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Effects of liming and fertilization on tree growth and nutrient cycling in a Scots pine ecosystem in Norway

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Abstract

Tree growth and nutrient cycling of N, P, K, Mg, Ca, S, and B were examined after four growing seasons in a pine ecosystem in southern Norway. The Scots pine (*Pinus sylvestris* L.) stand, growing on a Cambic Arenosol, was 33 years old and had a medium site index class. The randomized block experiment had six treatments and three replicates: (1) control, (2) 3000 kg ha^{-1} lime, (3) 3000 kg ha^{-1} dolomite, (4) 3000 kg ha^{-1} dolomite and (5) 6000 kg ha^{-1} dolomite, both treatments (4 and 5) with the fertilizers KCl and superphosphate, and (6) 3000 kg ha^{-1} dolomite with KCl, superphosphate, NH_4NO_3, kieserite, and borax, and denoted as ''optimal'' treatment.

The ''optimal'' treatment gave a significantly higher annual increase in tree height and diameter, stand basal area and volume than the control and lime treatments. The dry mass of needles and branches increased slightly for the treatments nos. 3–5 compared to the control and lime treatments, with the most distinct increase for the ''optimal'' treatment. Highest dry mass of stem wood + bark was found for the treatments nos. 3–6.

The nutrient contents in needles were highest for the ''optimal'' treatment, while dolomite without fertilizer elevated the Mg content in both needles and branches. The nutrient concentrations in the current year's needles increased the most for the ''optimal'' treatment, except for Ca and Mg. The addition of lime gave the highest concentration of Ca in needles compared to the other treatments. The amounts of N, P, S, and B in the forest floor were also highest for the ''optimal'' treatment.

Soil uptake of N, P, and K from the unfertilized plots leads to a depletion of these elements, but also very little leaching. Upon addition of N, P, K, Mg, Ca, and S, soil uptake and nutrient accumulation in the soil usually increased at the same time. The high doses of N, P, K, and S in the ''optimal'' treatment gave a distinct response with higher uptake from the soil and higher accumulation in the soil. No P was leached from the soil, while about one fourth to one third of the applied N, K, and Mg were leached. The treatment induced an unacceptably high nitrate leaching, and must therefore be regarded as ''suboptimal''.

Keywords: Acidification; *Pinus sylvestris*; Cambic Arenosol; Liming; Vitality fertilization; Nutrient cycling; Nutrient deficiency; Nutrient budget

1. Introduction

During the past decades, forests in central and northern Europe have experienced increased amounts of acidifying deposition in form of sulphur and nitrogen compounds. While the sulphur deposition peaked around 1980 and thereafter decreased, the deposition of nitrogen has stayed almost on the same level. This acidifying deposition was expected to change the nutritional status of the forest trees. To compensate for possible nutrient imbalances, lime and nutrients were added in other proportions than previously, which often was denoted vitality or compensatory fertilization. The term ''vitality'', e.g. of a tree or an ecosystem, can be defined as the ability to resist the effects of various stresses and is thus a combination of many single factors. In this study we used vitality as a function of balanced mineral nutrient conditions in the tree and the ecosystem as a whole, as discussed by Andersson et al. (1998).

In the early 1970s, liming was introduced as a countermeasure to the higher degree of soil acidification caused by acidic deposition. Liming alone and in combination with acid were applied in large field experiments in forests (Kreutzer and Göttlein, 1991; Abrahamsen et al., 1994). Focus was then

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directed at the study of the effects of liming on soil pH, base saturation, and Al chemistry, but also the general nutritional status of the forest. However, a high load of acidic deposition induced Mg deficiency in Scots pine in the Norwegian field experiments (Abrahamsen, 1980), and the same symptoms were also seen in the field in different parts of Europe (Hüttl, 1991; Katzensteiner et al., 1995; Kreutzer, 1995; Landmann and Bonneau, 1995; Jandl et al., 2001). Since the 1980s, forest liming (dolomite) has been extended in Germany, mostly to prevent the soil from further acidification caused by acid rain, and the forest stands from suffering Mg deficiency (Kreutzer, 1995).

It was early pointed out that the increased deposition of inorganic N by precipitation would most likely increase tree growth in the short term, but that the long term effect was comparable to the long term effects of applying unbalanced N fertilizers and would thereby decrease forest vitality (Abrahamsen, 1980). This has been linked to the possibility of increased NO_3^- leaching (Aber et al., 1989; Dise and Wright, 1995; Emmet et al., 1998; Kreutzer et al., 1998).

An increased future harvesting of tree biomass, e.g., for bioenergy purposes, may induce nutrient imbalance or deficiency on nutrient-poor sites. The depletion of nutrients and the decrease of forest production are most severe after whole-tree harvesting with relatively short rotation lengths (e.g. Kimmins, 1977; Burger, 2002; Egnell and Valinger, 2003), making compensatory fertilization highly relevant (e.g. Egnell et al., 1998; Jacobson et al., 2000a; Ingerslev et al., 2001; Burger, 2002).

Different remedies have been used to correct for nutrient imbalances in forest ecosystems. Depending on the N status of the forest ecosystem, rapidly soluble fertilizers may cause problems of nitrate leaching (Insam and Palojärvi, 1995; Katzensteiner et al., 1995). Slowly soluble lime, on the other hand, will raise the soil pH and base saturation and lead to increased humus decomposition and thereby increased nitrate leaching (Kreutzer, 1995). In a comprehensive experiment in a Norway spruce (*Picea abies* (L.) Karst.) stand in southern Sweden, the effects of irrigation, artificial drought, ammonium sulphate, N-free fertilization, and irrigation with a complete set of nutrients were evaluated (Nilsson and Wiklund, 1995). A fertilizer including all necessary macronutrients except N resulted in an above-ground accumulation of Ca, Mg, K, P, and B, and this fertilizer was efficient when aiming at restoring nutrient imbalances in Norway spruce. However, N alone was generally the growth limiting nutrient for Norway spruce in southern Sweden. The growth and vitality of Mg-deficient trees has been shown to be most effectively improved by fertilizers in combination with pH-stabilization measures (Katzensteiner et al., 1995; Schaaf, 1995). Use of slow-release fertilizers containing macro- and micronutrients was more favourable in correcting nutrient deficiencies than rapidly soluble fertilizers (Flückiger and Braun, 1995).

The aim of the present study was to evaluate the effects of adding commercially available lime, dolomite, and fertilizers on tree growth and nutrient cycling in a Scots pine ecosystem. The following hypotheses were tested: (1) addition of lime alone will not increase tree growth and foliar nutrient content in the short term, but increase the calcium content of the forest floor; (2) addition of dolomite alone will not increase tree growth, but increase the foliar and forest floor content of Mg and Ca; (3) addition of dolomite in combination with N-free fertilizers will increase tree growth, foliar nutrient content of added nutrients and forest floor content of Ca and Mg; (4) addition of "optimal" mixed fertilizers will increase tree growth and foliar nutrient content to a higher level than the other treatments, in addition to an increased leaching of nutrients from the soil.

2. Materials and methods

2.1. Site and stand description

The field experiment was established at Gangseimoen in Åmli, southern Norway (8°29′38″E, 58°48′15″N) in a pure, even-aged, naturally regenerated Scots pine (*Pinus sylvestris* L.) stand, 155 m a.s.l. and about 35 km from the coast. Frank and Stuanes (2003) have published information on the site and forest stand at Gangseimoen, and a summary of these data is reported in Table 1. The annual mean precipitation at our site was 1000 mm for the years of investigation (1993–1996), while the throughfall varied between 83 and 86% of total precipitation due to the variation in tree crown cover. At present, the site receives moderate loads of atmospheric pollutants. In contrast, the deposition of both S and strong acids has decreased by approximately 40% during the period 1980–1995 according to monitoring data, while the mean pH in precipitation has increased 0.2 units.

Table 1
Site and stand description of the experimental area, published by Frank and Stuanes (2003)

Parameters	Values	References
Climate		
Annual mean temperature[a]	5.6 °C	Aune (1993)
Mean January temperature[a]	−3.7 °C	Aune (1993)
Mean July temperature[a]	15.5 °C	Aune (1993)
Growing season	180–190 days	Moen (1999)
Mean annual precipitation[a]	1230 mm	Førland (1993)
Atmospheric pollutants	6–7 kg S ha^{-1} $year^{-1}$	Tørseth (1996)
Atmospheric pollutants[b]	8–10 kg N ha^{-1} $year^{-1}$	Tørseth (1996)
Wet deposition	0.3 kg H^+ ha^{-1} $year^{-1}$	Tørseth (1996)
Mean pH in precipitation	4.5	Tørseth (1996)
Scots pine stand		
Vegetation zone	Boreonemoral	Moen (1999)
Vegetation section	Markedly oceanic	Moen (1999)
Vegetation type	Vaccinio-Pinetum	Fremstad (1997)
Stand age	33 years	Own measurements
Mean height	11.9 m	Own measurements
Mean diameter	12.7 cm	Own measurements
Stand density	1594 trees ha^{-1}	Own measurements
Basal area	20.2 m^2 ha^{-1}	Own measurements
Stem volume	125 m^3 ha^{-1} o.b.[c]	Own measurements
Site index	Medium (F 16)	Own measurements

[a] Nelaug meteorological station, normal period 1961–1990.
[b] About equal amounts of NH_4-N and NO_3-N.
[c] Stem volume over bark.