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The interaction of fertilization in nursery and field on survival, growth and the frost heaving of birch and spruce

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ABSTRACT
The interaction of nursery fertilization and field fertilization at the time of planting on survival, growth and frost heaving of container seedlings of birch (*Betula pubescens*) and Sitka spruce (*Picea sitchensis*) was tested in a factorial trial on four sites in Iceland. A trial with nutrient loading of seedlings was done during a four week period in May-June in a nursery prior to planting. Seedlings were divided into three groups and irrigated twice weekly for four weeks with; control = pure water; Sc1 = 10 g fertilizer m^{-3} water and Sc2 = 20 g m^{-3}. Field experiments were established on two sites in east Iceland and two in west Iceland. On each site the three nursery treatments were split up by giving the seedlings either a single application of 15 g $seedlings^{-1}$ of the fertilizer "Gróska II" or no fertilizer. The pre-treatments Sc1 and Sc2 increased the shoot growth significantly during the first summer, and this effect was still seen on the volume growth three years later. The field fertilization at planting had a positive effect on survival and growth and also reduced frost heaving, and the best growth and survival rates were obtained by pre-treatment Sc2 followed by field fertilization.

Keywords: afforestation, containerized seedlings, forest fertilization

YFIRLIT
Samspil áburðargjafar í gróðrarstöð og útjörð á lifun, vöxt og frostlyftingu birkis og sitkagrenis
Mikil aukning hefur orðið í skógrækt á síðustu árum á Íslandi með tilkomu landshlutabundinna skógræktarverkefna sem styrkt eru af ríkinu. Miklir hagsmunir felast í því að faglega sé staðið að ræktun, meðferð og gróðursetningu trjáplantna. Í greininni eru kynntar niðurstöður tilraunar þar sem skoðuð voru áhrif mismunandi áburðarstyrks í vökvunarvatni á bakkaplöntur af birki (*Betula pubescens*) og sitkagreni (*Picea sithensis*) síðustu fjórar vikurnar fyrir gróðursetningu og einnig áburðargjafar við gróðursetningu í foldu, og áhrif meðferðanna á lifun, vöxt og frostlyftingu. Tilraunin var gerð í gróðrarstöð í maí og voru plöntur vökvaðar tvisvar í viku í fjórar vikur með þrenns konar áburðarvatni, viðmiðun = hreint vatn, Sc1 = 10 g áburður m^{-3} og Sc2 = 20 g m^{-3}. Voru plönturnar svo gróðursettar í fjóra tilraunareiti, tvo á Fljótsdalshéraði og tvo í Skorradal,

skv. blokkartilraunaskipulagi með 4 blokkum á hverjum stað. Á hverjum tilraunastað voru plöntur úr hverjum tilraunalið úr gróðrarstöðinni gróðursettar með eða án 15 g „Grósku II" áburði. Áhrif áburðargjafarinnar í gróðrastöð voru áberandi fyrsta sumarið eftir gróðursetningu og uxu þær plöntur almennt best sem fengið höfðu Sc2 skammtinn. Þremur árum eftir gróðursetningu sáust enn tölfræðilega marktæk áhrif af vökvuninni á lifun og vöxt og uxu þau tré mest sem fengu stærsta áburðarskammtinn, Sc2, í gróðrarstöð ásamt áburði við gróðursetningu. Áburðargjöf við gróðursetningu jók lifun og vöxt, auk þess að draga úr frostlyftingu á einum af tilraunastöðunum. Mestur vöxtur fékkst þegar plöntur voru vökvaðar með sterkustu áburðarlausninni, Sc2, og þeim gefinn áburður við gróðursetningu.

INTRODUCTION

Some research has been carried out on the fertilization and nutrient status of tree seedlings during recent years in Iceland (Óskarsson & Sigurgeirsson 2001, Óskarsson et al. 2006, Óskarsson & Halldórsson 2008), all showing the importance of fertilization at the time of planting on survival and early growth. However, the interaction between nursery management and field performance has not gained much attention. The nutrient status of seedlings produced in local nurseries in Iceland has in some cases been poor (Óskarsson pers. obs.), which affects seedling performance in the field. In northern areas seedlings are commonly kept in cold winter storage at approximately -4°C to protect from damage due to fluctuations in temperature. During recent years an increasing number of seedlings grown in Iceland are winter stored. However, a large proportion of seedlings are still stored outdoors under natural conditions during the wintertime.

Nutrient uptake of tree seedlings that are stored outdoors starts as soon as the first roots start growing before the bud break (Kozlowski & Pallardy 1997). The root tips absorb available nutrients from the surrounding soil. Fertilization prior to bud burst might improve the nutrient status and prevent depletion of nutrients stored in the roots or root collar. Rapid root growth following planting is essential to ensure good survival and initial growth (Brockley 1988). A lack of nutrients adversely affects the plant and can cause discontinuation of growth (Kozlowski & Pallardy 1997), reduce cohabitation with mycorrhiza (Marchner 1995), and increase the risk of frost heaving (Óskarsson et al. 2006). Frost heaving is the process of ice needles growing from below and upwards and forming ice needles at the soil surface that then lift the vegetation up (Goulet 1995). The repeated shifting between freezing and thawing in Icelandic soils increases this process and is the main reason for die back on land with scarce vegetative cover (Aradóttir & Grétarsdóttir 1995). The same may also apply to scarified sites.

This paper presents the results of an experiment that was begun in 2001 to look at the interaction between nursery fertilization and field fertilization. The aim of this study was to assess whether fertilization with irrigation water of downy birch and Sitka spruce seedlings during four weeks in May-June could substitute for fertilization at time of planting in the field. The effects of the fertilizer treatments on survival, growth and frost heaving were measured three years after planting.

MATERIALS AND METHODS

Nursery treatment

A pre-treatment where fertilizer was applied to tree seedlings in containers with irrigation water was carried out at the Barri tree nursery in Egilsstaðir, east Iceland. This form of fertilizer application will hereafter be referred to as "nutrient loading". The plant material used in the trial was one-year-old container of seedlings of Sitka spruce (*Picea sitchensis* (Bong.) Carr.) and downy birch (*Betula pubescens* Ehrh.). The container (BCC HIKO, Sweden) volume was 93 cm^3, with 526 cells per square meter. At the beginning of the pre-treatment the birch seedlings were on average 13.6 cm in height and 2.98 mm in diameter, while the spruce seedlings were 14.6 and 2.63, respectively.

The pre-treatment started on 9 May and ended 10 June of the same year. A total of

1320 seedlings of each species were split into three groups, each of which received the following treatments: Control, Sc1 and Sc2 (Table 1). The fertilizer was mixed with water and the seedlings were irrigated twice every week for four weeks with a watering can, 22 ml pr seedling each time. The fertilizer used in the trial was a mixture containing 60% Superex plant NPK 19-4-20 and 40% calcium nitrate (15.5% N and 27.5% CaO) (Kekkilä Co., Tuusula, Finland).

At the end of each of the four weeks, 10 seedlings were randomly selected from each of the three pre-treatments and the electrical conductivity (EC) measured in the root collar. This was done by squeezing the water of each root plug into a container where EC was measured with a Mesur EC, pH and Temperature Hand Instrument (DGT-Volmatic, Denmark).

Table 1. The treatments applied to birch and spruce seedlings in the nursery trial. The fertilizer was mixed with irrigation water and applied with a watering can twice a week for four weeks, from 9 May until 10 June 2001.

	$g\ m^{-3}$	EC mS/ cm^1	Nr. of seedlings
Control	0	0	440
Sc1	10	1	440
Sc2	20	2	440

Field treatment

Site description

The study was located on two sites at the Hvammur farm in eastern Iceland (65°09'N , 14°33'V, 62 m a.s.l.) and at two sites at Litla-Drageyri in western Iceland (64°31'N , 21°31'V, 67 m a.s.l.). These sites will be identified as the E sites and the W sites, respectively. The two E sites were located on a gentle west-facing slope at an interval of 100 m, where site E 1 was located on gravel soil with less vegetative cover. The area, which was former grazing land, is partially eroded and in an early succession recovery stage and could be classified as grass heath. It was sparsely vegetated, primarily by low shrubs (*Empetrum nigrum* L. and *Thymus praecox* ssp. arcticus (Dur.) Ronn. and grass species (*Kobresia*, sp., *Festuca* sp. and *Agrostis* sp.). The two W sites were located on a flat gravel flood plain from a nearby river at an interval of 200 m. One of the sites (site W 1) was located in a more sparsely vegetated area, while the vegetation cover at the more northerly site (site W 2) was more dense. The vegetation at the W sites was similar to that of the E sites, but without the *Kobresia* sp. However, *Rhacomitrium* sp. moss was abundant on the W sites. The soils at both sites can be defined as Andisols, a volcanic soil type that accounts for about 80% of Icelandic soils (Arnalds 2004).

The vegetation surface at the sites was scarified prior to planting at both sites using a TTS-10 disc trencher (TTS Forest Oy, Finland). The trencher creates pairs of continuous furrows 10-20 cm deep and 20-40 cm wide and mounds the soil into a ridge about 20 cm high. This is a common site preparation method used in afforestation in Iceland, especially on grassland.

The seedlings were planted manually in the middle of June 2001 and were placed at the bottom of the furrows with 2 m spacing in the row and 2 m between the rows, giving a total of 2500 seedlings per hectare.

The weather conditions at meteorological stations in the vicinity of the experimental sites (Table 2) showed higher average annual precipitation at the W sites. No temperature data exist for the vicinity of the E sites for the years 2001-2003. Average annual temperature during the years 1985-2000 at the nearby station of Birkihlíð (65°00'N 14°37'W) was 3.1°C (Icelandic Meteorological Office 2009). The weather during the first winter after planting was shifting between thawing and frost combined with rather high precipitation at all sites. The annual precipitation at the W sites was more than double that of the E sites, except in 2002 when it was similar (Icelandic Meteorological Office 2009).

Experimental design

A split plot design with five replications (blocks) was used, where species constituted

Table 2. Annual precipitation and annual average temperature from meteorological stations close to the experimental sites (Icelandic Meteorological Office 2009). There were no temperature measurements available from meteorological stations near the E site during 2001-2003.

	Andakílsárvirkjun	Grímsárvirkjun	Stafholtsey
	W site	E site	W site
	64°32' N 21°41' W	65°08' N 14°31' W	64°38' N 21°35' W
Year	Precipitation (mm)		Temperature (°C)
2001	1413	841	3.4
2002	1360	1420	3.6
2003	1773	713	4.6

Table 3. Treatments tested in the field trials on spruce and birch.

Treatment	In nursery	Fertilizer in field	Nr. of seedlings
1	Control	Fertilizer (f)	200
2	Control	Without (w)	200
3	Solution 1 (Sc1)	Fertilizer (f)	200
4	Solution 1 (Sc1)	Without (w)	200
5	Solution 2 (Sc2)	Fertilizer (f)	200
6	Solution 2 (Sc2)	Without (w)	200

whole plots and fertilizer treatments sub-plots. On each of the four sites the six treatments (Table 3) were tested on spruce and birch separately. The species were randomized within each block, as were the six fertilizer treatments within species. Each sub-plot contained 10 seedlings, resulting in a total of 1200 seedlings of each species.

Each of the fertilizer treatments from the nursery trial was planted at all sites, with 15 g of the fertilizer "Gróska II" (f) or without fertilizer (w) (Table 3). The fertilizer was scattered by hand over a 15 cm circumference around the seedlings. The Gróska II fertilizer is a blend of NP easily soluble monoammonium phosphate (9-42-0) and controlled release fertilizer, Osmocote (32-0-0). Gróska II content (N) is 14%, of which half is "controlled release" with a solubility time of 8-9 months at 21°C. The phosphorus content (P) is 34% of water-soluble P_2O_5.

Data sampling and processing

Assessment of the trials was done in 2001, 2002 and 2003. The percentage of surviving seedlings was assessed at the end of each growing season, along with seedling total height, annual increment and root collar diameter. The assessments in 2001 and 2002 were not complete for all sites and therefore the focus in this paper is on the growth measurements and survival data from 2003. The shoot elongation data from 2001 are also presented to show the after-planting effect of the nursery pre-treatments on growth during the first summer. The annual shoot elongation was measured on all sites except for site E 1. The volume index ([root collar diameter in 2003]^2 x [height in 2003]) was used as a standard to compare the fertilizer effect. Frost heaving of tree seedlings was measured in the spring of 2002, but was only quantifiable on site W 1, and was rarely visible on the other sites. The frost heaving was measured as the lifting of the root collar surface in cm compared to the level of the surrounding soil surface. The seedlings that had been lifted by frost were left as they were found and not replanted.

The general linear model (GLM) procedure of the SAS system for Windows, release 8.02 (SAS Institute Inc., Cary, NC) for randomized block designs, was used to statistically test the effects of sites, tree species, blocks and fertilizer treatments on the survival, volume index and frost heaving. The PROC CORR function in SAS was used to calculate the Pearson correlation coefficients between the frost heaving, survival and volume index.

Before the statistical analyses the plot means were calculated for survival, frost heaving and volume index. The survival data were trans-

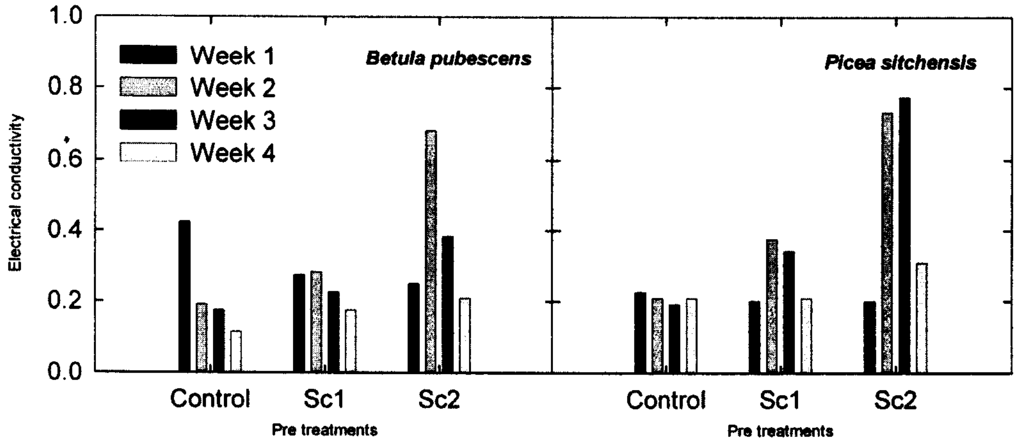

Figure 1. Electric conductivity (mS/cm) measured in water obtained from the roots of birch and spruce seedlings during the four week pre-treatment phase at the nursery

formed with the arcsine transformation and volume index was transformed with a natural log transformation to ensure normality of residuals. Differences among class means were evaluated using the Duncan's test.

Table 4. P-values for statistical analyses of transformed survival data and volume index.

Factors	Survival	Volume index
	p-values	
Model	<0.0001	<0.0001
Site	<0.0001	<0.0001
Treatment	<0.0001	<0.0001
Species	0.1807	<0.0001
Site*Species	<0.0001	<0.0001
Site*Treatment	<0.0001	<0.0001
Block	0.0007	0.0227
R-square	0.69	0.83
N	240	234

RESULTS

Electrical conductivity

The EC measured in the water obtained from roots of birch and spruce seedlings was approximately 0.2-0.25 mS cm^{-1} at the end of the first week of the pretreatment (Figure 1) for all treatments except for control seedlings of birch, 0.4. The EC was highest after the second week in the Sc2 treatments or 0.7-0.8, but dropped in the third and fourth week down to a similar level as at the beginn-ing of the pre-treatment (Figure 1).

Survival

Three years after planting a highly significant ($p>0.0001$) difference was seen in survival between sites and fertilizer treatments (Table 4). The survival was on average higher on the E sites, 91%, than on the W sites, 65% (Figure 2). The difference in survival between the species was not significant ($p=0.1807$). Both species had on average 78% survival after three years.

There was a significant effect both of the nursery treatments alone ($p=0.004$) and the field fertilization ($p<0.0001$). On average the seedlings that received the Sc2, Sc1 and control treatments in the nursery had survival rates after three years of 83%, 78% and 74%, respectively. Seedlings receiving fertilizer at the time of planting had 89% survival, while those not receiving fertilizer in the field had a survival rate of only 68% (data not shown).

Seedlings receiving the nursery treatment Sc2 and field fertilizer (treatment no. 5) had on average the highest survival, 94%, while seedlings irrigated with pure water and not receiv-

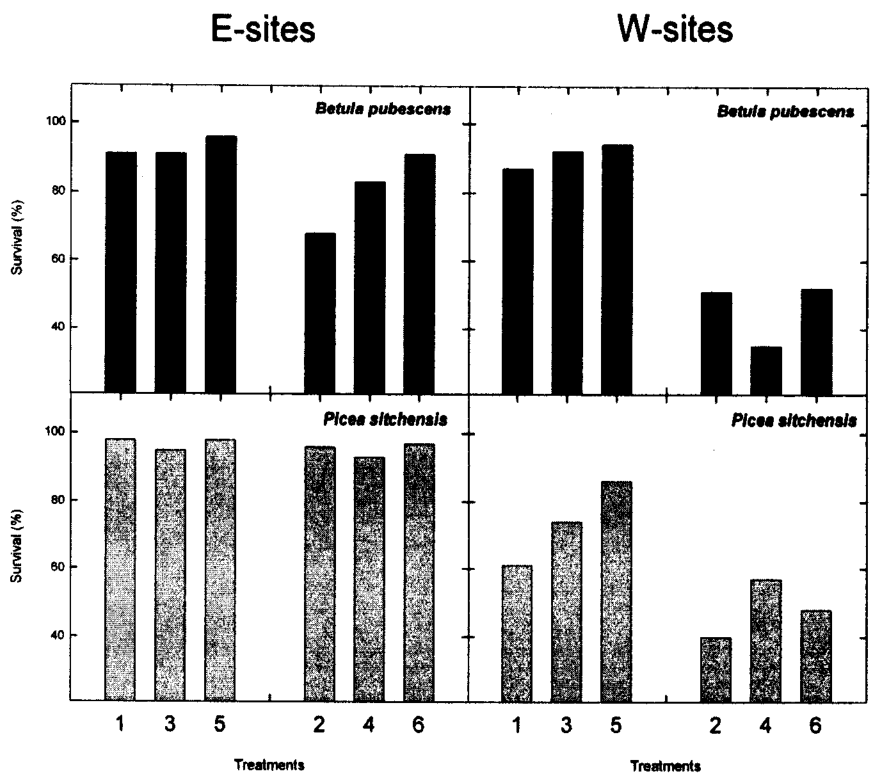

Figure 2. The average survival (%) of birch and spruce seedlings on the E sites and W sites three years after planting. Treatments 1, 3 and 5 received fertilizer at the time of planting, while treatments 2, 4 and 6 did not.

ing any fertilizer (treatment 2) had the lowest average survival rate of 64% (Figure 2).

Growth factors

There was a significant difference in volume index between sites, treatments and species ($p<0.001$) (Figure 3, Table 4). The log volume index was higher at the two W sites, 7.5 and 7.1, while it was 6.5 on the E sites. The growth of birch was slightly higher than that of spruce or 7.1 compared to 6.8. The Sc2, Sc1 and control nursery treatment gave on average log volume indexes of 7.2, 6.9 and 6.6, respectively (Figure 3). The seedlings receiving fertilizer at the time of planting (treatments 1, 3, 5) were higher in log volume index for both species at all sites (Figure 3). There was a clear trend towards increased volume of seedlings for seedlings receiving the highest dosages of Sc2 (treatments 5 and 6), while the control seedlings from the nursery were the lowest (Figure 3).

There was a clearly significant effect of the nursery fertilization on the shoot elongation during the first growing season, both for birch and spruce ($p<0.0001$) (data not shown). The greatest annual shoot elongation for birch was 15 cm for trees receiving Sc2 and fertilization in the field (treatment 5) (Table 5). There was no significant difference for spruce between the Sc1 and Sc2 treatments with or without fertilizer in the field. However the seedlings that received only pure water in the nursery (treatment 1 and 2) had the smallest shoot elongation (Table 5).

Frost heaving

One year after planting a significant difference was seen in frost heaving among fertilizer treatments ($p<0.0001$) and species ($p<0.0001$)

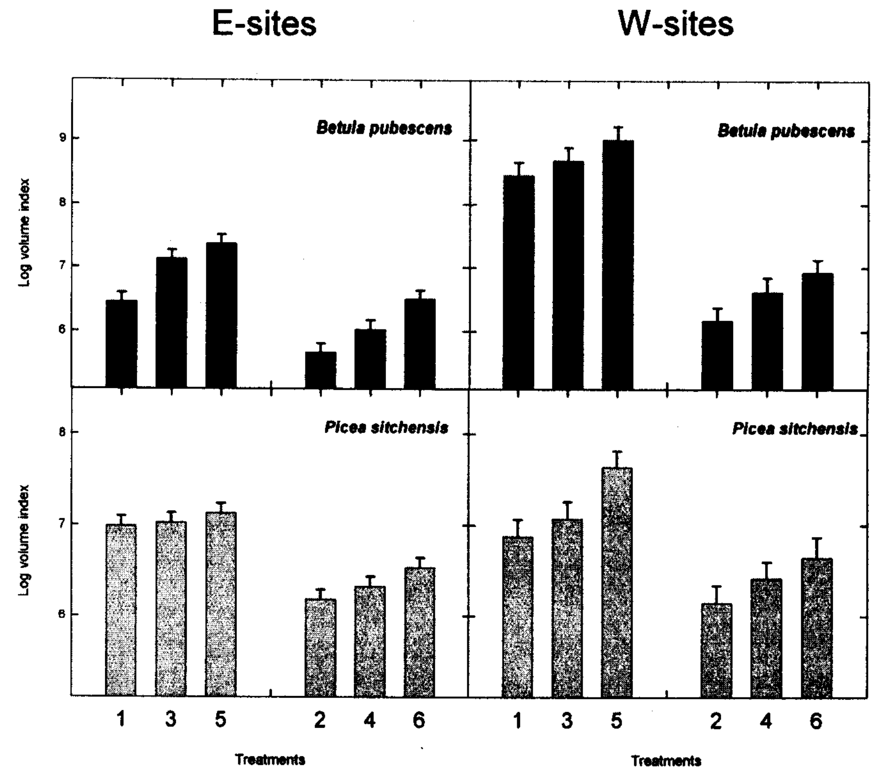

Figure 3. The average natural logarithm of the volume index of birch and spruce seedlings on the E sites and W sites three years after planting. The error bars show the standard error of the mean. Treatments 1, 3 and 5 received fertilizer at the time of planting, while treatments 2, 4 and 6 did not.

recorded on site W 1. The frost heaving was on average 3.7 cm on spruce and 2.5 cm on birch. There was less frost heaving for seedlings (Figure 4) receiving fertilizer at the time of planting in the field, 1.7 cm, while those seedlings not receiving any fertilizer in the field were lifted 4.5 cm on average (Figure 4). There was a high negative correlation between the frost heaving in 2002 and the survival in 2003, -0.88 for birch but much lower or only -0.34 for spruce (data not shown). The correlation for frost heaving and volume index was -0.64 for birch and -0.46 for spruce (data not shown).

Table 5. The average shoot elongation for birch and spruce in 2001. Means within columns followed by the same letter are not significantly different ($P < 0.05$) using Duncan's test.

	Birch			Spruce		
Treatments	**N**	**cm**		**N**	**cm**	
5	60	15.0	a	60	6.8	ab
6	60	11.7	b	60	7.3	a
3	60	11.6	b	60	6.4	ab
4	60	8.5	c	59	6.3	ab
1	60	6.6	d	60	5.3	c
2	60	4.7	e	60	5.1	c

DISCUSSION

This study shows that irrigation in the nursery with 20 g m^{-3} fertilizer solution during the last 4 weeks before planting in the field had a positive effect on survival and growth. However, fertilizer application at the time of planting further improved both survival and growth rates, and especially reduced the amount of frost heaving of tree seedlings at site W 1. These results are in accordance with earlier studies in Iceland on the effects of fertilization just after planting (e.g. Óskarsson et al. 1997, Óskarsson et al. 2006).

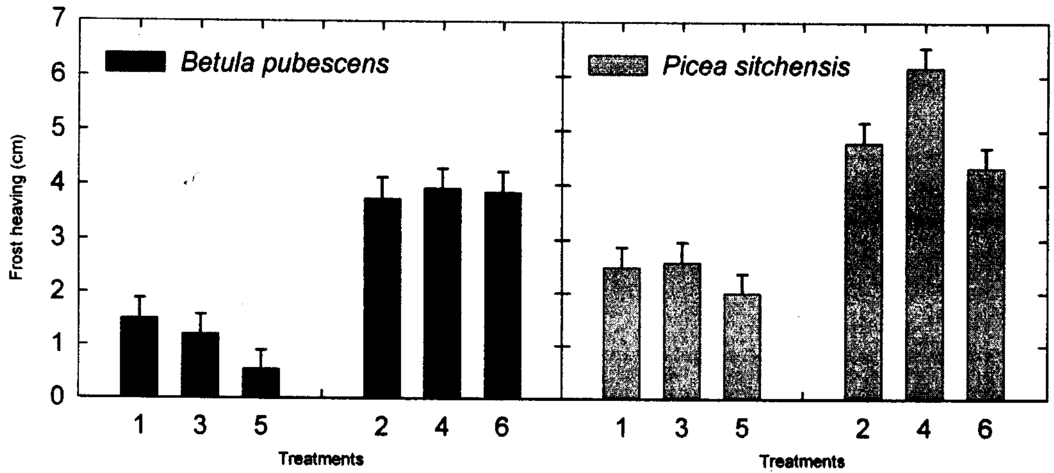

Figure 4. Average frost heaving of birch and spruce seedlings on the site W 1 measured during the spring of 2002, one year after planting. Treatments 1, 3 and 5 received fertilizer at the time of planting, while treatments 2, 4 and 6 did not. The bars show the standard error of the mean.

During the last few years some research has been done on nutrient loading and exponential nutrient loading with the aim of producing well nourished tree seedlings that are better capable of fast initial growth (e.g. Malik & Timmer 1995, Salifu & Timmer 2001). The exponential nutrient loading and related methods are adjusting the nutrient additions to tree seedlings to their growth rhythm (Malik & Timmer 1995). The method used in the present study is much simpler than these methods, but the aim was similar, i.e. to improve the nutrient status of the seedlings. The EC of the water obtained from the roots during the four weeks (Figure 4) decreased at the end of the pre-treatment after rising high in treatments Sc1 and Sc2, especially in week 2. This indicates that the tree seedlings were extracting the nutrients and storing them in their tissues.

The birch seedlings had more rapid shoot elongation when irrigated with 20 g fertilizer m^{-3} water compared with the controls (Table 5), which could make the seedlings better capable of competing with grasses and other weeds. In Canada "nutrient loaded" seedlings are regarded as well suited to sites with affluent vegetation cover, such as grasslands (Malik & Timmer 1995).

Foliar samples were not analysed in the present study. However older foliar analyses show that tree seedlings planted in Icelandic soils are rapidly depleted of nutrients if they do not get fertilizer at the time of planting (Óskarsson et al. 2006, Óskarsson & Halldorsson 2008). McAlister and Timmer (1998) showed that nutrient loading of white spruce seedlings induced increased biomass after planting. They explained this by the superior ability of nutrient loaded seedlings to subdivision of nutrients within the seedling at the onset of growth, in spite of little or no uptake of nutrients during the first summer after planting (McAlister & Timmer 1998). These results verify that seedling nutrient status at planting time is important and thus it is advisable that equipment for nutrient irrigation is available, both at nurseries and at seedling distribution sites, so as to maintain good nutrient status of seedlings prior to planting. However, the results show, beyond doubt, that fertilization at planting time is essential for maintaining plant survival and growth.

Icelandic soils are mostly of volcanic origin and tend to be high in amorphous clays and soil organic matter (Arnalds et al. 1995). From September until May frequent shifts between freezing and thawing are common, and these shifts, high precipitation and soil moisture intensify the frost heaving of plants (Arnalds 2004). There was a rather high negative correlation (r = -0.84) between the frost heaving after the first winter and the survival rate in 2003 for birch at the W 1 site. Much lower correlation was seen for spruce (r = -0.34). This could be interpreted as that the frost heaving might explain almost all the mortality in birch but not in spruce. Personal observation in the field indicated that the spruce might be more likely to survive frost heaving than the birch. The field fertilization in general had a clear positive effect on reducing frost heaving (Figure 4), an observation which is confirmed by an earlier study that was done on a similar soil with the same soil treatment (Oddsdóttir et al. 1998). The fact that seedlings receiving treatment 5 suffered less frost heaving might be a combination of more vegetation being formed around the seedlings thanks to the field fertilization and more effective root system.

CONCLUSION

Survival and growth of birch and spruce seedlings can be improved by fertilizer irrigation in the nursery during the last weeks before the seedlings are delivered for planting. However, this treatment does not substitute for fertilization in the field at the time of planting, which has a positive effect on the survival and growth and also stabilizes the soil surface and thereby reduces frost heaving of the tree seedlings.

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