COMPETITION FOR WATER AND NUTRIENTS BETWEEN GROUND VEGETATION AND PLANTED *PICEA ABIES*

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ABSTRACT

A field experiment was established between 1989 and 1993 on four sites in southern Sweden to study the effects of the clearcut age on damage by pine weevils and competing vegetation. On each site, Norway spruce (*Picea abies* (L.) Karst.) seedlings were planted on 0- to 4-year-old clearcuts. In the study reported here, the effects of clearcut age, mounding, herbicide, mowing, and removal of slash on growth of ground vegetation were investigated. The study was restricted to analysis of second-year growth of planted Norway spruce seedlings, i.e., established seedlings. Ground vegetation was sparse on fresh and 1-year-old clearcuts. On older clearcuts the dry weight of ground vegetation ranged between 1 and 4 Mg/ha, with a considerable variation between years and sites. Seedling growth was negatively influenced by ground vegetation. Mounding and herbicide treatments reduced ground vegetation and increased seedling growth, especially on older clearcuts, while mowing had no effect. Slash removal had no significant effect on the amount of ground vegetation and did not affect seedling growth. Carbon isotope analysis (^{13}C abundance), predawn water potential, and needle conductance did not reveal a consistent difference in water stress between seedlings in undisturbed and vegetation-controlled plots, even during dry periods. There was no evidence that competitor effects on radiation were related to seedling growth response. Therefore, it was concluded that competition between ground vegetation and planted seedlings for water and light alone could not explain the observed differences in growth. The results indicate that growth was restricted by nitrogen availability.

Keywords: ground vegetation; competition; slash; herbicide; mounding; mowing; water potential; needle conductance; nitrate; ^{13}C abundance; ^{15}N abundance; *Picea abies*.

INTRODUCTION

Most of the forest plantations in southern Sweden are found in areas which previously consisted mainly of Norway spruce and Scots pine (*Pinus sylvestris*). After clearcutting, the biomass of ground vegetation is usually small. The colonisation of ground vegetation is often slow, but after 2 to 3 years most clearcuts are covered by grass (mainly *Deschampsia flexuosa*), a number of herbs (e.g., *Rubus idaeus* and *Chamaenerion angustifolium*), and bracken (*Pteridium aquilinum*). By planting on fresh clearcuts competition from vegetation can normally be avoided. However, the risk of damage to seedlings by pine weevil (*Hylobius abietis*) is high on fresh clearcuts (e.g., Beijer-Petersen *et al.* 1962) if the seedlings are not protected with insecticides. Damage by pine weevil can be avoided by planting on clearcuts older than 3 to 4 years, but the seedlings will then be negatively affected by competition from ground vegetation. In a survey it was found that about 39% of the mortality in planted Norway spruce in southern Sweden was caused by competition from ground vegetation (Skogsstyrelsen 1987). Furthermore, Nilsson & Örlander (1995) found that mortality among newly planted Norway spruce seedlings during a dry year was high on old clearcuts where there had been no vegetation control, while mortality was negligible on fresh clearcuts or when competition had been reduced (by mounding). Competition from ground vegetation may reduce the growth rate of established seedlings. Several studies have shown increased growth after removal of competing ground vegetation (e.g., Bärring 1967; Margolis & Brand 1990; Coates *et al.* 1991).

Vegetation control may be achieved either by the use of herbicides, by site preparation, or by planting in shelterwoods. Several studies show positive correlation between all these methods of vegetation control and seedling growth (Margolis & Brand 1990; Coates *et al.* 1991). However, little is known about the causes of improved growth, and these will probably differ between sites. For plantations in northern Europe, mowing of the vegetation often has no positive effect on seedling growth (Davies 1987; Nilsson & Örlander 1995). It has therefore been concluded that competition below ground for water and nutrients is more important than competition above ground for light. Nitrogen fertiliser has often failed to increase the growth of newly planted seedlings (Cole *et al.* 1990; Sutton 1995), probably because nitrogen is abundant on the clearcuts as a result of high mineralisation rates (Vitousek *et al.* 1992). In addition, foliar nutrient concentration seldom differs between seedlings subjected to different competition levels (Morris *et al.* 1993), and therefore competition for water has often been regarded as more important than competition for nutrients.

There is, however, increasing evidence that competition for nutrients may play an important role in the early stages of seedling establishment (e.g., Nambiar & Sands 1993). In a comparison between seedlings growing in herbicide-treated plots and seedlings growing in mown and control plots, there was no evidence of differences in water stress in spite of large differences in growth rates (Nilsson *et al.* 1996). Nambiar & Sands (1993) argued that "a better understanding of the dynamics of nutrients in the vegetation and the effect of silviculture on them could open ways for innovative management".

The use of stable isotopes in ecological studies has increased during the last few decades. Commonly used isotopic ratios are $^{13}C/^{12}C$ and $^{15}N/^{14}N$. The ^{13}C abundance is correlated with the water use efficiency of the seedlings, because the amount of fractionation with respect to the air-source composition can be related to intercellular carbon dioxide concentration, which is greatly controlled by stomata (Farquhar *et al.* 1989; O'Leary *et al.* 1992). After clearcutting, mineralisation of nitrogen increases rapidly because of increased soil temperature and improved substrate quality for mineralisation and nitrification (Vitousek *et al.* 1992). Clearcuts in southern Sweden are often "nitrogen saturated", i.e., the combined inputs from nitrogen mineralisation and atmospheric deposition exceed the nitrogen uptake capacity by plants and micro-organisms (Staaf & Olsson 1994). However, on older clearcuts, where the biomass of ground vegetation is higher, nitrification and leaching are reduced owing to nitrogen uptake from the ground vegetation (Emmett *et al.* 1991; Fahey *et al.* 1991). Högberg & Johannisson (1993) and Garten & Van Miegroet (1994) have shown that foliar $\delta^{15}N$ values are more positive in nitrogen-rich areas because the soil nitrogen is depleted in ^{14}N by the leaching process. $\delta^{15}N$ may therefore be used as an indication of nitrogen-availability in the soil.

A field experiment was carried out at four sites in southern Sweden between 1989 and 1993 in order to study the effects of clearcut age on damage by pine weevils and competing vegetation. Nilsson & Örlander (1995) reported that growth of established seedlings was reduced during a dry year. The aim of the study reported here was to examine whether the growth reduction caused by the presence of field vegetation was a consequence of competition for water.

MATERIAL AND METHODS

The experiment was established over a 5-year period on four sites in two main locations in southern Sweden (Fig. 1). Two of the sites (Bråtarna and Lammhultsvägen) were situated near the Asa forest research station, about 40 km north of Växjö (57°08'N, 14°47'E), and two of the sites (Skällåsvägen and Strömma) were situated near the Tönnersjöheden forest research station, 25 km east of Halmstad (56°40'N, 13°10'E). The sites are representative of relatively fertile sites in the south of Sweden and the original stands were dominated by Norway spruce. The sites were chosen to represent a variety of soil moisture and soil texture conditions. Thus, the two sites in Tönnersjöheden are dry and have coarse-textured soils whereas the soils in Asa are mesic to wet and are more finely textured. Details of the stands have been given by Nilsson & Örlander (1995).

Experimental Design

In 1988, five future clearcuts were chosen on each site. After randomisation, one area approximately 1–4 ha in size, was cut each year from 1989 until 1993 (Fig. 1). In addition to this, one area of equal size was left uncut on each site for reference purposes. Each clearcut was divided into two parts (slash treatments); on one half the slash was removed while on the other half the slash was retained (Fig. 1). The slash was evenly distributed over the clearcut and piles of slash were avoided. After removal of the slash, about 20% of the total weight of the slash remained on the ground, consisting mainly of needles and small twigs.

The experimental design was randomised blocks with subplots (split-split-split-split-plot). Each slash-treatment was divided into two blocks. These were subdivided into 1–5 planting areas depending on the year of clearcut (Fig. 1), and one area in each block was planted each year. Thus, in 1989 only fresh clearcuts (A) were planted, in 1990 fresh (A) and 1-year-old clearcuts (A+1) were planted, and so on. The age of the clearcuts is given according to the definitions used earlier by Beijer-Petersen *et al.* (1962).

Plant Material

Three-year-old bare-rooted (1.5/1.5) and 2-year-old containerised (Blockplanta 64) Norway spruce seedlings were planted alternately along rows (Fig. 1). All seeds originated

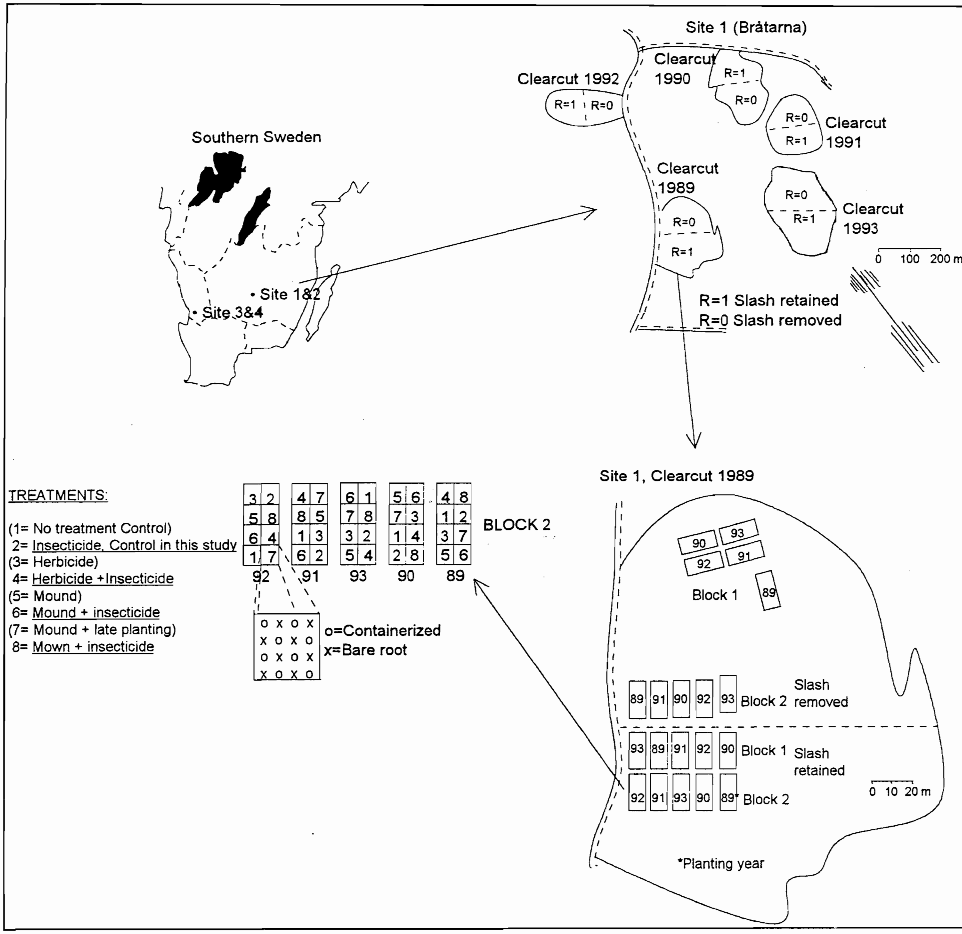

FIG. 1–Location and layout of the experimental plots. Treatments reported in the present study are underlined.

from the Maglehem seed orchard and all seedlings were from the same seedlot. The seedlings were sorted before planting, and bare-rooted seedlings shorter than 25 cm and containerised seedlings shorter than 15 cm were rejected. Planting was carried out manually around 1 May each year, except for the "late planting" treatment, which was planted about 10 June.

Within a block, the area planted each year consisted of eight treatments, with 16 seedlings in each plot (Fig. 1). As there were four blocks per clearcut, 64 seedlings were planted per year, per treatment, and per clearcut, making a total of 256 seedlings planted per year and per treatment for all sites. In total, about 31 000 seedlings were planted in the experiment, including all sites and planting years.

Before planting, insecticide-treated seedlings were dipped in a permethrin emulsion consisting of 1% active ingredient (a.i.). The seedlings were then resprayed with permethrin (0.5% a.i.) each autumn (August) and each spring (April/May). Since untreated seedlings were severely damaged by pine weevil, only the data from treatments that included the insecticide treatment (treatments 2, 4, 6, and 8 in Fig. 1) were analysed for this study.

Soil Treatments

Soil scarification (mounding) was carried out in early April in the year of planting. The mounds consisted of about 20 dm^3 mineral soil, were about 10 –20 cm high, and were carefully compressed in order to avoid air-holes, etc. On Lammhultsvägen, which was wet, the mounds were placed on upturned humus; on all other sites they were placed on mineral soil after patch scarification. The humus layer was affected by the scarification treatment to an extent of about 0.5 m^2 around each seedling.

The herbicide treatment consisted of two applications of glyphosate emulsion (12% a.i.) per growing season or whenever necessary, applied to the leaves of the ground vegetation with a wick mounted on an acrylic staff. All ground vegetation on the herbicide treatment plots was treated, except for an area of about 0.1 m^2 around each seedling, which was manually weeded.

The vegetation in the mowing treatment plots was cut whenever necessary to keep the height of the ground vegetation on each plot below 20 cm, and was also removed in the immediate neighbourhood of the seedlings. Vegetation was mowed simultaneously on all plots as soon as mowing was necessary on the plot where ground vegetation was the most abundant.

Seedling Growth and Damage

Height and ground-level diameter of newly planted seedlings were recorded directly after planting each year. Seedling height and current leader length were recorded for all seedlings after the end of the growing season (October-November) each year. Diameter at ground level was recorded for the 2-year-old seedlings at the same time. The degree of damage from each of three causes (pine weevils, competing vegetation, and the most severe of other causes of damage) was recorded at the beginning of July for seedlings planted the same year and in October for all seedlings. The degree of damage was recorded using a six level scale where 0=undamaged, 1=slightly damaged, ... 4=severely damaged, and 5=dead.

Vegetation

The amount of vegetation on the clearcuts was estimated by destructively harvesting all the ground vegetation within circular plots (0.5 m^2) at the end of August. The vegetation sample plots were located at random before planting in untreated ground adjacent to the experimental plots. On each occasion, 10 plots were harvested on each clearcut, five on the area where slash was removed and five on the area where the slash was retained. The harvested vegetation was stored in plastic bags at –20°C until it could be weighed. Fresh weight was recorded for each sample. After that, fresh and dry weights were recorded for different fractions (grass, herbs, dwarf shrubs, foliage from woody material, stems from woody materials, and other material) from a bulked sample for each harvest and slash treatment (five original sample plots per bulked sample). Mean height and percentage cover of the vegetation in a circular area (0.5 m^2) surrounding each seedling were also recorded each autumn.

Precipitation, Soil Water Potential, and Soil Temperature

The amount of precipitation was recorded with a rain-gauge (Environmental Measurements Ltd, UK) on each site. The rain-gauges were connected to Campbell CR10 dataloggers (Campbell Scientific Inc., USA) and total precipitation was recorded each day.

Soil water potential 10 cm below the soil surface was measured weekly with gypsum blocks (Soil Moisture Inc., USA). Ten gypsum blocks per clearcut were placed in untreated ground adjacent to the experimental plots (five on the part of the clearcut where the slash was removed and five on the part where the slash was retained). Four gypsum blocks per clearcut were placed in the herbicide-treated plots, two being placed in plots where the vegetation was mown and two placed in mounds. In addition, two gypsum blocks were placed each year in newly made mounds on old clearcuts. All gypsum blocks were replaced with new ones after 3 years of use.

Soil temperatures at 10 cm depth were recorded on the 1989, 1991, and 1993 years' clearcuts, using thermistors inserted in small cylinders of brass. The thermistors were connected to dataloggers. Temperatures were measured every minute; after that, hourly and daily mean temperatures were calculated. The thermistors were placed in the same way as the gypsum blocks, except that no temperature measurements were made in the "new" mounds.

Needle Conductance and Needle Water Potential

Water relation measurements were made on two different days (13 July and 4 Aug.) during a dry period (July to August) in the summer of 1994 on seedlings planted in 1993 on site 1, Bråtarna (cf. Fig. 1). At the same time, soil water potentials and weather conditions were recorded. Two different ages of clearcuts were included, one representing a fresh clearcut (cut 1993) and one an old clearcut (cut 1989). Measurements were made on two randomly selected seedlings per plot on control, herbicide, and mounding treatments. In total, the experiment consisted of 48 seedlings (eight seedlings per treatment per clearcut).

Needle conductance (g_n) measurements were made with a nullbalance porometer (Licor LI-1600, Licor Inc., Nebraska, USA). Measurements were made on current-year shoots, and a projected needle area of 5–10 cm^2 was enclosed in the chamber. Needle water potential (Ψ_n) was measured on detached shoots with a pressure chamber before sunrise (predawn water potential) and at noon, while g_n was measured at noon only. Between sampling and measurement, the shoots were stored in darkness in tubes with 100% RH.

Nitrogen and Carbon Isotope Ratios

In 1993, samples for isotope analysis were taken from current (C), 1-year-old (C+1), and 2-year-old (C+2) needles (*c.* 30 per seedling). Only shoots exposed to the south were selected. Two randomly selected seedlings per plot that were planted in 1990 on clearcuts from 1989 and 1990 on Site 1 (Bråtarna) and Site 4 (Strömma) were sampled. Further, sampling was split on slash treatment and vegetation treatment (control, herbicide, and mounding). In total 96 seedlings were sampled in 1993. In 1994, sampling was similar to 1993, except that only C and C+1 needles were taken from the same seedlings where water relation measurements had been performed.

Needles were dried in an oven at 70°C for 48 h and ground to a powder in a ball mill. Analysis of ^{13}C and ^{15}N abundance was carried out by ANCA-MS (Europe Scientific, UK).

Results are reported in $\delta^{13}C$ and $\delta^{15}N$ (per mill):

$$\delta^{13}C = 1000 \times (\text{Rsample–Rstandard})/\text{R(standard)}$$

$$\delta^{15}N = 1000 \times (\text{Rsample–Rstandard})/\text{R(standard)}$$

where R = $^{13}C/^{12}C$ and $^{15}N/^{14}N$, repectively and the working standard was wheat flour calibrated against three independent secondary standards (olive oil, sawdust, and pea protein). A higher (or less negative value) of $\delta^{13}C$ or $\delta^{15}N$ means a higher abundance.

Soil Water Sampling and Analysis

Soil water was collected at 50 cm depth using suction lysimeters. Ceramic lysimeters of P80 material (KPM AG, Berlin) were installed on Site 1 (Bråtarna) and Site 4 (Strömma). Half of the lysimeters were placed where slash was retained and half where slash was removed. Samples were taken in undisturbed soil and in mounded soil, but other vegetation control treatments were not sampled. Water from two lysimeters in the same block (*see* Fig. 1) was mixed and analysed together. In total, 152 lysimeters were installed and 76 water samples were analysed on each occasion. Sampling was done every second month from May 1993 except when soil was either frozen or too dry. In total, water was sampled on eight different dates in 1993 and 1994. After collection, water was immediately (within 1 day) sent to the Swedish Environmental Research Institute, Aneboda, Sweden, for chemical analysis.

Calculations and Statistical Analysis

Soil moisture data were presented as the number of days when the median soil water potential was lower than –0.1 MPa. This cut-off point was chosen because newly planted seedlings might be expected to suffer from water stress when the soil water potential is below –0.1 MPa (Örlander & Due 1986). For undisturbed soil, data from both slash treatments were used since slash had no effect on soil moisture (cf. Nilsson & Örlander 1995).

Temperature sums were calculated as the accumulated daily mean temperature exceeding a threshold value of 5°C.

Growth of the seedlings was calculated as the mean value of living barerooted + containerised seedlings, since preliminary analysis showed that differences in stem volume between bare rooted and containerised seedlings after only 2 years of growth did not reflect differences in growth rates but merely differences in size at the time of planting. Before the analysis of variance the mean value per plot was calculated. Stem volume was derived using the formula for a cone.

The General Linear Models (GLM) procedure for split-plot designs of SAS (SAS Institute Inc. 1988) was used to perform the statistical tests. Differences between class means were evaluated with Tukey's significant differences (HSD) mean separation test if clearcut age or treatment were significant ($p=0.05$) in the analysis of variance.

RESULTS

Weather Conditions, Soil Drought ,and Soil Temperatures

In 1992, an unusually dry period occurred beginning in May and lasting to the beginning of July. Only negligible amounts of rain fell during that period. A water deficit in the upper soil layers was found on all clearcuts older than 2 years (Table 1). The drought was most severe on Site 3, Skällåsvägen, where the median soil water potential was lower than –0.1 MPa for 41 days. More details about precipitation and soil water potentials have been reported by Nilsson & Örlander (1995). In 1994, the drought was most severe in July. Median soil water potentials below –0.1 Mpa were recorded for 26 days on site 3 (Table 1). During the other years of the study, which lasted from 1989 to 1994, precipitation was higher and low soil water potentials were not recorded at any of the locations. On fresh and 1-year-old clearcuts, soil water potentials were high even during dry years. Thus, soil water potentials below –0.1 Mpa were never recorded at any of the fresh clearcuts. Soil water potentials were higher on herbicide and mounding treatments than on the controls, even though some drought was recorded in those treatments.

Soil temperatures measured as temperature sum were highest in scarified plots; other treatments were similar to each other (Table 2). Herbicide treatment increased soil temperature on old clearcuts (A+4). Generally the soil temperature increased with increasing age of the clearcuts. This was especially evident for the herbicide treatment.

TABLE 1–Number of days per year from May to October when median of soil water potential at 10 cm depth in control plots was lower than –0.1 Mpa. Data are for clearcuts older than 2 years at four different sites

Year	Båtarna	Lammhultsvägen	Skällåsvägen	Strömma
1991	0	0	0	0
1992	18	15	41	26
1993	0	0	4	0
1994	19	21	26	18

TABLE 2–Effect of mounding, herbicide treatment, and mowing on temperature sum (accumulated daily mean temperatures exceeding the threshold value of 5 °C). Soil temperatures were measured at 10 cm depth during the vegetation period of 1993. Mean value for Båtarna, Lammhultsvägen and Strömma: A=fresh clearcut, A+2= 2-year-old clearcut, A+4= 4-year-old clearcut.

	Age of clearcut		
	A	A+2	A+4
Control	987	1056	1068
Mown	1056	1093	1125
Herbicide	994	1075	1161
Mound	1120	1206	1215

Ground Vegetation

Ground vegetation was sparse on fresh and 1-year-old clearcuts (Fig. 2). On clearcuts older than 2 years, the mean dry weight of ground vegetation was in the range of 1–4 Mg/ha and the mean vegetation cover was 50–80% for untreated plots (Fig. 2 and 3). However, the variation in the amount of vegetation—mainly grass (*Deschampsia flexuosa*)—was considerable between years and sites. The vegetation cover was reduced by herbicide and mounding treatments (Fig. 3), while slash treatment had no significant effect. The mean dry

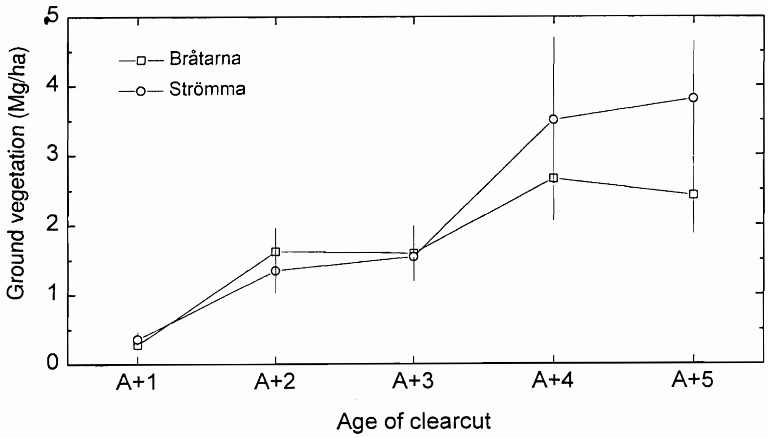

FIG. 2–Dry weight of ground vegetation (Mg/ha) on clearcuts of different ages on the study sites Båtarna and Strömma. A+1 = 1-year-old clearcut, A+2 = 2-year-old clearcut, etc. Ground vegetation was sampled in the autumn of 1994. One standard error of the mean is indicated with vertical bars.

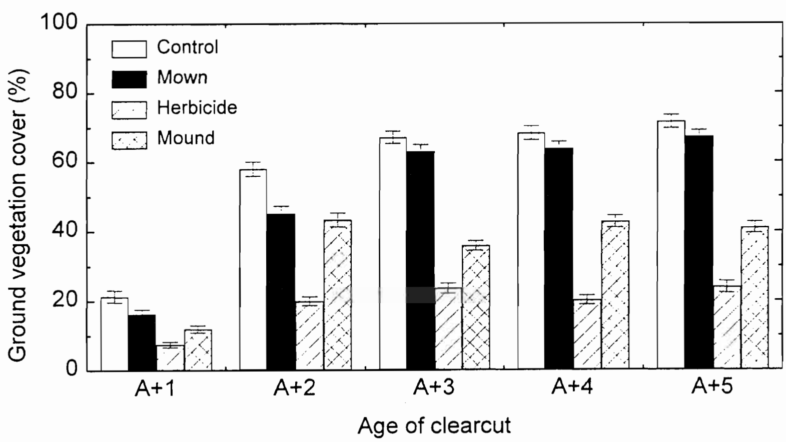

FIG. 3–Ground vegetation cover (%) around seedlings planted in 1993 in plots subjected to different vegetation control treatments on fresh to 4-year-old clearcuts. A+1 = 1-year-old clearcut, A+2 = 2-year-old clearcut, etc. Average values of measurements made in the autumn of 1994 on all four sites (n=229–254). One standard error of the mean is indicated with vertical bars.

weights for all sites and clearcuts (A+1–A+5) in 1994 on plots where slash was retained and removed, were 1859 ±187 kg/ha and 1688 ±172 kg/ha respectively.

Seedling Growth

There was a significant difference in growth between the different sites (Table 3), but the effects of the treatments were similar on all locations. As a mean for control seedlings the volume 2 years after planting was 8.7 cm^3 at Båtarna, 7.2 cm^3 at Lammhultsvägen, 14.8 cm^3 at Skällåsvägen, and 16.3 cm^3 at Strömma.

TABLE 3–Split plot analysis of variance table for stem volume index (cm^3) and length of leading shoot (cm) of Norway spruce seedlings planted in May 1993 and measured in the autumn of 1994. Five levels of clearcut ages (Age), two levels of slash treatments (Slash), and four levels of soil and vegetation treatments (Treatments) are included in the model.

	Volume index				Leading shoot			
	df	Mean Sq.	F-val.	p-val.	df	Mean Sq.	F-val.	p-val.
Site	3	2239	22.1	0.0001	3	104749	5.24	0.0153
Age	4	106.9	1.05	0.4202	4	17274	0.86	0.5125
Error A*	12	101.3			12	19978		
Slash	1	257.2	3.95	0.0614	1	136.7	0.04	0.8387
Error B†	19	65.07			19	3209		
Block	1	95.39	5.45	0.0249	1	3512	5.01	0.0309
Error C‡	39	17.52			39	700.0		
Treatment	3	515.6	33.9	0.0001	3	12200	18.4	0.0001
Treatment × Age	12	50.56	3.32	0.0002	12	1063	1.61	0.0899
Model	94	136.0	8.95	0.0001	94	8131	12.3	0.0001
Error D§	225	15.2			225	659.9		

* Denominator for the site and age effects
† Denominator for the slash effect
‡ Denominator for the block effect
§ Denominator for the treatment and treatment × age effects

On old clearcuts (A+2 and older at the time of planting), both volume and shoot growth increased significantly as a result of the vegetation control treatments (Fig. 4, Table 3). Growth of seedlings planted on fresh or 1-year-old clearcuts was about the same as those planted on older clearcuts in spite of less competition from ground vegetation. Seedlings planted in herbicide-treated or mounded plots grew better on older than on fresh clearcuts. Mowing of vegetation had no positive effect on seedling growth. The mean volume 2 years after planting of the control seedlings was about 12 cm^3 whereas the volume of seedlings planted after mounding and herbicide treatments on old (A+2 and older) clearcuts was 17 cm^3 and 18 cm^3 respectively. Slash removal increased mean volume of seedlings planted in 1993 irrespective of age of the clearcut (Table 3). The mean volume 2 years after planting for seedlings planted on fresh clearcuts during the period 1989 to 1993 was 17.7 ±0.5 cm^3 where slash was removed, and 16.0 ±0.6 cm^3 where slash was retained. Four to 6 years after planting on fresh clearcuts there was no significant effect of slash removal (data not shown).

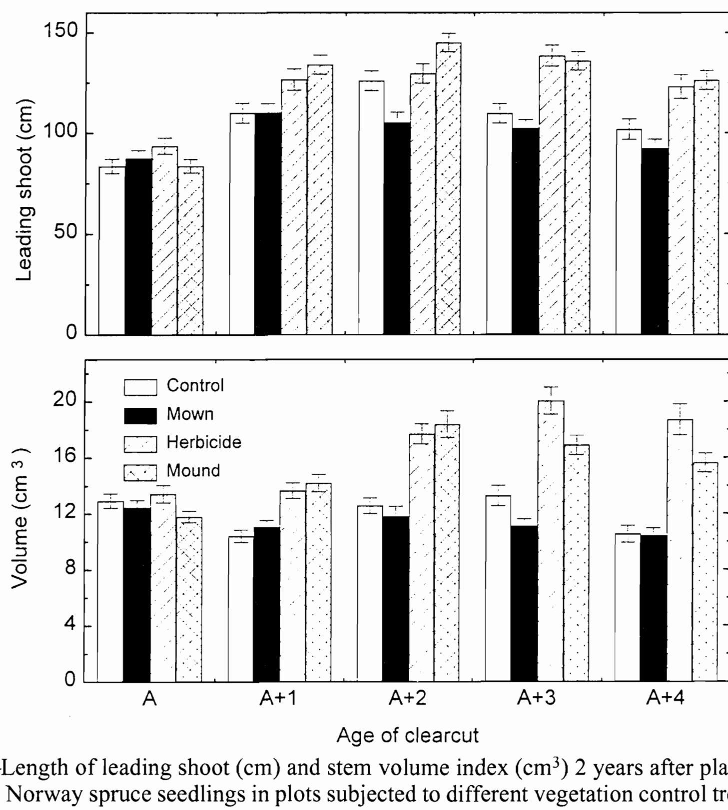

FIG. 4–Length of leading shoot (cm) and stem volume index (cm^3) 2 years after planting for Norway spruce seedlings in plots subjected to different vegetation control treatments on fresh to 4-year-old clearcuts. A = fresh clearcut, A+1 = 1-year-old clearcut, etc. Average values for seedlings planted in 1993 on all four sites (n=229–254). One standard error of the mean is indicated with vertical bars.

Nitrogen in Soil Water

The concentration of nitrate in the soil water at 50 cm depth was low on fresh clearcuts at both Båtarna and Strömma (Fig. 5). The increase in nitrate concentration followed the

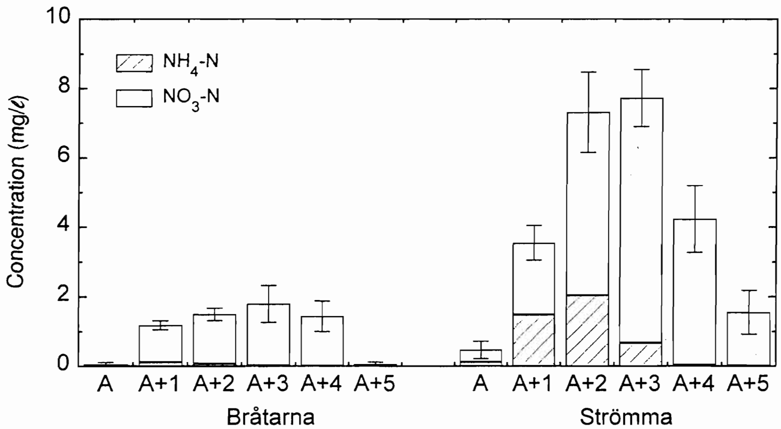

FIG. 5—Concentration (mg/ℓ) of NH_4-N and NO_3-N in soil water at 50 cm depth in control plots on clearcuts of different ages. Soil water was sampled during the summer of 1993 on fresh clearcuts (A), during the summers of 1993–94 on 1-year-old to 4-year-old clearcuts (A+1–A+4), and during the summer of 1994 on 5-year-old clearcuts (A+5). One standard error of the mean is indicated with vertical bars.

same general pattern in both locations and increased to a maximum 3 years after clearcutting (Fig. 5). Ammonium in the soil water was recorded in significant amounts only at Strömma where the nitrogen concentration reached a value of nearly 2 mg/ℓ on the 2-year-old clearcuts (A+2). However, the amount of ammonium was considerably lower than that of nitrate. On the 3-year-old clearcuts (A+3) the sum of ammonium and nitrate-nitrogen reached a value of about 7 mg/ℓ at Strömma and about 2 mg/ℓ at Bråtarna. On 4- and especially on 5-year-old clearcuts (A+5) there was a decrease in nitrogen leakage, which coincided with the time when vegetation regrowth reached its maximum values (Fig. 2). Higher mean concentrations of nitrate-nitrogen were found on plots where slash was retained (3.80 ±0.60 mg/ℓ) compared to plots where slash was removed (2.28 ±0.36 mg/ℓ.) Values refer to samples taken on all clearcuts in 1993 on both sites. The effect of slash was most pronounced on 2- to 3-year-old clearcuts (data not shown). Mounding had no effect on nitrate leaching on fresh and 1-year-old clearcuts. On clearcuts older than 2 years the mean nitrate-nitrogen concentration was 4.46 ±0.84 mg/ℓ in control and 5.05 ±0.98 mg/ℓ in mounded plots.

1992 Drought

The drought that occurred in 1992 could be detected by the ^{13}C abundance in needles of control seedlings planted in 1990 on 1-year-old clearcuts. Thus, $\delta^{13}C$ was –27.69, –26.92, –27.73 for needles from 1991, 1992, and 1993 respectively. There were no consistent differences in $\delta^{13}C$ between the vegetation control treatments and the untreated control, despite large differences in soil water potential at 10 cm depth and growth of the seedlings (for details *see* Nilsson & Örlander 1995). $\delta^{13}C$ was higher (less negative) for seedlings planted in slash than where slash was removed, thus indicating more drought stress if slash was retained (data not shown).

Although not significant, the vegetation treatments affected ^{15}N abundance in current-year needles. Mean value ±SE of $\delta^{15}N$ for controls, herbicide, and mounded treatment was –0.19 ±0.42, 1.04 ±0.39, and 0.67 ±1.06 respectively. Seedlings planted in plots where slash was retained showed higher $\delta^{15}N$ than in plots where slash was removed ($\delta^{15}N$ =1.29 ±0.35 and 0.16 ±0.59, respectively). The ^{15}N abundance varied considerably between sites. At Strömma the mean $\delta^{15}N$ was 1.16 ±0.47 compared to 0.29 ±0.53 at Bråtarna.

1994 Drought

Intensive measurements of water relations, growth, and nutrient uptake were made on Site 1 (Bråtarna) during a dry period in 1994; the following results are confined to this site only. The regrowth of field vegetation corresponded approximately with the mean value for all sites concerning the effect of age of the clearcut and treatments (Table 4 and Fig. 3). Soil water potentials at 10 cm depth in control plots were less than (–0.4 Mpa) on the old clearcut and the drought was less intense on the 1-year-old clearcut. On herbicide-treated plots no drought was recorded on either of the clearcuts (Table 4). The soil water potential at 10 cm depth in mounds was low on both fresh and old clearcuts, thus showing that the topsoil of the mounds dried out during the dry period.

Needle water potentials and stomatal conductance measured at noon showed no significant differences between the vegetation control treatments (control, mound, herbicide—Table 4). Stomatal conductance was lower on the fresh clearcut than on the old clearcut. However, practical limitations did not allow measurements to be made at exactly the same time of day and comparisons between clearcut ages cannot therefore be made. Predawn water potential was higher in seedlings on the 1-year-old (A+1) than the 4-year-old (A+4) clearcut. There were only small differences between control, mound, and herbicide treatments and these were not statistically significant. However, on the old clearcut, seedlings planted on mounded plots showed somewhat higher predawn water potentials. Slash removal had no effect on predawn water potential or noon water potential. Stomatal conductance was lower where slash was retained than where it was removed. For seedlings planted on the fresh clearcut, mean stomatal conductance was 0.148 ±0.011 cm/s, and 0.115 ±0.010 cm/s on plots where slash was removed or retained, respectively.

No difference in ^{13}C abundance was found between the different treatments or ages of clearcuts (Table 4). There was a tendency for lower $\delta^{13}C$ if slash was removed (–27.23 ±0.18) in relation to where slash was retained (–26.94 ±0.18). $\delta^{15}N$ was significantly higher in seedlings planted on the fresh clearcut than those planted on the old (Table 4). Mounding tended to increase $\delta^{15}N$ relative to controls on both fresh and old clearcuts, whereas there was a tendency for low $\delta^{15}N$ in the herbicide treatment on the old clearcut. Seedlings planted on plots where slash was retained showed higher $\delta^{15}N$ than plots where slash was removed ($\delta^{15}N$=1.06 ±0.34 and 0.51 ±0.46, respectively).

The growth of the seedlings followed the same general pattern as the mean for all sites (Table 4, Fig. 4). Seedlings planted in mounds grew better in height than controls. On the 1-year-old clearcut there was no difference in seedling volume between the different treatments. On the old clearcut, seedlings planted after vegetation treatment showed considerably higher growth than controls.

DISCUSSION

Seedling Growth

The measures of plant water stress (predawn water potential, stomatal conductance, and $\delta^{13}C$) did not relate to observed differences in growth between seedlings in plots with and

TABLE 4– Mean predawn and midday needle water potential, and midday needle conductance of Norway spruce seedlings planted in 1993 on fresh (A) and old clearcuts (A+2–A+4), and soil water potential at 10 cm depth averaged for 13 July and 4 August 1994 at Bråtarna. Other variables were measured in October 1994. Standard error within brackets

	Fresh clearcut			Old clearcut		
	Control	Herbicide	Mound	Control	Herbicide	Mound
Vegetation cover (%)	37.0(3.9)	8.8(1.6)	21.1(2.3)	63.0(2.1)	20.9(1.4)	30.8(1.5)
Leading shoot (cm)	8.0(0.6)	8.2(0.6)	10.0(0.6)	6.9(0.4)	6.3(0.4)	10.8(0.4)
Volume index (cm^3)	11.1(1.0)	12.1(1.1)	12.2(0.8)	7.8(0.5)	9.4(0.5)	11.6(0.5)
$\delta^{13}C$ (%)	–26.88(0.18)	no value	–27.04(0.62)	–27.19(0.07)	–27.40(0.58)	–26.99(0.14)
$\delta^{15}N$(%)	1.82(0.26)	no value	2.78(0.18)	–0.34(0.59)	–1.02(0.39)	0.34(0.62)
Soil water potential (-MPa)	0.15(0.06)	0.03(0.01)	0.98(0.04)	0.43(0.05)	0.08(0.02)	0.34(0.12)
Predawn water potential (-MPa)	0.25(0.04)	0.20(0.02)	0.22(0.04)	0.41(0.06)	0.35(0.03)	0.29(0.02)
Noon water potential (-MPa)	1.01(0.05)	1.02(0.06)	1.02(0.06)	1.17(0.04)	1.11(0.07)	1.07(0.04)
Needle conductance (cm/s)	0.15(0.02)	0.10(0.01)	0.14(0.01)	0.17(0.01)	0.17(0.02)	0.16(0.02)

without vegetation control treatments. This has also been found in other studies (Petersen *et al* 1988; Coates *et al.* 1991; Morris *et al.* 1993). Therefore, water stress does not seem to be an important explanation for poor growth of established Norway spruce seedlings on clearcuts in southern Sweden, even during dry years. Sands (1984), Örlander & Due (1986), and Grossnickle (1988b) have shown that poor root-soil contact after planting may result in water stress for planted seedlings, especially if the seedlings are planted in areas with low soil water potential caused by, for example, competition from ground vegetation. The difference in water stress susceptibility between newly planted and established seedlings is evident if the present results are compared with previously reported data from the same sites (Nilsson & Örlander 1995). In that study ground vegetation competition caused severe water stress in the newly planted seedlings. In the present study, with established seedlings, initial problems with poor root-soil contact were not so important.

When the seedlings have established root systems, water uptake from levels below the rooting zone of the ground vegetation may secure the water supply of the seedlings and they may therefore not compete for water with the ground vegetation (Nambiar & Sands 1993). In this study, the rooting depth of planted seedlings and competing ground vegetation was not measured. However, measurements of predawn potential and soil water potential at 10 cm indicated that the planted seedlings might have been supplied with water from greater depths. There were only small differences between seedlings in different vegetation control treatments in predawn water potential while the differences in soil water potential at 10 cm depth were more significant. As mentioned above, stomatal conductance and ^{13}C abundance also showed that the water status of the seedlings was poorly correlated to water availability as indicated by measurements of soil water potentials 10 cm below ground.

Our data indicated that growth of planted Norway spruce seedlings was restricted by the availability of nitrogen. The nitrogen availability was estimated using the abundance of ^{15}N, since a high value of ^{15}N is assumed to indicate nitrogen-rich sites (Shearer *et al.* 1974; Garten & van Miegroet 1994). Higher $\delta^{15}N$ and better growth were found on Strömma than on Bråtarna, and generally vegetation control resulted in higher $\delta^{15}N$ and better growth. Further, seedling growth would be positively correlated to the age of the clearcut if the effect of competing vegetation was removed because nitrogen availability increases in the years after clearcut. Data obtained in this study also support this hypothesis (cf. Fig 4). When slash was removed nitrogen availability decreased, but this did not negatively affect early seedling growth (*see also* discussion below). Therefore, further studies are necessary to validate the importance of nitrogen availability for seedling growth in relation to management practices.

Besides competition for water and nutrients, vegetation control treatments also influence the microclimate. Most obvious is the reduction in light levels as a result of shading. In this study, the reduction in light caused by competing ground vegetation probably had little influence on seedling growth as that was not increased as a result of mowing ground vegetation. Vegetation control also resulted in increased soil temperatures. Since root growth is highly correlated to soil temperature (Grossnickle 1988a; Lopushinsky & Max 1990) this might have great impact, especially on the early establishment of the seedlings but also on later growth of the established seedlings. It is, however, difficult to determine to what extent the observed differences in soil temperature between treatments affected the growth of the seedlings. The high soil temperature values observed in mounds are most certainly an over-estimation of the soil temperature that the roots are subjected to because the root systems were probably to a large extent spread beside and below the mounds.

Leakage of Nitrogen

Nitrate-nitrogen in soil water was positively correlated to $\delta^{15}N$ values in current needles of Norway spruce seedlings. Both nitrate-nitrogen in soil water and $\delta^{15}N$ values in current needles were higher on clearcuts in Strömma than in Bråtarna, higher in 1-year-old clearcuts than on 5-year-old clearcuts, and higher in areas where the slash was retained than in areas where the slash was removed. The hypothesis put forward by Högberg & Johannisson (1993) and Garten & van Miegroet (1994) that foliar $\delta^{15}N$ values are more positive in nitrogen-rich areas, was therefore supported by the results obtained in this study.

Herbicide treatments and soil preparation increase leakage of nitrogen (Smethurst & Nambiar 1989; Vitousek *et al.* 1992; Staaf & Olsson 1994). In this study, $\delta^{15}N$ values indicated higher leakage of nitrogen as a result of both herbicide and scarification treatments. Analysis of soil water in the scarified plots showed only limited increase in the concentration of nitrate-nitrogen. A similar result was found by Ring (1996), who suggested that low leaching below the exposed mineral soil cancels out the high amount in the mounds. Another explanation is that the favourable environment for root growth in the mounded plots (Örlander *et al.* 1990) gave high uptake of nitrogen, and therefore scarification did not cause increased nitrate-nitrogen concentrations in the soil water.

Slash Removal

Slash removal decreased leaching of nitrogen in accordance with findings in several investigations (Rosén & Lundmark-Thelin 1987; Fahey *et al.* 1991; Emmet *et al.* 1991; Staaf & Olsson 1994). Fahey *et al.* (1991) found that regrowth of ground vegetation was considerably higher if slash was left on the clearcut. The difference in leaching could therefore be partly explained by higher nitrogen uptake in the ground vegetation on plots where slash was removed. In the present investigation slash treatment had no effect on the amount of ground vegetation and could not explain the effect of slash treatment on nitrogen leaching. The most probable explanation for the difference in nitrogen leaching was therefore increased mineralisation and nitrification below the slash (cf. Smethurst & Nambiar 1990; Emmett *et al.* 1991) as a result of improved moisture conditions in the humus layer (Rosén & Lundmark-Thelin 1987; Jansson 1987).

The decrease in nitrogen availability when slash was removed had no adverse effect on early growth of the seedlings. Our data indicate that seedlings planted in areas where slash was retained suffered from water stress. A possible explanation for this was decreased soil temperatures (Örlander & Due 1986; Jansson 1987; Smethurst & Nambiar 1990) which might lead to reduced water uptake and decreased root growth (e.g., Örlander *et al.* 1990). Another explanation, not validated, was that seedlings in the slash-retained areas were more shallow rooted because of higher moisture and nutrient availability in the humus layer, and were therefore more sensitive to drought. No soil water potential measurements were made in the humus layer, but it is likely that soil moisture was higher in the humus layer if slash was retained (cf. Emmett *et al.* 1991). During dry periods soil water potentials at 10 cm depth in the mineral soil fell to approximately the same levels irrespective of slash treatment, thus indicating that the humus layer dried out even if slash was left.

Environmental Considerations

Ground vegetation is an important sink for nitrogen after clearfelling (Emmett *et al.* 1991; Fahey *et al.* 1991). This was also demonstrated in the present investigation. Thus, there was a decrease in nitrogen in the soil water when the clearcuts were colonised by grass (Fig. 2 and 5). In order to avoid leaching of nitrogen from clearcuts it might therefore be advisable to avoid methods of total weed control. In a *Pinus radiata* D. Don plantation, weed control in strips along seedling rows decreased leaching to about half compared with complete treatment (Smethurst & Nambiar 1989). Regarding mechanical soil treatment, it might also be advisable to avoid complete treatments. In particular, the combination of mechanical soil treatment and herbicide treatment could increase risks for nitrogen leaching (Vitousek *et al.* 1992).

Practical Considerations

Results indicate that the risk of drought damage on established seedlings in southern Sweden is small, whereas the risk for newly planted seedlings is substantial. The decrease in production during dry periods can be avoided with proper vegetation control—for example, by mechanical scarification. If planting is done on fresh clearcuts, seedlings will normally grow without ground vegetation being a serious hindrance (Eis 1980). Vegetation control is necessary to achieve a high production if planting is made on 2-year-old (A+2) and older clearcuts. The vegetation control should be made spot- or strip-wise to avoid unnecessary leakage of nitrogen.

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