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Frost hardiness of nutrient-loaded two-year-old *Picea abies* seedlings in autumn and at the end of freezer storage

Jaana Luoranen · Markku Lahti · Risto Rikala

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Abstract The effects of nutrient loading (NLOAD) on the frost hardening and dehardening of *Picea abies* (L.) Karst. seedlings were investigated under nursery conditions. Before NLOAD, second-year container seedlings were either short-day (SD) treated for 3 weeks in July or left for the natural photoperiod (CO). By mid-September, after 5 weeks of NLOAD, the fertilization of three foliar nutrient concentration levels (low = L-SD, medium = M-SD, and high = H-SD) for the SD-treated seedlings and one (medium = M-CO) for the CO-seedlings was completed. The NLOAD resulted in foliar nitrogen concentration 10.6, 16.1, 22.3, and 17.5 g kg^{-1} for L-SD, M-SD, H-SD and M-CO seedlings, respectively. The NLOAD had no effects on the morphology or dry mass variables of the seedlings, while SD-treatment reduced the dry mass of shoots, but not that of roots. The frost hardiness (FH) of different batches of the seedlings was assessed by the visual scoring of damage in their needles, stems and buds after their controlled exposure to freezing during frost hardening and dehardening. The low nutrient concentration in the SD-treated seedlings (L-SD seedlings) resulted in poor FH, to an even lower extent than that of the M-CO seedlings. The NLOAD did not affect the dehardening of the seedlings at the end of the freezer storage in the following spring.

Keywords Frost hardiness · Morphology · Nitrogen · Norway spruce · Short day treatment

Introduction

Nutrient loading (NLOAD), meaning an increase in the nutrient concentration without a change in the morphology of seedlings, has been shown to improve the planting performance of the forest tree seedlings of various conifer species (Timmer and Munson 1991). This improvement is based on their greater nutrient storage, their increased nitrogen

J. Luoranen (✉) · M. Lahti · R. Rikala
The Finnish Forest Research Institute, Suonenjoki Research Unit, Juntintie 154,
77600 Suonenjoki, Finland
e-mail: jaana.luoranen@metla.fi