Effects of soil acidity on Douglas fir seedlings. 2. The role of pH, aluminium concentration and nitrogen nutrition (pot experiment).

H. P. Smit[1,2], W. G. Keltjens[1] and N. van Breemen[2] ([1]Department of Soil Science and Plant Nutrition, Wageningen Agricultural University, P.O. Box 8005, 6700 EC Wageningen, Netherlands; [2]Department of Soil Science and Geology, Wageningen Agricultural University, P.O. Box 37, 6700 AA Wageningen, Netherlands)

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Abstract. In a greenhouse experiment the growth of one-year-old Douglas fir seedlings decreased with increasing soil acidity when soil pH (pH(H_2O)) was 4.0 or lower. Also mortality of the plants was high at low soil pH. Biomass of roots and of upper plant parts and shoot length were used as growth parameters. Growth reduction due to low pH was significantly stronger upon fertilization with NH_4^+ than with NO_3^--N. Below a pH of about 4, aluminium in the soil solution increased exponentially with decreasing soil pH, especially when NH_4^+ was used as nitrogen fertilizer. Aluminium concentrations in the needles of plants grown on the extreme acid soils were high and probably reached toxic levels.

Key words: aluminium concentration, Douglas fir, growth reduction, nitrogen source, mortality, soil acidity

Introduction. Soil acidification by atmospheric deposition can have negative effects on growth of forest trees (van Breemen & Mulder, 1986). These effects are probably due to high concentrations of aluminium in the soil solution (Ulrich et al., 1979). Under such conditions roots can become injured and root growth as well as nutrient uptake (P, Ca, Mg) are often restricted (Foy et al., 1978; Rost-Siebert, 1985). As a consequence, a growth reduction induced by aluminium can be intensified by nutrient deficiencies. Also the nitrogen nutrition of plants may be important to plants grown on acid soils. Especially in areas with intensive animal husbandry, the nitrogen content of forest soils can be very high as a result of high NH_4^+ deposition. By nitrification, a pH-dependent microbiological process, NH_4^+ is converted into NO_3^- and simultaneously soil pH will decrease. Consequently, under such conditions nitrogen in the soil can be present in different forms. If nitrification is hampered, for example at extremely low soil pH, NH_4^+ is the dominant N source in the soil and nutrient uptake will usually result in excess cation-over-anion uptake. A compensatory net proton release from the roots will acidify the root vicinity and consequently lead to increased aluminium solubility in the root rhizosphere. Significant changes in pH of the bulk soil cannot be expected. On the other hand, after complete nitrification a pure NO_3^- supply will increase rhizosphere pH, while the bulk soil pH will be lowered.

The aim of this experiment was to test the hypothesis that:
- growth of Douglas fir seedlings is reduced at low pH, and that this growth reduction is positively correlated with both external (soil solution) and internal (needle) aluminium concentration,
- negative effects of extreme soil acidity are less if plants are supplied with NO_3^--N than with NH_4^+-N.

Materials and methods. One-year-old seedlings of Douglas (*Pseudotsuga menziesii*) were grown in pots. An acid forest soil, a medium coarse sand, was collected from 0–20 cm depth in a Douglas fir forest near Nunspeet (Netherlands) and air-dried. Soil characteristics were: pH(H_2O) 4.0, pH(KCl) 3.5, organic matter content 5.1%, cation exchange capacity (AgTU method according to Chabra et al., 1976) 65.1 mmol(+) kg^{-1}, ionic equivalent of exchangeable Al 45.6 mmol kg^{-1}, ionic equivalent of exchangeable Ca 4.0 mmol kg^{-1}, and relative base saturation 7.7%. Four pH(H_2O) levels were created by a treatment of the original soil with H_2SO_4 (to pH 3.3), with $Ca(OH)_2$ (to pH 4.5 and 5.5) and no further treatment (pH 4.0). Besides a basal K, P and Mg dressing, 100 kg ha^{-1} of N was supplied as NO_3^- or as NH_4^+, both in combination with a nitrification inhibitor (N-serve). Plants were grown for 6 months in a glasshouse. Pots with plants were placed on carts which were wheeled into an open-air cage during dry and warm weather. Twice a week the pots were weighed in order to add enough water to restore a moisture level of 60% of the maximum water-holding capacity of the soil. Prior to harvest, soil solution was collected in ceramic cups connected to vacuum bottles (van Breemen et al., 1986). At harvest, mortality, shoot and root length and dry weights of roots and shoots were estimated. Also the colour of the 6-month-old needles was observed. In the dry plant material chemical analyses were carried out for all major elements as well as Al.

Results and discussion. At low soil pH, mortality of Douglas fir seedlings was considerable, especially when NH_4^+ was the only nitrogen source. At pH 3.3, with NH_4^+ and NO_3^- as nitrogen source, 100 and 90 % of all plants died, respectively. At pH 4.0, mortality decreased to 55 % (NH_4^+) and 10 % (NO_3^-). Colour observations of the 6-month-old needles showed that needles became more yellow at lower pH. Needles were darker green when plants were supplied with NO_3^--N. In gener-

Table 1. Total root length (cm/plant) of Douglas fir seedlings grown for 6 months on soils with different acidity and supplied with NO_3^- or NH_4^+ as nitrogen source.

N source	Initial soil pH, pH (H_2O)			
	3.3	4.0	4.5	5.5
NO_3^-	23	88	121	134
NH_4^+	–	65	122	158

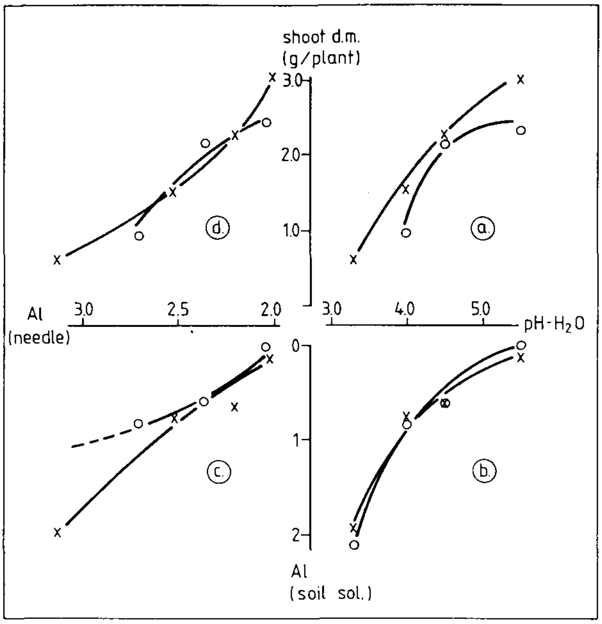

Fig. 1. Relationships between (a) initial soil pH and shoot growth (g/plant), (b) initial soil pH and final Al concentration in soil solution (mg l^{-1}), (c) final Al concentration in soil solution and needle Al concentration (mg kg^{-1} d.m.), (d) needle Al concentration and shoot growth. Measurements carried out before or after a 6-month growth of the Douglas fir plants with NO_3^- (x) or NH_4^+ (o) as nitrogen fertilizer.

al, dry weight of shoots (Fig. 1a), total root length (Table 1) and shoot length were reduced significantly by increasing soil acidity. Reductions in growth were more severe when NH_4^+ was used as nitrogen source. Analyses of the soil solution, collected at the end of the experiment, indicate an exponential increase in Al content in lower pH treatments (Fig. 1b). Differences in Al concentrations between the soil solution of the NH_4^+ and NO_3^- treatments were not observed. With the technique used, pH of the solution extracted from the bulk soil will probably mask deviations in rhizosphere pH. Fig. 1c shows a close correlation between external (soil solution) and internal (needle) Al levels. However, at an equal Al concentration of about 7 mg l^{-1} in the bulk soil solution (initial soil pH 4.0), needle Al concentrations in plants fed NH_4^+ and NO_3^- are 510 and 335 mg per kg dry matter, respectively. Higher internal Al concentrations of the NH_4^+-supplied plants will probably be the result of rhizosphere acidification. On the other hand, NO_3^- nutrition diminishes rhizosphere acidity and the consequent negative effects on plant growth. Relationships between growth and internal Al concentration are completely identical for the two nitrogen sources (Fig. 1d). This indicates that negative effects of NH_4^+ are probably due to rhizosphere acidification, rather than to a direct NH_4^+ toxicity. A lower rhizosphere pH will lead to increased Al solubility and to enhanced needle Al concentrations.

All observations presented in Fig. 1 and Table I support our hypothesis of negative effects of extreme low soil pH on Douglas fir plants. Mortality, growth inhibition and needle discoloration are more severe when plants are fed NH_4^+ than with a pure NO_3^--N supply.

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