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The effects of clear-cut on net nitrogen mineralization and nitrogen losses in a grey alder stand

Hardo Becker[a], Veiko Uri[a], Jürgen Aosaar[a], Mats Varik[a], Ülo Mander[b,e,*], Kaido Soosaar[b], Raili Hansen[b], Alar Teemusk[b], Gunnar Morozov[a], Sander Kutti[c], Krista Lõhmus[d]

[a] Institute of Forestry & Rural Engineering, Estonian University of Life Sciences, Tartu, Estonia
[b] Department Geography, Institute of Ecology & Earth Sciences, University of Tartu, Estonia
[c] Department Environmental Protection, Tartu College, Tallinn University of Technology, Estonia
[d] Department Botany, Institute of Ecology & Earth Sciences, University of Tartu, Estonia
[e] Irstea, Hydrosystems & Bioprocesses Research Unit, Antony, France

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ABSTRACT

Grey alder is a wide spread tree species in the Baltic region and a promising species for short rotation forestry. The symbiotic dinitrogen (N_2) fixation ability makes this tree important for the regulation of nitrogen (N) cycle in forested areas.

In a homogeneous 32-year-old natural grey alder stand (GAS) and an adjacent clear-cut (CC) in South-East Estonia (58°17′ N; 27°17′ E; set up in May 2011) we analyzed net nitrogen mineralization (NNM; with incubated bags), N leaching (with plate lysimeters), and nitrous oxide (N_2O) fluxes (with static chambers).

The total annual NNM did not intensify in the CC area: in the upper 0–20 cm soil layer the NNM was 169.9 and 157.0 kg ha^{-1} in the (GAS) and in the CC, respectively. In both cases, the share of nitrification was 100% and NNM intensity was the highest in July. During the snow-melt in April, both in the GAS and in the CC site the leaching of total N was up to 25 kg N month^{-1}, whereas in the rest of study period it was negligible in both sites. Harvesting slightly decreased N_2O emission, however, it was low at both study sites (−0.55 to 19.75 and −0.77 to 7.43 kg N_2O ha^{-1} yr^{-1} in the GAS and the CC, respectively). Management of grey alder stands by traditional silvicultural methods (clear-cuts) did not to increased hazardous N losses through leaching.

1. Introduction

Research of the nitrogen cycle in forest ecosystems has gained importance since N availability is one of the crucial factors limiting photosynthetic capacity and tree growth in boreal forests (Luo et al., 2004). Most of the N used for plant biomass is produced by *in situ* mineralization of native organic matter (Tate, 1995) and nitrogen net mineralization (NNM) is an essential flux in the whole N cycle of boreal and temperate forests. The intensity of NNM depends on many factors like soil properties, tree species, land use history, disturbances etc. (Zak et al., 1990; Goodale and Aber, 2001; Lovett et al., 2002; Uri et al., 2008) and their interactions. In deciduous stands NNM varies roughly between 25 kg ha^{-1} and 200 kg ha^{-1}, which covers a major part of the annual N demand of deciduous stands (Aber et al., 1989; Scott and Binkley, 1997; Magill et al., 2000). However, the effect of N_2-fixing tree species on different soil processes may sometimes be more sophisticated and extensive compared with the effect of other deciduous trees. According to Wang et al. (2010), forests of N_2-fixing tree species may have 40–50% higher soil organic matter and 20–50% higher total N concentration in the 0–5 cm topsoil compared with non-N_2-fixing forests.

The increasing demand for bioenergy resources will make the management of short rotation forestry (SRF) more likely in Europe, and it will potentially become an alternative to traditional long rotation forestry. According to several studies (Granhall and Verwijst, 1994; Rytter, 1996; Uri et al., 2002, 2009, 2011; Miežite, 2008; Hytönen and Saarsalmi, 2009; Aosaar et al., 2012), grey alder (*Alnus incana* (L.) Moench) is a widespread and perspective tree species for short rotation forestry in the Nordic and Baltic states. In Estonia, as well as in the other Baltic countries the resource of grey alder stands is substantial but its management intensity

* Corresponding author.
E-mail addresses: ulo.mander@ut.ee, ulo.mander@irstea.fr (Ü. Mander).

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is still modest (Kuliešis and Kulbokas, 2009; Yearbook Forest 2013).

Grey alder ecosystems are also well known as effective buffer zones for N and P (Mander et al., 1997, 2008; Soosaar et al., 2011) and alders are accumulating a large amount of N into biomass and in the soil (Hytönen and Saarsalmi, 2009; Uri et al., 2011). *Alnus* species can be used effectively for the biological fertilization of soil with N (Granhall, 1994).

However, more intensive use of alder stands for bioenergy presumes a better knowledge of possible environmental impacts and hazards related to the N cycle (Granhall and Verwijst, 1994; Rytter, 1995, 1996; Mander et al., 1997, 2008; Hytönen and Saarsalmi, 2009), however scientifically based suggestions for forest management, which take into account possible environmental risks, are rare (Uri et al., 2014). Since alders can introduce an appreciable N flux into the forest ecosystem and cover a large part of the annual N demand by symbiotic N_2 fixation (Šlapokas, 1991; Rytter, 1996; Uri et al., 2003, 2011; Lõhmus et al., 2002; Mander et al., 2008), environmental risks (N leaching, N_2O gaseous emission) are likely to be involved. More attention should be paid to nitrous oxide emissions which is an important greenhouse gas with 298-fold Global Warming Potential (GWP) in a 100-years time horizon compared to CO_2 (IPCC, 2007). N_2O is a product of the nitrogen cycle and is mainly produced by denitrification and nitrification (Lavoie et al., 2013). However, there is very little information about the effect of clear-cut on N_2O emissions from deciduous forest on automorphic soils in the boreal or temperate zone (Page et al., 2011).

The working hypotheses of the present study were: (1) NNM will increase after clear-cut of grey alder stand; (2) clear-cut initiates larger N losses from the ecosystem due to more intensive leaching and N_2O emissions.

The main aim of the study was to clarify the effect of harvesting on annual NNM and the related possible post-clearcut environmental hazards in a mature grey alder stand. The specific aims were: to analyze the effect of the dynamics of soil moisture and temperature on NNM and on its intensity; to estimate the effect of clear-cut on N leaching and N_2O emissions and to compare soil microbial characteristics in post-clearcut and grey alder stand.

2. Materials and methods

2.1. The study area

The study area was set up in May 2011 in South-Eastern Estonia (58°17′ N; 27°17′ E) in a homogeneous 32-year-old natural grey alder stand. Two study sites (20 × 35 m) were established and clear-cut was carried out in one site while the other one was left as the control area. The stand characteristics were: the mean height of the stand 17.3 m, the mean breast height diameter (DBH) 15.4 cm and the growing stock 250 m^3 ha^{-1} (Uri et al., 2014). The highly fertile site type was classified as *Aegopodium* according to a local forest site classification (Lõhmus, 1984). The thickness of the humus layer at both study sites was 40–50 cm, and it is known from the site history that this grey alder stand is growing on previous agricultural land. The region's long-term average annual precipitation is 650 mm and the average temperature in July is 17 °C and in January −6.7 °C; the growing season usually lasts 175–180 days (Kupper et al., 2011). The soil of the study area was classified according to WRB (FAO, 2006) as *Umbric Planosol* (Table 1). For estimating soil bulk density, ten soil pits were dug on both sites. Soil bulk density samples (sampling cylinder 50 cm^3) were taken from the depth layers of 0–10, 10–20 and 20–30 cm. The samples were dried at 105 °C to constant weight and weighed to the nearest 0.01 g. For the estimation of soil nutrient content, the samples were taken from different depths (0–10, 10–20 and 20–30 cm) with a soil corer (d = 40 mm). From fifteen random points over both sites, subsamples were taken to form a composite sample for chemical analyses (Table 1).

There were no statistically significant differences in the soil properties (pH, N, P, K, Ca, Mg, organic matter) between the study sites after clear-cut.

2.2. Incubation method and monitoring of environmental factors

The NNM experiment was performed by using the method with incubated polyethylene bags (Eno, 1960; Adams et al., 1989; Hart et al., 1994; Uri et al., 2003, 2008, 2011). Polyethylene bags with a thickness of 18 μm, ensure permeability to gases (O_2, CO_2, N_2, etc.), but prevent leaching and addition of soluble N, as well as nitrogen uptake by plants. The study was performed in two soil depths: 0–10 cm and 10–20 cm.

The dynamics of NNM was studied *in situ* in the 0–10 cm soil layer in both sites from June 2011 to June 2012. The sampling and incubation were done with an approximately monthly interval. It is the optimal time period when changes are assumed to take place in the concentration of mineral nitrogen forms (Adams et al., 1989). Each sampling time, 24 samples were taken from both subsites and the first samples were incubated in the experimental area on 5 June 2011. At each random point an intact soil core was taken from the upper 10 cm soil layer. All samples were taken with a cylindrical soil corer (Ø 48 mm), which internal diameter of the inner part was 1.6 mm larger than the diameter of the cutting edge to avoid compression of the soil. Then the sample was sealed in a polyethylene bag, to avoid the damaging of soil structure, was placed in the same hole for incubation (Uri et al., 2008). Mixing of soil structure affects the NNM significantly (Raison et al., 1987; Persson and Wirén, 1995; Stenger et al., 1995). Sampling was done monthly throughout the year, except when the soil was frozen. Simultaneously with the incubation of new sample, each time adjacent initial sample was taken next to the incubated sample site. Both the incubated and the initial samples from each sampling place were collected separately and then composite into three complex samples and were transported to the laboratory on the same day. For the estimation of NNM in the deeper soil layer (10–20 cm) a monthly experiment was carried out from May 2012 to June 2012. Soil cores were taken from the upper 20 cm layer and separated according to the two layers (0–10 cm and 10–20 cm). Both samples were sealed in the polyethylene bags and incubated in the same hole in the same order. At the same time, also the initial samples for the subsequent 0–10 cm and 10–20 cm layers were taken next to the incubated samples.

For the estimation of the effect of some environmental factors on NNM, soil and air temperature were continuously measured *in situ* with stationary sensors. Soil temperature was measured every hour at a depth of 10 cm and the data was stored with a data logger (WatchDog 1425, Spectrum Technologies, Inc., USA) during the growing seasons of 2011 and 2012. Two sensors and one data logger were placed in each stand. Additionally the soil pH from the initial and incubated samples was measured.

The NNM for a time interval unit was calculated from the difference between the contents of each inorganic nitrogen form, i.e. NH_4^+-N and NO_3^--N, and the their sum in the initial and incubated samples. A detailed description of the calculations is presented in our earlier studies (Uri et al., 2003, 2008).

2.3. Soil chemical analyses

Chemical analyses were performed at the Biochemistry Laboratory of the Estonian University of Life Sciences. From the soil samples, Kjeldahl nitrogen, nitrite-nitrogen (NO_2^--N) (only from the first sampling), nitrate-nitrogen (NO_3^--N) and ammonium-nitrogen (NH_4^+-N) were determined. Assessment of NNM and net nitrification was based on the comparison of a nitrate and