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Developmental disorders in buds and needles of mature Norway spruce, *Picea abies* (L.) Karst., in relation to needle boron concentrations

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Abstract Dieback of the terminal shoot and consequently bushy growth induced by boron deficiency have been reported widely throughout the world in several tree species. Recently, similar growth damage was documented in half of the young spruce stands in eastern Finland. To clarify the role of B deficiency, the light microscopic structure of emerging buds and of developing and previous-year needles of mature Norway spruce (*Picea abies* L. Karst.) from damaged (D stand), partly damaged (PD stand) and healthy (H stand) stands were analysed. The samples, on which needle nutrient concentrations were also determined, were taken seven times between early spring (April) and early winter (November). Cell death characterized by precipitation of the cell content, possibly due to the release of tannins after membrane rupture, was seen in the apex of emerging buds, and this led to fatal damage in about half of the buds in the trees from the D stand, where the needle B concentration was well below the deficiency level of 4-5 mg kg⁻¹. Furthermore, an increase in living cells that accumulated tannins in the vacuoles, which is a common stress and/or defense reaction, was found in the primordial shoots of buds and in the differentiating needles in the PD and D stands. The increase in the areas of the central cylinder and of the xylem found in the needles indicate structural plasticity during needle differentiation to drought. The time frame for bud emergence from late May up to mid-September means that an adequate N supply is necessary throughout the summer in order to avoid fatal bud damage and thus bushy growth of the trees.

Keywords Boron deficiency • Bud emergence • Light microscopy Needle • *Picea abies*

Introduction

Growth disturbances on trees characterized by a loss of apical dominance and shoot dieback and, consequently, the development of multiple-shoots resulting in bushy topped trees, have been reported widely throughout the world (Stone 1990). These symptoms have often been connected to boron deficiency (Silfverberg 1980, Aronsson 1983; Braekke 1983; Raitio 1983; Tamminen and Saarsalmi 2004), as well as to magnesium and calcium deficiencies (Rehfuess et al. 1983) and to diseases like *Pucciniastrum areolatum* (Fr.) Otth. (Lilja 1907) and Sirococcus blight (*Sirococcus conigenus* (DC.) P. Cannon & Minter) alone (Halmschlager et al. 2000), or together with nutrient (Mg, Ca, P, Mn) deficiencies (Anglberger et al. 2003). Spring and autumn frost (Silfverberg 1980), and in some cases insects (Saalas 1949), may also kill the leader shoot and lead to a bushy appearance of the trees.

The occurrence of bushy topped trees in half of the young spruce stands on fertile sites in the province of North Savo (Tamminen and Saarsalmi 2004), have raised increasing concern about forest health and productivity in eastern Finland. Healthy-looking and bushy topped trees grow side

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