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Published in:
Effects of afforestation on ecosystems, landscape and rural development

Publication date:
2007

Document Version
Publisher's PDF, also known as Version of record

2.21 Loss of nitrate after gap formation: Studies in Danish beech (*Fagus sylvatica* L.) forests of different management intensities

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Abstract

In the ongoing discussion about sustainable forestry, gap regeneration has been suggested as an alternative forest management practice with the aim of reducing losses of nitrate (NO_3^-) with seepage water. In the studies presented on the poster, changes in NO_3-N concentrations in soil solution below the rooting zone (90 cm depth) were followed for 2–3 years after gap formation. Losses of NO_3-N were estimated using the water balance model WATBAL. The study was carried out in a semi-natural and two managed beech *(Fagus sylvatica* L.) forests in Denmark. Gap diameters ranged from 18 to 30 m.

Soil solution NO_3-N concentrations and losses were increased in all gaps as compared to under the canopy. Nitrate-N concentrations were highest in the semi-natural forest, but this was not attributed to the gap formation as concentrations were high, both in the gap and under closed canopy. Nitrate losses from the gaps started to decrease along with gap closure above and below ground. No significant effect of gap size was found within the range of the investigated gap diameters and canopy heights.

Keywords: Forest ecosystems, gap, nitrate, soil solution, *Fagus sylvatica* L., WATBAL

Introduction

In recent decades, Danish research on forest ecosystems was motivated by an increasing interest in sustainable and nature-based forest management. Nature-based management seeks to maintain the biological and geochemical integrity of forest ecosystems along with a continuous timber production by applying natural forest dynamics (Attiwill, 1994). Gap formation, a typical small-scale disturbance in natural forest ecosystems, is therefore considered as a possible approach. However, practical experience with gap formation is scarce in Denmark. The objectives of the studies summarized on the poster were to investigate the effect of gap formation in beech (*Fagus sylvatica* L.) forests of varying structure and management intensity on concentrations and losses of nitrate-nitrogen (NO_3-N) in soil solution below the rooting zone (90 cm). Management intensities ranged from a semi-natural forest to conventionally managed forest stands. The effect of gap size was examined by creating four gaps of two different sizes in the managed forest stands. The results presented in this paper are a summary of the data published in Ritter and Vesterdal (2005) and Ritter et al. (2005).

Material and methods

The study was carried out in gaps of beech forests located on Zealand, Denmark, on nutrient-rich soil. The semi-natural forest reserve (Suserup Forest) is a heterogeneous forest with a high regeneration potential. The forest has never been intensively managed and has been protected for more then 100 years. It has nowadays regained the typical mosaic structure of natural forests of the temperate region. The gap investigated (~18 m diameter) was established naturally during a storm in December 1999. Average canopy height is 31 m. The two managed forest stands (Ravnsholte Forest and Hejede Overdrev) are homogeneous in structure and age class (75 years and 80 years, average canopy height 27 m and 28 m, respectively) and had no or only little regeneration and ground vegetation. Two gaps (~20m and ~30m diameter) were created in each stand by felling 3–12 trees in January 2001.

Measurements were carried along a north-south and a west-east (except for in Hejede Overdrev) transect running from the gap centre into the surrounding stands. Measurement periods were up to three years after gap formation, and samples were taken at approx. monthly intervals. Soil solution was sampled from below the rooting zone (at 90 cm depth) using teflon suction cups. Leaching losses of NO_3-N were estimated by the water balance model WATBAL (Starr 1999). For further details see also Ritter and Vesterdal (2005) and Ritter et al. (2005).

Results and discussion

Nitrate in soil solution

At all three sites, NO_3-N concentrations were generally higher in the area of the gaps than under the closed canopy. However, in the semi-natural forest differences between gap and closed canopy were only significant during growing seasons. Concentrations were unexpectedly higher in the semi-natural than in the managed forests: the maximum seasonal mean in the gap was 34 mg NO_3-N l^{-1}. No effect of gap size was seen in the two managed forest stands, and mean NO_3-N concentrations were 7.2 mg NO_3-N l^{-1} in the gaps compared to 2.2 mg NO_3-N l^{-1} under closed canopy. Overall NO_3-N levels were lowest in the gap where ground vegetation was almost absent (Hejede Overdrev, large gap). This was in contrast to numerous studies that have shown a decrease of elevated concentrations along with the development of a dense vegetation cover (Foster et al. 1989; von Wilpert and Mies 1995). Concentrations of NO_3-N in the semi-natural forest were also high compared to other Danish forest sites not managed for wood production. A study on NO_3-N concentrations below the rooting zone reported 0.7 mg NO_3-N l^{-1} for such forest sites (Callesen et al. 1999). Gap formation was not credited with the high NO_3-N levels because concentrations were generally high both in the gap and under closed canopy. These high concentrations occurred despite vigorously growing regeneration in the gap and no significantly increased N input by wet deposition or mineralization (Ritter and Bjørnlund 2005; Ritter et al. 2005). It is suggested that the status of this semi-natural forest as a long-term non-intervention forest reserve may have resulted in a high storage of N in living biomass and soil. Long rotation periods were shown to reduce the output of nutrients with export of biomass in managed forest stands (Hüttl and Schaaf 1995). This assumption is supported by a study in a traditionally managed forest in the vicinity of Suserup Forest. Receiving comparable amounts of N input by throughfall, NO_3-N concentrations below the rooting zone in that forest were still less than 1 mg l^{-1} (Beier et al. 2001). Thus, it seems that the internal N cycle of an ecosystem is important for the N balance after disturbances, as also reported in other studies (Gundersen et al. 2002).

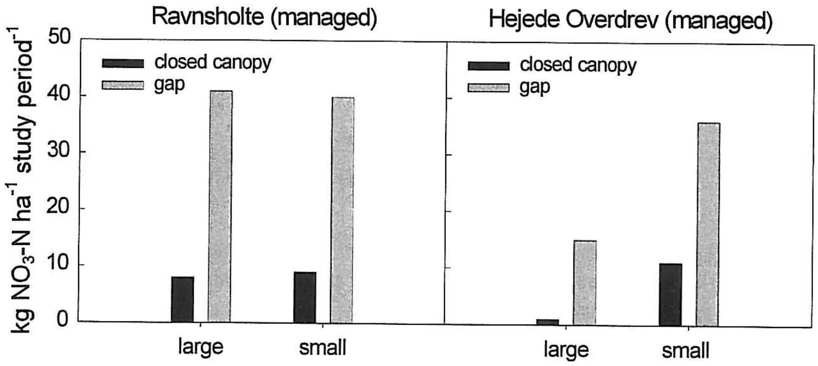

Figure 1. Leaching losses of nitrate-N at the four gap sites in the two managed forest stands: Nitrate losses are illustrated as the sum of the total model period of 20 months (September 2001 to June 2003)

Leaching of nitrate

Leaching loss of NO_3-N was increased in all gaps. This was attributed to both increased soil solution NO_3-N concentrations and increased soil water fluxes in the gaps. Leaching losses of NO_3-N decreased with time after gap formation, and no leaching losses occurred under the canopy during growing seasons. In the managed forest stands, seasonal average NO_3-N losses from the gaps ranged from 1.1 to 2.2 kg NO_3-N ha^{-1} (Ritter et al. 2005). For the whole study period, losses of NO_3-N were 3- to 13-fold higher in the gaps than in the surrounding forests (Figure 1). In the semi-natural forest, leaching losses from the gap were much higher, with seasonal averages decreasing from a range of 57 to 37 kg NO_3-N ha^{-1} in the first two years after gap formation to 3.8 kg NO_3-N ha^{-1} in the third growing season after gap formation (Ritter and Vesterdal 2005). Total losses from the gap were about four times higher than under the closed canopy in the first two years after gap formation, but almost the same in the third year (January–October) (Figure 2). This reduction in leaching losses was attributed to the vigorously growing regeneration in the semi-natural forest. Other studies have shown that leaching of NO_3^- decreases again as soon as available N is utilised by developing understorey vegetation and microbial activity (Barg and Edmonds 1999).

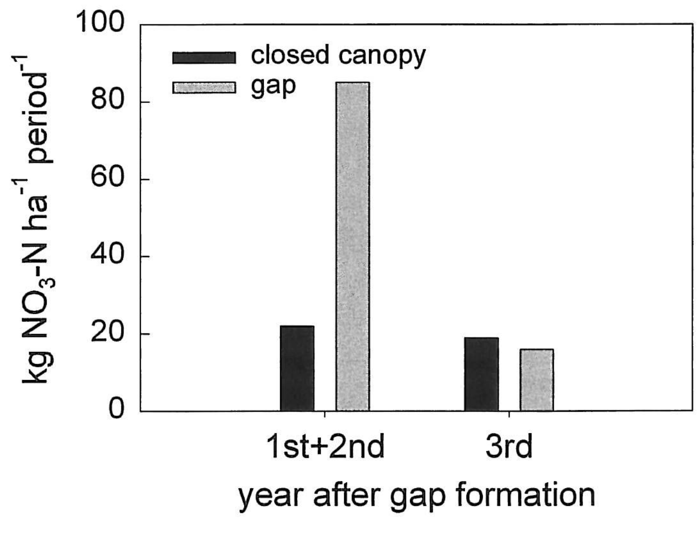

Figure 2. Leaching losses of nitrate-N in the semi-natural forest Suerup. Nitrate losses are illustrated as the sum of the first two calendar years and the third year (until October only) after gap formation, respectively.

Although no effect of gap size was found on NO_3-N losses in the managed forest stands in the first years after gap formation, it can be assumed that the small gaps are closed earlier than the large ones (Valverde and Silverton 1997) and that NO_3-N losses thus stop earlier as well. This would be a positive aspect which should be considered in the application of gap formation to nature-near forest management. However, further monitoring is required to determine if NO_3-N leaching declines earlier in smaller gaps and in the presence of ground vegetation. Results indicated furthermore that both above and below ground closure of the gap by roots, regeneration and mature trees bordering the gap contribute to gap closure.

Conclusion

Gap formation resulted in increased NO_3-N concentrations in the soil solution below the rooting zone in all gaps investigated. Gap size had no impact on the level of NO_3-N concentrations in gaps, but may be important when a more rapid closure of the gap contributes to decreasing NO_3-N concentrations. Factors which are generally considered to enhance high NO_3-N levels could not always explain the observations of the present study. High concentrations of NO_3-N occurred despite no significant N input by wet deposition, no increased mineralization, and a vigorously growing regeneration; low NO_3-N concentrations were found even though ground vegetation was almost absent in gaps. Presumably, the combination of all these factors had an impact on NO_3-N concentrations anyway. A positive impact of gap formation on ground water quality may be seen in the fact that increased losses of NO_3^- were restricted to small areas within a forest stand.

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