COMPETING VEGETATION EFFECTS ON INITIAL GROWTH OF PLANTED *PICEA ABIES*

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ABSTRACT

Growth during the first two growing seasons in response to different levels of above- and below-ground competition was evaluated for Norway spruce (*Picea abies* L. Karst) seedlings on a clay moraine in southern Sweden. Spruce seedlings were planted in plots and left undisturbed, or mowed, or mowed and shaded, or treated with herbicides, or treated with herbicides and shaded. The aim of the shading treatment was to simulate the light levels below the canopy of the ground vegetation in the undisturbed plots. Spruce seedling growth was reduced by the presence of competing vegetation regardless of whether the vegetation was mown or not. Shading only reduced growth to a minor extent. Soil water potentials were reduced in all treatments during periods of drought. However, undisturbed plots showed the lowest levels of soil moisture and the periods of drought extended over longer periods of time than in plots where the vegetation was either mown or removed with herbicides. Carbon isotope analysis and measurement of needle lengths indicated no differences in water stress for seedlings in undisturbed plots compared to seedlings in herbicide-treated plots. Seedlings in undisturbed and mown plots had lower needle nitrogen concentrations than seedlings in herbicide-treated plots. Therefore, it was concluded that competition between weeds and seedlings planted on clay moraine was mainly below ground and that lower availability of nitrogen in untreated and mown plots may have been an important limitation for growth.

Keywords: water stress; nitrogen; light; weeds; herbicides; mowing; shade; *Picea abies*.

INTRODUCTION

Competing vegetation can reduce soil moisture, nutrients, light, and soil temperature of reforestation sites, thereby reducing successful seedling establishment (Gjerstad *et al.* 1984; Walstad & Kuch 1987; Grossnickle & Heikurinen 1989). Furthermore, herbaceous and woody weeds can provide a habitat for rodents that might cause damage to the planted seedlings, and damage by fungi may be more severe due to the moister conditions during autumn, winter, and spring below herbaceous weeds. A number of studies show that vegetation manipulation improves tree growth and/or survival (e.g., Sands & Nambiar 1984; Lanini & Radosevich 1986; Flint & Childs 1987; Petersen 1988). Therefore, vegetation management is an important silvicultural consideration when establishing new stands.

Many studies of vegetation manipulation have come to the conclusion that water stress as a result of competition is the factor most limiting growth of the crop trees (e.g., Conard & Radosevich 1982; Sands & Nambiar 1984; Cole & Newton 1986; Petersen *et al.* 1988). Newly planted seedlings are especially sensitive to competition for water because their root distribution is limited compared to naturally established ones. If soil water is limiting root growth, then photosynthesis might be impaired, leading to a negative cycle and ending up with slow growth or death of the seedlings (Burdett 1990).

Competition for light may also be important. Self-shading and costs of support tissues may raise the radiation requirement for maximum crown photosynthesis to nearly full sunlight (Givnish 1988). However, too much light may result in photo-inhibition, especially in combination with other environmental factors such as frost (Strand & Lundmark 1987). The planted seedlings may be insulated from surrounding air in the calm environment below herbaceous and woody weeds by an increased boundry layer. Then the role of stomata may decrease as a factor limiting transpiration (Jarvis 1985).

The role that competition for nutrients plays in determining competitor influence on spruce growth is less clear. On infertile sites, competition for nutrients may overwhelm other competitive influences (Smethurst & Nambiar 1989; Nambiar & Sands 1994). However, on more fertile sites, competition for nutrients is considered to be of minor importance in the early stage of seedling development (Harper 1977; Morris *et al.* 1993). In addition, competition may be exerted by the release of chemicals that are toxic to other species (Jarvis 1964; Nilsson *et al.* 1993).

The use of natural abundance of different isotopes has increased in ecological studies during the last few decades. Commonly used isotopic ratios are $^{13}C/^{12}C$ and $^{15}N/^{14}N$. The $\delta^{13}C$ abundance is correlated to 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 which is greatly controlled by stomata (Farquhar *et al.* 1989; O'Leary *et al.* 1992). Furthermore, 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. $\delta^{15}N$ abundance may therefore be used as an indication of nitrogen-availability in the soil.

To our knowledge, no studies have been undertaken that experimentally separate competition for water and nutrients below ground from competition for light above ground in a situation with interspecific competition between Norway spruce seedlings and ground vegetation.

This study is a part of a series of investigations aimed at increasing the knowledge of, and quantifying the importance of, competition for water and nutrients below ground, and for light above ground, with regard to tree seedlings. In this study, development of the growth of Norway spruce seedlings in response to different levels of above- and below-ground competition was examined.

MATERIAL AND METHODS

Experimental Sites

The field study areas were located about 25 km north of Lund in southern Sweden (lat. 55°50', long. 13°24', 85–105 m a.s.l.). The experiment was laid out on two clearcuts about 1 km apart. Before clearcutting in March 1990, one stand was dominated by 100-year-old oak (*Quercus robur* L.) and the other stand was dominated by 120-year-old beech (*Fagus sylvatica* L.). The soil was a clay-silty till on both sites (about 20% of small particles <0.02 mm). Ground vegetation in the former oak stand was sparse and dominated by herbs. In the former beech stand the ground vegetation was more plentiful and dominated by grass (*Deschampsia flexuosa* (L.) Trin.). Site index for Norway spruce (dominant height at a total age of 100 years) was about 34 m, according to transference function between beech and Norway spruce (Carbonnier & Hägglund 1969). Both sites were fenced against deer and roe deer in the spring of 1990, and the fences were complemented with rabbit net in the spring of 1991.

Experimental Design

The experiment was organised in three blocks, one in the former beech stand and two in the former oak stand. Within each block five treatments were randomly assigned to plots of 450 m^2 (15 × 30 m). Treatments examined were as follows:

- C Undisturbed area
- H Herbaceous weed control
- HS Herbaceous weed control, seedlings shaded with shading cloth
- M Herbaceous vegetation mown
- MS Herbaceous vegetation mown, seedlings shaded with shading cloth.

In each plot a total of 60 Norway spruce seedlings were planted in May 1990. Two-year-old containerised seedlings from the seed orchard Maglehem were used in the 1990 planting. In order to allow excavation of the root systems of a sample without disturbing the root systems of neighbours, the seedlings were planted in 10 groups within each plot. The distance between seedlings within a group was 0.3 m and the distance between groups was 1.5 m. In autumn of 1990 and 1991 all seedlings in five groups per plot were harvested (*see* below). In May 1991 and May 1992 the sites of the harvested groups were replanted. Seedlings used in 1991 and 1992 were bare-rooted transplants (1.5+1.5) originating from the same seed orchard as the seedlings used in 1990.

The H and HS plots were cleared of ground vegetation with a small excavator (1 T) before planting. When clearing the plots, care was taken not to disturb the soil which was loosened as little as possible but inevitably became somewhat compressed. Thereafter, the H and HS plots were kept free from competing vegetation by the use of herbicides. The herbicide treatment consisted of from three to six applications of glyphosate emulsion (12% a.i.) per growing season. The herbicide was applied directly to the leaves of the ground vegetation with a wick mounted on an acrylic staff (Zone Unkraut-Streichstab). All vegetation on the plots was treated, except for an area of about 0.1 m^2 nearest to the seedlings which was manually weeded. M and MS plots were mowed with a clearing saw whenever necessary to keep the height of the ground vegetation below 20 cm. Seedlings in MS and HS treatments were shaded with shading cloth (Spectral neutral aluminium shading material: AB Ludvig

Svensson, Kinna, Sweden). The shading cloth was mounted above the seedlings, permitting about 25% of incident PAR (photosynthetic active radiation $\mu mol/m^2/s$) to penetrate to the seedling level.

Measurements

Total height and diameter at ground level were measured at the end of each growing season for all seedlings (in total 900 seedlings each growing season). At the same time, cause and degree of damage to the seedlings were recorded. At the end of the growing seasons of 1991 and 1992, seedlings planted in 1991 and 1992 were destructively harvested. Dry weight of seedling components was recorded after drying at 70°C for 48 hours. Numbers of seedlings measured are listed in Table 1. Average needle length of 20 needles from current shoots on the top branches was measured for needles sampled from the harvested seedlings.

TABLE 1–Number of seedlings per treatment on which different measurements of dry weight were made

	Planting year 1991		Planting year 1992
	Year 1	Year 2	Year 1
Total above-ground weight	30	30	30
Dry weight separated into current shoots and older shoots	15	30	30
Dry weight separated into current needles, current twigs, older needles, and older twigs (including stem)	15	30	15
Dry weight of the root system	15	30	30

Needle Nitrogen Concentration, and ^{15}N and ^{13}C Abundance

In the autumn of 1992, samples of current-year needles were taken from all current shoots of seedlings planted in 1991 and 1992. All treatments were sampled and the number of samples varied between 9 and 16 per treatment. The needles were oven-dried at 70°C for 48 hours and ground to a fine powder in a ball mill. All samples were analysed separately. Analyses of ^{13}C and ^{15}N abundance and nitrogen concentration were carried out by ANCA-MS (Europe Scientific, UK). Results are reported in $\delta^{13}C$ and $\delta^{15}N$ (per mill):

$$\delta^{13}C=1000 \times (R_{sample}-R_{standard})/(R_{standard}) \quad (1)$$

$$\delta^{15}N=1000 \times (R_{sample}-R_{standard})/(R_{standard}) \quad (2)$$

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

Assessment of Ground Vegetation

Biomass of grasses, herbs, and woody vegetation was assessed in the middle of the third growing season (July 1992). Five 0.49-m^2 circular plots were located immediately outside each C plot. After cover assessment, the vegetation was clipped at groundline, separated into grasses, herbs, and woody fractions, bagged, and dried at 70°C for 48 hours before dry weight was registered. Also, light penetration down to seedling levels was registered on two occasions during the third growing season.

Meteorological and Hydrological Measurements

In one block in the former oak stand, soil temperature 10 cm below ground level was recorded hourly at two positions in each plot. The measurements were made with thermocouples (copper-constantan, ø= 0.2 mm) connected to a data logger (Campbell, CR10, Campbell Scientific Inc., USA). Furthermore, air temperature at ground level and 1.7 m above ground was recorded hourly and precipitation was recorded daily. Air temperature was measured with thermocouples (copper-constantan, ø=0.05 mm) and precipitation was measured with a rain-gauge (Environmental Measurements Ltd, UK).

Soil water potential 10 cm below ground level was registered with gypsum blocks (Soil Moisture Inc., USA) at two positions in each plot in all blocks. The readings from the gypsum blocks were recorded once a week during all three growing seasons.

Photosynthetic active radiation (PAR) (Model LI-190SA, LiCor Inc, Lincoln, Ne, USA) and red-far red ratio (Skye, SKR 110, UK) were measured at seedling level and above the ground vegetation in July 1992. Measurements were made on 10 locations in each block in the middle of the day (11.00–13.00) when the sky was clear.

Data Analysis

The General Linear Model (GLM) procedure of SAS® was used to perform the statistical tests (SAS Institute Inc. 1988). The following model was used in analyses that included planting year:

$$y_{ijk} = m+A_i+B_j+AB_{ij}+C_k+BC_{jk}+e_{ijk} \quad (3)$$

where A_i = block effects
B_j = effects of planting year
AB_{ij} = interaction between block and planting year
C_k = effects of vegetation management and shading treatments
BC_{jk} = interaction between planting year and treatments.

The above model was a mixed model. Effects of block (A_i) and the interaction between block and planting year (AB_{ij}) were regarded as random effects, while effects of planting year (B_j), effects of treatments (C_k), and the interaction between planting year and treatments (BC_{jk}) were regarded as fixed effects. The following mean squares were used as denominators for the fixed effects and their interactions: (1) $MS(AB)_{ij}$ for the B_j effect; (2) $MS(e_{ijk})$ for the C_k and $(BC)_{jk}$ effects.

The following model was used for analysis of second-year dry weight of seedlings planted in 1991 (planting year not included in the model) and for analyses of needle nitrogen concentration, and ^{15}N and ^{13}C abundance for each seedling age separately:

$$y_{ik} = m+A_i+C_k+e_{jk} \quad (4)$$

where A_i = block effects, and
C_k = effects of vegetation management and shading treatments.

Differences among class means were evaluated with Tukey's significant differences (HSD) mean separation test.

RESULTS

Environmental Factors

During the early summer of 1990 there was no drought in any treatment because of frequent precipitation (Fig. 1 and 2). In August 1990 precipitation was low and soil water potential decreased in all treatments. However, average soil water potential 10 cm below ground did not drop below –0.1 MPa in the H and M treatments although it dropped below –0.4 MPa in the C treatment (Fig. 2). During 1991, drought was not recorded on any occasion owing to abundant precipitation during the whole growing season (data not shown). During the early summer of 1992, a drought affected southern Sweden (Fig. 1). As a consequence, average soil water potentials below –0.1 MPa were registered in all treatments from the beginning of June to the middle of July. The drying out of the soil was slower in the H plots

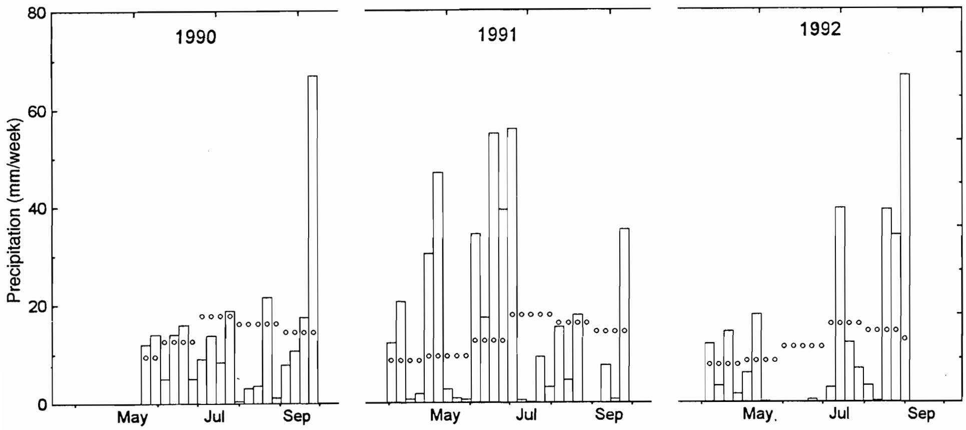

FIG. 1–Precipitation (mm/week) during the periods 15.5.90–30.9.90, 1.4.91–30.9.91, and 4.1.92–1.9.92 (bars). Average precipitation during a 30-year-period (1931–60) on a nearby weather station is indicated by circles.

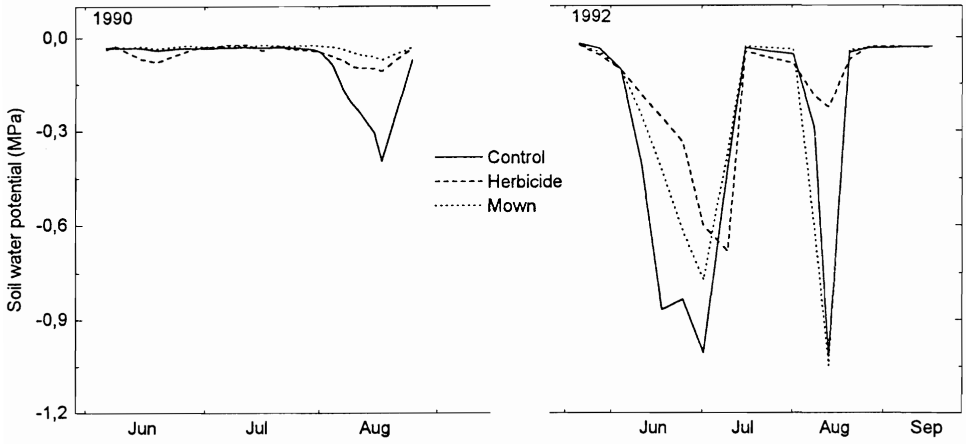

FIG. 2–Soil water potential 10 cm below ground in control (C), herbicide-treated (H), and mown plots (M). The soil water potential was recorded weekly during the growing season and values are shown from the measurements in 1990 and 1992.

than in the M and C plots but when the drought was most severe (in the beginning of July) the average soil water potential was below –0.4 MPa in all treatments (Fig. 2).

Soil temperature 10 cm below ground was highest in the H treatment, lowest in the C treatment, and intermediate in the M treatment during all three years (Fig. 3). The differences in soil temperature between treatments were greatest in the beginning of the growing seasons and greater in 1992 than in 1990. The soil temperature was on average about 4°C higher in the H treatment than in the C treatment between 15 May and 1 July 1992. During the same period, the average difference in soil temperature between H treatments and M treatments was about 2.6°C.

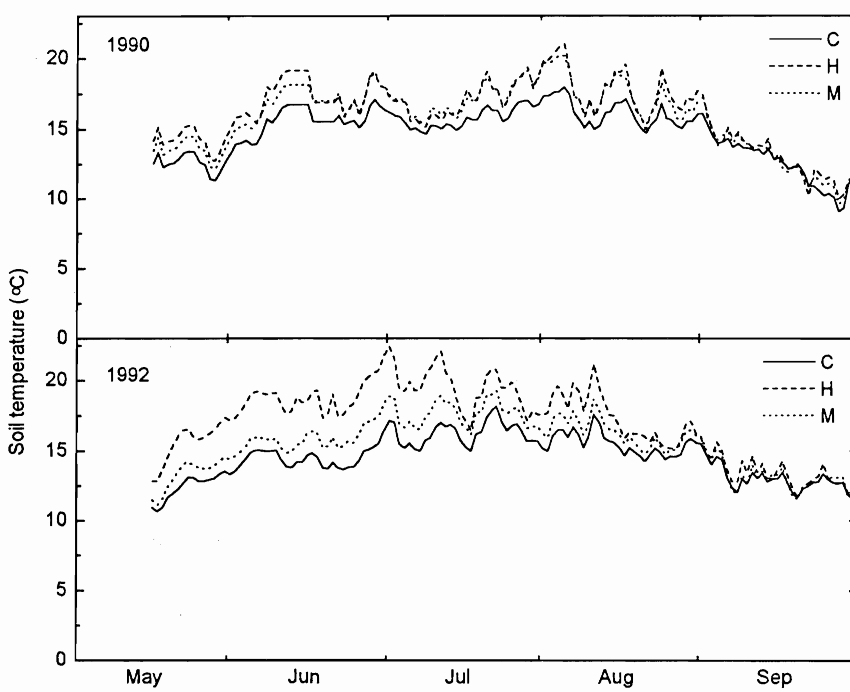

FIG. 3–Soil temperature 10 cm below ground in control (C), herbicide-treated (H), and mown plots (M). The soil temperature was recorded continuously during the growing season and values are shown from the measurements in 1990 and 1992.

Light measurements during a cloud-free day in July 1992 revealed that seedlings in the C plots in blocks one and two received about 30% of the light on the H plots. Incident photosynthetic active radiation (PAR) was 1440±20.5 μmol/m^2/s above the ground vegetation and 421±32.7 μmol/m^2/s below the vegetation. The red-far red ratio was 1.02±0.007 above the ground vegetation and 0.65±0.017 below it.

In July 1992 the biomass of ground vegetation was on average about 5000 Mg/ha in the C plots. Species composition and biomass varied considerably between different blocks. In blocks one and two (the old oak site) a considerable amount of the ground vegetation consisted of woody and herbaceous plants while the ground vegetation in block three (the old beech site) consisted exclusively of grasses.

Seedling Growth

Spruce seedling diameter, shoot biomass, and root biomass were increased by the herbicide treatment (Table 2). Seedlings in the M plots had significantly (p = 0.05) higher groundline diameter after the first growing season compared to seedlings in C plots. After the second growing season, no statistically significant differences were found between seedlings in M and C plots. No significant effect of the treatments was found on first-year height, but second-year height was greater for seedlings in the H treatment than for seedlings in M, MS, and C treatments.

Shade affected first-year groundline diameter and root biomass negatively for seedlings in H plots but not for seedlings in M plots (Table 2). In the 2-year-old seedlings, shade had no statistically significant effect on the size of the seedlings, either in H plots or in M plots.

TABLE 2–Height, groundline diameter, volume index, shoot biomass, root biomass, and shoot-root ratio after one and two growing seasons for seedlings planted 1990–92 in plots with different vegetation control treatments (H=herbicide; HS=herbicide and shade; M=mown; MS=mown and shade; C=control). Values on the same row within growing season followed by the same letter are not significantly different (p=0.05)

	Planting year	First growing season					Second growing season				
		H	HS	M	MS	C	H	HS	M	MS	C
Height (cm)	90	39.3	37.8	38.1	38.2	36.2	62.1	57.4	48.6	54.9	49.2
	91	42.9	43.1	42.1	40.8	43.9	60.8	59.4	54.3	49.8	49.2
	92	42.3	41.1	41.1	42.6	39.2					
		a	a	a	a	a	a	ab	b	b	b
Groundline diameter (cm)	90	0.89	0.78	0.71	0.7	0.64	1.54	1.33	1.04	1.06	0.71
	91	0.92	0.85	0.76	0.76	0.77	1.48	1.33	1.01	1.03	0.89
	92	0.79	0.75	0.75	0.72	0.66					
		a	b	c	d	a	a	b	b	b	
Shoot biomass (g)	91	28.4	23.6	22.3	19.6	20.1	98.9	90.2	48.4	44.1	34.7
	92	26.8	22.6	19.6	19.7	18.4					
		a	ab	b	b	b	a	a	b	b	b
Root biomass (g)	91	13.4	9.9	10.7	6.7	7.1	45.7	41.4	20.6	18.5	12.6
	92	18.1	13.2	11.3	10.8	9.2					
		a	b	bc	bc	c	a	a	b	b	b
Root/shoot ratio (g/g)	91	0.47	0.42	0.48	0.34	0.35	0.46	0.46	0.43	0.42	0.36
	92	0.68	0.58	0.58	0.55	0.50					
		a	ab	abc	bc	c	a	a	a	a	a

Seedlings planted in 1991 had statistically significantly lower root biomass than seedlings planted in 1992 while no statistically significant effect of the planting year was found in shoot biomass (Tables 2 and 4). No statistically significant interaction between year of planting and vegetation control treatment was found (Tables 3 and 4).

Seedling Morphology

First year root-shoot ratio was lower for seedlings in the C plots than in the M plots (Table 2). After the second growing season there were no differences between vegetation

TABLE 3–Analysis of variance table height and diameter for Norway spruce seedlings planted in 1990, 1991, and 1992 in different vegetation control treatments. Plant=planting year, Treat=vegetation control and shading treatment.

		Height year 1			Height year 2			Diameter year 1			Diameter year 2		
	df	MS	F	p	MS	F	p	MS	F	p	MS	F	p
Plant	1	9660	8.04	0.0396	194	0.03	0.871	215	4.98	0.082	0.041	0.0	0.9898
Block	2	6510			38741			18			1249		
Block*Plant	2	1200			5734			43			210		
Treat	4	250	0.7	0.5536	12952	5.6	0.0053	449	30.6	0.0001	4550	18	0.0001
Treat*Plant	8	593	1.81	0.1236	2095	0.9	0.4875	16	1.12	0.3813	52	0.2	0.9285
Error	20	327			2330			14			247		
Model	9	2177	6.55	0.0001	11487	4.93	0.0017	128	9.02	0.0001	1640	6.6	0.0003

TABLE 4–Analysis of variance table for shoot and root biomass and root/shoot ratio for Norway spruce seedlings planted in 1991 and 1992 in different vegetation control treatments. Plant=planting year, Treat=vegetation control and shading treatment

		Shoot biomass			Root biomass			Root/shoot ratio		
	df	MS	F	p	MS	F	p	MS	F	p
Year 1										
Plant	1	16.3	1.30	0.3719	68.4	1865	0.0005	0.22	29.8	0.032
Block	2	14.2			1.24			0.002		
Block*Plant	2	12.5			1.24			0.002		
Treat	4	70.2	5.99	0.0038	56.5	14.79	0.0001	0.022	8.21	0.0009
Treat*Plant	8	2.32	0.20	0.9357	3.83	1.0	0.4344	0.002	0.93	0.4706
Error	12	11.7			3.82			0.003		
Model	17	27.7	2.37	0.0525	24	6.29	0.0004	0.026	9.5	0.0001
Year 2										
Block	2	482			37.6			0.007		
Treat	4	2626	11.43	0.0022	655	14.51	0.001	0.005	1.23	0.3706
Error	8	229			45.2			0.004		
Model	6	1911	8.32	0.0043	450	9.95	0.0024	0.006	1.34	0.3422

control treatments in root-shoot ratio (Tables 2 and 4). Furthermore, no effect of the shade treatment on the root-shoot ratio could be found either for seedlings in herbicide-treated plots or for seedlings in mown plots (Table 2).

No differences were found in current needle length between seedlings in different vegetation management treatments or between shaded and unshaded seedlings. The needles on current shoots in 1991 were statistically significantly longer than needles on current shoots in 1992, both for 1-year-old and for 2-year-old seedlings (Table 5).

Nitrogen Concentration, $\delta^{13}C$, and $\delta^{15}N$

Analysis of variance showed no statistically significant difference in ^{13}C abundance between treatments, either between vegetation control or between shade treatments (p=0.71 and 0.32 for 1- and 2-year-old seedlings, respectively) (Fig. 4). Two-year-old seedlings had lower ^{13}C abundance than 1-year-old seedlings. For 1--year-old seedlings, the vegetation

TABLE 5–Length of current needles (cm) for 1- and 2-year-old seedlings planted in plots with different vegetation control treatments (H=herbicide; HS=herbicide and shade; M=mown; MS=mown and shade; C=control). Within seedling age values from needles sampled in 1991 and 1992 are shown. Standard error of the mean is indicated in parentheses.

	1-year-old seedlings		2-year-old seedlings	
	1991	1992	1991	1992
H	1.43 (0.091)	0.74 (0.044)	1.47 (0.091)	0.96 (0.141)
HS	1.44 (0.112)	0.85 (0.034)	1.64 (0.111)	0.90 (0.095)
M	1.36 (0.085)		1.61 (0.071)	
MS	1.43 (0.085)	0.75 (0.049)	1.54 (0.085)	1.12 (0.180)
C	1.42 (0.072)	0.78 (0.040)	1.56 (0.072)	0.90 (0.058)

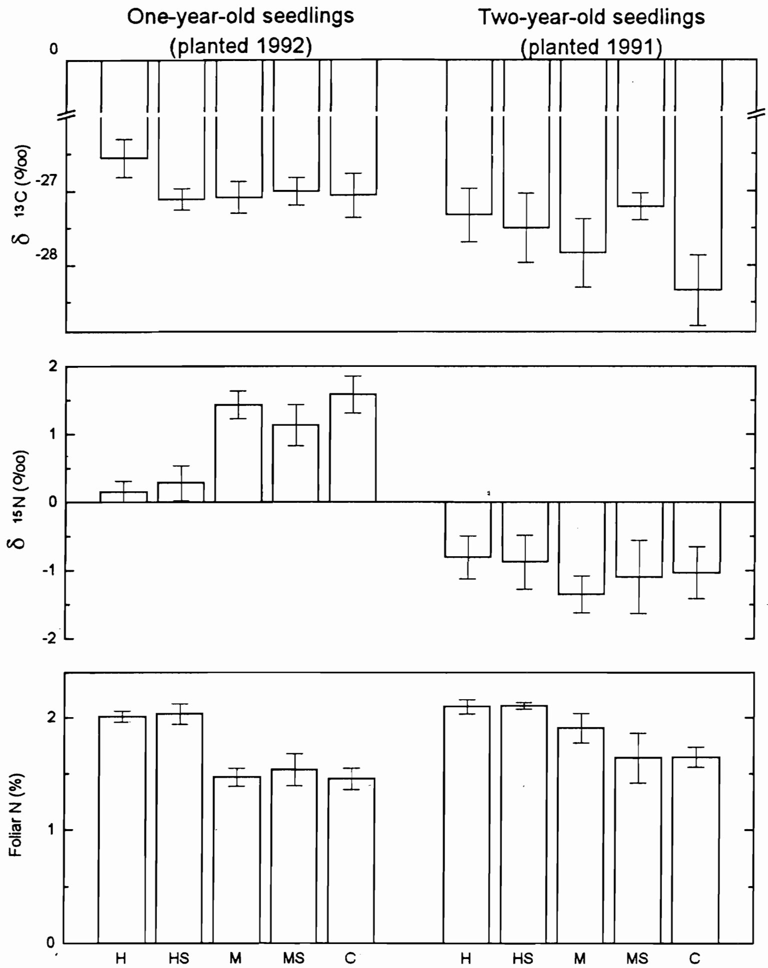

FIG. 4–$\delta^{13}C$ (top), $\delta^{15}N$ (middle), and foliar nitrogen concentration (bottom) for seedlings planted in different vegetation control treatments (H=herbicide; HS=herbicide and shade; M=mown; MS=mown and shade; C=control). Standard errors of the mean are indicated with vertical bars.

control and shading treatments had significant effects on ^{15}N abundance (p=0.019). One-year-old seedlings in the H treatment had statistically significantly lower ^{15}N abundance than 1-year-old seedlings in the C treatment (Fig. 4). For 2-year-old seedlings no statistically significant effect of the treatments on ^{15}N abundance was found (p=0.88). Two-year-old seedlings had lower ^{15}N abundance than 1-year-old seedlings. Vegetation control and shading treatments significantly affected needle nitrogen content for 1-year-old seedlings (p=0.003). After one growing season the needle nitrogen content was significantly higher for seedlings in herbicide-treated plots than for those in mown and undisturbed plots (Fig. 4). When seedlings were compared after two growing seasons, the vegetation control and shading treatments had no significant effect on nitrogen content (p=0.17) but there was a tendency for seedlings in herbicide plots and those in mown plots without shade to have higher needle nitrogen concentration than others (Fig 4).

Seedling Survival

Survival rate was high on all treatments. The proportion of dead or severely damaged seedlings was never higher than 2%. The main cause of damage was frost and fungi. No effects of the vegetation management treatments or the shade treatment on damage could be found.

DISCUSSION

Many other studies have shown the overwhelming importance of competition for water compared to competition for light and nutrients (e.g., Conard & Radosevich 1982; Sands & Nambiar 1984; Cole & Newton 1986; Walstad & Kuch 1987; Petersen 1988; Morris *et al.* 1993). The results of this study also indicated that the growth of newly planted spruce seedlings in areas with severe competition from weeds was more restricted by competition below ground than by competiton above ground. However, the results also indicated that water availability in the soil might not have been the only limiting factor for growth. Firstly, analysis of ^{13}C abundance failed to show a more severe water stress for seedlings in undisturbed plots than for those in herbicide-treated plots. Secondly, although differences in soil water potentials were registered between treatments during periods of drought, the soil water potential in herbicide-treated plots also dropped to levels that might have brought about severe water stress to the planted seedlings. Thirdly, analysis of variance showed no significant interactions between effects of the planting years and effects of the vegetation treatments on seedling size, which means that the vegetation treatment affected seedling growth in the same way for seedlings planted in 1991, when no drought was registered, as for seedlings planted in 1990 and 1992 when periods of drought were registered. Fourthly, there were no differences between treatments in the length of current needles when needles sampled in the same year were compared, while there was a significant difference in the length of current needles between needles sampled in 1991 and needles sampled in 1992. Therefore, more factors than mere differences in water stress were probably the cause for the observed differences in growth between seedlings in different vegetation control treatments.

Newly planted seedlings can become severely water stressed during the initial stage of development in spite of high soil water content (Örlander 1984; Grossnickle 1988). This increased seedling water stress immediately after planting results from poor root-soil contact (Örlander 1984; Sands 1984). Therefore, root growth is of utmost importance in this early stage (Burdett 1990; Brisette & Chambers 1992). One factor restricting root growth is soil temperature. For conifers in northern Europe, root growth has an almost linear correlation to soil temperature for soil temperatures between 10°C and 20°C (Lopushinsky & Max 1990; Cooper 1973). Soil temperature was higher in the H treatments during the growing seasons, and the differences were largest during the start of the growing seasons; this increased soil temperature may to some extent explain the differences in growth between treatments (cf. Table 4).

Petersen *et al.* (1988) found that the pre-dawn water potential of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) in competition with shrubs and forbs appeared to be dependent on the maximum soil water potential to which tree roots are exposed. In the present study, soil water potentials were measured at 10 cm below ground. Although the majority of the root systems were found in the upper 10 cm of the soil profile when the root systems were excavated, water uptake from greater depths may have been sufficient to reduce water stress.

Needle nitrogen concentrations were lower for seedlings in undisturbed plots than for seedlings in herbicide-treated plots. Differences in needle nitrogen concentrations between treatments may arise from differences in root growth due to soil temperature, differences in nitrogen mineralisation due to soil temperature and soil moisture, and competition for nitrogen between weeds and planted seedlings. Although needle concentrations were well above levels indicative of deficiencies, the differences in nitrogen content might have affected the growth rate of the seedlings. Furthermore, needle samples for measurements of nitrogen content were taken in late autumn when concentrations for conifers are known to peak, while concentrations in early summer during budflush are much lower because of retranslocation to developing needles (Nambiar & Fife 1991).

Analyses of $\delta^{13}C$ of the needles did not reveal any specific effect of the drought during 1992 in any of the treatments. Drought-stressed spruce needles usually show higher ^{13}C abundance, and $\delta^{13}C$ values above -25 (per mill) are not unusual during dry years (Högberg *et al.* 1995). The lower abundance of ^{13}C in current needles of seedlings in C plots cannot therefore be explained by water stress. The most likely explanation is a small shading effect, since these seedlings were surrounded by high grass and herbaceous vegetation. Under shade conditions, lower photosynthetic rates and lower abundance of ^{13}C are to be expected. Similar effects of shading conditions in $\delta^{13}C$ have been observed before (Francey *et al.* 1985; Broadmeadow & Griffits 1993).

Another factor with some possible influence might be that high soil respiratory activity contributes to an atmosphere surrounding the seedlings depleted in ^{13}C, i.e., more negative $\delta^{13}C$. Therefore, the higher soil temperature, especially in the H treatment, may be of some importance. However, the contribution of this increase in soil temperature to the observed $\delta^{13}C$ values is not known. We expected this factor to be relatively insignificant, since the differences in $\delta^{13}C$ values between treatments were small.

In other studies, herbicide treatment has caused increased net N mineralisation and nitrification in the treated plots (Vitousek *et al.* 1992). Seedlings in the herbicide treatments would therefore have been expected to be more enriched in ^{15}N than seedlings in the control treatment due to discrimination against ^{15}N during nitrogen cycling processes (Högberg & Johannisson 1993). However, that was not observed in this study. The lower ^{15}N abundance in the herbicide treatments than in the control treatment for 1-year-old seedlings may have been due to differences in ^{15}N-abundance between the fertiliser used in the nursery and the nitrogen-pool in the soil. If the ^{15}N abundance was higher in the fertiliser than in the soil nitrogen-pool, and if seedlings in the herbicide treatments had taken up more nitrogen from the soil, lower ^{15}N-abundance would be expected. For 2-year-old seedlings no differences between the different treatments could be found. This may indicate that the losses of nitrogen through leaching were about the same in the different treatments.

Shading reduced first-year seedling growth when the plots were treated with herbicides and weeds were absent, but had little or no effect when the weeds were mown. These findings agree with those of Kolb *et al.* (1990). Under conditions of heavy herbaceous interference, competition below ground is probably the major factor limiting growth. Unshaded seedlings cannot utilise the high light levels for additional growth and a reduction in light will not therefore reduce growth (cf. Harper 1977; Newman 1983; Tilman 1990).

The aim of the shading treatment was to simulate the light levels below the canopy of the ground vegetation in the C treatment. The reduction in light levels by shading screens simulates, or slightly exaggerates, the reduction in light in a normal clearcut in southern Sweden. However, because the shading screens were placed above the seedlings in order to allow wind below the screens, light levels in early mornings and late afternoons were higher in the MS and HS than in the C treatment. Furthermore, because weed biomass increased to levels beyond a normal clearcut, the light levels reaching down to ground level in the C treatment were lower than in the HS and MS treatments, even around noon during the second and third years of the experiment.

In conclusion, low differences in ^{13}C abundance, low soil water potential in all vegetation control treatments, no interaction between planting year and vegetation control treatment, and low differences between treatments in the length of current needles indicated that more factors than mere differences in water stress were the cause for the observed differences in growth. It is proposed that the availability of nitrogen may also have been a limiting factor to growth.

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