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Seasonal Changes in Soil Temperature and in the Frost Hardiness of Scots pine Roots under Subarctic Conditions: Comparison with Soil Temperature and Snow-Cover under Different Simulated Winter Conditions

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Summary

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Seasonal changes in soil temperature and in the frost hardiness of adult Scots pine (*Pinus sylvestris* L.) trees were studied between August 1991 and May 1993 in a pine forest growing on dry heathland soil (67 °N, 29 °E). The temperature in the humus layer varied between +21.2 °C and -3.2 °C and in the mineral soil (down to 10 cm) between +21.6 °C and -2.4 °C. The temperature in the humus layer was continuously slightly colder than in the mineral soil from late August until May. The frost hardiness of the pine roots was lowest (about -5 °C) in May and during the first week of September. Frost hardiness stayed at its maximum of about -20 °C during November and December and slightly decreased in January and February. During most of the sampling time, the frost hardiness of the roots in the humus layer was greater than in the mineral soil. There was a clear relationship between the soil temperature and the frost hardiness of roots. Soil temperature and precipitation as snow in different winter conditions were simulated using the SOIL model. The simulations show that the insulating effect of the snow cover is crucial for the frost survival of Scots pine roots even during a moderate winter.

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Introduction

The frost hardiness of roots has been proposed as one critical factor in the winter survival of conifers in boreal forests (SAKAI & LARCHER 1987). However, the frost hardiness of the roots of adult Scots pines growing in central and northern Fennoscandia is unknown. Previous studies with Scots pine of more southern provenances have shown that the roots of adult trees can withstand temperatures down to -28 °C (KOROTAEV 1994).

Model simulations predict that in the extreme winter conditions of Finnish Lapland, with long-lasting, extremely low air temperatures and a late or thin snow cover, the temperature in the upper part of coarse-textured surface soil can drop down to -30 °C (JALKANEN & al. 1995). These findings raise questions about the survival of roots under prolonged severe freezing temperatures in the soil, and also about the nature of the ameliorating effect of the snow cover. Freezing damage to roots during extremely cold winters, with a late or thin snow cover, has been suggested as one cause of the needle loss on adult Scots pines growing in the coarse-textured soils of Fennoscandia (KULLMAN 1991, TIKKANEN & RAITIO 1990/91, RITARI 1990, JALKANEN & al. 1995). However, the verification of this hypothesis is difficult since there are no data on seasonal changes in the frost hardiness of the roots of adult Scots pines growing in natural conditions in central and northern Fennoscandia.

Materials and Methods

The study site is a naturally regenerated Scots pine (*Pinus sylvestris* L.) stand located in eastern Finnish Lapland (67°30'N, 29°30'E, 270 m a.s.l.). The forest site type is the *Empetrum-Cladina* type (CAJANDER 1949) and the soil is sandy.

The temperature of the air (2 m above the ground) and in the soil (at a depth of 5 cm) were recorded between August 1991 and May 1993 at intervals of two hours.

The snow precipitation data are based on recordings made at the weather station of the Finnish Meteorological Institute located 25 km from the study site.

Root samples (diameter less than 2 mm) for the frost hardiness determinations were collected at 2 to 4 week intervals from September 1991 to February 1993. The frost hardiness of roots was estimated by means of the electrolyte-leakage method (SUTINEN & al. 1992).

Soil temperature (at a depth of 5 cm) and snow accumulation were simulated using the SOIL model (JANSSON 1990) on the basis of the air temperature and precipitation data for the time period 1961-1990 recorded at the weather station of the Finnish Meteorological Institute located 25 km from the study site. Twelve different winters were simulated with three different daily average air temperature regimes and four different precipitation levels. The mild, moderate and harsh winters were simulated using the warmest, average and coldest, respectively, daily average air temperature on each day between August 1 and February 28 from the time period 1961-1990. The precipitation levels were chosen such that snow accumulation resembled the winter with the earliest and thickest snow cover, the winter with an average snow cover, the winter with the latest and thinnest snow cover and the winter without a snow cover between August 1 and February 28 during the time period 1961-1990.

Results

The air temperature was consistently below 0 °C after the first week of October in the fall 1991. Snow accumulation started at this time. The coldest month was January with the daily average air temperature of -10.2 °C (Fig. 1A).

The coldest month in the winter 1992 was February with the daily average temperature of -10.3 °C. Snow accumulation started in the first week of October and reached the level of 129 cm in April (Fig. 1C).

The temperature in the humus layer varied between +21.2 °C and -3.2 °C in the fall of 1991 (Fig. 1C). The temperatures in the mineral soil varied between +21.6 °C and -2.4 °C. The temperature in the humus layer was after late August continuously lower than in the mineral soil Similar results were obtained in the fall of 1992.

The frost hardiness of the Scots pine roots was lowest (about -5 °C) in May and during the first week of September. Frost hardiness stayed at its maximum of about -20 °C during November and December (Fig. 1C). The frost hardiness was clearly lower in January and February than during the preceding two months. During most of the sampling time, the frost hardiness of the roots in the humus layer was greater than in the mineral soil. There was a clear relationship between the soil temperature and the frost hardiness of roots.

Discussion

The maximum frost hardiness of the roots measured during the course of the study was -21 °C (November-December 1992). This is much smaller than has been reported for more southerly provenances (KOROTAEV 1994). However, the study period represents normal winter conditions without any temperature extremes. It is possible that the roots could have reached a greater level of frost hardiness if the air temperature and thereby the soil temperature would have been lower.

The results obtained in this study indicate that cold acclimation of the roots is much slower than that of the shoots (SUTINEN & al. 1996). Previous studies conducted on the same study site showed that, during the early phase of cold acclimation (August-September), the frost hardiness of the needles clearly exceeded the lowest minimum air temperatures ever measured on the study site. The needles survived temperatures of -20 °C even though they had not experienced air temperatures of below 5 °C. Roots attained a similar frost hardiness level only after experiencing temperatures of 0 °C or below for a period lasting many weeks.

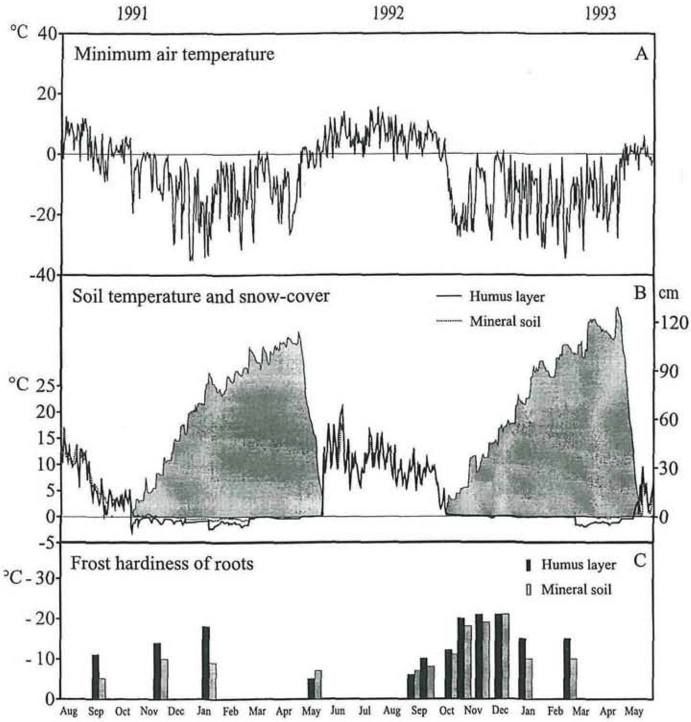

Fig. 1. Meteorological record and seasonal changes in the frost hardiness of Scots pine roots between August 1991 and May 1993 in the study area. (A) The daily minimum air temperature (2 m above ground) (B) Daily average temperature in the humus layer (solid line) and in the soil at the depth of 5 cm (dashed line) and daily snow depth values (C) The frost hardiness of Scots pine roots between September 1991 and February 1993 in the humus layer (black column) and in the mineral soil (dashed column). SD less than 20% of average of 3 sample plots (data not shown).

The simulation of soil temperature under different winter conditions showed that the frost hardiness which Scots pine roots attain during normal winter conditions can be insufficient under the conditions of a late and thin snow cover. Even during the simulated moderate winter the soil temperature dropped to below the recorded frost hardiness of the roots if the snow started to accumulate exceptionally late and slowly (Fig. 2G). A harsh winter would be a risk with all types of snow accumulation (Fig. 2I-2L). The frost hardiness of the roots recorded in this study represents the hardiness level of moderate winter conditions with a normal snow cover. The soil temperature in this study dropped to 0 °C in late September and remained almost constant during the following months. The frost hardiness of the roots increased from -11 °C to -20 °C between October and November, and remained at this level for two months. The results show that the

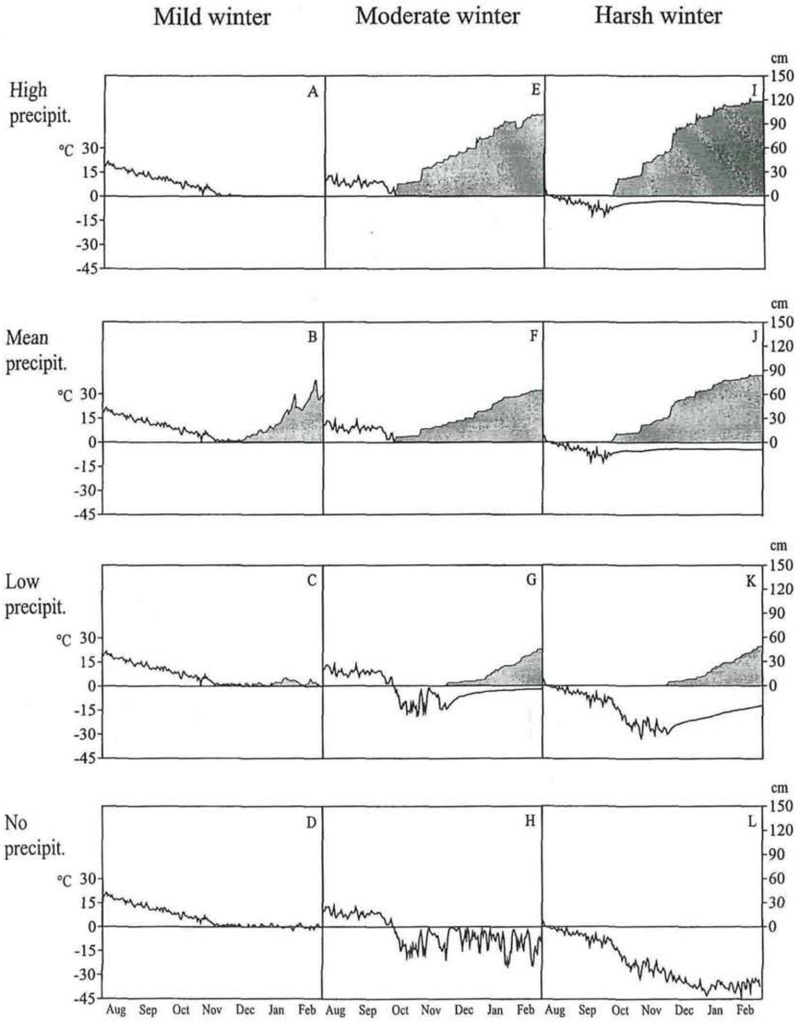

Fig. 2. Simulated soil temperature (at depth of 5 cm) and snow accumulation during the mild, moderate and harsh winter with four different precipitation levels. Simulations were conducted using the SOIL model (JANSSON 1990) on the basis of air temperature and precipitation data for the time period 1961-1990 recorded at the weather station of Finnish Meteorological Institute located 25 km from the study site.

roots cold acclimate very slowly. More than two weeks was needed to reach a stable level of frost hardiness in roots under constant soil temperature. This suggests that during winter with exceptionally fast decrease in soil temperature the roots of Scots pine may be damaged. The simulation results of soil temperature during winter with late or shallow snow cover suggest this conclusion.

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