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Effects of soil temperature on gas exchange and morphological structure of shoot and root in 1 yr old Scots pine (*Pinus sylvestris* L.) seedlings

J. Lippu and P. Puttonen

Department of Silviculture, University of Helsinki, Unioninkatu 40 B, 00170 Helsinki, Finland

Introduction

Low soil temperature is one of the environmental factors affecting early growth and survival of forest seedlings in boreal ecosystems. With regard to gas exchange and growth, soil temperature is often underoptimal in spring and early summer (Söderström, 1974).

In cold soils, the viscosity of water increases and the permeability of roots to water decreases (Lopushinsky and Kaufmann, 1977) which leads to decreased gas exchange and growth.

The aim of this study was to examine certain structural and physiological attributes of acclimation in Scots pine (*Pinus sylvestris* L.) seedlings at different soil temperatures.

The following structural factors were examined: 1) timing and amount of shoot growth; 2) amount of needle and root growth.

The following physiological factors were examined: 1) net CO_2 assimilation rate *(A)*; 2) transpiration *(E)*; and 3) conductance to water vapor *(g)*.

Materials and Methods

One yr old Scots pine seedlings growing 30 d at 13°C, 18 h photoperiod, 250 $\mu mol \cdot m^{-2} \cdot s^{-1}$ irradiance and 7 mbar vapor pressure deficit in a mixture of low humified *Sphagnum* peat and perlite were exposed to 3 different soil temperature treatments (8°C, 12°C and a changing temperature from 5.5 to 13.0°C). Soil temperature was controlled by immersing sealed pots into a water bath thermostated by a Lauda RS-102 thermostat. Net CO_2 assimilation *(A)*, transpiration *(E)* and leaf conductance to water vapor *(g)* were measured by an LI-6200 portable photosynthesis system (LI-COR, Inc.), which includes an LI-6250 infrared gas analyzer, an LI-6200 control console and a leaf chamber.

The relative height growth rate *(RHGR)* was calculated using the equation: $RHGR = 1/H \times dH/dt$. An index of photosynthetic efficiency *(PE)* or photosynthetic utilization of internal CO_2 was derived by dividing the rate of net photosynthesis by the internal CO_2 concentration (Sasek *et al.*, 1985).

Results

The patterns of *A* at 2 constant soil temperatures (12.0 and 8.7°C) were quite similar but at 12°C the photosynthetic rate was higher (Fig. 1). However, after 11 d, differences were no longer significant.

A in seedlings at a changing soil temperature acted unusually: photosynthesis declined as soil temperature increased. After 18 d, photosynthesis recovered up to the level of other treatments. Photosynthetic efficiency decreased to 50–60% of the initial values in all treatments. The largest decrease occurred in seedlings at a changing soil temperature (Table I).

The transpiration rate increased in seedlings at constant 12°C during the first 11 d and then declined sharply (Fig. 2). At constant 8.7°C, the transpiration rate remained at the same level for 11 d and then declined. The transpiration rate in seedlings at changing soil temperature increased slightly and then decreased after 11 d. All seedlings recovered 18 d after the onset of the experiment.

The patterns of *g* evolution at the constant temperature of 8.7°C and at a changing soil temperature were quite similar throughout the experiment but the former was usually 20–30% higher (Fig. 3). Conductance at a constant 12°C increased slightly during the first 11 d and then declined. The shape of the curve is similar to that for transpiration.

Conclusions

Initiation and development of current yr needles affected the results of gas exchange measurements. The decline in *A* after 11 d in all treatments may be due to new needles (see Teskey *et al.*, 1984), which were included in the measurements. The photosynthetic capacity of the developing current yr needles is fairly low (Troeng and Linder, 1982). Enclosing them in a cuvette causes errors in *A, E* and *g*.

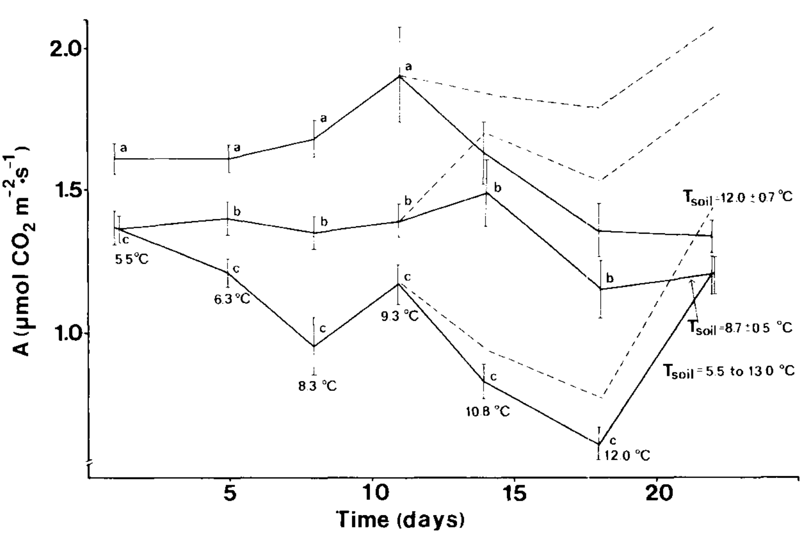

Fig. 1. The rate of net CO_2 assimilation *(A)* at different soil temperatures during the experiment (mean ± SE). Broken line: *A* when developing current yr needles are not taken into account.

Table I. Photosynthetic efficiency (PE) at different soil temperatures for Scots pine.

Time (days)	*PE at soil temperature (°C)* 5.5–13.0	8.7 ± 0.5	12.0 ± 0.7
1	0.12 ± 0.01	0.12 ± 0.007	0.15 ± 0.006
5	0.09 ± 0.007	0.12 ± 0.009	0.15 ± 0.02
8	0.06 ± 0.007	0.09 ± 0.005	0.10 ± 0.007
11	0.07 ± 0.005	0.08 ± 0.005	0.10 ± 0.007
14	0.06 ± 0.007	0.09 ± 0.009	0.09 ± 0.005
18	0.04 ± 0.007	0.07 ± 0.007	0.08 ± 0.005
22	0.05 ± 0.002	0.07 ± 0.005	0.08 ± 0.007

The unit for PE is: (mol CO_2 fixed·m^{-2}·s^{-1}) (mol·l^{-1} intercellular CO_2)$^{-1}$.

Soil temperature affected gas exchange in pine seedlings. In general *A* and *E* were higher in warm than in cold soil. At a changing soil temperature, the situation is more complicated. The net assimilation rate declined, although the temperature was increasing, and the relative growth rate and the amount of root tips were high (Table II). A possible reason is that low initial soil temperature resulted in a shock from which the seedlings did not recover until in the end of the experiment. Conifer seedlings coming out of cold storage require a period of almost 3 wk to acclimate physiologically to low soil temperatures (Grossnickle and Blake, 1985). Low soil temperature restricts new root growth which in turn slows recovery from water

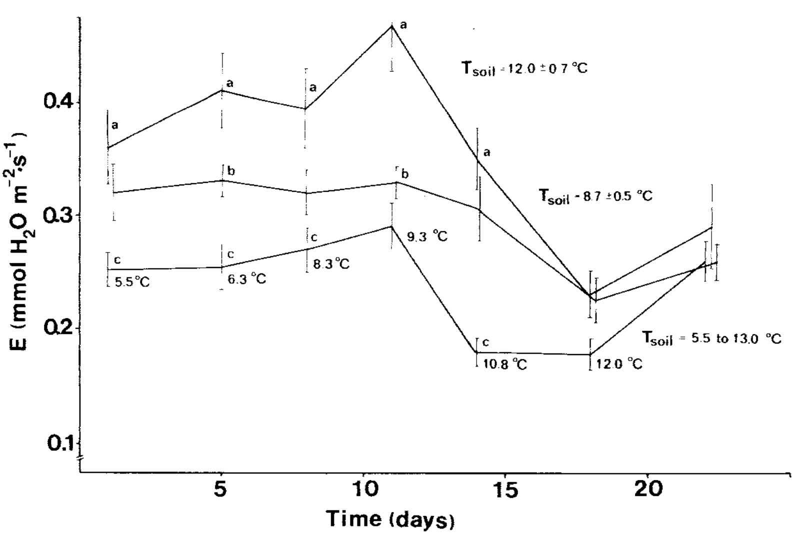

Fig. 2. The rate of transpiration *(E)* at different soil temperatures during the experiment (mean ± SE).

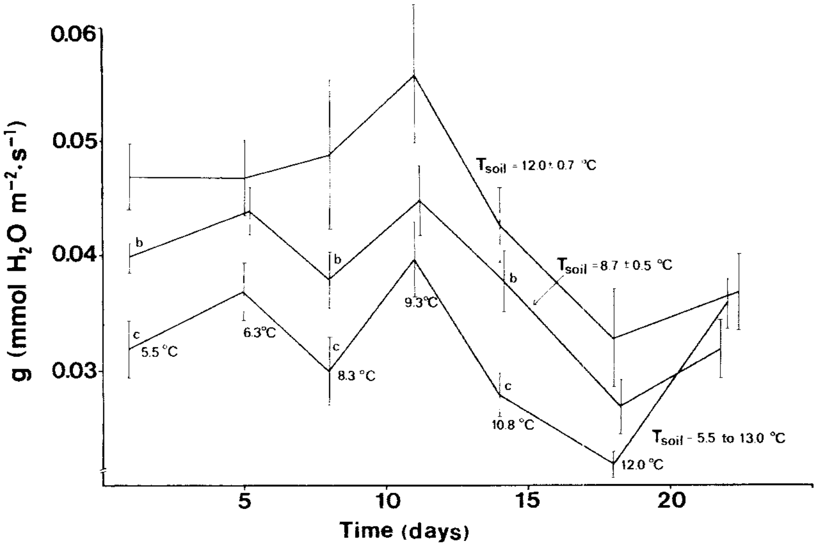

Fig. 3. The stomatal conductance *(g)* at different soil temperatures during the experiment (mean ± SE).

Table II. Relative growth rate *(RGR)* and some parameters of the root systems of Scots pine seedlings at different soil temperatures.

	Soil temperature (°C)		
	5.5 – 13.0	8.7 ± 0.5	12.0 ± 0.7
RGR (%)			
d 6	2.38 ± 0.21	2.14 ± 0.41	1.82 ± 0.42
d 12	1.48 ± 0.36	1.70 ± 0.45	1.44 ± 0.41
d 19	0.99 ± 0.8	1.18 ± 0.31	0.99 ± 0.28
d 22	0.39 ± 0.12	0.44 ± 0.22	0.44 ± 0.23
Amount of root tips *(A)*	24 ± 13	9 ± 7	15 ± 10
Dry weight of roots, mg *(B)*	344 ± 97	371 ± 88	375 ± 108

stress in plants, despite the adequate supply of soil water (Nambiar *et al.*, 1979).

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