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Nutrient Loading Has a Transitory Effect on the Nitrogen Status and Growth of Outplanted Norway Spruce Seedlings

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In recent years increased fertilization provided to tree seedlings in the nursery in the previous autumn has been introduced in order to promote good outplanting performance. In this paper this nutrient loading has been studied in order to determine how the increased seedling nutrient status with unaffected seedling size affects both the growth and the nutrient concentration, content and uptake of two-year-old Norway spruce container seedlings (*Picea abies* (L.) Karsten) after outplanting. Seedling development was monitored for three years at two contrasting soil fertility levels on a sandy test field in two planting years and on one natural forest outplanting site in central Finland. Nutrient loading was shown to increase shoot and root growth in a poor fertility soil during the first growing season after planting, while, after the first growing season, nutrient loading was not found to affect seedling performance. However, although nutrient loading cannot compensate for the availability of nutrients to the seedlings from the soil, it may provide an additional input for fast plantation establishment on poorer sites during the first crucial growing season after outplanting.

Keywords nursery fertilization, plantation performance, soil fertility
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1 Introduction

Fast shoot growth and root egress into the soil in outplanted seedlings are crucial prerequisites for good forest tree plantation establishment. In practice, the newly outplanted seedlings often encounter a retarded growth phase (Burdett 1990, Margolis and Brand 1990, Grossnickle 2000). This planting shock has often been associated with post-planting water availability stress, but it may also be related to a low uptake of nutrients after planting (Björkman 1953, Grossnickle

2000). Nitrogen (N) is the most growth-limiting soil nutrient in boreal forests (Viro 1965, Grossnickle 2000, Ingerslev et al. 2001). The net rate of seedling N uptake during the first growing season after planting is usually positively correlated with growth in the following season (Nilsson and Örlander 1999, Nordborg et al. 2003). After a couple of growing seasons succeeding outplanting, increasing surface vegetation competes with the seedlings and reduces the soil and seedling N concentrations (Nilsson and Örlander 1999, Smolander et al. 2000, Thiffault et al. 2003).

The growth response of seedlings may vary according to the nutrient availability of the outplanting site. The inherent site fertility and site preparation method used prior to outplanting both affect the nutrient availability to seedlings (Örlander at al. 1990, Nordborg et al. 2003, Heiskanen and Rikala 2006). An increase in the seedling N status to be planted (Malik and Timmer 1996, Rytter et al. 2003) as well as the soil N status at the planting site (Nordborg et al. 2003) can enhance the early growth of the plantation. The impact of the seedling N status at planting on its post-planting growth has been documented with reference to several tree species (e.g. Benzian et al. 1974, Margolis and Waring 1986, Malik and Timmer 1996, Rytter et al. 2003, Rikala et al. 2004). Consequently, in recent years the nutrient loading of seedlings has been introduced in order to promote good outplanting performance. This nutrient loading is defined as an increased dosage of fertilization at the nursery in order to increase the internal nutrient concentrations without increasing the size of the seedlings. However, only a few studies have been made where the nutrient loading effect on the seedling performance has been followed for more than one growing season on actual outplanting sites (Malik and Timmer 1996, Way et al. 2007). Furthermore, the nutrient loading effect has not been studied on outplanting sites with varying soil fertility.

The aim of this study was to determine how fertilization provided in the previous autumn at the nursery and the subsequently increased seedling nutrient concentration affect the growth and nutrients (concentration, content and uptake) of Norway spruce seedlings (*Picea abies* (L.) Karsten) after transplanting in soils differing in fertility. An effort was made to examine the effects of nutrient loading with higher dosages and on a larger and more prolonged scale than was done in a previous pilot study (Rikala et al. 2004) in order to confirm the implications of the results for the establishment of Norway spruce plantations. The seedling development was monitored for three years in two contrasting soil fertility levels on a sandy test field with two different outplanting years and on a natural forest outplanting site.

2 Materials and Methods

2.1 Field Experiment 1

2.1.1 Seedling Material

Norway spruce seeds from a seed orchard supplying Central Finland were sown in hard plastic, side slot containers (Plantek, PL-64F, cell volume 110 cm^3, growing density 432 cells m^{-2}, Lännen Oy; current producer BBC Oy, Säkylä, Finland) 12th June 1999. The containers were filled with fertilized (0.8 kg m^{-3} N-P-K in the proportions of 16-8-16 with micronutrients) and limed (2 kg m^{-3}) medium coarse sphagnum peat (M6, Kekkilä Oy, Tuusula, Finland). The amounts of N, P and K given in the base fertilizer were 14, 7, and 14 mg per seedling, respectively.

The seedlings were grown for two growing seasons at a research nursery (Suonenjoki, central Finland). The need for irrigation was determined by weighing a sample of the container trays weekly. The aim was to keep the water content of the peat medium at the optimum level (40–55 vol.%). The seedlings were fertilized using a commercial fertilizer solution (Superex 9, N-P-K (19-5-20) with micronutrients, Kekkilä Oy, Tuusula, Finland). Before the nutrient loading treatments, each seedling was fertigated (in addition to base fertilization) with on average of 7, 2 and 7 mg of N, P and K, respectively, during the first year, and likewise 47, 12 and 47 mg of N, P and K during the second year. During the first winter, the seedlings were stored outdoors under the snow cover.

2.1.2 Nutrient Loading Treatments (NLTs)

After height growth cessation and bud set on 24 August 2000, 12 container trays each with 64 seedlings were selected for the experiment. The container trays were randomly assigned to three blocks and three nutrient loading treatments (NLTs) (low, medium and high) with four container trays in each block. In the low NLT the seedlings received no additional nutrients. In the medium NLT they received Superex 9 fertilizer solution twice (24 and 29 August), in total 9.0, 2.5 and 9.3 mg of N, P and K. In the high NLT the seedling received double the amount given in the medium NLT (25 and 28 August).

On 25 October, 60 seedlings from each treatment (15 seedlings per tray) were randomly selected for morphological and nutrient measurements. Seedling height, length of the new shoot and stem diameter 1 cm above the peat surface were measured. The dry masses of all needles, stems and roots were weighed after drying at 60°C for 48 hours. For the nutrient analysis the compartments of the seedlings were pooled for samples by treatments and blocks. The samples were ground and N concentrations were analyzed using a LECO CHN 1000 element analyzer (LECO Corp., MI, USA). Other foliar nutrients were determined using dry ashing. The ash was dissolved in hydrochloric acid (HCl) and the analyte concentrations were determined by means of an inductively coupled plasma atomic emission spectrometer (TJA Iris Advantage, Thermo Jarrell Ash Corporation, Franklin, MA,USA).

The rest of the seedlings were packed into closed cardboard boxes (one container tray in each box) and stored over the winter at –3°C. In the following spring, on 25–28 May 2001, the seedlings were thawed in the storage boxes at +8°C. The seedling trays were transferred outdoors under a shading roof on 29 May.

2.1.3 Field Planting

The effect of the nutrient loading on the seedling performance was tested on a test field with two soil fertility levels (poor and rich). The field was a former nursery field with a mixture of sandy soil and peat (organic matter content 5.1%). Four days before planting, the rich soil plots were fertilized with a slow-release NPK fertilizer (1300 kg ha^{-1}) (Taimiston kestolannos 1, Kemira Oy, Finland) (current producer Yara Suomi Oy, Finland), which contain 9% N (methylene-urea), 3.5% P (apatite), and 5% K (biotite) and micronutrients yielding 11.7, 4.6 and 6.5 g m^{-2} N, P and K, respectively. In the spring following fertilization the soluble soil N was higher in the rich soil than in the unfertilized poor soil (Fig. 1). In the subsequent autumn, however, there was no difference ($p = 0.067$). The total soil N was 100 and 95 mg 100 g^{-1} in the spring and 83 and 75 mg 100 g^{-1} in the autumn ($p > 0.05$), respectively. The soil P did not differ between the poor and rich soils, while K was higher in the rich soil (Fig. 1) (see soil analyses below). After planting, weeds were moderated with a lawn mower.

In the experiment the poor and rich soils were positioned as the main plots, while the low, medium and high NLTs were used as subplots. Hence, the experimental layout was a split-plot design replicated in four blocks (each 30.6 m^2). The treatments were randomly assigned to the main and subplots. One basic plot unit consisted of 20 seedlings in two rows with one meter spaces between the seedlings and rows. Thus, 480 seedlings were planted ($2 \times 3 \times 4 \times 20$) on 31 May 2001.

2.1.4 Measurements

For the soil nutrient analyses 20 samples of 41.5 cm^3 were taken from the 0–10 cm soil layer and pooled for each subplot on two occasions (5 June and 5 November). For the N analysis, the organic debris was removed and the soil samples were sieved through a 2 mm sieve, dried at 40°C until reaching constant mass and stored at room temperature. The soluble soil N concentrations were determined spectrophotometrically from the extract of 1 M KCl by using a FIA analyzer (Tecator 5012, Tecator Ab, Sweden). The total soil N was determined using a CHN analyzer (LECO-1000).

The seedlings were measured in the autumn for three years, 2001–2003. The stem diameter of the planted seedlings was measured at two centimeters above the soil surface. The height of

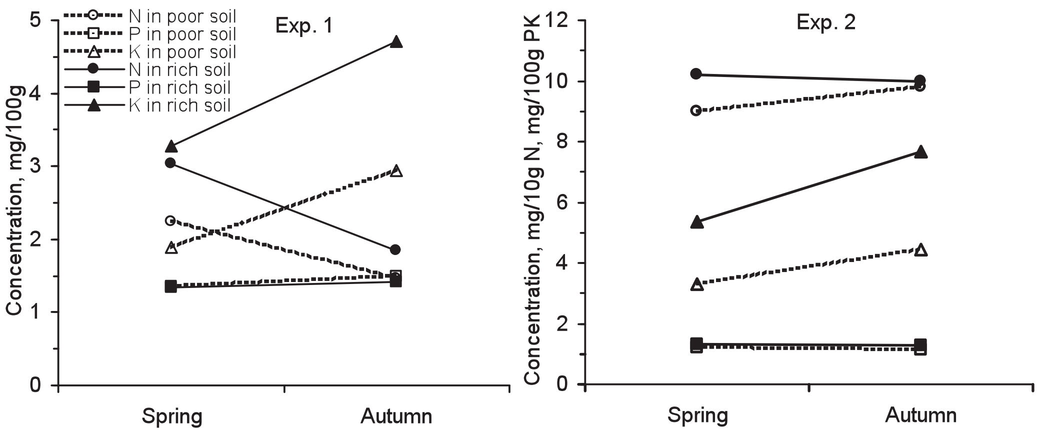

Fig 1. Means of soluble soil nitrogen and exchangeable phosphorus and potassium (N, P, K) during the first growing season of 2001 and 2002 in experiments 1 (n = 4 blocks) and 2 (n = 5 blocks).

the seedlings was measured from the soil surface to the apex of the shoot terminal bud.

One row with 10 seedlings was sampled randomly from each subplot between 17 and 21 September 2001. The seedlings (n=240) were cut at the soil surface and the root plugs with all their outgrown roots were lifted carefully. Both the shoots and the roots were stored in darkness at +5°C. After harvesting, the seedlings were divided into new (current=C) and old (C+1 and C+2) needles and stems and into new roots (outgrown from root plugs, cut with scissors) and old roots (old and new roots inside the root plug). The seedling compartments were then dried at 60°C for 48 hours and their dry masses were weighed. The samples were then ground for N analyses. The foliar nutrient concentrations were determined following the same procedure as that used after the NLTs. The total nutrient uptakes were each calculated by subtracting the nutrient content in the previous autumn from the total content in the current autumn.

2.2 Field Experiment 2

2.2.1 Seedling Material

Norway spruce container seedlings (Plantek PL64F) were grown for one year in a commercial tree nursery (FinTaimi Oy, Tuusjärvi, central Finland) according to standard growing procedures, as in field experiment 1. The seeds were sown on 12 June 2000 and the grown seedlings were transported on 27 June 2001 to the Suonenjoki nursery (Suonenjoki, central Finland), where the seedlings were short-day-treated (4–25 July) using 14-hour nights (for details, see Luoranen et al. 2008). Before the NLTs, each seedling was fertigated (in addition to base fertilization) with on average of 4, 3 and 5 mg of N, P and K, respectively, during the first year and likewise 23, 5 and 21 mg of N, P and K during the second year.

The seedlings were nutrient loaded by applying a fertilizer solution (Taimi Superex, Kekkilä Oy, Tuusula, Finland) with a watering can five times at one-week intervals (2–30 August) (for details, see Luoranen et al. 2008). Because the aim was to achieve three different foliar N levels, approximately 11, 17 and 23 mg g^{-1} for low, medium and high levels, respectively, the solution was given in three different concentrations; 0–0.1% (low), 0.1–0.15% (medium) and 0.15–0.30% (high). During the nutrient loading, each seedling received N in totals of 8 mg (low), 22 mg (medium) or 37 mg (high).

The nutrient loading had no effect on the seedling height or diameter (Luoranen et al. 2008). The seedling measurements were done likewise as in field experiment 1.

Table 1. Mean monthly temperature and precipitation for the summer months as wells temperature sums (TS) (day degrees, threshold 5°C) for the growing season of the study and the long-term average (1972–2000) at Suonenjoki, central Finland.

	Temperature, °C					Precipitation, mm				
	1972–2000	2001	2002	2003	2004	1972–2000	2001	2002	2003	2004
June	14.4	14.2	15.7	12.0	10.6	67	61	105	28	102
July	16.5	18.7	18.3	19.9	14.8	84	81	73	80	58
August	14.1	14.6	17.1	14.3	16.2	81	81	48	68	147
TS, dd	1220	1296	1456	1310	1200					

2.2.2 Field Planting

The seedlings were stored over winter in a freezer storage (–3°C), after which they were thawed at 7°C for 5 days and planted on 16 May 2002 in the sandy field used in field experiment 1. The soil was either fertilized or not with a slow-release fertilizer, as in field experiment 1, in order to emulate two different levels of soil fertility (poor and rich). The experimental layout was a split-plot design where the combinations of the three NLTs and two soil fertility treatments were replicated in five blocks. In total, 450 seedlings were thus planted (3 nutrient loadings × 2 soil fertilities × 5 blocks × 15 seedlings). 180 seedlings (3×2×5×6) were harvested on 9 October and measured for the dry mass of the seedling compartments. The remaining seedlings were left growing and their height growth was monitored for three years. Weeds were moderated with a lawn mower.

The seedling and soil measurements were performed as in field experiment 1. Other soil nutrients than N were analyzed from the extract of acidic (pH 4.65) 1 M ammonium acetate by inductively coupled plasma atomic emission spectrophotometry (ICP/AES, ARL 3800, Applied Research Laboratories, Ecublens, Switzerland). The total soil N did not differ significantly between soil fertility levels either in the spring or after the growing season in the autumn ($p > 0.05$) (Fig. 1). The soil K differed both in spring and in autumn, and the soil P in the autumn for the different soil fertility levels.

2.3 Forest Experiment

To test the early plantation performance in a typical forest site, seedlings were also planted on a fresh clearcut site (*Myrtillus* site type) in central Finland (Pieksämäki). The soil was sandy till with proportions of 25, 63 and 12% of particle sizes >0.6, 0.6–0.06 and <0.06 mm (by dry sieving). The total soil N was, on average, 0.9 mg g^{-1}. Similar reforested site types in the district have been described in more detail previously (Heiskanen and Rikala 2003, Heiskanen and Viiri 2005). The seedlings were planted in mounded spots on 22 May 2002. The NLTs were randomized in eight blocks. A total of 480 seedlings were planted (3 nutrient loadings × 8 blocks × 20 seedlings). The seedling growth was measured for three years. The seedling and soil measurements were performed as in field experiment 1.

2.4 Weather Conditions

The weather data was obtained from a nearby weather station (Finnish Forest Research Institute, Suonenjoki, central Finland). The mean air temperature and precipitation in the summer months 2001 were roughly the same as over the long-term (1972–2000) (Table 1). The temperature sum (threshold 5°C) for the 2001 growing season was slightly higher than the long-term average. Compared with the long-term averages, the whole summer of 2002 was warmer and the precipitation was higher in June but lower in July and August. The temperature sums for the growing seasons of 2002 and 2003 were higher than the long-term average. Summer 2004 had a temperature sum close to the long-term average.

Table 2. Seedling height, diameter, dry biomass and shoot to root ratio and foliar nitrogen concentration (mg g^{-1}) and content (mg $seedling^{-1}$) after nutrient loading in autumn 2000 (n = 4 trays) and 2001 (n = 3 trays) in the experiments 1 and 2 (se in parentheses). The different letters denote a significant difference within the columns in each experiment.

Nutrient loading	Height cm	Diameter mm	Dry mass g	Shoot/root	Foliar N mg g^{-1}	Foliar N mg $seedling^{-1}$
Field experiment 1						
Low	30.1 (0.9)a	3.3 (0.1)a	3.7 (0.3)a	4.8 (0.4)a	12.1 (0.2)a	36.6(2.9)a
Medium	30.9 (0.8)a	3.2 (0.1)a	3.6 (0.2)a	4.6 (0.2)a	15.6 (0.4)b	44.1(1.9)ab
High	29.5 (0.7)a	3.2 (0.1)a	3.4 (0.2)a	4.9 (0.3)a	17.5 (0.5)c	48.5(1.8)b
Field experiment 2						
Low	14.6(2.8)a	2.6(0.2)a	1.5(0.1)a	2.0(0.2)a	10.6 (0.05)a	13.9(0.9)a
Medium	16.6(2.5)a	2.8(<0.1)a	1.7(<0.1)a	2.1(0.2)a	16.1 (0.02)b	24.5(0.8)b
High	16.7(3.4)a	2.9(0.1)a	1.8(0.1)a	2.1(0.2)a	22.3 (0.07)c	35.8(1.3)c

The early summer of 2003 and 2004 was cooler and the summer of 2004 was also rainier than the long-term averages.

2.5 Statistical Analysis

The differences in the seedling morphology and nutrient concentrations and contents among the treatments at the nursery and after outplanting were compared using one-way Anova. Differences in the soil N concentration were tested using two-way Anova, where the soil fertility (two levels) and sampling time (two occasions) were used as fixed factors. The effects of nutrient loading, soil fertility (fixed factors) and block (random) were also tested with linear mixed models. The mixed models with repeated measurements were used for variables with several temporal replicates. Multiple comparison by means of estimated marginal means with Bonferroni adjustment was used to test the significance of the differences between the tested groups at $p<0.05$.

3 Results

3.1 Field Experiment 1

After autumn fertilization in the nursery the seedlings were similar in size (Table 2), while the seedling N concentration and content were the higher the higher was the NLT. The seedling P concentration and content also increased with NLT (data not shown). The nutrient concentrations of the C needles and also the N and P content of seedlings did not differ by soil fertility or NLT at harvest after the first growing season in 2001 (Table 3). The seedling K content did, however, differ by soil fertility and NLT, and the interaction effect was also significant. In poor soil the seedling P and K content also differed between low and medium NLT.

The uptake of N and P in shoot and roots did not differ between the NLTs during the first growing season (Fig. 2). The K uptake, however, increased especially with NLT in poor soil, and it also differed with the soil fertility and NLT (data not shown). The K uptake in the NLTs also differed with the soil fertility (interaction effect).

During the first growing season, the increased NLT increased the dry masses of shoot and roots in poor soil (Fig. 3). The shoot dry mass also differed between soil fertility levels and NLTs, and their interaction was also significant ($p<0.05$). In poor soil the shoot mass was lower in low NLT than in medium or high NLT. The shoot and total root masses were, on average, 48 and 38% higher in high NLT than in low NLT, respectively. In rich soil, however, the NLT had no effect on the dry masses of shoot or roots, and it also had no effect on the root to shoot ratios. There was a significant interaction between the NLT and soil fertility in the total seedling dry mass, which indicates a relatively stronger effect of NLT in poor soil than in rich soil.

During the first growing season after planting,

Table 3. Seedling nutrient concentrations and contents after the first growing season in 2001 (n = 4 blocks) and 2002 (n = 5 blocks) in field experiments 1 and 2 (se in parentheses). The different letters denote a significant difference within the columns and soil fertility treatment in each experiment.

Nutrient loading	N	P	K	N	P	K
	Concentration in new needles, mg g^{-1}			Content, mg whole $seedling^{-1}$		
Field experiment 1						
Poor soil						
Low	15.6(3.5)a	2.3(0.2)a	6.8(0.3)a	76.3(19.0)a	12.8(2.2)a	39.2(3.7)a
Medium	13.3(2.8)a	2.1(0.2)a	6.4(0.1)a	89.3(18.1)a	15.6(2.6)ab	48.5(4.5)ab
High	14.0(1.5)a	2.2(0.1)a	6.8(0.3)a	99.3(9.8)a	17.9(1.2)b	58.9(1.9)b
Rich soil						
Low	18.8(0.8)a	2.3(0.1)a	6.8(0.4)a	136.2(11.8)a	20.6(1.8)a	69.2(6.8)a
Medium	15.7(1.9)a	2.1(0.0)a	6.4(0.1)a	112.8(7.2)a	18.1(0.7)a	59.9(2.2)a
High	19.9(1.2)a	2.4(0.1)a	7.3(0.4)a	136.9(7.1)a	20.4(0.9)a	69.3(4.4)a
Field experiment 2						
Poor soil						
Low	19.2(1.8)a	2.6(0.1)a	7.4(0.4)a	69.1(10.1)a	10.6(1.2)a	28.2(2.7)a
Medium	18.5(2.0)a	2.6(0.2)a	7.6(0.4)a	76.6(10.6)ab	12.1(1.5)ab	33.0(2.8)ab
High	18.1(1.6)a	2.5(0.1)a	7.6(0.3)a	87.7(9.7)b	13.6(1.3)b	38.8(2.5)b
Rich soil						
Low	18.1(0.6)a	2.3(0.1)a	7.9(0.2)a	77.9(9.1)a	11.0(1.4)a	35.9(4.4)a
Medium	18.8(1.2)a	2.4(0.1)a	7.9(0.3)a	82.1(7.4)a	11.3(0.9)a	37.3(2.9)a
High	18.8(1.1)a	2.4(0.1)a	7.7(0.2)a	92.2(7.0)a	12.7(1.1)a	42.3(2.8)a

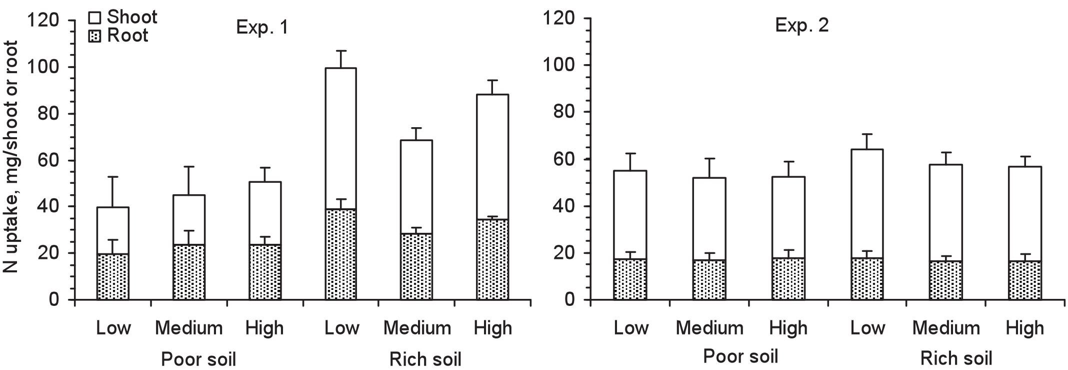

Fig 2. Uptake of nitrogen in the seedlings during the first growing season of 2001 and 2002 in the experiments 1 (n = 4 blocks) and 2 (n = 5 blocks) (mean+se). The initial nutrient contents have been assumed to be equal within the loading treatments.

height growth was lowest in the lowest NLT in poor soil (Fig. 4). There was no difference in the stem diameter among the NLTs in the combined data overall (data not shown). According to the rich soil data, however, the seedlings grew best and had largest stem diameter in the highest NLT. In the following seasons in 2002 and 2003, the height growth differences leveled off between treatments. The NLT had no effect on diameter, height or height growth in the second and third growing seasons after planting (all data not shown). Fewer than 5% of the seedlings died during the experiment, most of them (3%) died during the first growing season after planting.

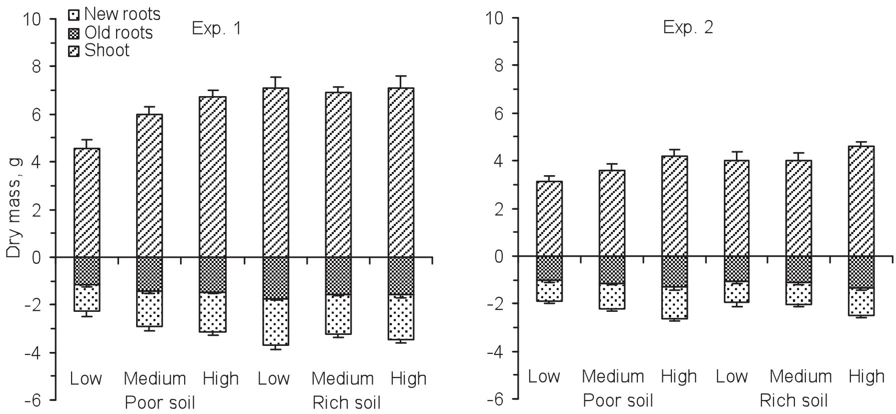

Fig 3. Seedling dry masses of shoot, new roots (root egress) and old roots after the first growing season in experiments 1 (n = 4 blocks) and 2 (n = 5 blocks) (mean+se).

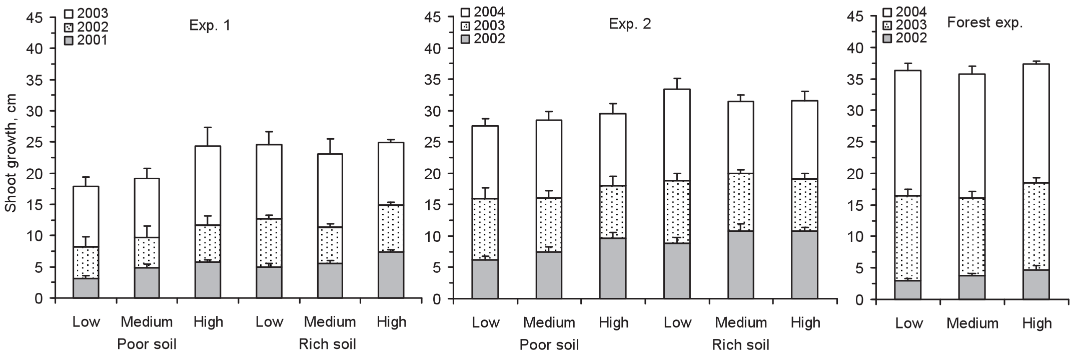

Fig 4. Yearly seedling height growth in experiments 1 (n = 4 blocks) and 2 (n = 5 blocks) and in the forest site experiment (n = 8 blocks) (mean + se).

3.2 Field Experiment 2

After the NLTs in 2001 the seedlings were similar in size as well as in their shoot to root ratio and dry masses (Table 2). The NLTs yielded average foliar N concentrations of 11 (low), 16 (medium) and 22 mg g^{-1} (high). By the following spring of 2002, after freezer storage, the respective foliar N concentrations increased to 11, 22 and 27 mg g^{-1}, probably due to the decreased dry mass of lower needles or winter respiration.

After the first growing season in 2002 the seedling N, P and K foliar concentrations did not differ by soil fertility or NLT except in K between the soil fertility levels (Table 3). According to the combined data overall, the seedling nutrient contents differed significantly among the soil fertility levels and NLTs. In rich soil the nutrient contents did not differ among the NLTs, whereas in poor soil the nutrient contents differed between low and high NLT.

The seedling N (Fig. 2) and also P (data not shown) did not differ among the NLTs after the first growing season. The soil fertility did, however, have a significant effect on the uptake of N in shoot and on the uptake of P in roots. The uptake of K differed significantly among NLTs; the soil fertility also affected the K uptake in the shoot (data not shown). The K uptake in the shoot was greater in high NLT than in low NLT in poor soil. The K uptake in roots differed also between low and high NLT in both poor and rich soils.

The seedling shoot dry mass differed after the first growing season by NLT and soil fertility in the combined data overall (Fig. 3). In the poor soil the shoot and total root masses were 35 and 40% higher in the high NLT than in the low NLT, respectively. The new root mass (root egress) did not differ by soil fertility. In poor soil the new root mass formed in low NLT and medium NLT did not differ from each other. In rich soil only low and high NLTs differed from each other, while the old root mass did not differ by soil fertility.

The higher the NLT, the greater was the seedling height growth during the first growing season (Fig. 4). Growth was also better in rich soil than in poor soil. NLT and soil fertility produced no significant interaction. In the subsequent two years the seedling height did not differ by NLT in terms of soil fertility, but the height was higher, on average, in rich soil. Within the same soil fertility the largest differences in height were approximately 5 cm or 10% for the NLTs after three growing seasons.

3.3 Forest Experiment

The post-planting height growth on the forest site was best with the highest NLT after the first growing season ($p<0.05$), but was, on average, only 1.8 cm at its largest compared with the other two NLTs (Fig. 4). In subsequent years there was no difference in seedling height between the NLTs.

4 Discussion

Prior to outplanting, the studied nutrient-loaded Norway spruce seedlings differed in their N concentrations for the different NLTs, but not in their size or dry mass, as the term of nutrient loading defines (Timmer 1997). Following the nursery phase and outplanting, nutrient loading was shown to improve seedling height growth for one growing season after outplanting (Fig. 4), as was also found in a previous study made with Norway spruce (Rikala et al. 2004). Effects lasting as long as even six years of increased growth by nutrient loading have, however, been achieved with black spruce (*Picea mariana* (Mill.) B.S.P) (Malik and Timmer 1996, Way et al. 2007).

During nursery culture, continuous growth type under conditions of high nutrient supply can inhibit root development in seedlings (Timmer 1997). High fertilization in the early stage of seedling development has also been observed to diminish the natural colonization and species richness of ectomycorrhizal fungi in Norway spruce (Flykt et al. 2008). In the present study seedlings were fertilized similarly until the NLTs commenced in late summer. During the NLTs the electrical conductivity of peat water extract increased to about 1 mS cm^{-1} (Luoranen et al. 2008) which is not harmful to roots (Landis et.al. 1989). Thus, it is obvious that the root system was not hampered by high fertilization in any NLT. Good root growth in high NLT during the planting year also suggested a good root system (Fig. 3). Hence, differences in tree species, fertilization amounts and procedures, edaphic site conditions and also climate could explain the longer duration of the nutrient-loading effect in black spruce seedlings found by Malik and Timmer (1996) and Way et al. (2007).

Nevertheless, in the present study nutrient loading was found to have no effect on the seedling height growth in rich soil, where the growth was, on average, better than in poor soil (Figs. 3 and 4). Previous studies have also shown the positive effect of nutrient loading on growth in rich soils, but usually to a lesser degree than in poor soils (Timmer and Munson 1991, Idris et al. 2004, Rikala et al. 2004). This suggests that seedlings in rich soils are less dependent on the internal N stores than seedlings in poor soils (Salifu and Timmer 2001, 2003). The fact that, in this experiment, seedlings with high NLT grew similarly in poor soil to seedlings with low NLT in rich soil during the first growing season indicates that nutrient loading could somewhat compensate for the effect of low soil fertility on seedling growth (Salifu and Timmer 2003).

The relatively minor and short-term effect of nutrient loading on seedling growth found here at the forest outplanting site can indicate relatively high soil fertility. Furthermore, clearcutting and site preparation tend to increase soil temperature and thus also enhance the nutrient mineralization (Kraske and Fernandez 1990, Örlander et al. 1990, Kubin and Kemppainen 1994, Nordborg et al. 2003). The availability of different forms of N in the soil (Heiskanen 2005, Smolander and Heiskanen 2007) could therefore be high enough to increase the foliar N concentration of outplanted seedlings (Heiskanen and Rikala 2006).

NLT was found to have no clear systematic effect on the mass of outgrown roots either in poor or in rich soil (Fig. 3). Instead, the mass of roots inside the root plug was greater in seedlings with the highest NLT than in the other NLTs. It may be the case that, despite autumn rains, a higher amount of nutrients, which have been dissolved with some delay in the root plugs of high NLT (Idris et al. 2004), may have reduced the need of the roots to grow out of the root plugs. Nevertheless, NLT had only a small effect on the root growth. This may partly be due to a decreasing difference in the soil N content between the two soil fertility levels during the growing season, either because of part of the applied fertilizer possibly being leached or because part was bound by the surface vegetation.

The present results support the idea that outplanted Norway spruce seedlings growing in N-deficient poor soils with reasonable water availability allocate proportionally more N to the shoot growth than to the root growth (Rikala et al. 2004, Heiskanen 2005). Boivin et al. (2002) also suggest that the shoot is the primary sink of retranslocated nutrients in newly planted black spruce seedlings, since, in their experiment, increased root growth was accompanied by relatively lower N content accumulation than that in the shoot. There are, however, also opposite indications of primary allocation to the roots if water or nutrients are limiting growth (Burdett 1990, Ericsson et al. 1996). The sensitivity of the root growth response to soil N availability may be partly due to dependence on current photosynthesis, since shoot growth in conifer seedlings can utilize a previous year's photosynthate reserves, while new root growth is more dependent on current photosynthates (van den Driessche 1985). It is thus probable that outplanted seedlings cannot invest much in their root growth until height growth ceases (Kaakinen et al. 2004). Neither the present nor previous short-term experiments, however, have found any differences in the shoot to root ratios of outplanted seedlings (Salifu and Timmer 2001, 2003, Rikala et al. 2004).

5 Conclusions

Nutrient loading was shown to be capable of increasing shoot and root growth in a poorer fertility soil during the first growing season after planting. Following the first growing season after planting, nutrient loading was not found to affect seedling performance. Seedling growth was, on average, better in rich than poor soil. On forest outplanting sites in general the soil N content and its availability to seedlings depend mainly on the organic matter content and its mineralization rate (Kraske and Fernandez 1990, Nordborg et al. 2003). This suggests that not only good seedling material but also the right choice of outplanting sites and site preparation are important for good seedling N status and subsequent plantation performance (Nordborg et al. 2003, Heiskanen and Rikala 2006). However, although nutrient loading cannot fully compensate for the availability of nutrients to the seedlings from the soil, it may provide an additional input for fast plantation establishment on poorer sites during the first crucial growing season after outplanting.

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