International Symposium "Root Research and Applications"
RootRAP, 2–4 September 2009, Boku – Vienna, Austria

Does the removal of the snow layer enhance the adverse effects of soil frost on *Picea abies* (L.) Karst. ?

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ABSTRACT

Snow is known to act as an important insulator of forest soils against frost in northern latitudes. Consequently, the lack of a snow layer may result in more severe soil frost, thereby increasing freezing injuries to tree roots. Frozen soil may cause stress in spring, when the demand for evapo-transpiration is high. We studied the effects of the timing of soil frost thawing on the roots and foliage of Norway spruce. A snow manipulation experiment was conducted in a 47-year-old Norway spruce stand in eastern Finland during winter 2005-2006 and 2006-2007. The treatments (with three replicates) were: 1) CTRL with natural snow accumulation and melting, 2) OPEN: artificial snow removal during two consecutive winters, and 3) FROST: same as OPEN, but the ground was insulated with a layer of hay between plastic sheeting in early spring in order to delay soil thawing until July. The growth and physiology of nine trees per treatment were monitored in 2006 and 2007. FROST reduced shoot and needle growth, but not fine root biomass. FROST also delayed bud development and interfered with carbohydrate metabolism. FROST reduced the proportion of healthy buds and increased resource allocation to male flowers. The foliar nitrogen concentration in the current year needles was lower in the FROST treatment than in the control in 2006. Chlorophyll fluorescence and electrical impedance of current-year needles were affected by FROST in 2006, but not in 2007. Ion leakage measurements on the needles indicated no damage in 2007. Trunk diameter growth and bud burst were delayed in the FROST treatment in 2006, but not in 2007. Overall, the results indicate that the physiology of Norway spruce responded in varying ways to delayed soil frost melting.

KEYWORDS: soil frost, snow, *Picea abies*, root growth, needle physiology

1. INTRODUCTION

Winter precipitation and soil freezing in the boreal zone are predicted to change as a result of climate warming. It is possible that areas with a deep snow cover in the present climate will have no or only a thin insulating snow cover in the future, and therefore become susceptible to deeper soil frost. Predictions of the future soil frost and snow cover are associated with considerable uncertainties (Räisänen 2007). It is probable that soil temperature and moisture will change over wide areas, resulting in changes in carbon fluxes between the soil and the atmosphere. According to the predictions about climate change in Finland, both temperature and precipitation will increase in the winter. Regional changes in snow cover will be the immediate consequence of such a development. Regions with a deep snow cover in the present climate may, in the future, have only a shallow or no snow cover at all (Venäläinen et al. 2001). Because of the low incoming irradiation at northern latitudes, however, winters with low temperatures are still probable in the future. Such a development would change the regional distribution of soil freezing. Deep soil frost may occur in those areas where it is shallow under the present climate. Furthermore, it is probable that freeze-thaw events of both the soil and snow layer become more frequent in winter, leading to elevated mortality of fine roots and mycorrhizae (Tierney et al. 2001).

Our aim was to investigate the effects of timing of soil frost thawing on the growth and physiology of Norway spruce (*Picea abies* L. Karst.).

2. MATERIAL AND METHODS

The experiment was carried out in a 47-year-old Norway spruce stand growing in the boreal coniferous zone near to the city of Joensuu, Finland (62°36´N, 29°43´E) in 2005 to 2007. The average height of the trees in the stand was 17 m, stand density 864 trees/ha, stand volume 211 m^3/ha and basal area 25.4 m^2/ha. The soil was glacial till and the pedological soil type ferric podzol. The organic matter (OM) content in the organic horizon was 70.8 %, and in the uppermost mineral soil layer (3-10 cm) 9.0 %. Soil pH (H_2O) in the organic horizon was 4.2 and in the mineral soil 4.4 (Maljanen et al., unpublished).

The experiment was established in 2005 with three different treatments, and three replicate plots for each treatment. The size of each plot was 12 x 12 m and there was a 5 m buffer zone between the plots. The snow manipulation treatments were: 1. CTRL: snow accumulated and thawed according to the natural rhythm, 2. OPEN: snow was removed in winter 2005-2006 and 2006-2007, And 3. FROST: same as OPEN, but the ground was insulated with a layer of hay set between plastic sheeting in March in order to delay soil thawing until July. The insulation was removed on July 21 and July 4 in 2006 and 2007, respectively.

Air (at 2 m) and soil temperature (depths 5, 15 and 50 cm) and soil moisture (15 cm) were recorded in each plot. Three trees per plot were randomly selected for physiological measurements and phenological observations of bud burst with binoculars. Trunk diameter growth was monitored on two trees per plot by means of microcore sampling.

Needles were sampled 14 times during the two-year period for the analysis of chlorophyll a and b, soluble sugar and starch, nitrogen and carbon concentrations and for electrical impedance spectroscopy (EIS). Electrolyte leakage of the needle cells was measured on both current and previous-year needles during the second study year on seven occasions from April to October. Needle anatomy was analysed in late spring in 2007 on needle generations from 2005 (formed before the treatments) and 2006, as well as in autumn 2007 on the current year needles. The length of the current branches, as well as the condition and number of the buds formed in 2006 and 2007, were measured/recorded in April 2007 and 2008, i.e. before any externally visible sign of bud burst.

Root biomass was determined in different soil layers by soil coring in 2007. Roots were separated from the soil, and root length and size distribution, number of root tips and the root surface area were determined by WinRhizo scanning. In addition, root growth was monitored by means of minirhizotron imaging during 2006 -2007. Soil samples were taken for nutrient analyses and soil texture determination.

The statistical analyses were carried out using procedure MIXED in SPSS.

3. RESULTS AND DISCUSSION

3.1. Soil frost, temperature and moisture content

The frost period in 2006 was longer than that in 2007. This resulted in deeper soil freezing and, consequently, to slower soil thawing in 2006 than in 2007, especially on the plots where the snow had been removed. In midwinter, the soil temperature was approximately the same in the OPEN and FROST treatments - it decreased to -15^{o}C at the depth of 5 cm. At the same time the temperature in the CTRL treatment was only a few degrees below zero. Insulation in the FROST treatment delayed the rise in soil temperature in spring, whereas in the CTRL and OPEN treatments it increased at approximately the same time and rate. The soil moisture content was low in winter, and increased with soil thawing in spring and early summer. Due to insulation, the soil moisture content increased with some delay in the FROST treatment compared with the other treatments. Thawing proceeded slowly during early summer in the FROST treatment when the soil temperature was still around 0^{o}C. At that time water was gradual released, thereby increasing the soil water content. The insulation treatment prevented evaporation from the soil surface during the early phase of the growing period, and the soil moisture content was therefore typically higher in FROST than in the OPEN or CTRL treatments.

3.2. Growth and anatomy

In the FROST treatment, annual shoot growth, the average needle cross-sectional area and the proportion of healthy buds on the shoots decreased. The number of male buds increased by as much as twofold in the FROST treatment compared to the CTRL trees, which indicates increased resource allocation to the reproductive processes.

The FROST treatment brought about an increase in the fine root biomass in the mineral soil layer (depth 10 to 20 cm) compared to the controls. Neither the fine root length nor the number of root tips were affected by the treatments.

Formation of new tracheids in the trunks was delayed in the FROST treatment compared with the CTRL or OPEN treatments in 2006, but not in 2007. The same order between the treatments was observed in bud burst, which was delayed for two weeks in FROST compared to the CTRL treatment in 2006.

3.3. Needle physiology

In general, the physiological responses of the needles depended on their age and the season. There was also clear year-to-year variation. Chlorophyll fluorescence and electrical impedance (EIS) of the current-year needles were affected by the FROST treatment in 2006. The interaction sampling time x treatment was significant for apoplastic and symplastic electrical resistance and relaxation time in the previous-year needles in 2007. Chlorophyll fluorescence, ion leakage or EIS did not indicate any severe needle damage in 2007.

The water content in the current year needles was higher in the FROST than in the OPEN and CTRL treatments in late June in 2006, which could indicate delayed development of the needles. Also, the soluble sugar concentration was lower in the FROST than in the CTRL treatment in the newly flushed needles. In August, the starch concentration in the current-year needles in the FROST treatment was two-fold that in CTRL, which could be related to disturbances in carbohydrate transport. At the same time, the average nitrogen concentration in the current-year needles was 1.07% and 1.24% in the FROST and CTRL treatments, respectively. The lower foliar nitrogen concentration in the FROST treatment was in agreement with the nitrogen level in the organic layer in 2006 (CTRL 1.82%, FROST 1.39%, OPEN 1.92%). In 2007, there were no significant differences in needle or soil nitrogen concentrations between the treatments.

3.4. Conclusions

Our results suggest that delayed soil thawing had a clear effect on the physiology and growth of spruce. Moreover, our results highlight the need for long-term monitoring of the shoot and root responses of mature trees to soil frost in the field.

Figure 1. Snow was removed from the experimental plots in two successive years. The control plots were left intact.

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