Annual net nitrogen mineralization in a grey alder
(*Alnus incana* (L.) moench) plantation on abandoned
agricultural land

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Received 16 April 2002; received in revised form 29 January 2003; accepted 23 March 2003

Abstract

The dynamics and annual rate of net nitrogen mineralization in a grey alder plantation growing on abandoned agricultural land was assessed in situ using the method of buried polyethylene bags. Nitrogen mineralization was assessed in the upper 0–10 and 10–20 cm soil layers, where 47.5 and 26.3% of the fine roots, respectively, were situated. Net nitrogen mineralization was the highest in May and September, 314 and 306 mg kg\(^{-1}\) N per day, respectively. Annual net nitrogen mineralization and net nitrification in the upper 0–10 cm soil layer were estimated as 84 and 87 kg ha\(^{-1}\) per year, respectively. Annual net nitrogen mineralization in the upper 0–20 cm soil layer was estimated as 141 kg ha\(^{-1}\), which accounted for 62% of the annual nitrogen used by trees and the understorey vegetation. Among various environmental factors related to mineralization, pH played a significant role.

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Keywords: *Alnus incana*; Net nitrogen mineralization; Net nitrification; Abandoned agricultural land

1. Introduction

Nitrogen availability is frequently the most limiting factor for plant growth in boreal and temperate forests. Usually, most of the nitrogen used for the synthesis of plant biomass is produced by in situ mineralization of native organic matter (Tate, 1995). According to Rosswall (1976) up to 95% of nitrogen circulates in the system of plant–microorganism–soil. The availability of nitrogen owing to mineralization of organic matter ranges from 50 to 150 kg ha\(^{-1}\) per year in deciduous stands (Aber et al., 1989).

However, net nitrogen mineralization in young deciduous stands, formed on abandoned agricultural lands as a result of natural or artificial afforestation, is relatively poorly investigated in Europe. At the same time, there is a clear tendency to increase in such areas, which is more pronounced in East-European countries owing to drastic changes in the political and economical situation there (Mander and Jongman, 2000). During the last decade, e.g. in Estonia, 223 000 ha of abandoned agricultural land have come into existence (Meiner, 1999). Abandoned agricultural areas are often characterized by rapid natural afforestation with fast-growing pioneer tree species, among
them grey alder, which lead to increase, both in the woodland area and in the area of grey alder stands growing on previous agricultural land.

Grey alder is a fast-growing deciduous tree species on mineral soils (Granhall and Verwijst, 1994; Saarsalmi, 1995; Telenius, 1999). In Estonia the current annual increment of grey alder stands is the highest being 7.6 m$^3$ ha$^{-1}$ per year (Aastaraamat Mets, 2000). Hence, considering the limited reserve of fossil fuels as non-renewable natural resources and the need for reducing greenhouse gases including CO$_2$, grey alder is a promising species for energy forestry.

However, the potential area of application of grey alder stands is not limited to energy forestry or other industrial purposes. Grey alder as an actinorhizal N$\_2$-fixing tree species can be effectively used by means of the biological fertilization of the soil with nitrogen (Granhall, 1994). Alder species have a positive impact on the diversity and activity of soil microbial communities, this has also been reported concerning increased soil phosphorus availability under alder species (Giardina et al., 1995; Binkley, 1984). Microbial communities affecting soil processes and the dynamics of the stand’s nitrogen pools in the soil and in the vegetation are different for agricultural and forest soils. Thus in newly afforested abandoned agricultural areas the overall soil biota affecting nitrogen transformations is in transition from one stage to another. Owing to its symbiotic nitrogen fixation capacity, grey alder is able to cover a large proportion of its annual nitrogen demand with nitrogen from the atmosphere. According to Šlapokas (1991) even up to 81% of alder N used may originate from symbiotic fixation.

Despite this, nitrogen mineralization may still play a significant role in the nitrogen budget of grey alder stand. Considering our further aim to compile a nitrogen budget, we measured net nitrogen mineralization in situ. An important feature of in situ studies of net nitrogen mineralization is that it is possible to calculate the uptake of inorganic nitrogen, derived from mineralization, by plants (Adams et al., 1989). A method with buried polyethylene bags was used, because it permits gas exchange between the incubated samples and the environment, while temperature conditions are close to natural and the input or output of nitrogen, except in gaseous forms, is excluded (Hart et al., 1994). Thus the study of net nitrogen mineralization in situ allows to estimate the proportion of the annual nitrogen requirement covered by mineralization of native soil organic matter. To minimize within-stand variability, a grey alder plantation was established on abandoned agricultural land to follow the dynamics of the stand’s productivity and soil processes.

The aims of the present study were:

- to estimate the dynamics of net nitrogen mineralization and its annual rate in a grey alder plantation growing on abandoned agricultural land;
- to analyse the impact of environmental factors on net nitrogen mineralization;
- to estimate the share of annual net nitrogen mineralization in the annual N demand of the stand.

2. Material and methods

2.1. Plantation

The experimental plantation of grey alder (Alnus incana (L.) Moench) was established on abandoned farm-land in spring 1995. The experimental area is located in the southeastern part of Estonia, Põlva county, 58° 3’N and 27° 12’E. According to the data of the Võru meteorological station, which is the closest to the experimental area, the mean annual temperature is 6 °C, the mean amount of precipitation 653 mm and the mean length of the vegetation period 191 days. The soil was classified as Planosol (according to FAO classification). Before the establishment of the experimental plantation, this area had been out of agricultural use for 2 years. The soil was not prepared before planting. Transplants of natural origin aged 1–2 years were used. Planting arrangement 0.7 × 1.0 m was employed. Growth of the planting stock of different origin, biomass production and the nutrient status of trees in each year after establishment have been analysed previously (Uri and Tullus, 1999; Uri et al., 2002). The main stand characteristics of the grey alder plantation at the beginning of the experiment in 1998 were: 12 662 trees per hectare; mean height 4.6 m; mean DBH 2.6 cm; basal area 7.49 m$^2$ ha$^{-1}$.

Most fine ($d < 2$ mm) roots (73.8%) were situated in the 0–20 cm soil layer, approximately half the biomass of fine roots (47.5%) was located in the uppermost 10 cm. Thus net N mineralization was studied in the soil layers 0–10 and 10–20 cm. The N pool in upper 20 cm soil layer was distributed
evenly and formed 2.64 t ha\(^{-1}\) at the beginning of experiment in 1998. Bulk density, pH (KCl) and the C/N ratio in the 0–20 cm soil layer were 1.27 g cm\(^{-3}\), 5.5, and 13–15, respectively.

2.2. Incubation method

The dynamics of nitrogen mineralization was studied in situ in the soil layer 0–10 cm in the experimental grey alder plantation from 28 June, 1998 to 25 July, 1999. The experiment was performed using a method with incubated polyethylene bags. The method is based on the measurement of mineral nitrogen in an environment, where the impact of intact roots is excluded. Incubation of the soil in buried bags is widely used in in-field measurement of net nitrogen mineralization and nitrification (Eno, 1960; Adams et al., 1989; Hart et al., 1994). The first samples (24 in number) were incubated in the experimental area on 28 June, 1998. At each random point an intact soil core was taken from the upper 10 cm soil layer with a cylindrical soil corer (Ø 48 mm) and was incubated, sealed in a polyethylene bag, without damaging soil structure, in the same hole. The internal diameter of the upper part of the corer was 1.6 mm larger than the diameter of the cutting edge to avoid compression of soil layers as suggested in Vogt and Persson (1991), since according to literature data soil structure influences the rate of mineralization a great deal (Raison et al., 1987; Stenger et al., 1995). The thickness of the polyethylene film was 18 μm, which guarantees gas permeability (O\(_2\), CO\(_2\), N\(_2\), etc.) and avoids leaching or addition of the soil solution (Eno, 1960). Also, a thin film prevents any introduction of mineral nitrogen as well as its assimilation by the plant roots. At the same time, denitrification is not hampered. Simultaneously, with the incubation of new samples, an adjacent initial sample was taken from beside the incubated sample each time. Both the incubated and the initial samples were gathered by threes into composite samples and were transported to the laboratory on the same day. Sampling and incubation were performed until the ground was frozen, with a monthly interval, during which measurable changes are assumed to take place in the concentration of nitrate and ammonium nitrogen (Adams et al., 1989). In the following spring, samples were taken immediately after the thawing of the ground (19 April). 

Comparison of the amounts of a particular form of nitrogen in the initial and incubated samples permits to assess net nitrogen mineralization from the amount of introduced mineral nitrogen, and net nitrification from the amount of introduced nitrate (see the calculations).

For assessment of net nitrogen mineralization in the soil with a depth of 0–20 cm, a monthly repeated experiment was carried out in the same plantation from 3 May, 2001 to 4 June, 2001. Soil cores were taken from the upper 20 cm layer and divided into two layers (0–10 and 10–20 cm), which were incubated separately, sealed in polyethylene bags in the same hole and in the same order. The initial samples for the subsequent 0–10 and 10–20 cm soil layers were also taken from beside the incubated samples.

To find out the effect of different environmental factors on net mineralization, soil pH (KCl), soil dry matter content and temperature were measured. Soil dry matter content and pH were measured for the initial and incubated samples. Soil temperature in the experimental area was measured with a weekly interval. For prognostication of temperature dynamics in the upper 10 cm layer in the unfrozen soil (April–November), the data of soil temperature from the meteorological station, closest to the experimental area (Võru, 35 km), were used.

2.3. Calculations

Net nitrogen mineralization for a time interval was calculated from the difference between the contents of inorganic nitrogen in the initial and incubated samples. Taking into account soil bulk density, the change in inorganic available nitrogen was calculated for a soil layer (1).

For a time interval \(\Delta t \equiv t_{i+1} - t_i\),

\[
\Delta N_{\text{MIN}} = \Delta \text{NH}_4^+ - N_i + \Delta \text{NO}_3^- - N_i
\]

where \(\Delta N_{\text{MIN}}\) is the net increment in available inorganic nitrogen, \(\Delta \text{NH}_4^+ - N_i\) the net ammonification, and \(\Delta \text{NO}_3^- - N_i\) the net nitrification in the time interval \(\Delta t\).

Net ammonification (4) and net nitrification (5) were calculated as follows:

\[
\Delta c(\text{NH}_4^+ - N) = c(\text{NH}_4^+ - N)_{i+1} - c(\text{NH}_4^+ - N)_i
\]

(2)

\[
\Delta c(\text{NO}_3^- - N) = c(\text{NO}_3^- - N)_{i+1} - c(\text{NO}_3^- - N)_i
\]

(3)
where \( c(\text{NH}_4^+ - N)_i \) is the mean concentration of ammonium nitrogen in the initial samples, \( c(\text{NH}_4^+ - N)_{i+1} \) the mean concentration of ammonium nitrogen in the incubated samples at the end of the incubation period, \( c(\text{NO}_3^- - N)_i \) the mean concentration of nitrate nitrogen in the initial samples, and \( c(\text{NO}_3^- - N)_{i+1} \) the mean concentration of nitrate nitrogen in the incubated samples at the end of the incubation period.

\[
\Delta \text{NH}_4^+ - N = k \Delta c(\text{NH}_4^+ - N)_i
\]

\[
\Delta \text{NO}_3^- - N = k \Delta c(\text{NO}_3^- - N)_i
\]

where \( k \) is the weight of a soil layer per hectare.

Annual net nitrogen mineralization in the upper 10 cm soil layer was calculated as the sum of the values of net nitrogen mineralization for each incubation period. Only statistically significant net increments were considered. Annual net nitrification was calculated analogously. Annual net N mineralization represents the sum of the amount of mineral nitrogen, available to plants, and leaching, while the latter is generally insignificant (Tate, 1995).

To estimate annual net N mineralization and net nitrification in the 10–20 cm soil layer, the ratios—net nitrification\(_{0-10\ cm}\):net nitrification\(_{10-20\ cm}\) and net N mineralization\(_{0-10\ cm}\):net N mineralization\(_{10-20\ cm}\) were assumed to be constant.

### 2.4. Laboratory analysis

Kjeldahl nitrogen, nitrate nitrogen (\( \text{NO}_3^- - N \)) and ammonium nitrogen (\( \text{NH}_4^+ - N \)) were determined from composite soil samples, pH (KCl) and the content of organic matter were determined as well. For testing soil samples for nitrogen according to Kjeldahl, Tecator ASN 3313 was used. Determination of \( \text{NO}_3^- - N \) and \( \text{NH}_4^+ - N \) in the soil were performed by flow injection analysis with the use of Tecator ASN 65-32/84 and Tecator ASN 65-31/84, respectively.

### 2.5. Statistics

Normality of variables was checked by \( \chi^2 \)-test, the Kolmogorov–Smirnov and Lilliefors’ tests were used for small samples. To analyse the effect of qualitative factors on response variables, one-way ANOVA was applied. ANOVA assumptions—normality, homogeneity of group variances and insignificant relationship between group means and standard deviations—were checked. Tukey HSD test was used for comparison of the means in case the assumptions were satisfied. Mann–Whitney U-test was used as nonparametric test. Regression models were used for estimating the relationships. In all cases the level of significance \( \alpha = 0.05 \) was accepted.

### 3. Results

#### 3.1. Seasonal dynamics of soil mineral nitrogen

The concentration of \( \text{NO}_3^- - N \) and \( \text{NH}_4^+ - N \) in the initial composite samples for the upper 10 cm soil layer varied from 0.24 to 8.09 and from 6.56 to

![Fig. 1. Dynamics of NO\textsubscript{3}^{-} - N, NH\textsubscript{4}^{+} - N and NO\textsubscript{3}^{-} - N + NH\textsubscript{4}^{+} - N concentration in the upper 10 cm soil layer in grey alder plantation.](image)
36.24 mg kg$^{-1}$, respectively. The mean concentration of soil nitrate nitrogen (3.44 ± 0.19 mg kg$^{-1}$) was on average one quarter of the concentration of ammonium nitrogen (13.15 ± 0.44 mg kg$^{-1}$). The seasonal dynamics of nitrate nitrogen in the experimental area was characterized by the steady low level of nitrate nitrogen (Fig. 1). For NH$_4^+$ – N as well as for total mineral nitrogen, the mean concentrations from October to April were significantly higher than the respective values in May to September. A maximum was observed in October when the mean concentration of ammonium nitrogen was 22.05 mg kg$^{-1}$ and the mean concentration of inorganic nitrogen was 25.99 mg kg$^{-1}$. Increase in soil mineral nitrogen in upper 10 cm layer from September to October was 14.2 kg ha$^{-1}$. The pool of mineral nitrogen in 0–10 cm soil layer varied from 15.9 to 33.0 kg ha$^{-1}$.

### 3.2. Net nitrogen mineralization

Analysis of the difference between the mean concentrations of inorganic (ammonium and nitrate) nitrogen in the initial and incubated samples in 0–10 cm soil layer by months showed that the difference in the concentration of both soil nitrate nitrogen and soil inorganic nitrogen was significant in all studied time intervals ($P < 0.01$). Thus the respective increments for all incubation periods were included into the calculations of annual net nitrification and mineralization. For ammonium nitrogen, the difference between the initial and incubated samples was revealed in September and October 1998 and in May 1999, while in the other months it was statistically insignificant ($P > 0.05$).

Daily net nitrogen mineralization had two maxima: a spring maximum in May and a less pronounced autumn maximum in September when net nitrogen mineralization was the highest (Fig. 2). It was not possible to estimate net nitrogen mineralization separately for different winter months, because the ground was frozen; Fig. 2 presents average net N mineralization for the winter months (November–March).

Annual net nitrogen mineralization in the upper 10 cm soil layer was calculated as the sum of the values of net nitrogen mineralization for each incubation period from 1 July 1998 to 1 July 1999 and it formed 84 kg ha$^{-1}$. Annual net nitrification in the upper 0–10 cm soil layer was estimated as 87 kg ha$^{-1}$.

In May 2000, monthly net nitrogen mineralization in the 0–10 cm soil layer and in the 10–20 cm layer was 21.7 and 14.8 kg ha$^{-1}$, respectively. Thus the amount of mineralized nitrogen in the 10–20 cm soil layer accounted for 68% of the nitrogen that was mineralized in the upper 10 cm soil layer. Using the proportionate level of net nitrogen mineralization for the subsequent soil layers for the whole year, annual net N mineralization in the upper 0–20 cm soil layer was estimated as 141.2 kg ha$^{-1}$.

![Fig. 2. Dynamics of net N mineralization, net nitrification and net ammonification (mg kg$^{-1}$ N per day) in the upper 10 cm soil layer in grey alder plantation.](image-url)
3.3. Impact of environmental factors on net nitrogen mineralization

According to literature data, net nitrogen mineralization is affected by soil temperature and soil moisture content (Tietema et al., 1992). Soil temperature was lower under the canopy of the grey alder plantation than at the meteorological station according to Eq. (6):

\[ t = 0.867t_M, \quad P < 0.000001, \quad r^2 = 0.991, \quad \text{S.E.} = 0.01 \]  

(6)

where \( t \) is soil temperature in the upper 10 cm soil layer and \( t_M \) is the soil temperature in the 20 cm layer in a vegetation-covered area at the meteorological station; \( P, r^2, \) and S.E are level of probability, coefficient of determination and standard error of estimate, respectively.

Moisture content in the 0–10 cm soil layer was significantly smaller in June than in the other months \( (P < 0.05) \). However, although there were revealed seasonal differences in the moisture content of the initial samples, their range was relatively small (16.3–19.8% of fresh mass). Our study established no significant correlation between net nitrogen mineralization and such environmental factors as monthly mean soil temperature, and moisture content.

Among the studied environmental factors, only initial soil pH (Fig. 3) played an important role. The corresponding Eq. (7) accounts for more than 70% of the total variability of net mineralization.

\[ \ln \Delta \text{NMIN} = -23.4 + 4.6 \text{pH}, \quad r^2 = 0.72, \quad P < 0.01 \]  

(7)

we also used pH of the incubated samples and the change in pH during incubation as independent variables for regression analysis, but the relationship was statistically insignificant in both cases.

Comparison of soil moisture content, organic matter, and Kjeldahl nitrogen in the initial and incubated samples revealed no significant differences for the whole study period \( (P < 0.05) \). Soil acidity increased significantly \( (P < 0.05) \) in the incubated samples in August 1998 (initial pH decreased from 5.65 to 5.51) and in September 1998 (initial pH decreased from 5.54 to 5.38).

For all sampling occasions with incubated bags, mean pH, and moisture content inside and outside the bags were compared. For pH no statistically significant difference was revealed, i.e. the dynamics of pH was similar in natural soil conditions and in the polyethylene bags. The impact of polyethylene bags on soil moisture was significant, moisture content was higher in natural conditions \( (P < 0.05) \) except for

Fig. 3. Seasonal pH dynamics in the 0–10 cm soil layer (means and their 95% confidence intervals).
August–October, but the mean difference was smaller than 5%.

4. Discussion

The pool of total nitrogen in the upper 50 cm layer in the experimental area was 4.79 t ha\(^{-1}\) (Uri et al., 2002), which remains in the range of the total nitrogen pool in boreal forest ecosystems, being as a rule 1–8 t ha\(^{-1}\) (Gundersen, 1995). Most of nitrogen is bound to soil organic material, while only about 0.1–1% is available to plants in the form of inorganic nitrogen in boreal forest (Helmisäari, 1995). In the upper 0–10 cm soil layer of the investigated grey alder plantation inorganic nitrogen accounted for 1.2–2.5% of the soil nitrogen pool, which falls in the range of 1–3% reported for soils containing clay minerals (Baldock and Nelson, 2000).

The concentration of soil ammonium nitrogen was considerably higher than the concentration of soil nitrate nitrogen (Fig. 1). A steady lower level of NH\(_4^+\)–N compared with that of NO\(_4^+\)–N may indicate that nitrogen was assimilated mainly in the form of nitrate. Also, NH\(_4^+\)–N is much less mobile than NO\(_3^-\), because NH\(_4^+\) has strong affinity for negatively charged clay and organic matter particles (Groffman, 2000). However, as nitrate in the soil incubated in polyethylene bags was not available to plants, the content of this form of nitrogen increased there. Hence the significantly lower concentration of mineral nitrogen in the soil in May to September was probably caused by a more intensive uptake by plants at this time. The significant increase in the soil mineral N pool in October and its stable size until the beginning of the following growing period are most probably related to the release of readily mineralizable N from decomposing litter as well as to its reduced uptake by plants.

The most critical assumption on which the validity of the measurement rests is that the method of incubation does not alter the natural rate of mineralization significantly. Since net nitrification was slightly higher than net N mineralization, most of the ammonium nitrogen produced during mineralization was nitrified, which indicates, once more that the vegetation in the studied grey alder stand, established on abandoned agricultural land, had to assimilate nitrogen mainly in the form of nitrate. Which of the processes of nitrogen mineralization dominates depends on various factors, among them the C:N ratio for soil organic matter being highly important. Earlier, nitrification was considered impossible in low fertility soils for which the C:N ratio in the humus layer is >25–30 (Gundersen and Rasmussen, 1988). Since owing to its mosaic character the soil can provide suitable econiches for microbes, nitrification has been established even in acidic soils (Rudebeck and Persson, 1998). In the experimental plantation of grey alder the C:N ratio for the upper 10 cm soil layer in the study years ranged from 13 to 15, which is favourable for nitrification. Nitrification intensity is chiefly influenced by such environmental factors as soil moisture content, temperature and pH (Tietema et al., 1992).

At the time (August, September) when soil reaction in the initial sample and in the incubated samples revealed a statistically significant difference (\(P < 0.05\)), the intensity of mean daily net mineralization was also high (Fig. 2). Soil pH decreased in the course of mineralization, i.e. soil became more acidic as a result of mineralization. Thus soil reaction can be regarded both as a factor affecting mineralization and the result of this process.

Net nitrogen mineralization was positive in all cases (Fig. 2). Hence the negative values of net ammonification can be explained by N immobilization, or by gaseous losses at nitrification and denitrification (Maag and Vinther, 1996), as loss or leaching from the bags was excluded. Negative net ammonification also indicates that all available ammonium was oxidized into nitrate. The occurrence of N immobilization in the study area is confirmed by the fact that the soil N pool in the 0–20 cm soil layer in the plantation increased by 360 kg ha\(^{-1}\) during the first 6 years. Gaseous losses from the polyethylene bags (N\(_2\), N\(_2\)O) cannot be excluded either, but this requires further investigation.

As the dynamics of temperature, moisture content and soil reaction inside and outside the polyethylene bags was similar, the incubation method used had no impact on the environmental conditions. The dynamics of net nitrogen mineralization is consistent with that established by other researchers. According to Nadelhoffler et al. (1984), mineralization intensity is the highest in spring or early summer (May, June), while another peak occurs at the end of the vegetation
period (August, September). Holmes and Zak (1994) reported two peaks of nitrogen net mineralization in North American broad-leaved stands: one in midsummer (July) and the other in late autumn (November).

Annual net N mineralization can be used as an estimate of available mineral nitrogen assuming that leaching in grey alder stand on agricultural land is non-existent or insignificant. However, in Estonia, leaching of nitrogen has been observed in loaded riparian grey alder stands functioning as buffer zones (Kuusemets, 1999), but it formed less than 1% of the annual demand of plants (Lõhmus et al., 2002). Leaching of nitrogen from soil leads to soil acidification (Binkley and Richter, 1987). Although the 0.24 unit decrease in soil pH in the studied stand was observed from August to November (Fig. 3), it is impossible to draw any conclusion about leaching, as the soil H⁺ pool is affected by several processes.

The lower net nitrogen mineralization in the 10–20 cm soil layer results from less favourable soil conditions, especially lower microbial biomass and activity (data not shown here). The soil layers deeper than 20 cm were not considered even when some mineralization takes place in the deeper soil layers, as it would play an insignificant role in satisfying the annual nitrogen demand for plants, since the bulk of the fine roots (d < 2 mm) of alders and herbs are located in the upper 20 cm soil layer (Uri et al., 2002).

Annual net mineralization in the studied stand in the fourth year after planting was 141 kg ha⁻¹ in the upper 0–20 cm layer, which formed 62% (alders and herbs) of the annual demand of the vegetation. Such a level of annual net nitrogen mineralization can be considered relatively high, as for deciduous stands this parameter usually ranges between 50 and 150 kg ha⁻¹ (Aber et al., 1989) and is increasing with stand age. Mineralization of nitrogen in grey alder energy forest may reach the levels of 75 kg ha⁻¹ per year on highly fertile clay soils and 30 kg ha⁻¹ per year in originally nutrient poor peat bogs with alder (Granhall, 1994). In Estonia, in a 14-year-old natural riparian grey alder stand, net N mineralization amounted to 43 kg ha⁻¹ per year and in a 40-year-old heavily polluted mature riparian grey alder stand to 188 kg ha⁻¹ per year (Lõhmus et al., 2002).

We have estimated nitrogen demand of alders and ground vegetation as 122 and 104 kg ha⁻¹ per year, respectively. In the preliminary budget of N demand (8), modified after (Lõhmus et al., 2002) we neglected the input and output via subsurface and overland flow, as there is no slope in the study area. We considered the first approximation leaching from the stand to be negligible according to soil properties.

Demand (alders + ground vegetation)\(^a\) = Net mineralization of soil N\(^a\) + Leaching from decomposed leaf litter\(^a\) + Retranslocation in alder\(^a\) + Initial N pool of herbs\(^a\) + Deposition\(^b\) + Symbiotic \(\mathrm{N}_2\) fixation\(^c\) (8)

Superscript ‘\(a\)’ denote determined, ‘\(b\)’ estimated on the basis of literature (Mander et al., 1997) and ‘\(c\)’ calculated by balancing the other values.

The demand deficit was assumed to be covered by fixation of \(\mathrm{N}_2\) from the atmosphere and it formed 42 kg ha⁻¹ per year. Considering the total flux of symbiotically fixed nitrogen, it is evidently larger, because gaseous losses (mainly denitrification) are not excluded. Also, significant increase in soil N pool was found after 6 years. However, during first 5 years the increase in soil pool was statistically insignificant.

Thus for that time interval, net N mineralization is the main source of N use for alders and symbiotic fixation forms 34% of annual alder demand. After that first period, main N source for alders should be symbiotic fixation. According to literature data the amount of symbiotically fixed nitrogen in a 30-year-old grey alder stand can be as large as 43 kg ha⁻¹ per year (Johnsrud, 1978). Granhall and Verwijst (1994) reported the fixation rate of 29 and 24 kg ha⁻¹ per year in a 2-years-old stand. In Estonia, a 14-year-old natural riparian grey alder stand and a 40-year-old heavily polluted mature riparian grey alder stand fixed symbiotically 185 and 37 kg N ha⁻¹, respectively (Lõhmus et al., 2002). Although large part of the annual nitrogen demand of alders is usually covered through symbiotic fixation, there are a few exceptions from is a general rule (Granhall and Verwijst, 1994).

Concerning the N budget of the whole stand (trees and herbs), the annual net N mineralization was the largest flux in the N budget in this study. Hence, during first 4–5 years the possible impact of previous land use on the processes of nitrogen transformation in the soil is not excluded.
Acknowledgements

This study was supported by the Estonian Science Foundation Grant No. 4821. We thank Mrs. Ester Jaigma for revising the English text of the manuscript.

References


