volcanic material the peat lands have relatively high mineral contents too (Bragason 1995).

86 % of the soils are classified as Andosols which means that Iceland has the largest area of Andosols in Europe. Andosols are usually dark with a poorly developed structure. They often contain distinct horizon boundaries due to tephra layers and eolian depositions. Cryoturbation (the mixing of materials from different soil horizons due to freezing and thawing) is a typical phenomenom in Andosols (Arnalds 2004). The high water retention and hydraulic conductivity combined with Icelandic climate promotes intense cryoturbation.

The fine sandy structure of the soils combined with the wind exposition makes most of the soils susceptible to erosion (Óskarsson & Sigurgeirsson 2001). Erosion has removed much of the volcanic soils. This has contributed to the fact that desert areas with unstable surfaces cover 40 % of the country (Arnalds 2004).

The content of allophane clay in andosols varies between a few up to 30 % (Arnalds 2004). Allophane clay is formed through the weathering of volcanic ash into fine textured soil with high iron (Fe) and aluminum (Al) content. Fe/Al humus complexes bind phosphorous (P) and nitrogen (N) in insoluble compounds or stabile organic forms. Plants mainly absorb soluble and weakly bound forms of P and N from the soil solution. Since these forms occur in very low concentrations in andic soils, P and N could easily become growth limiting factors (Óskarsson & Sigurgeirsson 2001, Ritter 2007).

1.2 Afforestation in Iceland

Since the first large scale Icelandic forest plantation, in the late19th century, and the first forestry legislation (1907) afforestation efforts have intensified (Dagfinnsson 1995, Pétursson 2005, Sigurdsson et al 2005). Under the surveillance of the Icelandic Forestry Association (founded 1930) the number of tree seedlings planted annually has reached 6 million (Sigurdsson et al 2005, Holst & Jóhannesdóttir 2009). A large public donation, agricultural reforms and the public concern for environmental and recreational values of forests have facilitated the process (Dagfinnsson 1995, Pétursson 2005, Sigurdsson et al 2005). Practical afforestation experiences and research results have strengthened the belief in Icelandic forestry (Pétursson 2005). The goal decided by the Icelandic government is to reach a 5 % forest cover in the Icelandic lowlands (below 400 m a.s.l.) within 40 years; this would demand a yearly planting of ca 17 millions seedlings (Sigurdsson et al 2005).

1.2.1 Exotic tree species

As the native birch is slow growing and seldom produces a straight stem it is not suitable for timber production. Therefore research and afforestation efforts have focused on exotic tree species (Bragason 1995). A great deal of research has concentrated on finding suitable species and provenances. Almost 100 exotic species and about 700 provenances have been tested (Arnalds 1987). The most important species is Siberian larch (*Larix sibirica*), Lodgepole pine (*Pinus contorta*) and Sitka spruce (*Picea sitchensis*) (Arnalds 1987, Óskarsson & Ottósson 1990, Pétursson & Sigurgeirsson 2004, Sigurdsson et al 2005) (Figure 2).

The spruces and pines used today mostly originate from Alaska, Rocky Mountains and Canada. On fertile grounds in the southern and western part of the country Sitka spruce has proved to be the most high-yielding conifer species. An increased proportion of seeds are collected from Icelandic stands, both from first and second generations of imported Sitka spruce. The local seed have shown a good frost tolerance. Attacks by the green spruce aphid (*Elatobium abietinum)* have caused severe damages in several Sitka spruce plantations. Scots pine (*Pinus sylvestris*) was 1947-1961 one of the major exotics in Iceland. In the beginning it showed a promising growth rate. During the 1950s a large attack by the pine woolly aphid (*Pineus pini*) caused high mortality. The great mortality lasted for two decades leaving just a few living trees. One reason for the massive mortality is probably that the genetic base was to narrow, 94 % of the material originated from two locations in north Norway (Bragason 1995).

More than 100 provenances of eight different larch species have been tested. The major emphasis has been on Russian (*Larix sukaczewii)* and Siberian larch. The seeds have mostly been imported from NW Russia (Bragason 1995). Also larch plantations have encountered problems with insect and fungal attacks. Root predation in newly planted areas is caused by the weevil *Otiorhyncus nodosus* (Halldórsson et al 2000). Dieback caused by the fungi *Phacidium coniferarum* and the larch canker disease (*Lachnellulla wilkommii*) has damaged trees of poorly adapted provenances (Bragason 1995). Óskarsson and Ottósson (1990) suggested that Siberian larch is not very well suited for growing on the southern Icelandic lowlands. The species is adapted to a continental climate and therefore more susceptible to frost during the spring in a mild maritime winter environment.

Lodgepole pine has become very important for the afforestation and reforestation work in Iceland (Arnalds 1987, Óskarsson & Ottósson 1990, Pétursson & Sigurgeirsson 2004, Sigurdsson et al 2005). The different varieties of the species are well adapted to various conditions and can therefore grow on most sites (Elfving et al 2001). The first plantations in Iceland were carried out in 1940 with seed from British Columbia (600 m a.s.l.). In 1954 a large amount of seed was imported from Skagway in Alaska (close to the northern limit of coastal lodgepole pine). Since then the Skagway provenance has dominated the import of lodgepole pine seeds. Until 1992 a total of 170 kg of lodgepole pine seeds had been imported, of which 80 kg was from Skagway. This provenance has been used in plantations all over the country but the all-round suitability has been questioned and experiments with other provenances continue (Bragason 1995).

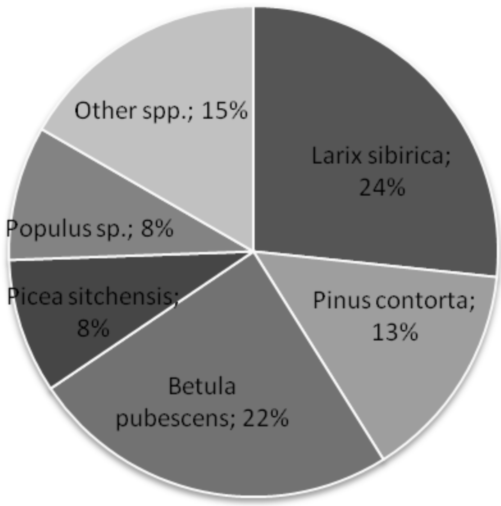

Figure 2. Main species planted in Iceland (Holst & Jóhannesdóttir 2009).

1.2.2 Obstacles for plantation establishment

So far plantation results (survival and growth) have been variable and several limiting factors have been identified. In general low average summer temperature is the single most growth limiting factor for trees (Pétursson & Sigurgeirsson 2004).

The high P-retention combined with low availability of N in the soils is believed to be another major limiting factor of plantation establishment in Iceland (Óskarsson & Sigurgeirsson 2001, Ritter 2007). Low atmospheric deposition (less than 1 kg/ha and year) of nitrogen and slow decomposition and mineralization rates (due to the cold climate) are growth limiting factors. Nutrient deficiency (especially P and N) has also been shown to reduce seedling survival (Óskarsson & Sigurgeirsson 2001).

Many sites chosen for plantation are situated at exposed windy locations and often display poor establishment due to erosion, mechanical tree damages and desiccation. Also better, more fertile, sites in sheltered locations have experienced slow growth and mortality, probably due to competing vegetation (Óskarsson & Ottósson 1990).

Volcanic soils, high annual precipitation, frequent air temperature fluctuations around 0º C and a limited snow cover contributes to a great risk of frost heaving (Pétursson &

Sigurgeirsson 2004, Óskarsson et al 2006). Frost heaving refers to a formation of ice crystals in the deeper soil layers or at the surface. The crystals grow from below and push upwards generating a vertical uplift of tree seedlings. This causes root breakages and desiccation that might result in mortality, deteriorated growth and instability (Goulet 1995, Sahlén & Goulet 2002).

1.3 Potential benefits of site preparation, stock selection and planting methods

Factors as a harsh climate, frost heaving, a poor nutrient supply, competition and erosion interacts and result in extremely difficult conditions for tree seedlings in Iceland. To reach the goal of 5 % forest cover within 40 years it is crucial to find afforestation methods that improve future growth and survival in Icelandic plantations. Improved afforestation results would, in the long-run, result in: higher timber production and lumber quality, a greater recreational area and improved shelter against wind and erosion.

On boreal sites scarification is generally considered to promote seedling survival and growth (Örlander et al 1990, Örlander et al 1998). The purpose of exposing mineral soil in mounds and ridges is to create a favorable microclimate for tree seedlings by increased water and nutrient supply (Örlander & Gemmel 1989), reduced frost (Langvall et al 2001) and pine weevil (*Hylobius abietis*) damages (Örlander & Nilsson 1999). Scarification is also known to reduce competition from surrounding vegetation (Örlander & Gemmel 1989).
Icelandic soils generally are unstable (due to the volcanic origin) and scarification might increase their susceptibility to erosion (Óskarsson & Ottósson 1990) and frost heaving (Bergsten et al 2001). Furthermore, an intensive preparation can increase the risk of leaching nutrients to soil- and groundwater and might affect the long-term site productivity in a negative way (Johansson 1987). In addition, the pine weevil is no major threat in Icelandic plantations (Thorbergur H. Jonsson pers. comm.). All together this suggests that the known positive effects of scarification could diminish under Icelandic conditions. As there have been establishment failures on many scarified Icelandic sites (Holst & Jóhannesdóttir 2009) the interest in alternative site preparation methods, such as herbicides and tree shelters is growing. Herbicide application has previously been shown to improve survival in Icelandic tree plantations (Óskarsson & Ottósson 1990). Tree shelters protect from wind (Davies 1985, Tuley 1985, Potter 1988, West et al 1999) and might therefore offer a favorable microclimate for seedlings during Icelandic conditions.
Choosing an elevated planting position can diminish frost heaving (Sahlén & Goulet 2002) and improve water and nutrient supply (Adelsköld & Örlander 1989). However, during Icelandic conditions such planting spots would expose seedlings to wind and erosion and might therefore be less preferable. Large seedlings can decrease frost heave frequency and increase the tolerance to competing vegetation (Örlander & Gemmel 1989). On the other hand, large seedlings are known of being subject to desiccation (especially during spring when sunny weather, strong winds and a frozen ground are common) in Iceland (Óskarsson & Ottósson 1990).

In 1989 a field experiment was initiated in Mosfell to investigate what benefits could be derived from various site preparation methods, planting positions and planting stock. There are few studies on these subjects in Iceland and almost no trials have lasted long enough to evaluate the long-term significance of different afforestation methods. The present study involves renewed measurements and analyses of the Mosfell trial.

1.4 Objectives

The overall objective was to compare afforestation results in a 19 year old planting trial on a typically difficult inland site on southern Iceland and to evaluate if the choice of planting stock and planting position can affect future yield and lumber quality. The following specific questions were addressed: Are there differences in height, survival, frost heaving, current year shoot growth and stem form that can be related to:

- Stock type / seedling size?
- Planting position?
- Site preparation method?

2. Materials and Methods

2.1 Study area

The study area is located in Mosfell in southern Iceland (64°08´N, 20°38´W, 70 m a.s.l.) (Figure 3). The area around the Mosfell hills was used for sheep grazing until 1989. Since then the area has been fenced off and used for afforestation (Pétursson & Sigurgeirsson 2004). The terrain is rather flat and wind exposed heath land. The soil on the site is freely drained brown andosol with a depth of 0.5-2 meters. The high clay content (15-30 %) contributes to high water retention in the soil (Arnalds 2004). The pH is 5.6-6.3 (Pétursson & Sigurgeirsson 2004). The ground vegetation is dominated by *Calluna vulgaris*, *Empetrum nigrum*, *Vaccinium myrtillus*, *Vaccinium uliginosum*, *Salix sp*. and a thick moss (mainly *Rachomitrium sp*.) floor.

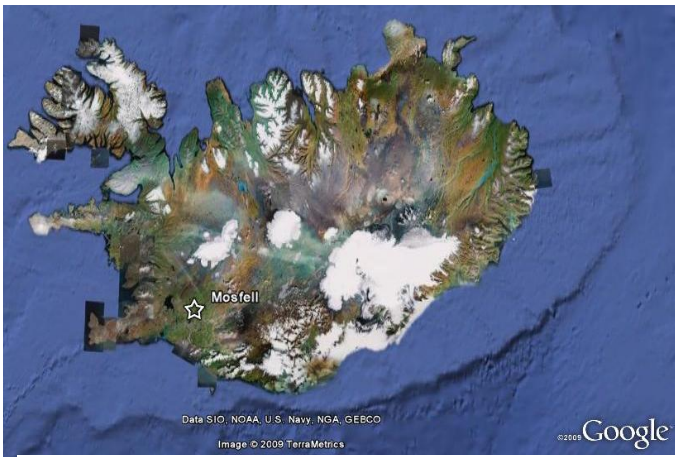

Figure 3.Location of the study area. (© 2009 Google).

2.2 Climate and weather conditions 1989-2006

Temperature data from Haell (64°09´N, 20°15´W, 121 m a.s.l.) and Eyrabakki (63°52´N, 21°09´W, 3 m a.s.l.) was used to calculate mean temperatures for 1989-2006 at Mosfell with the assumption that temperature decreases linearly with increasing height above sea level. Mean temperature for the period June-August (months with an average temperature above 7.5°C) was then compared to a long-term (1961-1990) reference. The mean temperatures for June-August at the period covered by the study were higher than the referent temperatures for the same months (Figure 4). Annual precipitation sums (1989-2006) from Haell was compared to the long-term normal for Haell. The precipitation was higher than normal during 1989-1993. Between 1994 and 2006 the annual precipitation was generally lower than normal (Figure 5) (Icelandic Meteorological Office 2008).

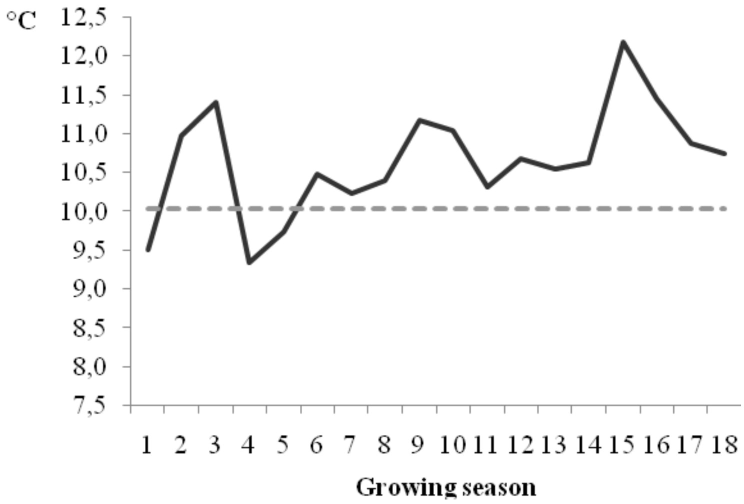

Figure 4. Calculated mean temperatures (°C) for the period June-August at the first 18 growing seasons of the experiment, dotted line represents long-term (1961-1990) mean temperature for the same annual period at the experimental area (Icelandic Meteorological Office, 2008).

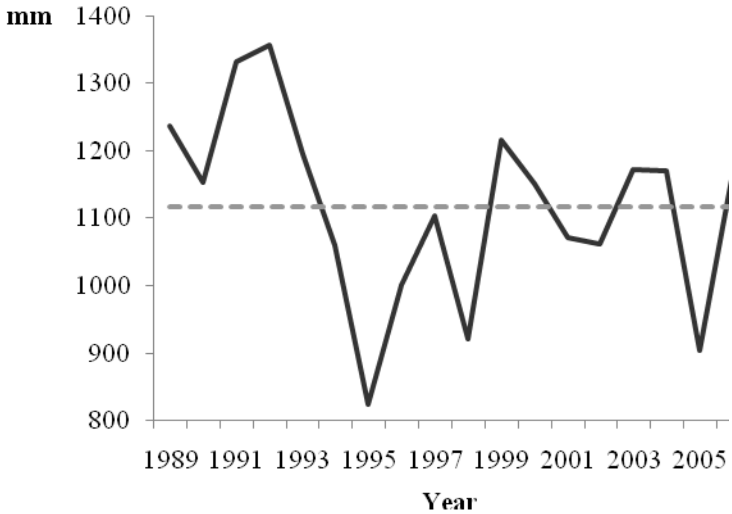

Figure 5. Annual precipitation (mm) 1989-2006 at Haell, dotted line represents the long-term (1961-1990) normal annual precipitation (Icelandic Meteorological Office, 2008).

2.3 Experiment design and treatments

The experiment was established 1989 using randomized block design with six site preparation treatments repeated ten times in each of two adjacent sites (site 1 and 2) (Figure 6). The whole experiment comprised 1920 lodgepole pine seedlings (provenance Skagway, 59°16´N, 135°19´W) planted in the spring of 1989.

Site preparation
Scarification included TTS trenching, patch scarification ("Skogsstjärnan" attached to a tractor) and mounding ("Kulla cultivator" attached to a tractor). The trial also comprised three treatments without mechanical scarification; glyphosate (Roundup®) application, tree shelters (a 40 cm high plastic protection placed around seedlings) and undisturbed areas (control). Treatments were carried out in straight lines where equal amounts of the different planting stock were planted in every row (Figure 6).

Planting positions
Within each mechanical treatment two to four planting positions was used (Figure 7). For glyphosate, tree shelters and control, planting was carried out in undisturbed soil (position 3). Distance between seedlings planted in the same position was 2 m.

Planting stock
The planting stock were container seedlings (1+0), size 12-16 cm and Nisula roll transplants (2+1), size 15-25 cm. Nisula roll transplants are grown as bare-root seedlings for the first two years. Then the seedlings are lifted and transplanted into peat rolls covered in plastic film for a final growing season in the nursery. After three years in the nursery, the plastic film was removed. The transplants then resemble bare-root seedlings with densely developed and slightly flattened root systems (Robson 1980). For each planting position four seedlings of each stock were planted within one treatment. This means 16+16 seedlings in one TTS treatment, 12+12 in each mounding treatment, 8+8 in every patch scarified area and 4+4 plants in each of the glyphosate, tree shelter and control treatment (Table 1).

Table 1. Total number of planted seedlings at different site preparation method

Site preparation	Container seedlings (1+0)	Nisula rolls (2+1)
Control	80	80
Glyphosate	80	80
Tree shelters	80	80
Patching	160	160
TTS trenching	320	320
Mounding	240	240

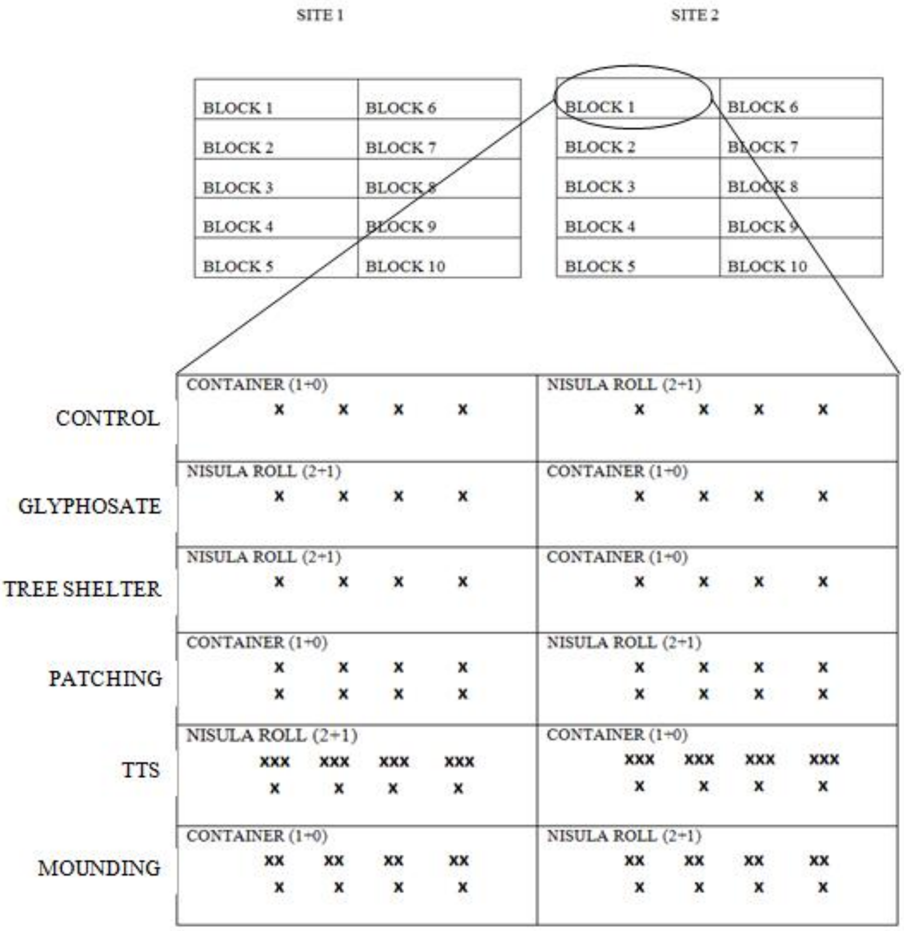

Figure 6. The experiment design comprised two (~ 0.5 ha) sites with ten blocks in each (top of figure). Each block was divided into six (5x16 meter) rows (lower part of figure). In every row one treatment was tested. Two different planting stock (container seedlings and Nisula rolls) were tested in each row. Every X in the figure represents a seedling.

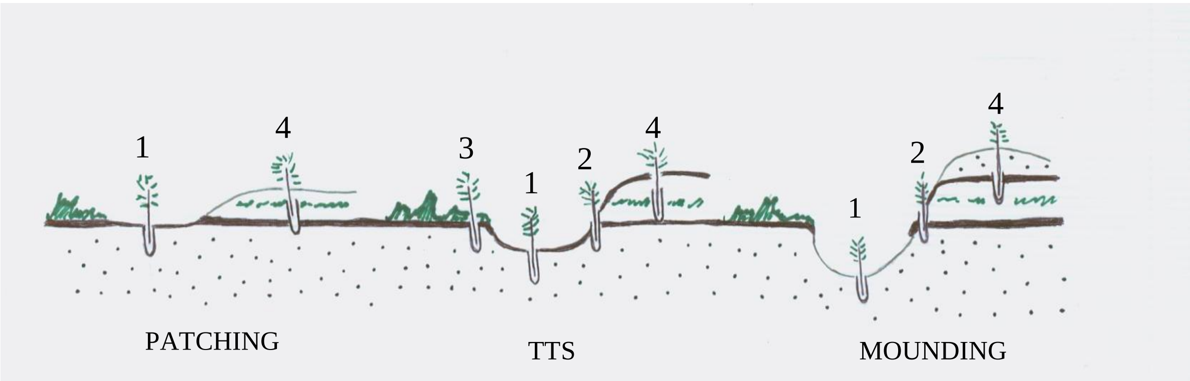

Figure 7. At the mechanical treatments different planting positions were used. TTS trenching comprised four different positions; furrow (position 1), in mineral soil at the same level as the surrounding soil surface (hinge planting) (position 2), in undisturbed soil (i.e. with vegetation cover left) approximately 50 cm from the furrow (position 3) and in inverted mineral soil at the top of the mound (position 4). In patch scarification, two different position were used; furrow (position 1) and in inverted humus (position 4). In the areas where mounding had been carried out, three different planting sites were used: in the pit (position 1), soil surface (hinge planting) (position 2) and in inverted mineral soil on top of the mound (position 4).

2.4 Measurements

Survival was recorded in 1990, 1993, 1995, 1997 and 2008. The measurements generally were carried out during late summer or early fall. The criteria used as definition for a living tree was: at least 10 % of the needles must be green. Frost heaving was measured to nearest cm and registered in 1997. This was done by measuring the length of the exposed original below ground part of each seedling alive. Reference points were ground level and the original root collar (Úlfur Óskarsson pers. comm.). In the analysis seedlings were registered as lifted ("1") or not lifted ("0") according to Óskarsson et al (2006).

Tree height, diameter at the base and top shoot height were measured 1997 and 2008. In 2008 stem diameter at 70 cm height was included in the measurements. Measurements were carried out on every living tree (see definition above) at the experimental area. In 2008 height and top shoot length was measured with a Nestle digital reading measure pole. For trees smaller than 142 centimeters a 2 meter ruler was used, all heights were rounded to the nearest half centimeter. Stem diameters were recorded at nearest 0.1 centimeter. In those cases where there were multiple tops or top breakage the highest green branch was measured for tree height and top shoot length. In cases of multiple stems the tallest stem has been measured both for heights and diameters.

The straightness of the stem was also classified by using a four graded scale (0-3) (Table 2).

Table 2. Definition of the different stem form classes used in the study

Class	Definition
0	Tree lower than 70 cm without any obvious fault and therefore impossible to classify.
1	Tree with a straight stem, minor crookedness accepted.
2	Tree with a crooked stem.
3	Tree with multiple stems and/or multiple tops (recent top breakage included) and/or severe crookedness.

2.5 Statistical analyses

The number of planted seedlings varied between the different combinations of site preparation and planting position (Table 1). After 19 years the competitive conditions differed between site preparation methods and complete comparisons according to the original design could not be made. Therefore, in the analyses, all the specific planting position x site preparation combinations were regarded as treatments. The resulting twelve treatments were Control (1), Glyphosate (2), Tree shelters (3), Patching planting position 1 (4), Patching planting position 4 (5), TTS planting position 1 (6), TTS planting position 2 (7), TTS planting position 3 (8), TTS planting position 4 (9), Mounding planting position 1 (10), Mounding planting position 2 (11) and Mounding planting position 4 (12). In order to determine effects of the twelve different treatments (site preparation x planting position) and planting stock in 2008 an analysis of variance (Table 3) was performed using the general linear model (GLM) procedure in SAS 9.1 (SAS Institute Inc. 2004) according to the following model;

$$Y_{ijr}=\mu+\alpha_i+\beta_j+c_r+(\alpha c)_{ir}+(\beta c)_{jr}+\varepsilon_{ijr}$$

Treatment (α_i) and block effects (c_r) were considered random, planting stock effects (β_j) were considered fixed. Hence, the included planting positions x site preparation combinations were considered to be a random sample from all possible combinations (cf. Zar 1984 p. 168). Tukey´s HSD test was used to identify statistically significant differences ($p<0.05$) between treatments.

In order to compare heights, survival and diameter between non-mechanical site preparation methods (1-3), planting positions (4-5, 6-9, 10-12) and planting stock in 1997 and 2008 paired t-tests were performed in Minitab® 15 (Minitab Inc.). To avoid type I errors in multiple comparisons Bonferroni correction ($p<0.05/n$) was used.

Table 3. Analysis of variance of the randomized complete block design as performed with PROC GLM in SAS (SAS Institute Inc 2004.)

Source of variation	Degrees of freedom (Df)	Mean Squares (MS)	F-value
Block (B)	19		
Treatment (T)	11	SS*)T / 11	MST / MSError
Stock (S)	1	SSS / 1	MSS / MSError
Stock*Block	19	SSSB / 19	MSSB / MSError
Treatment*Block	206	SSTB / 206	MSTB / MSError
Error	735	MSError	
Total	991		

*) TypeIII Sum of Squares

3. Results

3.1 Effects of treatment and planting stock in 2008

Treatment (site preparation x planting spot) was found to influence height, survival and diameter while no effect was seen on top shoot length. Planting stock significantly affected survival in 2008 but had no influence on height, top shoot length or diameter (Table 4). At the different treatments, survival was generally higher when Nisula roll was planted. No obvious trend on average height between stock within treatments was seen. Mounding (position 1and 4) and tree shelters resulted in significantly lower survival than the other treatments. Non-mechanical treatments generally resulted in lower average heights compared to the other treatments (Table 5).

Table 4. The influence of treatment (site preparation x planting spot) and stock (Nisula roll or container) on seedling height and survival 2008 (19 years after planting), according to analyses of variance (GLM)

Variable	Source of variation	Degrees of freedom	F	P
Height	Block	19	7.02	0.000
	Treatment	11	26.37	0.000
	Stock	1	0.01	0.904
	Stock*Block	19	1.71	0.030
	Treatment*Block	206	1.68	0.000
	Error	735		
Survival	Block	19	2.24	0.002
	Treatment	11	7.31	0.000
	Stock	1	15.09	0.000
	Stock*Block	19	1.59	0.055
	Error	735		
Top shoot length	Block	19	3.76	0.000
	Treatment	11	1.29	0.224
	Stock	1	0.74	0.389
	Stock*Block	19	1.89	0.012
	Treatment*Block	206	1.57	0.000
	Error	735		
Ground level diameter	Block	19	3.24	0.000
	Treatment	11	16.16	0.000
	Stock	1	3.99	0.046
	Stock*Block	19	1.41	0.114
	Treatment*Block	206	1.33	0.004
	Error	735		
Diameter at 70 cm	Block	19	4.55	0.000
	Treatment	11	18.61	0.000
	Stock	1	3.60	0.058
	Stock*Block	19	1.20	0.251
	Treatment*Block	206	1.52	0.000
	Error	735		

Table 5. Survival (%) and mean height (cm) at different planting positions and treatments in 2008, separated by planting stock, different letters indicate significant differences ($p<0.05$) (SD=standard deviation)

		Container seedlings (C)				Nisula rolls (NR)				C+NR	
Site preparation	Planting spot	Survival	SD	Height	SD	Survival	SD	Height	SD	Survival	Height
Patching	1	63,8	20,6	220	74	56,3	27,9	231	58	60,0a	223cd
	4	47,5	28,0	230	67	66,3	29,6	239	51	56,9a	237abc
TTS	1	42,5	31,5	244	69	47,5	29,1	229	61	45,0abc	236abc
	2	57,5	28,2	239	85	68,8	25,5	234	69	63,1a	237abc
	3	63,8	25,0	220	50	61,3	25,0	226	47	62,5a	223cd
	4	55,0	28,8	238	68	60,0	27,4	243	50	57,5a	241abc
Mounding	1	23,8	19,0	226	50	41,3	34,7	228	80	32,5c	227bcd
	2	51,3	27,5	276	51	66,3	28,4	252	62	58,8a	263a
	4	26,3	22,2	257	91	43,8	32,3	258	48	35,0bc	258ab
Control	3	47,5	19,7	139	80	61,3	26,3	127	43	54,4ab	132e
Glyphosate	3	53,8	27,2	201	71	62,5	28,9	200	54	58,1a	200d
Tree shelter	3	31,3	26,7	121	68	41,3	32,7	151	65	36,3bc	138e

3.2 Frost heaving

The frost heaving registered in 1997 was most frequent at the lowest planting position within every different mechanical site preparation method (Figure 8). At TTS treatment planting in the undisturbed soil resulted in the lowest registered frost heave seen over all treatments. A high planting position resulted in decreased frost heaving within every different mechanical treatment. Mechanical treatment generally resulted in more frost heaving than non-mechanical treatments. However, planting in position 3 and 4 in TTS resulted in reduced frost heaving compared to non-mechanical treatments. No significant difference was seen between the planting stocks although containerized seedlings had been more affected by frost heaving.

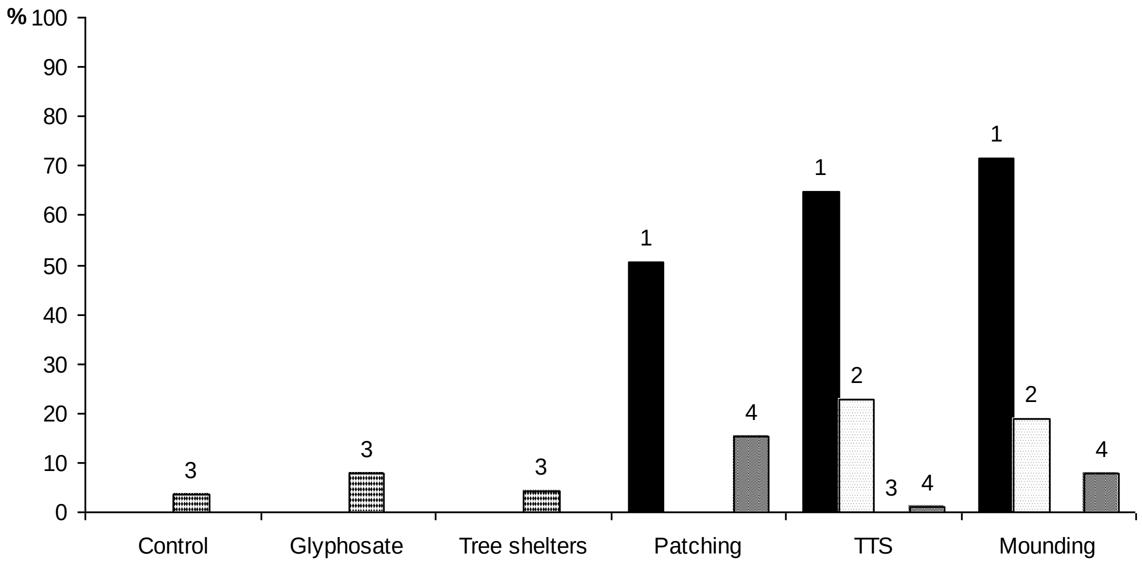

Figure 8. Frost heave frequency (%) in 1997 at the different planting positions (1-4) tested (After data collected by Úlfur Óskarsson).

3.3 Survival

In total 992 trees (out of the initial 1920) were counted alive in 2008. This contributed to an overall survival of 51,7 %.

3.3.1 Planting stock

In general, seedlings in Nisula rolls maintained higher survival rates than container seedlings throughout the whole study period (Figure 9). On average for all site preparation methods and planting positions the survival in 2008 was 47 % for container seedlings and 56 % for Nisula rolls. Nisula rolls survived significantly ($p<0.05$) better regardless of site preparation method compared to container stock in 1997 and 2008.

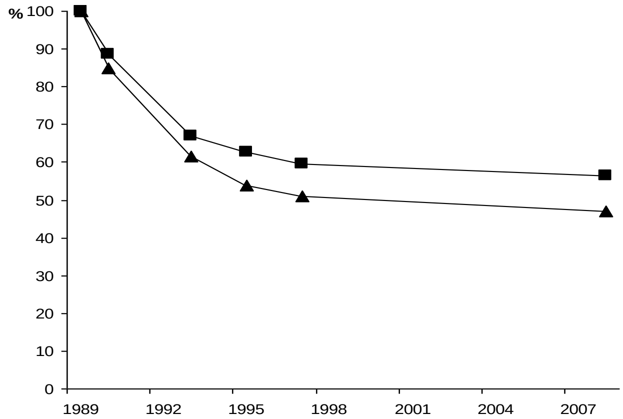

Figure 9. Survival (%) of Nisula roll transplants (2+1) (boxes) and container seedlings (1+0) (cones) between 1989-2008.

3.3.2 Planting position

The overall survival in the patch scarified areas was 58 % in 2008. No major difference in survival between the planting positions was discovered over the study period (Figure 10).

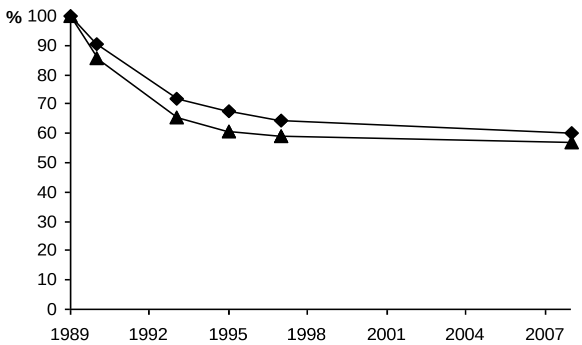

Figure 10. Survival (%) 1989-2008 at position 1 (diamonds) and position 4 (cones) after patch scarifying.

Overall survival in the TTS trenched areas was 57 % in 2008. The highest (position 4) and the lowest (position 1) planting positions showed lower survival than the other TTS positions throughout the study period. Planting position 2 had improved survival by 18 % compared to position 1 in 2008 (Figure 11).

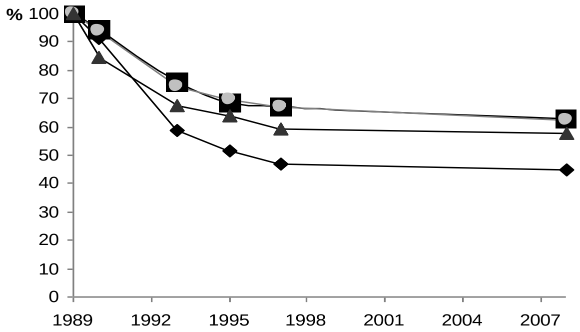

Figure 11. Survival (%) 1989-2008 at position 1 (diamonds), position 2 (boxes), position 3 (grey circles) and position 4 (cones) after TTS trenching.

Early mortality after mounding was evident at elevated and low positions resulting in an overall survival of 42 % in 2008. Planting position 2 then had improved survival by 26 % compared to position 1 and by 24 % compared to position 4. This corresponds to the situation in 1997 when similar differences was seen (Figure 12).

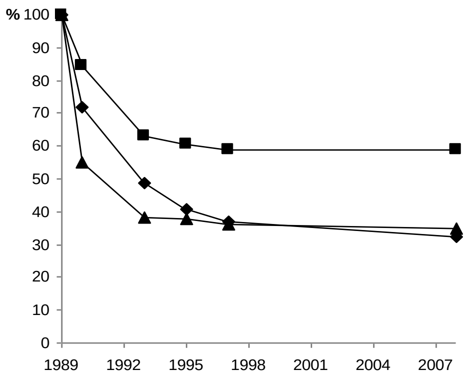

Figure 12. Survival (%) 1989-2008 at position 1 (diamonds), position 2 (boxes) and position 4 (cones) after mounding.

3.3.3 Non-mechanical site preparation methods

Initial (1990) average survival was higher after non-mechanical site preparation methods compared to scarification (Figure 10-13). Glyphosate and control treatment showed significantly ($p<0.05$) higher survival than tree shelter in 2008 (Figure 13). No significant difference was seen between control and glyphosate.

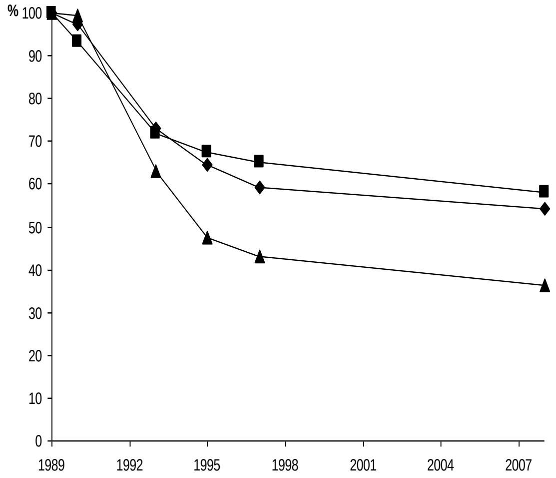

Figure 13. Survival (%) 1989-2008 for control (diamonds), glyphosate (boxes) and tree shelter (cones).

3.4 Height

The recorded mean height for the entire trial was 32 cm in 1997 and 219 cm in 2008. Mounding was the site preparation method that showed the highest mean height in 2008 (252 cm). There was a great variance in height amongst the measured trees, ranging from just 5 cm to 428 cm.

3.4.1 Planting stock

Mean height was significantly ($p<0.05$) greater for Nisula rolls in 1997 (Figure 14) but top shoot length was at that time greater (not significantly) for container seedlings. No difference in mean height between the two stock was seen in 2008 (219.2 cm for container stock and 219.0 cm for Nisula transplants) (Figure 14).When only counting the 300 highest trees of each stock in 2008, Nisula showed a 4 cm higher average than container stock. Planting stock had no influence on current year shoot length in 2008.

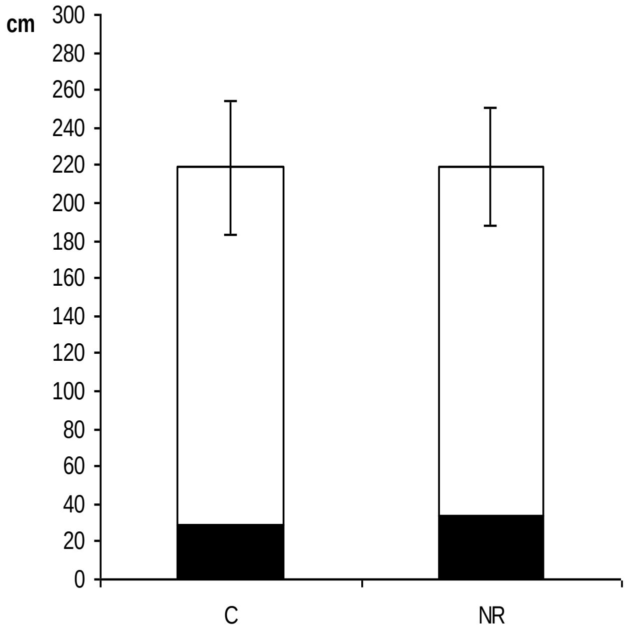

Figure 14. Mean heights (cm) of container seedlings (C) and Nisula transplants (NR) in 1997 (dark) and 2008 (bright), error bars indicate standard deviation.

3.4.2 Planting position

Where patch scarification had been carried out position 4 supported a higher mean height than position 1 in 2008 (Table 5). However, the difference was not significant.
Trees planted at position 4 showed the greatest mean height while position 3 resulted in the lowest mean height in the TTS trenched area (Table 5). Differences were not significant.
When mounding, position 2 significantly ($p<0.05$) improved mean height compared to position 1 in 2008.

3.4.3 Non-mechanical site preparation methods

In 2008 glyphosate had improved ($p<0.05$) mean height compared to both control and tree shelter trees, which then were lower than all other treatments (Table 5). Herbicide treatment resulted in the highest (not significantly) current year top shoot mean value off the non-mechanical treatments (data not showed).

3.5 Stem form properties

All scarification methods displayed poorer stem form properties than the three non-mechanical ones. A great deal of trees (39,4 %) had basal sweeps. The overall average diameter was 7.8 cm at ground level and 5.1 cm at 70 cm height.

3.5.1 Planting stock

A greater deal (27,3 %) of the surviving container had developed multiple stems compared to the Nisula stock (13,7 %) in 2008. No difference in diameter was found between the two stock.

3.5.2 Planting position

In 2008 trees planted in scarified ground displayed various stem form flaws. Top breakages and basal sweeps occurred frequently. Basal sweeps were most common in the lowest planting position for each scarification method. An elevated planting spot resulted in relatively low frequency of basal sweeps. Great deals of stems suffered from competition and were expected to die in the coming years. Also foliage damage was quite extensive and needles were often reddish in color. The only significant ($p<0.05$) planting spot effect on diameter was seen after mounding, where position 2 had increased ground line diameter compared to position 1 (Figure 15).

3.5.3 Non-mechanical site preparation methods

Trees growing where glyphosate once was applied had larger ($p<0.05$) diameters than control and sheltered trees at both heights measured in 2008 (Figure 15). The trees in non-mechanical treated soil had a low percentage of multiple stems and tops. However, trees in the undisturbed control area sometimes were unstable. The tree shelters had prevented branch growth on the lower part of the stem. The stem of the sheltered trees often had a bend at 40 cm, which was the height of the shelters. Severe rubbing damages from the shelters and from the supportive wooden pole were also noted.

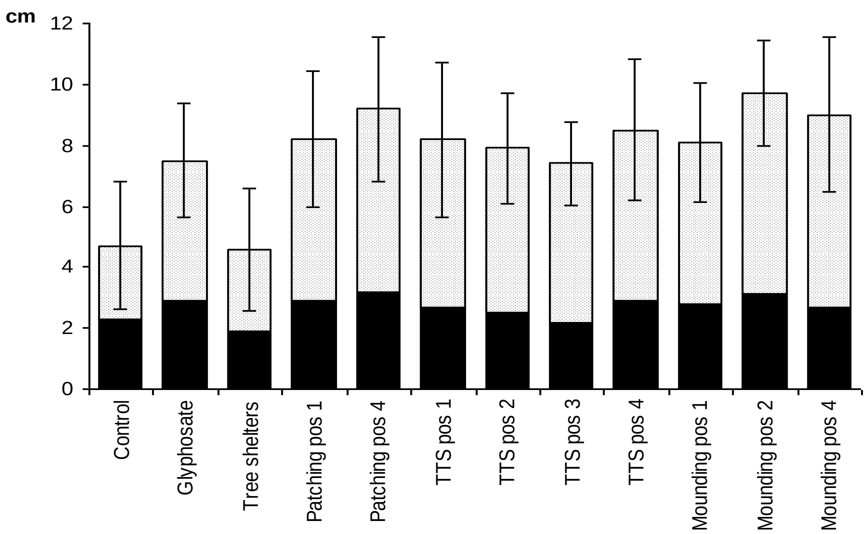

Figure 15. Ground level diameters (cm) at the different treatments in 2008, black indicate diameter at 70 cm and error bars standard deviation.

4. Discussion

4.1 Survival

4.1.1 Overall survival- a comparison to previous experiences

Experiences from previous trials show that soil scarification increases survival of lodgepole pine (Hunt 1987, Jansson & Näslund 1993, Bedford & Sutton 2000). The overall survival in this study was 51,7 %. This is quite low compared to other long-term site preparation trials in Scandinavia. However, it is hard to compare survival figures between different sites. The conditions on the study area in this paper are hardly seen elsewhere (outside Iceland) in Scandinavia. A site preparation experiment (Rätan trial) with lodgepole pine in northern Sweden resulted in 92 % of its originally planted seedling left at a "poor degenerated heath land" after 17 years (Mattsson & Bergsten 2003). Another site preparation trial with lodgepole pine in northern Sweden resulted in 90 % survival when mounding and 72 % survival in undisturbed control areas (Örlander et al 1998). Mäkitalo (1999) studied the effects of prescribed burning, patch scarification, disk trenching and ploughing for Scots pine. He received a 49 % overall survival 16 years after planting and sowing on dryish pine sites in northern Finland. Also Fries (1993) reported about high mortality for Scots pine after 13 years in northern Sweden and concluded that lodgepole pine is less dependent on soil scarification than Scots pine to survive. This corresponds to findings of Martinsson (1985). Fries (1993) results ranged from ca 65 % survival (no scarification) to over 80 % survival (mounding) for lodgepole pine and indicates that scarification improves the chance of survival for lodgepole pine in northerly areas with harsh climatic conditions. In the present experiment trees were still dying after 19 years. Late dying was also seen by Fries (1993) and Mäkitalo (1999). In the current study the causes of mortality are not easy to identify.

4.1.2 Possible causes of mortality

It seems as scarification only has a minor positive effect on survival of lodgepole pine in this study. This is indicated by the low survival of mounding and the relatively high survival of control. As mounding increases soil temperature compared to undisturbed ground (Nilsson & Örlander 1999) a low soil temperature cannot be assumed to be the major cause of mortality. A mound offer a high planting position and generally provides less initial competition for light, nutrients and water from other vegetation (Sutton 1993). Therefore neither competition would likely be the primary reason of mortality in the experimental area.

Frost heaving has probably contributed to the high mortality as temperatures often fluctuates around 0° C. The fine textured soil has high water content and is therefore highly susceptible to frost heaving (Goulet 1995). Frost heaving has also previously been seen at the specific site by Pétursson & Sigurgeirsson (2004) and Óskarsson et al (2006). The initial survival was fairly good (85 %) but after 4 years a rapid decline (61 %) was noted. This is well in accordance to the known effect of frost heaving on survival (Low 1975). It is likely that removal of ground vegetation has contributed to high frost heave frequency. The humus layer constitutes an insulating layer and retention of ground cover contributes to reducing the temperature fluctuation around 0° C (Bergsten et al 2001). Therefore soil temperature and moisture content becomes somewhat more protected from weather conditions if ground cover is left. This is probably one explanation for the relatively high survival for control. It is previous suggested that planting without site preparation can be a proper regeneration method on sites prone to frost heaving (Örlander & Gemmel 1989, Sahlén & Goulet 2002). Another

explanation to the survival figures might be the soil properties and structure. The volcanic origin of the soil makes it unstable and it is possible that soil preparation can lead to erosion problem (Óskarsson & Ottósson 1990). The allophane clay content contributes to that both P and N are mostly bound in stable forms in the soil. The availability of P and N for plants is therefore limited (Óskarsson & Sigurgeirsson 2001, Ritter 2007). Instead plants are dependent of N- and P supply from mineralization of organic matter (Ritter 2007). Thus, a removal of the humus layer would mean fewer nutrients available for seedlings (Simard et al 2003). On other sites in Scandinavia nutrient supply is not likely to affect tree survival. However, Óskarsson & Sigurgeirsson (2001) showed that fertilization with a combination of N and P decreases mortality in plantations on freely drained andosols. This indicates that the combination of N and P is an establishment limiting factor in plantations on andic soils in Iceland. It is therefore possible that retention of ground vegetation in control treatment contributed to more accumulated N in the top soil layer and therefore promoted early survival (Nilsson & Örlander 1999).
A lot of the trees in the different mechanical treatments (mainly TTS and mounding) were suffering of competition from trees in surrounding planting positions. During the field measurements a number of suppressed trees were seen at the scarified plots. The sheltered trees has received (and still are receiving) rubbing damages from the shelters causing breakage and mortality.

4.1.3 Hardiness development
Extensive foliage damage was observed in Mosfell. Many trees were showing reddish needles. The cause of this is believed to be due to salt exposure. The consequence of this is yet unknown but there are ongoing research on the subject (Thorbergur H. Jonsson pers. comm.). In provenance trials in Sweden (Karlman 1986) the Skagway provenance showed similar symptoms. The trials were laid out at Moskosel (65°56´N, 19°18´E, 400 m.a.s.l.) and Sävar (63°53´N, 20°33´E, 450 m.a.s.l.) in northern Sweden. It was concluded that the reddish color of the needles was caused by physiological stress due to weather damages. The symptoms where mostly seen at the southern and coastal provenances tested. It was therefore stressed that those provenances were poorly adapted to the climate in northern Sweden. The stress symptoms were believed to be caused by rapid temperature fluctuations, wind and frost. Sudden temperature changes often occur during spring when cold arctic air mixes with warmer winds in valley bottoms. The phenomenon, which causes mortality of needles and shoots, is common in areas with great topographic differences. It has previously been recorded at lodgepole pine plantations in Norway and Canada (where it is referred to as red belts). Wind is causing desiccation of shoots and branches resulting in greater discoloration at the wind exposed side of the tree. Therefore the red color of the needles seen in Mosfell might also (in addition to salt) be related to these kind of weather damages seen in Sweden. Moreover, the discoloration might indicate that the provenance used is susceptible to physiological stress and is therefore not well suited at the site.

4.1.4 Planting stock
The larger (bare-rooted) Nisula roll seedling showed the best survival all over the experimental time. However, small difference was registered the first 4 years. After 1993 the dying of containerized seedlings became more extensive. The difference between the different stocks was significant after 8 and 19 years (Figure 9). This does not support the finding of higher survival for container stock compared to Nisula roll made by Óskarsson and Ottósson (1990). The result of this study indicates that survival is dependent on seedling size. Consequently, planting larger seedlings promoted survival in this case.

The registered frost heaving in 1997 indicated that container seedlings might be more susceptible to frost heaving than Nisula rolls. It is likely that the higher frost heave frequency has reduced survival (Sahlén & Goulet 2002) amongst container seedlings. Örlander and Gemmel (1989) noted that the use of large seedlings is favorable on soils likely to promote frost heaving, due to satisfactory root anchoring during the growing season. The extensive root system of Nisula roll probably protected the seedlings against frost heaving. Goulet (1995) stressed that an extensive root system decreases the damages that frost heaving results in. It is likely that a seedling with a high number of roots can continue to grow even when lifted. Also, a deep and strong root system provides greater anchorage in the soil and therefore diminishes the vertical uplift (Goulet 1995). However, there is today small knowledge of how the weight of the root system and the number of root branches affect the extent of frost heaving.

The difference in survival can also be related to competition from surrounding vegetation (Örlander & Gemmel 1989). However, as stated above competition is not believed to be the primary cause of mortality in this study. Óskarsson and Ottósson (1990) noted that lodgepole pine has difficulties in competing at grassy Icelandic sites. Vegetation such as grass competes with tree seedlings mainly for water and nutrients (Davies 1985). During dry years this can lead to high mortality of tree seedlings (Nilsson & Örlander 1999). At dry conditions container stock is known to outperform bare-root in survival. Bare-rooted seedlings are generally better suited in regions with wet summers (Arnott 1975). This is due to the more efficient initial water uptake by container seedlings (Burdett et al 1984, Grossnickle & Blake 1987, Johansson 2005). Grass vegetation can also increase the risk for frost during summer (Örlander et al 1990). Frost damages are known to be greater for smaller seedlings and can in extreme cases lead to mortality (Langvall et al 2001). Choosing larger seedlings probably also diminishes the risk of mortality due to competition (Örlander & Gemmel 1989, Johansson 2005).

4.1.5 Planting position

The seedlings growing on the most elevated spots showed the poorest survival after the first year. This could be caused by water deficiency due to substantial exposure to sunlight (Örlander et al 1991), wind (Örlander & Gemmel 1989) and erosion.

Frost heaving was greater where mechanical site preparation had been performed (except for planting on the top of the mound at TTS trenching). The results also indicate that the risk of frost heaving is greater at lower planting positions. The three lowest planting spots showed a higher extent of frost heaving than the other microsites in 1997 (Figure 8). These findings are supported by observations made by Adelsköld & Örlander (1989), Örlander & Gemmel (1989) and Sahlén & Goulet (2002). The poor drainage (Adelsköld & Örlander 1989) and the low soil temperature (Örlander & Gemmel, 1989) in a depression contribute to a high water level in the uppermost parts of the soil. Therefore freezing temperatures would form ice needles which easily could reach the soil surface and the plants growing there. Furthermore, planting in the undisturbed humus by the side of the TTS trenched area resulted in the lowest frost heave. The conclusion is that the retention of humus decreased the degree of frost heaving. This is also in accordance with previous studies (Örlander & Gemmel 1989, Bergsten et al 2001, Sahlén & Goulet 2002). The humus layer reduces water capillarity and therefore diminishes the risk of ice formations at the soil surface (Örlander & Gemmel 1989). A removal of the insulating humus layer and the protecting ground vegetation contributes to higher diurnal temperature variations (Bergsten et al 2001). Hence, more fluctuations around

0° C and repeated freezing opportunities occur in scarified soil. It is therefore believed that frost heaving has decreased survival and height growth at the low planting positions in this study. The results are also in accordance with the finding: a high planting position within scarified areas decreases the rate of frost heaving (Sahlén & Goulet, 2002).
However, due to uncertainty concerning the precision in frost heave measurements these results should be looked upon as general patterns rather than exact figures.

The survival did not differ a lot between the two planting positions within the patch scarified areas. However, survival was higher at the furrow than at the inverted humus throughout the experimental time. Although the extent of frost heaving was greater at the furrow (Figure 8) it didn't seem to affect survival much. Patch scarification created the least difference in elevation between the planting positions. Therefore it was probably a small microclimatic difference between the planting spots used in the trial.
At the TTS scarified plots hinge planting showed the best survival. Planting in the undisturbed ground resulted in less frost heaving but almost the same survival. This implies that the seedlings planted outside the scarified area encountered other causes of mortality than the ones planted at the hinge. Consequently, TTS trenching had a positive effect on survival when seedlings were planted at the hinge despite an increased exposure to frost heaving. The lowest survival was seen in the furrow probably due to the high degree of frost heaving (Goulet 1995). A greater distance to the humus layer would also have contributed to a poor nutrient supply in the furrows (Örlander et al 1991).
The results seen in the mounded area was somewhat similar. Relatively high survival was obtained at the hinge and low survival in the pit. Planting on the top of the mound also resulted in low survival. This contradicts previous knowledge (Adelsköld & Örlander 1989). There are probably several reasons behind this finding. As mentioned above initial mortality was high at all of the highest planting positions. Reduced survival in mounds because of poor initial water supply has previously been seen by Hallsby & Örlander (2004). However, the initial annual precipitation at the study area was high (Figure 5) so water deficiency is therefore not likely. The seedlings planted on top of mounds are likely heavily exposed to wind and sunlight. Therefore desiccation (Örlander & Gemmel 1989) might still be a possible explanation to the initial mortality. During the measurements in 2008 it was noted that a lot of the mounds were "gone". It is therefore likely to assume that the volcanic origin of the soil, which is known to be very susceptible to erosion (Arnalds 1987), had contributed to that the mounds eroded away with time. The fact that scarification on andic soils can increase the risk of erosion was previously stressed by Óskarsson & Ottósson (1990). The mechanical soil preparation in the current study was performed the same year as the plantation. Therefore it is likely that the soil was not compact enough when planting. If scarification is performed the fall prior to planting the risk for erosion normally decreases (Martinsson 1985). Due to the risk of frost heaving deep planting is also needed at high planting positions (Adelsköld & Örlander 1989). In this study the planting depth used is not clarified therefore the primary cause of mortality on the mounds is somewhat uncertain.

The results of this study indicate that survival is improved by hinge planting when mounding (and TTS trenching) have been performed. This is probably due to closeness to the capped humus while the plants are protected from frost heaving, wind, erosion and offered adequate water supply. The choice of planting position was found to be of great importance in order to obtain good survival after mounding.

4.1.6 Non- mechanical site preparation methods

Although initial survival was high, tree shelters showed a poor survival in this study. The high initial survival is probably due to a decrease in air movement next to the seedling. This together with reduced exposure to sunlight would have contributed to a smaller risk for early desiccation. Extensive rubbing damages from the shelters and its supportive stakes were observed during the inventory in 2008. Similar damages were seen by Tuley (1985) at wind exposed sites in Britain. He concluded that the damages can cause stem breakages. It is intended that shelters should disintegrate or be removed after seedling establishment (Tuley 1985). This was not the case at Mosfell as the shelters still were in place after 19 years. The shelters in this study were 40 cm high it is therefore likely that the damages sooner or later would cause breakages at the lower parts of the stem. Such stem breakages is known to cause tree mortality (Valinger & Fridman 1995). Furthermore, Tuley (1985) suggested that the supportive wooden pole should be placed outside the shelters at windy sites. The pole was placed inside the shelters at Mosfell and probably contributed to the damages (Figure 16). It is therefore believed that rubbing damages were a major cause to the high mortality seen within tree shelters in this study. It is also possible that the temperature inside the shelters have been higher and less variable than in the surrounding air. Seedlings may therefore not have built up tolerance against frost and low temperatures (Cochran & Berntsen 1973). This could have made them more vulnerable once cold temperatures occurred. On the contrary, studies (LePage & Coates 1993) have shown that air temperatures play a minor role for establishment of lodgepole pine seedlings. In any case the way tree shelters were applied in the current experiment can not be recommended on similar sites.

Figure 16. The photo shows a tree shelter and its supportive stake rubbing against a tree. Photo: Lars Karlsson

Glyphosate application resulted in slightly higher survival than control. However, control showed higher survival than glyphosate during the first four years (Figure 13). This corresponds to previous findings made by Biring et al (2003). The registered frost heave after 8 years was slightly greater at herbicide treatment than control. Retention of ground vegetation might have reduced frost heaving by decreasing the effects of weather conditions at the soil surface (Bergsten et al 2001). Since repeated glyphosate application was not made the effect on frost heaving would have lasted until new ground vegetation had established itself. After 4 years normally a 30-40 % cover of invading grass vegetation can be expected (at least at scarified clear cuttings in northern Sweden) (Örlander & Gemmel 1989). Previous studies indicate that herbicide treatment promotes survival of conifers mainly where soil water is limited (Davies 1985, Nilsson & Örlander 1999, Simard et al 2003). The transpiration of vegetation such as grass leads to desiccation of the soil. Therefore, seedlings experience reduced water supply which can contribute to mortality and checked growth (Sands & Nambiar 1984). Because of the high precipitation (Figure 5) such effect would not likely be as obvious in this study.

4.2 Height

4.2.1 Overall height growth - a comparison to previous Scandinavian experiences

The results indicate that site preparation (scarification) enhanced long-term height growth. This finding is supported by results of Örlander et al (1996) and Mäkitalo (1999). Mattsson and Bergsten (2003) found that soil scarification support a long-term increase in growth and that the relative effects of soil scarification seems to be site dependent, higher effects was discovered at poor sites than on intermediate sites. Their study also show that the level of soil disturbance is of importance, intensive scarification methods (as ploughing) seem to affect growth of lodgepole pine more than less intensive methods. Fries (1993) compared how different soil preparation (no scarification, patching and mounding) affected survival and growth for lodgepole pine on harsh sites during a 13-year period. He found that mounding resulted in the highest mean heights. In the present study control trees were smaller than trees in every other treatment after 19 years. Mounding produced the highest trees and reached the highest mean height after 19 years. The relative height development achieved by the different scarification methods is well corresponding to similar trials in Sweden (Hansson & Karlman 1997, Örlander et al 1998, Mattsson & Bergsten 2003) (Table 6).

Table 6. Comparison of mean heights (cm) for different treatments in this study to mean heights (cm) in similar site preparation trials with lodgepole pine at Malmberget (Hansson & Karlman 1997), Böle, Rätan and Nästelsildret (Mattsson & Bergsten 2003) in Sweden

Site name	Site type	Location	Age	Control	TTS	Mounding
Mosfell	Poor	64°08´N, 20°38´W	19	132	233	252
Malmberget	Poor	66°49´N, 21°15´E	18	258		360
Böle	Poor	62°27´N, 14°20´E	17	120	260*	230*
Rätan	Intermediate	62°31´N, 14°32´E	17	430*	490*	560*
Nästelsildret	Intermediate	62°31´N, 14°22´E	17	420*	480*	490*

Note: *= Average height of sample trees.

4.2.2 Growth affecting factors

Growth was probably affected of a combination of factors, including frost heaving, soil temperature, air temperature, frost during the growing season, wind damages, nutrient supply and hardiness development. The improved growth seen at the mounded areas can be a result of the mineralization of embedded humus in the mounds (Örlander & Gemmel 1989). Root growth for lodgepole pine starts when soil temperature is over 5° C but is generally slow in temperatures below 10° C. Maximum root and shoot growth occurs at 20° C (Lopushinsky & Max 1990). The soil temperature in typically Icelandic lowland soils is generally 10-12° C during summers (Óskarsson & Ottósson 1990) and thus promotes root growth. Mounding is known to increase soil temperature (Nilsson & Örlander 1999) and to ameliorate deficient soil aeration and nutrient deficiency in the root zone, especially on moist sites (Sutton 1993). Therefore mounding probably enhanced growing conditions at Mosfell. It is likely to assume that the furrows in the trenched areas would accumulate more water during rainy periods compared to the mounds. This might have generated a somewhat lower air temperature around the seedlings which could slightly have affected height growth in a negative way (Mäkitalo 1999) compared to mounding. Mounding is also known to promote a greater soil warming compared to disc trenching (Örlander et al 1998). A large mound, as in this trial, contributes to a long-term drainage. Large mounds also improve the environment for seedlings by reducing frost damages and competition from surrounding vegetation. However, there is an increased risk of frost heaving if the mounds are large and in particular if the mineral soil cap is thick. In a large mound a seedling is not offered the important root-humus contact (Örlander & Gemmel 1989). This can explain the good height growth but also the high mortality seen on top of the mounds.

4.2.3 Planting stock

The bare-rooted Nisula roll showed the best initial height growth and was higher after 8 years. However, the annual growth was at that time greater for container seedlings. The results of a higher annual growth for the container seedlings were also seen after 19 years when there was no difference in height between the different planting stock (Figure 14).

There are two major phases of threats for a newly planted seedling. As root growth proceeds, shoot growth is limited firstly by moisture stress and secondly by mineral nutrient deficiency (Burdett et al 1984). Normally initial height growth is greater for container grown seedlings compared to bare-rooted ones (Burdett et al 1984, Nilsson & Örlander 1999, Johansson 2005). This is probably due to the fact that roots protected inside containers contributes to an immediately uptake of water and nutrients (Nilsson & Örlander 1999). Newly planted container seedlings also have a more developed root system in proportion to their shoot size (Johansson 2005) and have a greater initial root growth compared to bare-rooted seedlings (Grossnickle & Blake 1987, Binder et al 1990). Older seedlings can sometimes experience initial inability of water and nutrient uptake as their roots often are lignified and lack active root points (Johansson 2005). To achieve water and nutrient uptake a new root-soil contact must be established, therefore an older seedling must develop new vital roots. This means that the initial growth will be concentrated on root growth instead of height growth (Grossnickle & Blake 1987). The poorer quality and growth of roots at newly planted bare-rooted seedlings therefore often leads to initial slow-growth due to desiccation (Burdett et al 1984, Nilsson et al 2000, Johansson 2005). However, when the first phase (moisture stress) is overcome bare-rooted seedlings are likely to show equal or greater shoot growth compared to container seedlings (Burdett et al 1984, Grossnickle & Blake 1987). This indicates that bare-rooted seedlings are more sensitive to lack of water than nutrient deficiency in early years compared to container seedlings. It has previously been shown that bare-rooted seedlings are likely to show a greater initial growth on moist sites than container seedlings (Arnott 1975). As the high precipitation probably contributed to a high water level in the soil on this specific site it is likely that the seedlings received a fairly good early water supply and thus conditions where favorable for Nisula transplants.

Container seedlings were more susceptible to frost heaving. This probably affected mortality but also growth was likely inhibited. Normally lifted seedlings with root system still attached in the soil can survive. The growth is however probably less rapid because of less root-soil contact area and therefore a decreased nutrient and water supply. The stability is also most likely deteriorated due to a less anchored root system (Goulet 1995). Low (1975) concluded that even small degrees of lifting can cause serious limitations on height growth. Already in the second growing season such height differences can be detectable.

The Mosfell area has a history of plantation failure (Úlfur Óskarsson pers. comm.). As the area is located on the lowland the site is known to promote frost (Pétursson & Sigurgeirsson 2004) and frost heaving (Pétursson & Sigurgeirsson 2004, Óskarsson et al 2006). The afforestation attempts made in the past has therefore not been very successful. Several afforestation attempts with *Larix sibirica* has been carried out with poor results. Today adjacent larch plantations are suffering of severe damages made by frost. Although lodgepole pine is known as a frost tolerant species (LePage & Coates 1994, Elfving et al 2001) its early height growth can sometimes be inhibit due to frost stress (Karlman 1986, Simard et al 2003). A mild winter often decreases the frost hardiness. In addition, plants growing in an environment where changes between mild and cold temperatures occur are more likely to show frost sensitivity. Intracellular freezing has also been known to damage lodgepole pine (especially coastal provenances) (Karlman 1986). Therefore, frost combined with icing (Karlman 1981) and wind (Karlman 1986) may have affected growth in the present study. Container seedlings are known to be more susceptible to damages in early ages compared to bare-roots. This could be due to the more rapid establishment of container seedlings. An early shoot growth contributes to greater risks of early summer frost damages (Örlander et al 1991, Langvall et al 2001). Quite severe frost damages are needed to kill seedlings. However, frost damages can cause major limitations on height growth, especially if trees are exposed to frost repeatedly (Langvall et al 2001). Wind exposure leads to damages on shoots and branches due to desiccation (Karlman 1986) and breakage (Hansson & Karlman 1997). Current year needles contribute to a greater proportion of the total needle biomass for a container seedling compared to a bare-rooted one. This means that there are fewer reserves available if damages occur (Johansson 2005). Therefore it is likely that height growth for a containerized seedling is more negative affected by early damages.

Consequently, seedlings did not experience severe difficulties with initial water deficiency because of the climate. Therefore it is assumed that Nisula roll showed a relatively good early shoot growth which contributed to the maintained height difference between the different stock after 8 years. However, the main reason of the initial growth (the first 8 years) was probably that container seedlings were more affected by weather related stress. Frost, heaving and wind damages have probably contributed to a more halted early height growth for the smaller planting stock. It is however uncertain why the container stock have shown the best height growth between 1997 and 2008. One explanation could be the higher mortality for container seedlings. Due to this it is likely that more small slow growing trees have died off within the container stock than within Nisula stock. This would mean relatively fewer small container grown trees alive compared to small Nisula trees after 19 years. This could have affected the average heights seen in 2008. However, the mean height difference between the 300 highest trees of each stock was small. This indicates that container seedlings actually have grown better than Nisula rolls between 1997 and 2008.

4.2.4 Planting position

A low planting position resulted in the lowest mean height within every scarification method (although few significant differences were found). Therefore, also height growth indicates that a low planting spot offers poor conditions for seedlings. The reasons are believed to be somewhat similar to the constraints on survival mentioned above, i.e. frost heaving and poor nutrient supply. Seedlings in low planting positions could also have been suffering of lack of oxygen due to poor drainage resulting in reduced height growth (Örlander et al 1991). Planting in the undisturbed soil outside the TTS trenched area resulted in a lower mean height than the other planting positions within TTS. This is in accordance with the conclusion that scarification enhanced height growth.

4.2.5 Non-mechanical site preparation methods
Tree shelters improved height slightly compared to control but the effect was negligible. The effect was greater after 8 years. At that time mean height was 29 cm for sheltered trees (data not showed). This means that trees in general still were totally protected by the shelters. It is likely that trees have experienced a shock when they have grown taller than the shelters. Many trees showed obvious crookedness just above shelter height (Figure 17). This indicates that the trees have been unstable and suffered from wind induced stress (Martinsson 1985) when not protected by the shelters.

Herbicide treatment resulted in a improved mean height compared to control (Table 5). The roots of newly planted pines are confined to the uppermost part of the soil. Presence of grass roots would probably dry out this zone (Sands & Nambiar 1984). Therefore, initial growth could be reduced by water stress. Herbicide treatment is, due to increased solar radiation (Nilsson & Örlander 1999), known to contribute to a small increase in soil temperature compared to control. Therefore, the removal of ground vegetation might have improved water and nutrient uptake (Örlander & Gemmel 1989) and decreased the risk of summer frost (Nilsson & Örlander 1999, Simard et al 2003) in Mosfell. An increased soil temperature also promotes root and shoot growth (Lopushinsky & Max 1990) for tree seedlings. Glyphosate application can contribute to a higher needle N concentration compared to control (Nilsson & Örlander 1999) and scarification (Simard et al 2003). A higher level of N might explain the slightly longer top shoots seen at the herbicide treatment.

Figure 17. Tree with crookedness at shelter height, indicating an increased stress when not protected. Photo: Lars Karlsson.

4.3 Stem form properties

Basal sweeps were rather common as it appeared on 39 % of the trees. Basal sweeps occurs due to instability in the roots in early growth phases. The instability can be caused by root position changes and stem or root breakages (Rosvall 1994). In this study frost heaving and wind loads are believed to be the main reason of basal sweeps. Frost heaving has probably altered root positions. The relatively heavy crown and the poorly developed root system of lodgepole pine have contributed to leaning tree stems under the windy conditions at Mosfell. The leaning is compensated by the forming of compression wood as the trees strive to straighten out and thereby bends are formed (Martinsson 1985). Basal sweeps are permanently lasting and can contribute to wind felling in mature stands. Moreover, a low quality of saw timber and pulp can be expected due to the forming of compression wood (Burdett et al 1986).

4.3.1 Planting stock
Nisula rolls showed significantly greater stem form properties. This was mainly due to the high number of multiple stems recorded for containerized seedlings. It is likely that the multiple stems recorded were related to early frost damages (Nilsson et al 2000). This also

applies to the theory of container seedlings being more exposed to frost damages than Nisula rolls.
Instability problems for containerized lodgepole pine seedlings have previously been stressed by Martinsson (1985), Rosvall (1994) and Elfving et al (2001). However, no major differences in stability or crookedness were observed between the different planting stock.

4.3.2 Planting position
No major difference in stem form was seen between the different planting positions. However, top breakages and basal sweeps were rather common after all scarification methods. Top breakages are likely connected to tree height. The high trees are more exposed and therefore more susceptible to top breakage due to wind (Rosvall 1994, Valinger & Lundqvist 1994). Thus, top breakages were more common where scarification had been performed. Such top breakages would likely lead to reduced future growth (Valinger & Fridman 1995). Basal sweeps were most common in the low planting spots, probably due to greater exposure to frost heaving.

4.3.3 Non-mechanical site preparation methods
It seems as the shelters has suppressed the stem diameter as the ground line diameter was greater for control than for sheltered trees. This is probably due to the shady environment inside the shelter (Davies 1985, West et al 1999) and/or reduced mechanical bending stress (Valinger et al 1995). A small diameter at the lower parts of the stem would have contributed to a reduced stability (Potter 1988) and lower resistance to damages (Valinger & Lundqvist 1994). Almost no branches seem to have been developed inside the shelters as the stem often was branchless to the height of the shelter. Besides the bends at shelter height, the trees within all of the non-mechanical methods showed good stem form properties. This was mainly because of the low frequency of top breakages due to low tree height.
Herbicide treatment resulted in improved diameter growth compared to control (Figure 15). In previous studies radial growth has usually been more affected than height growth by the removal of competing vegetation (LePage & Coates 1993, Nilsson & Örlander 1999, Simard et al 2003). The controlling effect of glyphosate on mixed shrub vegetation can last for several years (Biring et al 2003). It was also noted visually during the measurements that shrub cover was lower at the herbicide treated areas compared to control. No difference in grass cover was observed. It is therefore suggested that the long-term effects of herbicide treatment is partly due to a long-term effective control of shrubs.
In many cases the control trees showed poor stability. Instability is generally common for lodgepole pines within the height interval 1-3 m. This is due to weak and poorly distributed roots combined with a relatively large green biomass area absorbing wind and snow (Rosvall 1994).

5. Conclusions

- Scarification enhanced long-term height growth but had a relatively low impact on survival. Scarification had a negative impact on stem straightness.

- Mortality was mainly due to frost heaving, erosion, nutrient supply and desiccation (due to wind exposure). Growth was probably affected by a combination of factors such as: frost heaving, soil temperature, air temperature, summer frost, wind damages, nutrient supply and hardiness development.

- The results of this study indicate that survival is dependent on seedling size. Container seedlings are more sensitive to early weather related damages which might affect survival, growth and quality in a negative way.

- The discoloration seen on needles might indicate that the provenance used is not well suited at the site. Further research is needed.

- TTS trenching and patch scarification are site preparation methods that can be used in order to receive a satisfactory afforestation result. Mounding produces high trees but the choice of planting position is crucial for survival.

- Hinge planting improves survival and growth, especially when mounding has been performed. This planting position offers an environment where seedlings are quite protected from wind, frost heaving and erosion while they are offered an adequate water and nutrient supply.

- A low planting position should be avoided regardless of scarification method.

- Glyphosate application is method which can improve long-term height and radial growth, mainly due to a long-lasting shrub control and is therefore an alternative to scarification.

- The use of tree shelters resulted in massive mortality and low average height, mainly due to rubbing damages. This site preparation method, as it were applied in this study, can not be recommended for afforestation on exposed heath lands at southern Iceland.

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