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# Tree girdling increases soil N mineralisation in two spruce stands

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**Abstract**

Tree girdling is a common practice in forestry whenever trees are to be killed without felling. The effect of tree girdling on soil nitrogen (N) mineralisation was estimated in both an old and a young spruce forest. The dynamics of mineral N ($NO_3^-$–N and $NH_4^+$–N) and soil microbial biomass carbon (MBC) and N (MBN) were determined for different seasons. The in situ net N mineralisation was measured by incubating soil samples in stainless steel cylinders and the gross N mineralisation rates were measured by $^{15}N$ pool dilution method. Mineral N concentrations increased significantly in the girdled plots in both old and young spruce forests and showed variations between soil horizons and between sampling times. Tree girdling significantly increased net N mineralisation in both spruce forests. Annual net N mineralisation was 64 and 39 kg N ha$^{-1}$ in O horizon of the girdled plots in old and young forest plots, respectively, compared to 25 and 21 kg N ha$^{-1}$ in the control plots. Annual N mineralisation in A horizon was similar between girdled and control plots (31 kg N ha$^{-1}$) in the old forest whereas in the young forest A horizon N mineralisation was about 2.5 times higher in the girdled plots. As a result, the annual carbon budget was significantly more positive in the girdled plots than in the control plots in both old and young forests. However, we found significantly higher gross N mineralisation rates in both horizons in the control plots than the girdled plots in the old forest, but no differences between the treatments in the young forest. The MBC and MBN contents only showed significant changes during the first three months of the experiment and were similar later on. They first decreased as girdling removed the root carbohydrate, amino and organic acid exudation from the C sources for microorganisms then increased two months after the treatment root dieback acted as a new source of C. Mineralising microorganisms enhanced the mineral N concentrations in girdled plots as a result of greater activity rather than larger population size.


*Keywords:* Ammonium; Microbial biomass; Nitrate; N mineralisation; Spruce forest; Tree girdling

## 1. Introduction

In forest soils, N mineralisation of soil organic matter is an important mechanism as it is the main source of mineral N in these ecosystems. N mineralisation is a process, which converts organic N into ammonium N ($NH_4^+$–N). During this ammonification, organic N is transformed into $NH_4^+$–N by a variety of bacteria and fungi. Nitrification is the process of oxidising the $NH_4^+$–N into nitrate N ($NO_3^-$–N) and it is performed by chemoautotrophic bacteria or heterotrophic microorganisms using, respectively, $CO_2$ or soil organic matter as C sources (de Boer and Kovalchuk, 2001; Brierley et al., 2001). The respective contribution of ammonification and nitrification depends for a great part on site and stand characteristics. The net N mineralisation, that is the addition of new $NH_4^+$ and $NO_3^-$ to the soil from organic matter, is calculated as the sum of net ammonification and net nitrification. It may be positive, which corresponds to an increase in ammonium and nitrate pool size over time, or negative, which is due to immobilisation and happens when mineral N is taken up by plants and microorganisms.

Since soil microorganims are the main actors of N mineralisation, factors that affect their activities and/or the

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size of their populations may also exert an indirect positive or negative regulation on soil N mineralisation. Factors that have been consistently reported to affect soil micro-organisms include soil temperature and humidity (Niklaus, 1998; Blumfield and Xu, 2003; Chen et al., 2003; Burton et al., 2007), C availability and the C/N ratio of the soil organic matter (Chen et al., 2004; Burton et al., 2007). Moreover, recent studies suggest that trees may also directly regulate soil N mineralisation. Colin-Belgrand et al. (2003) demonstrated that living tree roots can modify N mineralisation rate and that the rhizosphere seems to be the hotspot where regulation processes take place (Xu and Chen, 2006). Several studies have shown that nitrification is greater under deciduous tree species than under conifers (Augusto and Ranger, 2001). This may be due to a negative regulation of nitrification by the conifers that are well known to take up $NH_4^+-N$ rather than $NO_3^--N$ (Buchmann et al., 1995). Natural inhibitors of nitrification such as polyphenol compounds or monoterpenes have indeed been identified in pine litter and in spruce forests (Northup et al., 1995, Paavolainen et al., 1998). There also may be a direct root excretion of nitrification inhibitors or activators of specific micro-organisms beneficial for the plant N supply (Erickson et al., 2000).

Tree girdling is a common silvicultural practice used for killing trees without felling them, e.g. for thinning and controlling the stocking of young forest stands while enhancing the wildlife habitat diversity. This operation consists of removing the bark, cambium, and sometimes the sapwood in a ring that extends entirely around the trunk of the tree. If this ring is wide enough and deep enough, it will keep the cambium layer from growing back. After the phloem layer is completely removed, carbohydrates produced in the shoots can no longer be transported to the roots that will die once they exhaust their carbohydrate reserves. This treatment is often done during spring, as the plant sensitivity is greater when its reserves are low. However, little is known about the effect of this method on the soil despite its common use and there is no straightforward way to estimate it. Root dieback should benefit soil moisture and then microbes for N mineralisation, especially if girdling removes the control that tree roots may exert on the soil microbes. But the carbohydrate starvation in roots will also lead them to suppress the root carbohydrate exudation, which is an important source of C for heterotrophic N mineralising microorganisms. Högberg et al. (2001) reported that girdling reduced soil respiration to 37% of the control plots within 5 days in conjunction with a root exudation decrease. Moreover, needle fall will increase following root dieback, in the case of conifers, and this may increase the polyphenol concentration in soil organic matter above thresholds that inhibit microorganisms.

Our study took place in Wetzstein, Germany, and was performed on both a young and a mature spruce forest. We studied soil net and gross N mineralisation, net nitrification, microbial C and N and dissolved organic N (DON) in both organic and mineral soil horizons. Measures were taken from the girdling time for one year in the old stand and two years in the young one. The aims of our work were to: (1) evaluate the effect of tree girdling on soil mineral N contents ($NH_4^+$, $NO_3^-$); (2) measure net and gross rates of N mineralisation following girdling; (3) compare the response of N mineralisation to girdling between the lower organic and upper mineral soil on one hand and between young and an old forest on the other hand; and (4) study if the microbial biomass C (MBC) and N (MBN) would respond to girdling and whether the possible response would be positive or negative.

## 2. Material and methods

### 2.1. Study site

The experimental sites were 90-year-old and 35-year-old Norway spruce (*Picea abies* (L.) Karst.) stands, respectively, both located in a small mountain range in southeast Germany (Wetzstein, Thüringisches Schiefergebirge, 50°27′N, 11°27′E, about 780 m a.s.l.). There was no under-story vascular plant vegetation. The soil was sandy loam overlying quartzite bedrock. Extensive monoculture of spruce has resulted in low pH (3.75) of the upper soil strata and subsequent podzol formation. In the old spruce stand, the average depth of the organic layer was $10.0 \pm 0.7$ cm and it stored $4370 \pm 332\,g\,C\,m^{-2}$ and $202 \pm 12\,mg\,N\,m^{-2}$. The top 30 cm of the mineral soil contained $10403 \pm 374\,g\,C\,m^{-2}$ and $484 \pm 21\,mg\,N\,m^{-2}$. In the young spruce stand, the organic layers was on average $8.0 \pm 0.5$ cm deep and stored $3870 \pm 490\,g\,C\,m^{-2}$ and $388 \pm 49\,mg\,N\,m^{-2}$. The top 30 cm of the mineral soil in the young spruce stand contained $8080 \pm 1.050\,g\,C\,m^{-2}$ and $166 \pm 24\,mg\,N\,m^{-2}$. Annual precipitation averaged 1000 mm and the mean annual temperature was 6 °C.

### 2.2. Experimental design

In April 2002, four plots of equal areas (400 $m^2$) were selected in homogeneous parts of each forest stand (no canopy gap, regular tree spacing) for a total of eight plots. Two plots per stand were used as control and the two others were treated by tree girdling. Girdling consisted of removing the bark and phloem of all trees in the plot all around the stems over 50 cm long sections at about 1.5 m above ground. This allowed the transport of water from roots to shoots via the xylem but prohibited phloem transport of photosynthetic products from shoots to roots.

In all plots, a soil sampling area (4 m × 4 m) was defined in the middle of the plot. This allowed a large enough buffer zone to avoid any influence from the neighbouring ungirdled stands on the sampled soil materials. Sampling areas were chosen so as to have their sides roughly equidistant to the neighbour trees.

Net soil N mineralisation was estimated using in situ soil incubation. This method consisted of isolated soil cores in