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Amount of boron in Norway spruce stands in eastern Finland

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ABSTRACT

The aim of this study was to determine the amount of boron in three Norway spruce (*Picea abies* (L.) Karst) stands in eastern Finland, where boron deficiency is common. A further aim was to estimate the effects of logging-residue harvest on boron balance and the boron-to-nitrogen ratio on these sites. The data were obtained from a 30-year-old and a 62-year-old healthy spruce stand as well as from a 35-year-old spruce stand with boron deficiency and growth disorders. Altogether 2.1 and 2.4 kg ha^{-1} boron, respectively, were bound in trees + organic layer + 0–10 cm mineral soil layer in the two healthy stands, and 0.9 kg ha^{-1} in the boron deficient stand. For the amount of boron in the healthy stands the trees made up 43% and 49%, respectively, and in the boron deficient stand 38%. Stems contained 30% and 40%, respectively, of the boron in trees in the healthy stands and 37% in the boron-deficient stand. Only 11–13% of the tree boron was in the needles. The amount of nitrogen bound in the ecosystem studied was 2.1 and 2.5 Mg ha^{-1}, respectively, in the two healthy stands and 3.0 Mg ha^{-1} in the boron deficient stand. In the ecosystem the trees contained 21–29% of the amount of nitrogen. Stems contained 14–24%, respectively, and needles 26–36%, respectively, of the nitrogen in the trees on the studied stands. In stem-only harvestings, relatively more boron than nitrogen would be removed from a site. In the boron-deficient stand, boron fertilisation for 3 years nearly doubled the amount of boron in the ecosystem. Only 38% of the fertiliser boron (2 kg ha^{-1}) was found in the ecosystem components studied.

1. Introduction

Disorders due to boron deficiency on upland soils are most frequent in the eastern part of Finland (Tamminen and Saarsalmi, 2004; Saarsalmi and Tamminen, 2005). Slash-and-burn agriculture was typical for this part of country 1–2 centuries ago and up to the 1920s. In forests of this area many deciduous tree species grew, especially alder. Cattle, which grazed on burned forest sites, did not eat alder, hence more nitrogen was accumulated on these sites than on older conifer sites. In addition, repeated burning over the decades may have vapourised part of the boron. These sites can be described as nitrogen rich and boron poor (Saarsalmi and Tamminen, 2005). Later on, during the 1900s, these former slash-and-burn forests were planted mostly with Norway spruce under a shelter of alders and birches. Observations of forest owners and forest professionals in the 1990s prompted research on forest tree disorders in eastern Finland and development of hypotheses about their causes (Hynönen, 1998; Hynönen et al., 1999).

Boron deficiency is not uncommon in forestry outside Finland (Aronsson, 1983; Möller, 1983; Wikner, 1983; Hopmans and Flinn, 1984; Stone, 1990; Will, 1990; Shorrocks, 1997) but is seldom found in old, at least second generation, conifer forests unless they have been fertilised with nitrogen (Aronsson, 1983; Möller, 1983; Lipas, 1990; Brockley, 2003). Boron deficiency and growth disorders on Finnish upland sites seem to be most common in first generation conifer stands with a history of slash-and-burn and cattle-grazing followed by a birch and/or alder stand (Tamminen and Saarsalmi, 2004).

Previously it was assumed that trees take up boron only passively with the transpiration stream, but now some evidence for boron retranslocation has also been shown in Norway spruce (Lehto et al., 2000, 2004, 2010; Aphalo et al., 2002). Symptoms of boron deficiency occur first in the meristematic tissues of roots, restricting root growth and leading to an increased shoot/root ratio (Dell and Huang, 1997). Boron deficiency does not generally decrease growth in tree diameter, but causes the multileader appearance of tree tops by killing apical buds (Stone, 1990; Sutinen et al., 2006; Sutinen and Saarsalmi, 2008). Moreover, in many coniferous tree species, boron deficiency is known to decrease height growth of shoots (Hopmans and Flinn, 1984; Stone, 1990; Hopmans and Clerehan, 1991; White and Krause, 2001; Saarsalmi and Tamminen, 2005).

For Norway spruce the critical concentration of boron is 4–5 mg kg^{-1} in current year needles; below this concentration, growth disorders may be found (Aronsson, 1983; Braekke, 1983). Normally, the lower the boron concentration, the higher is the

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proportion of damaged trees (Tamminen and Saarsalmi, 2004; Saarsalmi and Tamminen, 2005). With low boron uptake trees can also grow almost normally when climate or edaphic stress is low (Braekke, 1983). A severe drought, for example, can trigger acute damage to such trees. In Finnish conditions not all trees in a stand are severely damaged, even though the boron concentration may be as low as 2 mg kg^{-1} (Aronsson, 1983; Saarsalmi and Tamminen, 2005).

Little information is available on the amount of boron in a boreal forest ecosystem (Wikner, 1983). According to Wikner, in a Swedish forest stand, the tree biomass contained 0.63 kg ha^{-1} boron; and the organic layer and 0–10 cm mineral soil layer contained 0.11 and 0.41 kg ha^{-1}, respectively, hot-water-soluble boron. According to Finér (1989), in a 100-year-old Norway spruce stand on peatland in eastern Finland the tree biomass contained 0.77 kg ha^{-1} boron, of which about 0.13 kg ha^{-1} was in the needles.

Boron deficiency can easily be avoided by application of boron fertilisers (White and Krause, 2001; Saarsalmi and Tamminen, 2005). The amount of boron used in fertilisation is usually 2–4 kg ha^{-1}. Boron fertilisation of 2 kg ha^{-1} has steeply increased boron concentration in needles up to 30–50 mg kg^{-1} in one growing season, being 15–20 mg kg^{-1} after three growing seasons (Saarsalmi and Tamminen, 2005). After fertilisation, boron concentrations in needles seem to remain at a level of 15–20 mg kg^{-1} for several years (Aronsson, 1983; Hopmans and Clerehan, 1991; Saarsalmi and Tamminen, 2005). Probable reasons for the long-term response of boron concentration in needles to boron fertilisation are suggested to be high retention capacity of the organic layer (Lehto, 1995) and retranslocation of boron within trees (Lehto et al., 2000, 2004; Aphalo et al., 2002). Boron fertiliser has been shown to increase height growth, also in cases with no loss of apical dominance, but diameter growth is not generally affected by boron fertilisers (Lipas, 1990; White and Krause, 2001; Saarsalmi and Tamminen, 2005).

In eastern Finland, attempts are continuously made to diminish growth disorders induced by boron deficiency by using boron fertilisation. At the same time, energy-wood harvesting, i.e. also harvesting the logging residues, has become more common. Logging-residue harvesting has, however, so far been avoided on areas where there are growth disorders. It would be important to know the distribution of boron within tree stands and how much boron there is in soil, so that we could estimate the effects of logging-residue harvest on boron balance and also anticipate the need for and effects of boron fertilisation.

The aim of this study was to determine the amount of boron in certain spruce forests in eastern Finland, where boron deficiency is rather common, and to determine the effects of boron fertilisation, i.e. how boron distribution had changed 3 years after fertilisation. At the same time we tried to estimate the possible effects of logging-residue harvest on boron balance on these sites.

2. Material and methods

2.1. Experiments

The material for this study consisted of one Norway spruce (*Picea abies* (L.) Karst) stand suffering boron deficiency and growth disorders (exp. 423) and two healthy Norway spruce stands in eastern Finland (exp. 31, exp. 417) (Fig. 1, Table 1). The oldest stand, exp. 31, is part of a large factorial fertilisation series established in the years 1959–1965. For the present study, two unfertilised plots were selected. The younger healthy stand, exp. 417, belongs to a fertilisation series established in the years 1990–1993, which concentrated on non-nitrogen fertilisers. For the present study, eight unfertilised plots were selected.

Exp. 423 was established in autumn 1999. This experiment consisted of experimental plots with a sample tree in the centre of each plot and all other trees located within a radius of 3 m from the sample trees, i.e. the total area of each plot was 28.3 m^2 (Saarsalmi and Tamminen, 2005). In addition to six unfertilised control plots, six plots that were fertilised with 2 kg ha^{-1} of boron (borax) in May 2000 were chosen for the present study.

Experiments 31 and 417 were pure spruce stands. In exp. 423 the proportion of other tree species, mainly alder (*Alnus incana*) and birch (*Betula pendula*), was, on average, 13% of the stand basal area and 5% of tree biomass (see Table 4). Stand 417 had been commercially thinned for the first time just before the stand was measured and sampled for biomass components and soil. When the experiment was established in 1999, the young disorder stand 423 was at the stage of first commercial thinning. The stands studied were situated on sandy loam till and all grew on very productive sites (Table 1). According to the C/N ratio in the organic layer, for Finnish conditions, young stands 417 and 423 were exceptionally fertile. Due to growth disorders, the stem form, H/D, was poorest in exp. 423, i.e. trees of the same diameter were shorter in this experiment than in exp. 31 and 417.

2.2. Tree stand measurements, plant and soil sampling

To estimate stem volume (Laasasenaho, 1982) and biomass components, trees from each sample plot were measured for breast height diameter and stem and crown height in exps. 31 and 417 in autumn 1992, and in exp. 423 in autumn 2002. Felled sample trees (10 trees in exp. 31, 16 trees in exp. 417 and 12 trees in exp. 423) were sampled for biomass components stemwood, bark, living and dead branches and needles of different ages. For nutrient analyses, samples from needles and living branches (two branches per sample tree for exp. 423 and four branches per sample tree for exps. 31 and 417) were collected from the lower and upper halves of the crown, and one dead branch below the living crown. From sample branches the needles were removed and sorted according to age. Sample discs from the stem were cut at heights of 1.3 m and 0.7 × stem height. Stemwood and bark were separated from the sample discs. Stump and roots were not measured or sampled for elemental analyses, but their biomass was predicted using the equations of Repola et al. (2007)). In exp. 423 deciduous trees were only measured for breast height diameter and height, but not sampled for elemental analyses. Biomass components for deciduous trees were predicted with the equations of Repola et al. (2007).

In exp. 31 soil was sampled in autumn 1991, in exp. 417 in spring 1993 and in exp. 423 in autumn 2002. A composite sample from the organic layer consisted of 15 subsamples in exp. 31 (a rectangular systematic grid of 3 × 5 points), 25 subsamples in exp. 417 (a rectangular systematic grid of 5 × 5 points) and eight subsamples in exp. 423 (eight points along the circumference of a circle with a radius of 2 m); these subsamples were taken with a steel cylinder (d = 58 mm). A composite sample of mineral soil from the 0–10 cm layer taken with a hand corer (d = 23 mm) consisted of 15 and 25 subsamples in exp. 31 and 417, respectively; but in exp. 423 the composite sample consisted of four volumetric subsamples taken with a volumetric sampler (d = 39 mm). Subsamples from mineral soil were taken according to the same systematic pattern as organic layer subsamples.

2.3. Analyses of plant and soil samples

Plant samples were air-dried in a ventilated chamber at 40 °C. The boron concentration was determined on finely ground samples. The sample was ashed with a Leco TGA 600 (550 °C) and the ash was then extracted with HCl as follows. First, 2–3 ml of