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Fine root biomass, necromass and chemistry during seven years of elevated aluminium concentrations in the soil solution of a middle-aged *Picea abies* stand

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Abstract

Toxic effects of aluminium (Al) on *Picea abies* (L.) Karst. (Norway spruce) trees are well documented in laboratory-scale experiments, but field-based evidence is scarce. This paper presents results on fine root growth and chemistry from a field manipulation experiment in a *P. abies* stand that was 45 years old when the experiment started in 1996. Different amounts of dissolved aluminium were added as $AlCl_3$ by means of periodic irrigation during the growing season in the period 1997–2002. Potentially toxic concentrations of Al in the soil solution were obtained. Fine roots were studied from direct cores (1996) and sequential root ingrowth cores (1999, 2001, 2002) in the mineral soil (0–40 cm). We tested two hypotheses: (1) elevated concentration of Al in the root zone leads to significant changes in root biomass, partitioning into fine, coarse, living or dead fractions, and distribution with depth; (2) elevated Al concentration leads to a noticeable uptake of Al and reduced uptake of Ca and Mg; this results in Ca and Mg depletion in roots. Hypothesis 1 was only marginally supported, as just a few significant treatment effects on biomass were found. Hypothesis 2 was supported in part; Al addition led to increased root concentrations of Al in 1999 and 2002 and reduced Mg/Al in 1999. Comparison of roots from subsequent root samplings showed a decrease in Al and S over time. The results illustrated that 7 years of elevated Al_{tot} concentrations in the soil solution up to 200 μM are not likely to affect root growth. We also discuss possible improvements of the experimental approach.

Keywords: Al toxicity; Fine roots; Norway spruce; Root biomass; Root chemistry

1. Introduction

In the context of acid deposition to forest ecosystems, the role of aluminium (Al) ions in the soil solution has been debated for more than 25 years, starting with the work of Ulrich et al. (1978). Numerous short time studies with Al addition to *Picea abies* (Norway spruce) seedlings grown in liquid, acidified growth media showed root effects of Al^{3+} concentrations between 80 and 300 μM at pH 3.8, like stunted growth and decreased tissue Ca and Mg concentrations (e.g. Göransson and Eldhuset, 1991; Godbold and Jentschke, 1998). However, young Norway spruce trees grown in pots with quartz sand have been shown to sustain far higher Al concentrations (at pH 3.8) than those mentioned above (Makkonen-Spiecker, 1985).

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Considering the slow growth and long life of trees, one would expect that effects from a subtle underground influence on forest ecosystems might not be seen until the influence had lasted for several years. The problem of scaling from individual small plants to mature forests should motivate performance of long-term (several years) forest manipulation experiments focusing on effects of acidification. Studies of Al effects on tree and fine root growth at the ecosystem scale are however scarce. Results from field experiments in Norway in the 1970s and Germany in the 1980s, where artificial acid precipitation was applied to stands of *P. abies* for several years, did not give clear indications of negative effects of Al (Abrahamsen et al., 1994; Hahn and Marschner, 1998a,b). It should be realized, however, that the Norwegian study mentioned was not designed for studying detrimental Al effects, and in the German study, the roots were studied 1 and 2 years after the cessation of the watering only. In both studies, the acid precipitation was given as sulphuric acid which might lead to formation of heavily soluble aluminium sulphate; no Al additions were performed in these experiments.

Thus, a field-scale aluminium amendment experiment for Norway spruce was lacking so far. The purpose of such an experiment would be to investigate nutrient contents of soil, soil solution, and most importantly in plants (roots and needles), focussing on possible toxicological effects on plant tissue. In the course of such an investigation, care has to be taken as to aluminium availability in plant microenvironments, i.e. the Al concentration in the soil solution has to be controlled to the extent possible. This paper discusses results of such a field manipulation experiment in a *P. abies* stand where dissolved aluminium was added during a period of 7 years. Our working hypotheses were as follows: (1) elevated Al concentration leads to a significant change in total biomass, or in biomass partitioning into fine, coarse, living or dead fractions and distribution with depth; it also leads to increased fine root mortality; 2) elevated Al concentration leads to a noticeable uptake of Al and reduced uptake of Ca and Mg; this results in Ca and Mg depletion in roots.

2. Materials and methods

2.1. Description of experimental location

The Nordmoen experimental forest in southeast Norway (11°06′E, 60°16′N) is located at a flat plain of glaciofluvial sandy sediments of about 60 m depth, overlaying Precambrian and Permian crystalline bedrock, at an elevation of 200 m above sea level. Mean annual precipitation is 862 mm and mean annual temperature is 3.8 °C (Stuanes et al., 1994). From 1997 to 2001, the mean annual total (dry plus wet) deposition of S (sulphur) and N (nitrogen) in the Nordmoen area was about 3.4 kg S ha^{-1} and 6.5 kg N ha^{-1} (numbers calculated after Hole and Tørseth (2002), based on a 50 × 50 km^2 (EMEP) grid). This level of air pollution at the Nordmoen forest is typical for Norway, and relatively low in comparison with forests in Central Europe (Prechtel et al., 2001; Wright et al., 2001).

The aluminium addition was done in a homogeneous Norway spruce stand (*P. abies* (L.) Karst) that was planted in 1951. The ground vegetation is dominated by *Vaccinium myrtillus*. Tree density varies between 1000 and 3500 ha^{-1}. In 1996, average tree height varied from 10.3 to 13.8 m and average tree volume varied from 100 to 200 m^3 ha^{-1} for the various experimental plots.

The homogeneous, sandy soil is classified as a Typic Udipsamment and has a thin (2–4 cm) O horizon consisting of Oe and Oi material. Selected soil chemical characteristics are presented in Table 1. The upper 30 cm of the soil of the experimental plots, where most of the

Table 1
Selected soil chemical characteristics of the treatment plots at Nordmoen

Depth (cm)	pH (H_2O)	CEC[a] (mmol$_c$ kg^{-1})	Base saturation (%)	Exchangeable acidity (mmol$_c$ kg^{-1})	Exchangeable cations (mmol kg^{-1})		
					Al	Ca	Mg
0+	4.85	331.6	65.7	76.2	3.7	76.0	15.1
0–5	4.02	88.4	7.1	80.8	26	1.6	0.7
5–10	4.36	61.6	4.2	57.6	20	0.5	0.2
10–20	4.44	33.4	5.5	31.0	11	0.3	0.1
20–40	4.45	17.2	7.7	15.8	5.6	0.2	0.1

Data are averages of all the twelve plots prior to initiation of the treatments. 0+ refers to the O horizon. Data are from de Wit (2000).

[a] CEC (cation exchange capacity) is the sum of acidity, Mn and base cations extracted with 1 M NH_4NO_3.