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Effect of planting and scarification on the water relations in planted seedlings of Scots pine

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Abstract

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The water relations in planted seedlings of *Pinus sylvestris* were measured to find out whether poor water uptake was an important factor affecting the planting result.

Seedlings were planted in the field on six different occasions. The soil was prepared in four ways: (*a*) Scarified patch, (*b*) A mound of mineral soil on the scarified patch, (*c*) A mound of mineral soil on a section of upturned humus, (*d*) No scarification. Needle conductance, needle water potential and plant water conductance (G_p) were measured on the seedlings during the period after planting (1–4 years). It was found that the planted seedlings suffered from water stress, G_p only being 2–46% of that in established references. Water uptake was reduced for several years after planting. Planting in mounds placed on mineral soil or in scarified patches favoured a high water uptake of the seedlings. The low water uptake of the seedlings after planting may explain the poor reforestation results frequently observed.

Key words: Pinus sylvestris, water relations, needle conductance, water potential, planting, scarification.

ODC 232.4 ; 181.31 : 174.7 Pinus sylvestris

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Introduction

The most frequently used reforestation method in Sweden is planting. Each year about 150,000 ha are planted with about 400 million seedlings. Since the mortality among the planted seedlings is considerable, there would be a lot to gain by increasing the number of surviving plants.

On most forest sites survival and growth can be improved by removing the humus layer (scarification) and planting in the mineral soil (e.g. Bärring, 1965). Scarification is therefore widely used in Swedish forestry. Söderström (1976) and Söderström et al. (1978) report that survival and growth can be further improved by planting in small mounds of mineral soil placed on the scarified patches. Thus, the micro-environment in which the seedlings are planted is very important for the planting success. In the last few years some methods for practical use have been developed for creating mounds of mineral soil and placing the mound either on mineral soil or on an upturned humus layer.

Survival percentage and height increment are the most commonly used parameters for determining the planting result. Extensive field experiments are often necessary to obtain results reliable enough to be applied to practical reforestation work. However, advances in plant physiology research have made it possible to measure variables in the seedlings, which may be useful for judging the vitality of a plant in a given situation (e.g. Gadgil & Harris, 1980; Schmidt-Vogt, 1980; Puttonen, 1982).

Kozlowski (1966) emphasizes the importance of a favourable internal water balance in transplants and considers that desiccation is the most important reason why planted seedlings do not survive. Söderström (1976) also stresses the importance of improving the water uptake in the seedlings by increasing the root growth. The water status in seedlings would obviously be one interesting physiological variable to study, especially in planted, not established, seedlings.

Several authors have found that the water uptake in seedlings of *Picea abies* is reduced by transplanting (Gürth, 1970; Lüpke, 1973: Havranek, 1975; Parviainen, 1979; Gross, 1980). Lüpke (1973) compared the transpiration and water potential of transplanted top- and root-pruned seedlings with unplanted controls. Thirteen days after transplanting the reduction in transpiration due to planting was more than 50 %. The shoot/root ratio of the seedlings was of great importance, and root-reduction decreased while top-pruning increased the transpiration (on a needle weight basis). Some important causes of the planting shock are, according to Gross (1980), water loss from the seedling before planting, loss and damage of roots and poor contact between root and soil. Since the water uptake in seedlings is of major importance after planting, it has been studied in planted seedlings of a number of forest tree species, e.g. *Pseudotsuga menziesii* (Lüpke, 1979; Childs, 1980), *Larix decidua* (Tranquillini, 1973), *Pinus sylvestris* (Hallman et al., 1978; Huss & Koch, 1982), *Pinus contorta* and *Pinus ponderosa* (Baldwin & Barney, 1976), *Pinus caribea* (Williams, 1975; Bacon & Bachelard, 1978) and *Picea glauca* (Blake, 1983). Some preliminary data concerning the effect of different scarification methods are presented by Örlander (1982).

The main objectives of the investigation were to study: (1) Is water uptake of planted seedlings of *P. sylvestris* negatively affected by planting? (2) Is water uptake influenced by the scarification method?, and (3) Are there correlations between early measurements of water relations in th field and subsequent survival and growth?

Material and Methods

Plant material

Seedlings of Scots pine (*Pinus sylvestris* L.) were planted in field experiments on six different occasions (Experiments 1–6) in 1979 and 1980. The seedlings were commercially produced at two local nurseries situated in the neighbourhood of the study areas and were selected to be of a provenance genetically suitable for the respective studty area. In Expts. 1–4 bare-root seedlings were used, and in Expts. 5 and 6 container-grown seedlings (Paperpot FH 408, Lännen, Tehtaat OY, Finland) (Table 1).

Table 1. *Description of the experimental sites, plant material and experimental design*

		Site description											
Expt.	Location	Soil texture	Soil moisture	Vegetation	Tickness of humus layer, cm	Planting date	Seedling, type	Seedling, mean height cm	Control, type	Controls, mean height at planting, cm	Number of seedlings /plot	Number of replica-tions	Total number of seedlings	Comment
1	Siljansfors, 60°50'N, 14°25'E Altitude 235 m	*Sand*-fine sand Till	Mesic	Dwarf-shrub type	3–5	31 May 1979	Bare-rooted 3 year old transplants (2/1)	22	Naturally regenerated	36	15	4 (8)	180	Treatment b: 8 replications, Treatment d: 4 replications
2	Johannisfors, (15 km NE Umeå) 63°55'N, 20°35'E Altitude 40 m	Silt	Ditched arable land	Grass	–	10 June 1980	Bare-rooted 2 year old transplants (1/1)	13	5 year old pine plantation	100	5	20	400	
3	Johannisfors, (15 km NE Umeå) 63°55'N, 20°35'E Altitude 50 m	Sand Till	Dry	Dwarf-shrub type	2–3	12 June 1980	Bare-rooted 2 year old transplants (1/1)	18	Naturally regenerated	18	10	1	40	Experiment continued to Aug. 1980
4	Vindeln, Svartberget, Field Res. Station 64°15'N, 19°45'E Altitude 225 m	*Sand*-fine sand Till	Mesic	Dwarf-shrub type	3–5	17 June 1980	Bare-rooted 2 year old transplants (1/1)	15	Naturally regenerated	16	10	2	80	Experiment continued to Aug. 1980
5	Johannisfors, (15 km NE Umeå) 63°55'N, 20°35'E Altitude 50 m	Sand Till	Dry	Dwarf-shrub type	2–3	12 Aug. 1980	Container-grown (paper-pots) 1 year old	14	Naturally regenerated	26	10	1	40	Planted in the same place as Exp. 3
6	Vindeln, Svartberget, Field Res. Station 64°15'N, 19°45'E Altitude 225 m	*Sand*-fine sand Till	Mesic	Dwarf-shrub type	3–5	14 Aug. 1980	Container-grown (paper-pots) 1 year old	13	Naturally regenerated	29	10	1	40	Planted in the same place as Exp. 4

Study areas

The experiments were carried out in three different localities: Siljansfors (60°50'N, 14°25'E), Johannisfors (63°55'N, 20°35'E) and at the Field Research Station of the Faculty of Forestry in Vindeln, Svartberget, (64°15'N,19°45'E). At Johannisfors two different sites were used. The sites are described in Table 1 according to the terminology of Hägglund & Lundmark (1977). The type of sites used for Expts. 1, 4 and 6 is rather frequent in Swedish forests, a mesic dwarf shrub type with a 3–5 cm thick humus layer on sandy till. Expts. 3 and 5 were carried out on dry, coarse soil. All forest sites were clear-felled 5–10 years earlier, and naturally regenerated Scots pine seedlings were present at the start of each experiment. Expt. 2 was made on formerly arable land which was partly planted in 1975. The soil was silty and grass-covered.

Experimental design

In each experiment the scarifiation was made in different ways prior to planting. The treatments were (see also Fig. 1):

(*a*) The humus layer was removed in a 0.4x0.4 m square (scarified patch) and the seedling was planted in the centre of the patch.

(*b*) A mound (10–15 cm high) of mineral soil was placed on the scarified patch, and the seedling was planted in the mound.

(*c*) A mound (10–15 cm high) of mineral soil was placed on a section of the humus layer, turned upside down beside the scarified patch.

(*d*) No scarification.

In Expt. 1, however, only treatments (*b*) and (*d*) were studied.

The scarification was made within 14 days before planting, except for Expts. 5 and 6, where the scarification was made in early June and the seedlings were planted in August.

The seedlings were planted so that the deepest part of the root system was 10 cm below the soil surface. The total number of seedlings per experiment varied from 40 to 400. The number of seedlings per plot and the number of replications in each experiment are shown in Table 1. On each experimental area some established, well-growing plants of Scots pine were selected as references (here denoted as controls). Except for Expt. 2, where plants from an older plantation were used, all the controls were naturally regenerated. The controls were chosen to be, as far as possible, of the same size as the planted seedlings.

Expt. 2 was ended in the autumn of 1980 because of high plant mortality. In Expts. 3 and 4 high seedling mortality was found already after two months, and the experiments were thus ended. The dead seedlings were removed and replaced by new seedlings in August 1980 (Expts. 5 and 6).

Measurements

The seedlings were studied rather intensively immediately after planting and thereafter less frequently (cf. Table 2, Fig. 6). On each measurement occasion needle conductance and needle water potential were usually measured on four or five randomly sampled living seedlings in each treatment. The number of

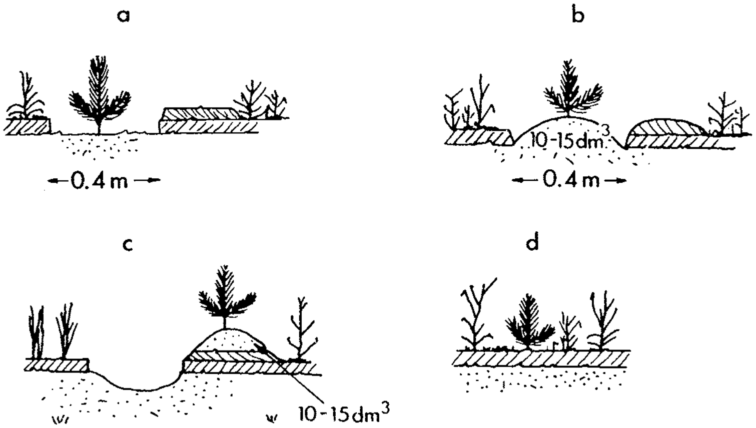

Fig. 1. Schematic picture of the scarification treatments and placing of the seedlings. a = Scarified patch. b = Mound on mineral soil. c = Mound on upturned humus. d = No scarification.

measured controls was 2–4. When the measurements were made only once a day they were normally performed between 9 and 12 a.m. On each occasion air temperature, relative humidity and irradiance were registered. Soil temperature and soil moisture were recorded at least during one growing season after planting, except for Expt. 5 where the recording was made only the first month after planting.

Needle water potential (ψ_n) was measured on detached needles in a pressure chamber (Scholander et al., 1965; Waring & Cleary, 1967) The pressure chamber was especially designed for coniferous needles (Djos, Uppsala, Sweden). Between sampling and measurements the needles were stored in darkness in tubes with 100 % relative humidity.

Needle conductance (g_n) was measured using three different types of null-balance porometers. In 1979 (Expt. 1) the measurements were made on shoots enclosed in a porometer chamber. The apparatus is described by Hellkvist et al. (1980). In 1980 (Expts. 2–4) the measurements carried out before Aug. 1 were made with a similar technique but with another instrument (Dingbat, Edinburgh, Scotland). From 1 Aug. 1980, a Licor LI-1600 null-balance porometer equipped with a square chamber (Licor Inc., Lincoln, Nebraska, USA) was used.

Measurements of ψ_n and g_n were made on one-year-old shoots or needles on spring and summer, and on current needles in autumn. The projected needle area was estimated from the number, length and mean width of measured needles.

The photon flux density was measured wth a Licor quantum sensor (Licor Inc.) attached to the porometer chamber.

Vapour concentration deficit (VCD) was calculated from air temperature and relative humidity-data measured close to the seedlings with an Assman psychrometer. The air temperature was assumed to be equal to the needle temperature (cf. Whitehead & Jarvis, 1981).

Soil water potential (ψ_s) was measured with tensiometers (Soil moisture equipment, Santa Barbara, California, USA), complemented with gypsum blocks in Expts. 1, 2, 4 and 6. The readings from the gypsum blocks were used when soil water potentials were lower than about −0.06 MPa. The soil moisture was measured 10 cm below the soil surface. If no reading of ψ_s was made it was set to zero.

The soil temperature was measured continuously with thermistors (Siemens M 843, München, West-Germany) or thermocouples (copperconstantan) inserted in small brass cylinders. placed 10 cm below the soil surface. At least 2 places/treatment were measured for soil water potential and soil temperature.

The plant water conductance (G_p) was calculated from the formula (Hellkvist et al., 1980; cf. Whitehead & Jarvis, 1981; Passioura, 1982):

$$G_p = \frac{q}{\psi_s - \psi_n}$$

where q is the water flux per unit needle area, estimated from the formula:

$$q = g_n \cdot \mathrm{VCD}$$

Growth measurements. The length of the leading shoots was measured at the end of each growing season. For estimation of the mean needle length one needle from the middle of the leading shoot was measured. In Expt. 1 some randomly chosen seedlings were excavated, and the growth of new roots was estimated by weighing.

Statistical methods

The mean, standard deviation and standard error were calculated for the registered data. Some standard deviation data are presented as coefficients of variation. Significance tests were made with the Mann Whitney U-test.

Weather conditions

The readings of air temperature and precipitation were obtained from the weather station at Siljansfors (Swedish Meteorological and Hydrological Institute) in Expt. 1 and from the Field Research Station at Vindeln, Svartberget (Expts. 4 and 6). Temperature and precipitation data for Expts. 2, 3 and 5 were obtained from Umeå airport (SMHI).

During the period of study the weather conditions varied considerably between the experimental areas and between years (Fig. 2). All study areas, except Siljansfors (Expt. 1), are located in a part of Sweden which is normally rather dry in spring and early summer. After planting Expts. 2, 3 and 4 in June 1980 very little rain fell during the rest of the summer, compared with normal conditions. As an example, the total precipitation at Umeå (Expts. 2 and 3) between May 9 and June 20 was only 4 mm and during July only 21 mm. 1981 had rather high precipitation during the summer months, while the summer of 1982 was dry at all experimental sites.

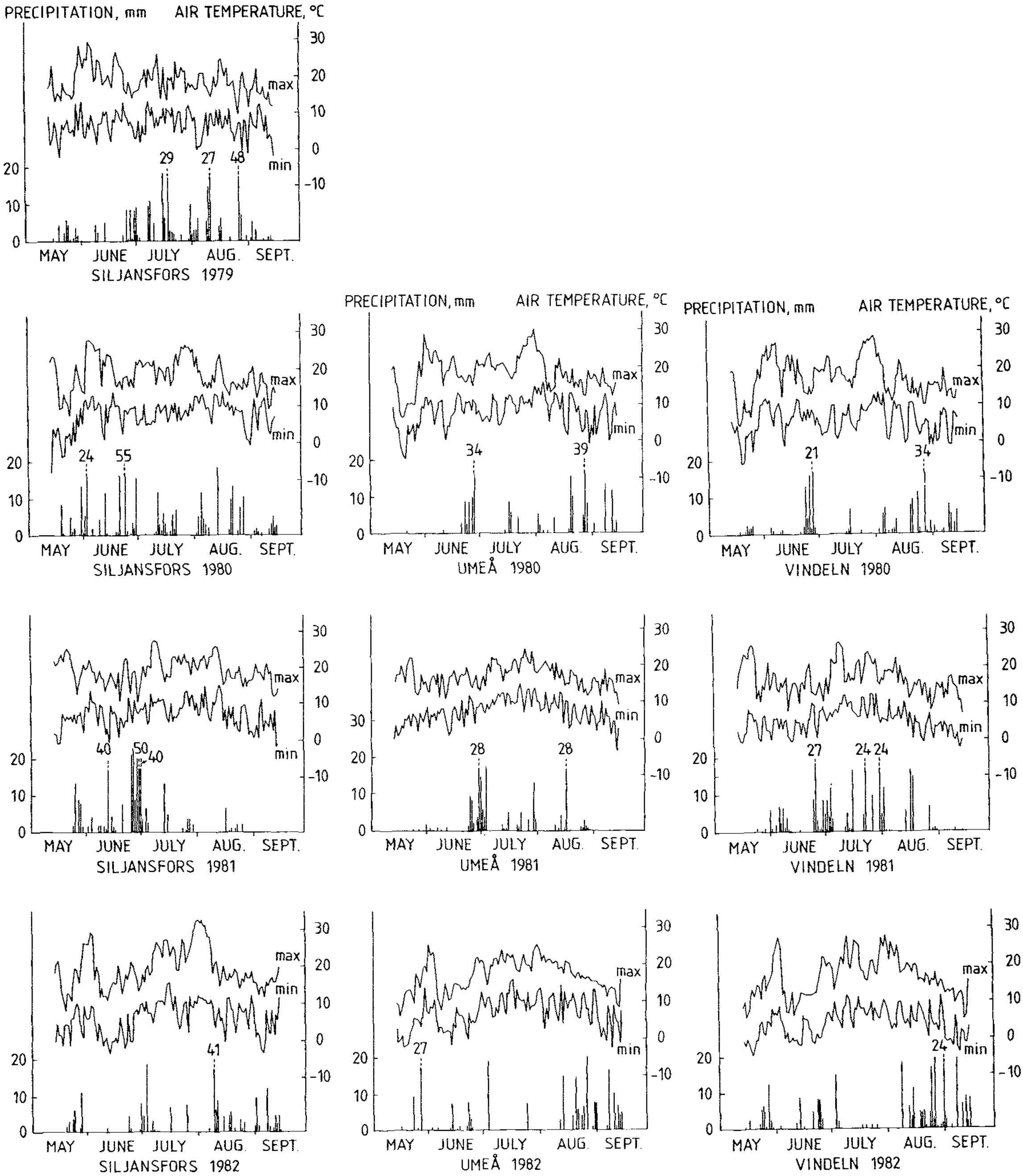

Fig. 2. Air temperature (daily maximum and minimum) and precipitation during the study period. Expt. 1 was performed at Siljansfors, Expts. 2, 3 and 5 close to Umeå, and Expts. 4 and 6 at Vindeln. Note the dry periods that followed planting in Umeå and Vindeln 1980.

Results

Soil moisture and soil temperature

Both soil moisture and soil temperature varied considerably depending on the type of scarification treatment (Fig. 3 and 4). During periods of low precipitation the soil in the mounds on upturned humus became dry (Fig. 3b–3d). The highest soil water potentials were found where no soil treatment was made or in the scarified patches. These two treatments resulted in approximately the same soil moisture. The soil water potential in the mounds on mineral soil was higher than in the mounds on upturned humus.

On sunny days in the summer the temperature differed approximately 10°C between the mounds on upturned humus and the untreated soil, but all types of scarification increased the soil temperature considerably. Typical temperature curves on a sunny day are shown in Fig. 4a. During cloudy, rainy periods,

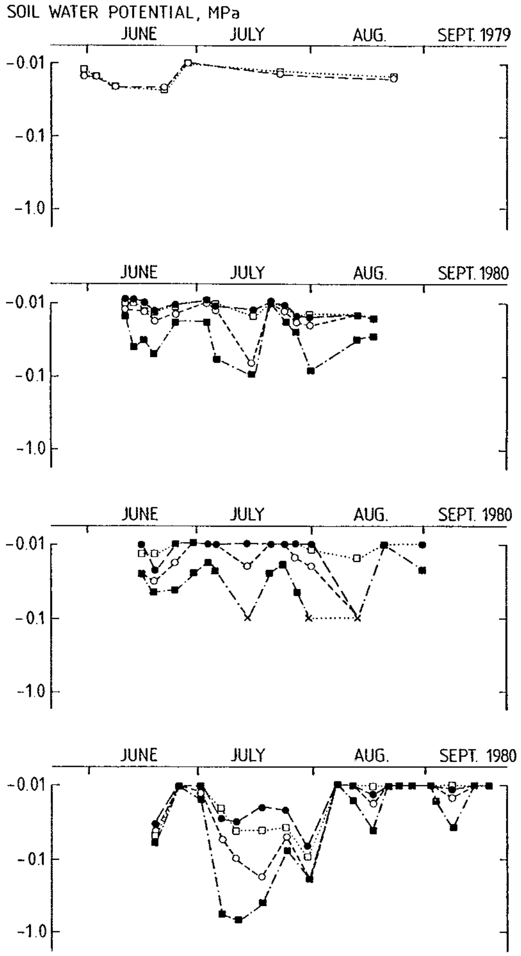

Fig. 3. Mean soil moisture (log. scale) 10 cm below soil surface in the different scarification treatments. a = Expt. 1 (n=4). b = Expt. 2 (n=5). c = Expts. 3 and 5 (n=2). d = Expts. 4 and 6 (n=2). (x = Soil moisure lower than the detection limit of the tensiometers.)
● = scarified patch. ○ = mound on mineral soil. ■ = mound on upturned humus. □ = no scarification

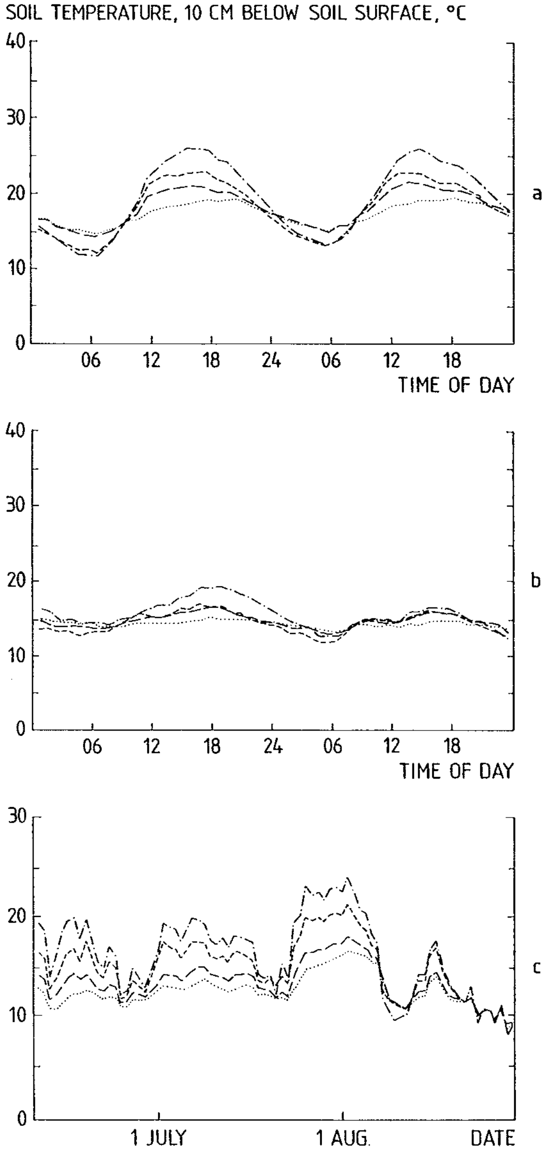

Fig. 4. Mean soil temperature 10 cm below soil surface. a = during a sunny period, Johannisfors (Expt. 2), 30–31 July 1980, n=5. b = during a cloudy period, Johannisfors (Expt. 2), 20–21 June 1980, n=5. c = daily mean temperatures, Vindeln (Expts. 4 and 6) June–August 1980, n=2. — — — = scarified patch, - - - - = mound on mineral soil, — · — · — = mound on upturned humus, · · · = no scarification.

with low insolation, the difference in soil temperature between the scarification treatments was small wich is exemplified in Fig. 4b.

Scarifying increased the daily mean soil temperature during the summer despite an often higher temperature at night below the unbroken humus layer (Fig. 4c). In autumn the soil temperature in the scarified patches or mounds successively became lower and finally decreased below zero earlier than where no scarification had been made.

Weather conditions during the measurements

Despite only dry and rather sunny days being chosen for the water relation measurements, the weather conditions on the different measurement occasions varied considerably, as shown in Table 2.

Varations in the G_p-measurements

Depending on measurement date the G_p of the control seedlings varied from 1 to 13 $\mu g \cdot cm^{-2} \cdot s^{-1} \cdot MPa^{-1}$ (Table 3). There was also a considerable variation between the individual G_p-values on the same measurement occasion (Table 4).

Water relations: general considerations

The general pattern in all experiments was that the planted seedlings, irrespectively of soil treatment, had low water uptake (Fig. 5). The most water-stressed seedlings, as compared to the controls, were found in Expts. 3 and 4, where the g_n of the planted seedlings was about 3 % of that of the controls. The corresponding value for the G_p was only about 2 %. In all experiments, except for Expt. 5, the ψ_n was more negative in the planted seedlings than in the controls (Fig. 5). In the comparison between planted seedlings and controls, G_p was more negatively affected by planting than was the g_n. The highest g_n and G_p levels immediately after planting were found in Expts. 5 and 6, where container-grown seedlings were planted in late summer.

Table 2. *Some climatic conditions on the measurement occasion. (x = missing value)*

Expt.	Date	Vapour concentration deficit, $g \cdot m^{-3}$	Photon flux density, $\mu E \cdot m^{-2} \cdot s^{-1}$	Air temperature, °C
1	4 June 1979	13.6	1 400	22.0
1	7 June 1979	11.7	1 100	25.0
1	22 June 1979	4.8	700	18.0
1	28 June 1979	4.5	700	14.0
1	24 July 1979	5.1	600	15.0
1	10 Sept. 1980	4.6	1 000	12.5
1	6 Sept. 1981	7.7	x	18.0
1	26 Aug. 1982	8.1	600	18.2
2	16 June 1980	9.0	1 400	21.0
2	30 June 1980	9.0	1 450	20.0
2	15 July 1980	8.0	900	20.0
2	15 Aug. 1980	6.8	x	20.0
3	14 June 1980	10.5	1 100	20.0
3	30 June 1980	11.3	1 200	21.0
3	15 July 1980	11.4	1 000	21.0
3	28 July 1980	12.0	800	23.5
4	5 July 1980	10.0	1 200	17.5
4	16 July 1980	6.1	500	15.0
4	30 July 1980	15.5	1 000	25.5
5	18 Aug. 1980	9.2	900	19.5
5	2 Sept. 1980	7.4	800	16.5
5	11 June 1981	6.8	1 050	16.0
5	2 Sept. 1981	6.4	700	17.5
5	5 June 1982	8.5	600	19.0
5	23 Aug. 1982	6.5	1 100	18.2
6	26 Aug. 1980	6.0	800	14.0
6	8 July 1981	8.2	1 300	18.0
6	26 Aug. 1981	6.5	1 000	15.0
6	29 June 1982	8.3	400	18.0
6	24 Aug. 1982	6.3	1 100	15.5

Table 3. *Mean plant water conductance (G_p) and needle conductance (g_n) of the control seedlings on different measurement days*

Expt.	Date	G_p, $\mu g \cdot cm^{-2} \cdot s^{-1} \cdot MPa^{-1}$	g_n $cm \cdot s^{-1}$
1	4 June 1979	1.76	0.173
1	7 June 1979	1.08	0.220
1	22 June 1979	2.48	0.610
1	28 June 1979	2.50	0.540
1	24 July 1979	1.95	0.380
1	10 Sept. 1980	6.65	0.740
1	6 Sept. 1981	5.14	0.680
1	26 Aug. 1982	8.77	1.097
2	16 June 1980	2.95	0.664
2	30 June 1980	10.13	1.398
2	15 July 1980	7.26	1.692
2	15 Aug. 1980	4.86	1.577
3	14 June 1980	8.84	0.946
3	30 June 1980	12.92	1.230
3	15 July 1980	4.49	1.054
3	28 July 1980	3.70	0.736
4	5 July 1980	8.56	1.287
4	16 July 1980	6.47	1.188
4	30 July 1980	4.73	0.573
5	18 Aug. 1980	1.41	0.490
5	2 Sept. 1980	3.65	0.816
5	11 June 1981	4.52	0.891
5	2 Sept 1981	2.92	0.660
5	5 June 1982	4.16	0.531
5	23 Aug. 1982	4.99	0.765
6	26 Aug. 1980	4.40	1.443
6	8 July 1981	7.94	0.959
6	26 Aug. 1981	6.33	0.805
6	29 June 1982	5.92	0.721
6	24 Aug. 1982	7.35	0.939

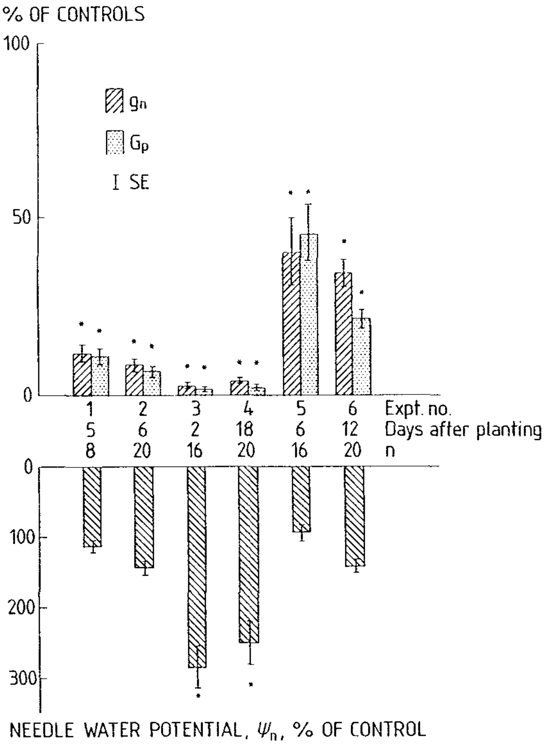

Fig. 5. Mean plant water conductance (G_p), needle conductance (g_n) and needle water potential (ψ_n) of seedlings of *Pinus sylvestris* measured within three weeks after planting. The mean value includes all planted seedlings and represents a mean for all scarification treatments. Values are given in % of that in established controls, * = significant difference ($p<0.05$) between planted seedlings and controls, using a nonparametric test (Mann-Whitney).

Table 4. *Mean coefficients of variation in the measurements of plant water conductance (G_p), in Expts. 1–6. (cf. Fig. 6). Lowest and highest values within brackets. Description of treatments, cf. Fig. 1. Controls = established reference seedlings. (a) = Scarified patch, (b) = Mound on mineral soil, (c) = Mound on upturned humus, (d) = No scarification*

	Coefficient of variation, %				
Expt.	Controls	Treatm. (*a*)	Treatm. (*b*)	Treatm. (*c*)	Treatm. (*d*)
1	46(4–74)	-	35(20–48)	-	59(9–93)
2	51(36–58)	64(37–104)	48(35–74)	136(63–223)	54(19–154)
3	44(8–86)	120(56–190)	101(32–200)	115(72–173)	83(31–113)
4	58(53–63)	75(59–90)	120(56–156)	85(84–86)	69(43–102)
5	22(8–45)	72(55–102)	53(27–87)	64(21–101)	56(46–106)
6	24(4–53)	35 (5–71)	30(17–52)	41(31–54)	26(6–49)

Water relations: recovery

The time needed for the G_p to recover varied between experiments and treatments (Fig.6). As already pointed out, the first measured values of G_p in the planted seedlings were low in comparison with the controls, but there was also a considerable difference between the scarification treatments. At the end of the first growing season after outplanting only a few of the planted seedlings had G_p-values as high as the controls (Fig. 6). Expts. 1, 5 and 6, wihch were measured for several years, showed that the recovery period for many seedlings lasted two years or more. In Expt. 1 the seedlings planted without scarification had G_p-values lower than the controls still four years after planting. Especially in Expts. 3 and 4, which showed high mortality, the seedlings recovered very poorly (Fig. 6). In most experiments the highest G_p-values were found in scarified patches or in mounds on scarified patches and the lowest in mounds on upturned humus.

Water relations: diurnal variation

The results in Figs. 5 and 6 are based upon measurements made only at one point of time each day. If the diurnal variations are different for different treatments, the water status of the seedlings might have been imperfectly described. An example of the diurnal variation from Expt. 6 is given in Fig. 7. The measurement was made on a day with a maximum air temperature of about 20°C and with some cloud-formation in the afternoon which is considered to be a "typical" day (Fig. 7a and b). Both ψ_n, g_n and G_p showed diurnal variation (Fig. 7c, d and e). Nee-

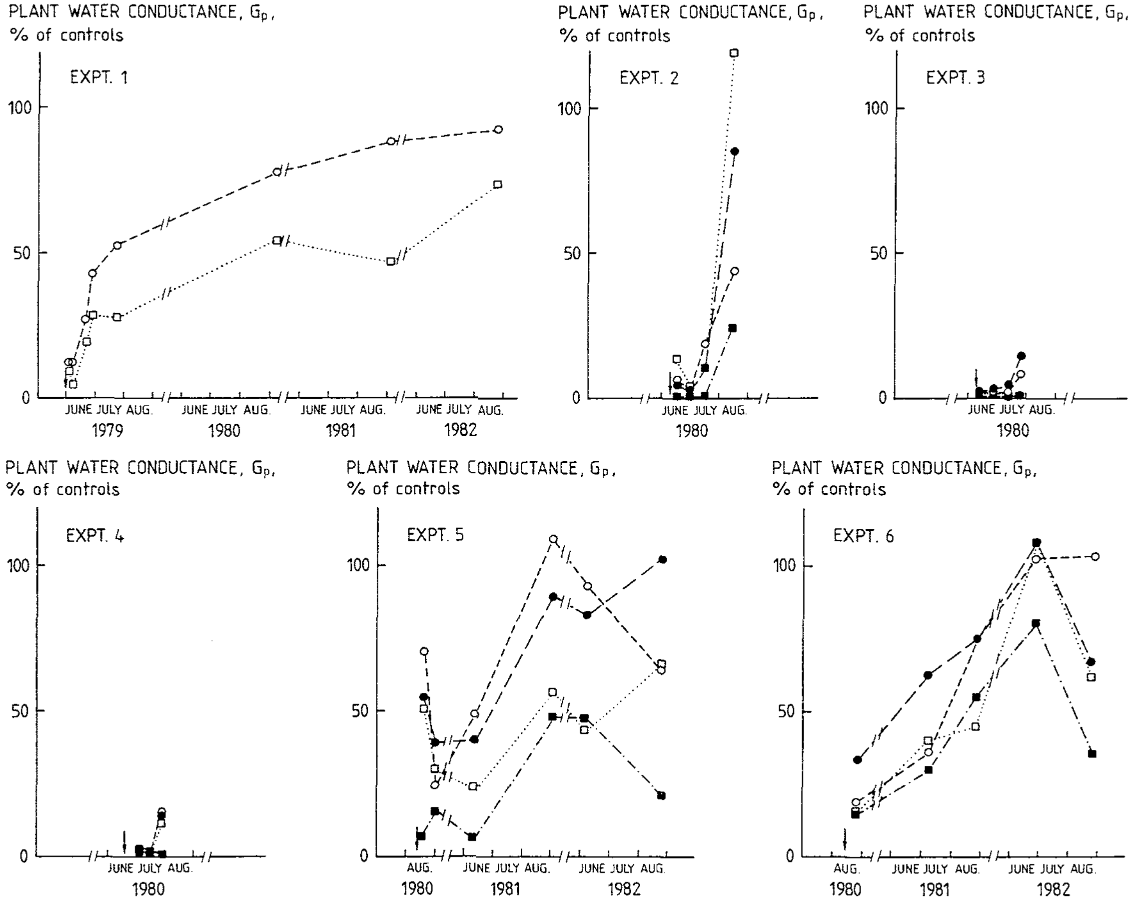

Fig. 6. The development of the mean plant water conductance (G_p) of seedlings planted in different scarification treatments. Values given in % of that in established controls. Planting date indicated with an arrow. ● = scarified patch, ○ = mound on mineral soil, ■ = mound on upturned humus, □ = no scarification.

dle conductance was highest at about 9 a.m., when the control seedlings reached a value of nearly 1.0 cm·s^{-1}. The G_p also varied during the day with a maximum in the morning. The controls and the planted seedlings followed the same general pattern in their diurnal variations, although the absolute values were lower for planted seedlings.

Survival and growth of seedlings

None of the control seedlings died during the experimental period, while the mortality among the planted ones was rather high (Table 5). The percentage of survival after the first year in the field varied between experiments as well as between treatments. The general pattern was that seedlings that did not survive had low G_p during the first period after planting (Table 6). Compared with the planted seedlings, the controls had high shoot and needle growth (Table 7, Fig 8). Planted seedlings with high G_p had in most cases longer shoots and needles than those with low G_p (Table 8). The height increment was impaired for a long period after planting (Fig. 8) and especially for seedlings with low G_p, the shoot growth seemed to be limited for several years after planting.

In Expt. 1 the root growth was measured 55 days after planting (Fig.9). The root growth of seedlings planted in the mounds was considerably better than in seedlings planted without any soil treatment. This coincided with a more rapid recovery in G_p (cf.Fig.6).

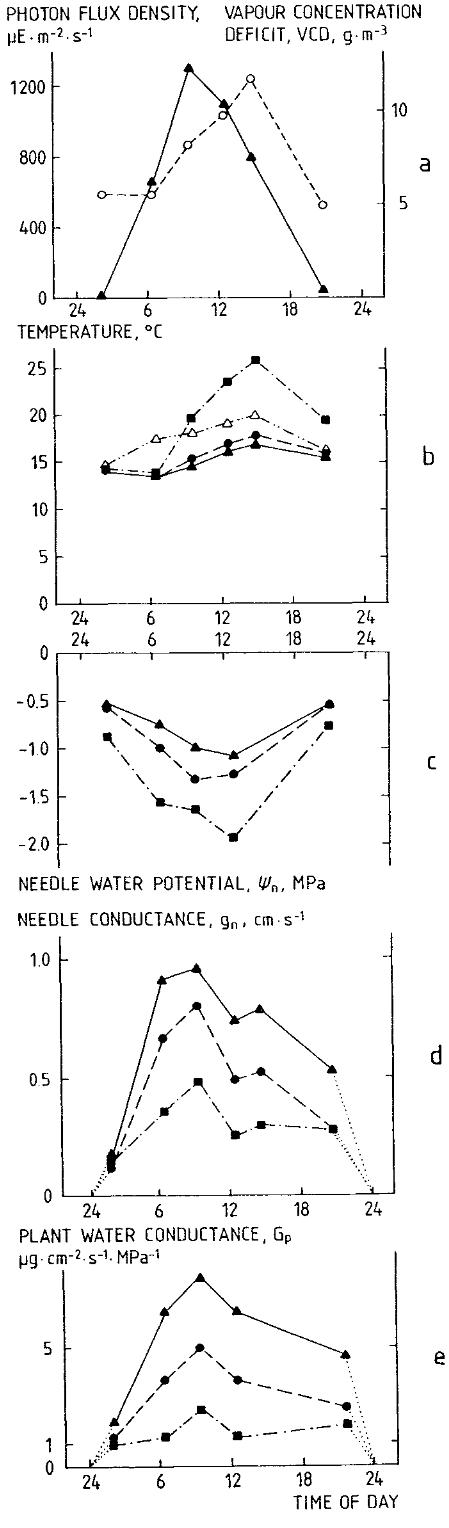

Fig. 7. Daily variation of needle water potential (ψ_n), needle conductance (g_n) and plant water conductance (G_p), Expt. 6, 8 July 1981. The photon flux density, vapour concentration deficit (VCD), air and soil temperatures during the measurement are shown in Fig. 7a and b.
▲ = controls, ● = scarified patch, ■ = mound on upturned humus, △ = air temperature, ○ = VCD.

Table 5. *The effect of four different scarification treatments (cf. Fig. 1) on survival one and two growing seasons after planting. Controls = established reference seedlings. (a) = Scarified patch. (b) = Mound on mineral soil, (c) = Mound on upturned humus, (d) = No scarification*

Growing seasons after planting	Survival, %					
	Expt.	Controls	Treatm. (*a*)	Treatm. (*b*)	Treatm. (*c*)	Treatm. (*d*)
1	1	100	-	99	-	84
1	2	100	96	60	25	85
1	3	100	50	30	0	20
1	4	100	85	45	10	35
1	5	100	100	90	30	100
1	6	100	100	90	80	70
2	1	100	-	93	-	81
2	5	100	100	80	20	100
2	6	100	90	80	80	70

Table 6. *Mean plant water conductance (G_p) ± standard error of seedlings that died (A) or survived (B) the first growing season after planting, respectively. G_p measured within 18 days after planting*

Expt.		Plant water conductance (G_p), $\mu g \cdot cm^{-2} \cdot s^{-1} \cdot MPa^{-1}$	*n*
2	A	0.09±0.05	7
	B	0.23±0.07	13
3	A	0.03±0.01	10
	B	0.26±0.07	6
4	A	0.12±0.03	10
	B	0.19±0.04	10
5	A	0.06±0.03	3
	B	0.78±0.11	13

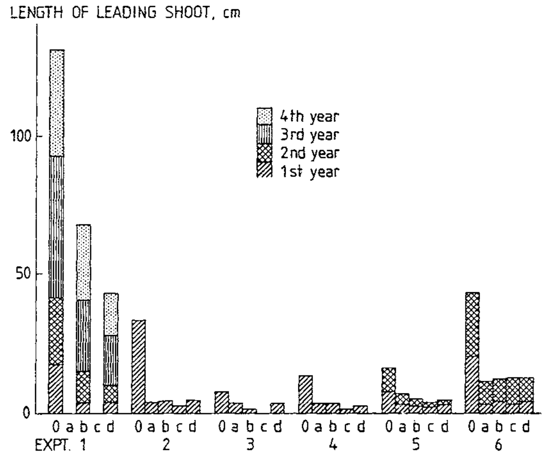

Fig. 8. Lenght of leading shoots the first years following planting of established control seedlings (= 0) and seedlings planted in different scarification treatments (cf. Fig. 1). a = Scarified patch. b = Mound on mineral soil. c = Mound on upturned humus. d = No scarification.

Table 7. *The effect of four different scarification treatments (cf. Fig. 1) on the mean needle length (± standard error) one growing season after planting. Number of observations within brackets. Controls = established reference seedlings. (a) = Scarified patch, (b) = Mound on mineral soil, (c) = Mound on upturned humus, (d) = No scarification*

	Needle length, mm				
Expt.	Controls	Treatm. (*a*)	Treatm. (*b*)	Treatm. (*c*)	Treatm. (*d*)
1	47.5±4.3(4)		18.1±0.9(74)		13.6±1.0(32)
2	43.6±2.5(10)	28.2±0.9(96)	24.8±1.1(60)	21.2±1.2(25)	30.5±1.0(85)
3	28.4±2.7(10)	14.8±3.1(5)	16.3±6.7(3)	All dead(-)	15.0±1.0(2)
4	44.7±2.0(10)	20.0±1.2(17)	24.9±2.7(9)	12.0±1.0(2)	12.7±2.6(7)
5	34.9±2.1(10)	18.7±2.9(10)	17.0±2.8(9)	6.0±1.0(3)	14.8±1.6(10)
6	44.9±2.1(10)	43.0±6.0(10)	39.0±6.4(9)	38.7±2.6(8)	44.3±2.5(7)

Table 8. *Length of shoots and needles ± standard error. The seedlings are grouped into two halves depending on their plant water conductance (G_p). G_p ± standard error measured within 18 days after planting. Needle and shoot length measured one growing season after planting. Dead seedlings are excluded from the table*

Expt.	Plant water conductance (G_p), $g \cdot cm^{-2} \cdot s^{-1} \cdot MPa^{-1}$	Shoot length, mm	Needle length, mm	*n*
1	High 0.25±0.04	26.5±5.7	20.5±2.0	4
	Low 0.13±0.01	35.0±5.4	16.5±1.6	4
2	High 0.40±0.13	46.7±6.4	29.0±4.0	6
	Low 0.07±0.02	29.2±9.7	22.7±6.1	6
3	High 0.37±0.11	41.3±8.5	16.0±1.2	3
	Low 0.14±0.02	23.0±10.8	5.7±4.3	3
4	High 0.29±0.04	28.2±6.2	13.4±2.1	5
	Low 0.08±0.02	5.8±2.7	3.6±3.6	5
5	High 1.12±0.12	31.7±2.1	15.0±3.4	6
	Low 0.45±0.06	23.3±4.2	13.3±2.8	6
6	High 1.33±0.13	34.0±5.2	49.0±5.1	10
	Low 0.52±0.05	44.5±10.7	38.5±2.8	10

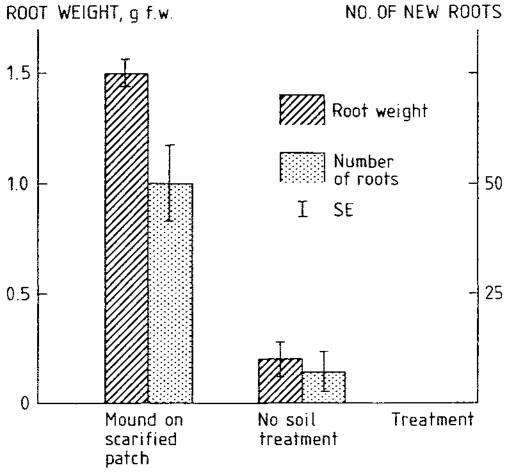

Fig. 9. Root growth (weight and number of new roots) of seedlings planted in mounds placed on mineral soil ($n=15$) and without soil treatment ($n=9$), respectively. Expt. 1, 55 days after planting.

Discussion

The water uptake was unexpectedly low in the planted seedlings in the present study. The reason for this was probably poor root functions, as the seedlings in most cases were planted in soils with high soil water potentials and the controls able to absorb water at a higher rate.

The results in this study are in agreement with the results of many previously reported experiments. Thus Mattson-Djos (1982) found ten times as high G_p in seedlings planted with a large clod of nursery soil as in bare-rooted ones. Other investigations (Lüpke, 1973; Tranquillini, 1973; Hallman et al., 1978; Lüpke, 1979; Parviainen, 1979) show a decrease in water uptake when seedlings were dug out and thereafter replanted in the same soil. The decrease in water uptake caused by planting was generally larger in the present experiments than in those mentioned above, which were made under nursery or laboratory conditions. This indicates that the water uptake is more disturbed after planting in the field.

Contradictory to Söderström et al. (1978), the mound placed on mineral soil was not superior to the other scarification treatments. The probable cause of this was that the soil water potentials were generally lower in the present experiments, one obvious reason being the dry weather. Another plausible explanation might be that the present investigation was carried out on old clearfellings with a lot of transpiring vegetation.

The highest G_p was, however, generally found in seedlings planted in scarified patches or in mounds on mineral soil. Low G_p was found in the mounds on upturned humus. When placing the mounds on an upturned humus layer the soil temperature increased and the soil moisture decreased compared to the other scarification treatments. According to the literature (cf. Cooper, 1973), the soil temperature in the mounds should not be so high even during warm days that negative effects on the water uptake capacity of the roots would occur. The probable reason for the low G_p in seedlings planted in the mounds on upturned humus is therefore low soil water potentials. Surprisingly enough, a very small decrease in soil water potential seemed to have large effects on the G_p. This is exemplified in Expt. 2, where the G_p was almost zero in the mounds on upturned humus, although the soil moisture never fell below −0.06 MPa during the first three weeks after planting (Figs. 3 and 6). The water uptake in unestablished seedlings seems to be more negatively affected by low soil water potentials than in established ones. According to previous investigations on established seedlings (e.g. Rutter & Sands, 1958; Jarvis & Jarvis, 1963; Lopushinsky & Klock, 1974; Havranek & Benecke, 1978), transpiration should be almost constant if the soil water potential is kept higher than −0.06 MPa.

The negative effect of low soil water potentials on unestablished seedlings is in accordance with the findings of Lüpke (1979) who detected that the transpiration in seedlings of *P. menziesii* fell to about 35 % when they were planted in dry sand (ca. −0.025 MPa) as opposed to wet sand (ca. −0.010 MPa).

When the seedlings were planted without scarification the soil water potentials were rather high but still they had low G_p. One reason for the low G_p could be that the low soil temperature below the humus layer negatively affected the water uptake in the seedlings (e.g. Cooper, 1973).

The planting depth might also be important for the water uptake. During dry periods the surface and the top layer will be dry and warm. Different parts of the root system will therefore be subjected to different soil moisture and soil temperature. Experiments with seedlings having their roots divided between soils of unequal soil water potentials show that if one part of the root system has sufficient water supply the water uptake and growth will be nearly as high as if the whole root system has high soil water potential (Coutts, 1982; cf. Farnum, 1977). The effect of different conditions at different depths could, however, have affected the interpretation of the results in this study.

The time needed for recovery varied between the different treatments and experiments. In most cases the G_p increased steadily with time after planting (Fig. 6). The increase was accompanied by the development of new roots (Fig. 9). In Expt. 1 the root growth, and consequently the increase in G_p, was considerably better in seedlings planted in the mounds than in those planted without scarification (Figs. 6 and 9). Tranquillini (1973) and Havranek (1975) also observed a relationship between growth of new roots and recovery of water uptake.

In Expts. 5 and 6 the increase in G_p was interrupted in the dry summer of 1982 (Fig.6). Especially in seedlings planted in mounds on upturned humus the G_p was lower in the autumn than in the spring of 1982. The probable reason for this was that low soil water potentials occurred in the mounds, and the roots had not reached the deeper soil layers with higher soil water potentials.

In the present study the length of the recovery period was up to four years. During this period both G_p and growth were lower than in the controls. In many studies the recovery period after planting was found to be fairly long. Hallman et al. (1978) observed only a slight increase in transpiration five weeks after planting of *P. sylvestris*. In two other experiments the transpiration of seedling of *P. abies* and *P. menziesii* had reached 39–75 % of the transpiration of unplated controls two months after plating (Lüpke, 1973, 1979). Planted seedlings of *L. decidua* reached normal water status after one year (Tranquillini 1973), whereas it took about two years for seedlings of *P. abies* (Havranek 1975). In subhumid areas Baldwin & Barney (1976) report even longer periods for seedlings of *P. ponderosa* and *P. contorta* to reach water potentials as high as those of established seedlings.

It is a well-known fact that cell expansion will be negatively affected if the plant is subjected to water stress (Hsiao, 1973). The poor shoot- and needle growth in seedlings with low G_p (cf. Table 8), especially when compared to the controls, can therefore be explained as a direct effect of water stress (cf. Gürth, 1970, Tranquillini, 1973; Havranek, 1975; Hallman et al., 1978; Lüpke, 1979; Parviainen, 1979). The high mortality among the planted seedlings (Tables 5 and 6) is probably also an effect of the water stress (cf. Gürth, 1970). The photosynthesis of the seedlings was probably very low after planting due to stomatal closure (cf. Hallman et al., 1978; Lüpke, 1979; Gross, 1980), and the growth could thus have been inhibited because of shortage of carbohydrates. In an investigation on Scots pine (Ericsson et al., 1983) it was observed, however, that the carbohydrate availability possibly did not limit the growth during the first period after planting. The poor growth and survival among the planted seedlings, especially those with low G_p after planting, can thus be explained in terms of water stress.

When measuring water stress there is always the problem of getting representative and comparable samples. The water status in a seedling varies with age, time of day, climatic conditions and location of the plant (Kramer & Koslowski, 1979). In the present experiments some established seedlings were chosen as controls. The controls were used as references to overcome the variations depending on differing environmental conditions, (e.g. differences in VCD, irradiance, and temperature) between different measurement occasions. However, the established seedlings were somewhat larger and older than the planted ones and were of different provenance, which might have affected the results of the study. There was also a clear variation in G_p during the day (Fig. 7), but the seedlings and the controls varied with approximately the same pattern. The relation between the different treatments was therefore relatively constant during the morning and day.

As a summary of the present findings, it may be stated that seedlings of *P. sylvestris* suffered from a pronounced water stress after planting, and the water uptake was reduced for several years which may explain the poor reforestation result frequently observed. The results also indicate that water uptake and planting success may be improved by planting in mounds placed on mineral soil or in scarified patches. However, planting in mounds placed on an upturned humus layer was unfavourable during the dry conditions prevailing in the present experiments. Furthermore, measurements of G_p a few days after planting seem to predict the planting result and might also be useful when, for example, studying different growing regimes, plant types or handling of seedlings.

References

Bacon, G. J. & Bachelard, E. P. 1978. The Influence of Nursery Conditioning Treatments on some Physiological Responses of Recently Transplanted Seedlings of Pinus caribaea. *Aust. For. Res.* 8, 171–183.

Baldwin, V. C. & Barney, C. W. 1976. Leaf Water Potential in Planted Ponderosa and Lodgepole Pines. *Forest Sci. 22,* 344–350.

Bärring, U. 1965. *On the importance of scalping and some other problems conneted with planting of Pinus silvestris L. and Picea abies Karst* (Studia For. Suec. 24).

Blake, T. J. 1983. Transplanting shock in white spruce, effect of cold storage and root pruning on water relations and stomatal conditioning. *Physiol. Plant.* 57, 210–216.

Childs, S. W. 1980. *Water relations of newly planted Douglas-fir seedlings.* Diss. Washington State University, USA.

Cooper, A. J. 1973. *Root temperature and plant growth* (Commonwealth Agricultural Bureaux, Research Review No. 4).

Coutts, M. P. 1982. Growth of Sitka spruce seedlings with roots divided between soils of unequeal matric potential. *New Phytol. 92,* 49–61.

Ericsson, A., Lindgren A. & Mattson, A. 1983. *Effects of cold-storage and planting date on subsequent growth, starch and nitrogen content in Scots pine (Pinus sylvestris) and Norway spruce (Picea abies) seedlings* (Studia For. Suec. 155).

Farnum, P. 1977. *Post-planting water relations of container-grown seedlings: A mathematic model using finite elements.* Diss. Univ. Of Washington, USA.

Gadgil, P. D. & Harris, J. M. (eds.) 1980. Planting stock quality. *N. Z. J. For. Sci. 10.* 303 pp.

Gross, K. 1980. Öffnungszustand der Stomata, Xylem-Wasserpotential und Netto-Photosynthese junger Fichten vor und nach der Verpflanzung. *Forstw. Cbl. 99,* 12–21.

Gürth, P. 1970. Wachstum und Wasserhaushalt von Fichtenverschulpflanzen unterschiedlicher Qualität nach der Verpflanzung in das Freiland. *Allg. Forst- u. Jagdztg. 141,* 160–172.

Hägglund, B. & Lundmark, J. E. 1977. *Site index estimation by means of site properties* (Studia For. Suec. 138). 38 pp.

Hallman, E., Hari, P., Räsänen, P. & Smolander, H. 1978. The effect of planting shock on the transpiration, photosynthesis and heigt increment of Scots pine seedlings. *Acta For. Fenn. 161.* 25 pp.

Havranek, W. 1975. Wasserhaushalt und Zuwachs von Fichten nach Versetzung zu verschiedenen Jahreszeiten. *Cbl. ges. Fortsw. 92,* 9–25.

Havranek, W. & Benecke, U. 1978. The influence of soil moisture on water potential, transpiration and photosynthesis of conifer seedlings. *Plant and Soil 49,* 91–103.

Hellkvist, J., Hillerdal-Hagströmer, K. & Mattson-Djos, E. 1980. Field studies of water relations and photosynthesis in Scots pine using manual techniques. In: Persson, T. (ed.), Structure and Function of Northern Coniferous Forests—An Ecosystem Study. *Ecol. Bull. (Stockholm) 32,* 183–204.

Hsiao, T. C. 1973. Plant responses to water stress. *Ann. Rev. Plant Physiol. 24,* 519–570.

Huss, J. & Koch, W. 1982. Frischezustand und Anwuchserfolg unterschiedlicher Kiefernpflanzen. *Forstw. Cbl. 101,* 13–24.

Jarvis, P. G. & Jarvis, M. S. 1963. The Water Relations of Tree Seedlings. II. Transpiration in Relation to Soil Water Potential. *Physiol. Plant. 16,* 236–253.

Kozlowski, T. T. 1966. *Physiological implications in afforestation.* Proccedings from the sixth world forestry congress, Madrid, 1304–1315.

Kramer, P. J. & Koslowski, T. T. 1979. *Physiology of Woody Plants.* New York: Acad. Press.

Lopushinsky, W. & Klock, G. O. 1974. Transpiration of Conifer Seedlings in Relation to Soil Water Potential. *Forest Sci. 20,* 181–186.

Lüpke von, B. 1973. Wasserhaushalt junger Fichten nach dem Verpflanzen. *Forstw. Cbl. 92,* 311–327.

Lüpke von, B. 1979. Wasserhaushalt und Trockensubstanzproduktion bei Douglasien nach dem Verpflanzen. *Allg. Forst- u. J-Ztg. 150,* 78–82.

Mattson-Djos, E. 1982. The use of pressure-bomb and porometer for describing plant water status in tree seedlings. In: Puttonen, P. (ed.), *Vitality and quality of nursery stock* (Proc. Univ. of Helsinki, Dept. of Silviculture, Res. note 36), 45–57.

Örlander, G. 1982. The effect of some different scarification methods on stomatal conductance, needle water potential and liquid pathway conductance in seedlings of Pinus sylvestris. In: Puttonen, P. (ed.), *Vitality and quality of nursery stock* (Proc. Univ. of Helsinki, Dept. of Silviculture, Res. note 36), 58–66.

Parviainen, J. 1979. Einfluss des Verpflanzens und des Wurzelschnittes auf den Tagesverlauf des Xylemwasserpotentials bei Fichtenpflanzen. *Forstarchiv 50,* 148–153.

Passioura, J. B. 1982. Water in the Soil-Plant-Atmosphere Continuum. *Encyclopedia of Plant Physiology, vol. 12 B,* 5–33.

Puttonen, P. (ed.) 1982. *Vitality and quality of nursery stock* (Proceedings of a Nordic symposium. Univ. of Helsinki, Dept. of Silviculture, Res. note 36). 138 pp.

Rutter, A. J. & Sands, K. 1958. The relation of leaf water deficit to soil moisture tension in Pinus sylvestris. L. I. The effect of soil moisture tension on diurnal changes in water balance. *New. Phytol. 57,* 50–65.

Schmidt-Vogt, H. 1980. *Characterization of Plant Material.* Proceedings from the IUFRO-Meeting Working Group S1.05–04. Univ. Freiburg, Waldbau Institut, 191 pp.

Scholander P. F., Hammel H. T., Bradstreet E. D. & Hemmingsen E. A. 1965. Sap Pressure in Vascular Plants. *Science 148,* 339–346.

Söderström, V. 1976. Analysis of the effects of scarification before planting conifers on some newly clear-felled areas in Sweden. *Sveriges Skogsvårdsförbunds Tidskrift 74,* 59–333. (In Swedish, Summary in English.)

Söderström, V., Bäcke, J., Byfalk, R., Jonsson, C. 1978. *Comparison between planting in mineral soil heaps and after some other soil treatments* (Royal College of Forestry. Dept. of Silviculture, Res. note 11). 177 pp. (In Swedish, Summary in English.)

Tranquillini, W. 1973. Der Wasserhaushalt junger Forstpflanzen nach dem Versetzen und seine Beeinflussbarkeit. *Cbl. ges. Forstw. 90,* 46–52.

Waring, R. H. & Cleary, B. D. 1976. Plant Moisture Stress: Evaluation by Pressure Bomb. *Science 155,* 1248–1254.

Whithead, D. & Jarvis, P. G. 1981. Coniferous forests and plantations. In: Koslowski, T. T. (ed), *Water deficits and plant growth, vol. 6,* 49–152.

Williams, J. 1975. Water relations of three planting stock types of Pinus caribaea following transplanting. *N. Z. J. For. Sci. 5,* 87–104.

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