The Budget of Demand for Nitrogen in Grey Alder (*Alnus incana* (L.) Moench) Plantation on Abandoned Agricultural Land in Estonia

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A budget of nitrogen demand in a 5-year-old grey alder (*Alnus incana* (L.) Moench) plantation growing on abandoned agricultural land was compiled. The annual nitrogen demand of the stand and ground vegetation was estimated proceeding from the amount of nitrogen bound in above-ground and below-ground biomass production, which was 226.2 kg $ha^{-1}yr^{-1}$ in the fourth year after planting. Net nitrogen mineralization in the upper 20 cm soil was 141.2 kg $ha^{-1}yr^{-1}$, which consisted 62.4 % of the annual N demand of the whole vegetation.

The other fluxes covered 1.9 – 8.6% of the annual demand: initial N pool of herbs (19.5 kg $ha^{-1}yr^{-1}$), litter decomposition (13.0 kg $ha^{-1}yr^{-1}$), deposition (6.4 kg $ha^{-1}yr^{-1}$) and retranslocation (4.4 kg $ha^{-1}yr^{-1}$). Symbiotic nitrogen fixation (41.7 kg $ha^{-1}yr^{-1}$) was estimated on the basis of the preliminary budget of the demand for nitrogen and it comprised 18% of the annual nitrogen demand of the stand and 34% of alders demand. During six study years the soil nitrogen pool increased (360 kg ha^{-1}) and hence total annual symbiotic fixation should be significantly larger.

Key words: grey alder, budget of nitrogen, abandoned agricultural land, nitrogen demand, nitrogen fixation

Introduction

The share of forests in Estonia has considerably increased during the last half-century, which is largely due to the afforestation of agricultural lands. As a consequence of the decline in agriculture in the last decade the area of abandoned land has reached at least 228 000 ha (Meiner 1999). There also is a clear tendency of an increase in such areas in Europe, which is more pronounced in Central and East European countries owing to drastic changes in political and economic situation there. Abandoned agricultural areas in Estonia are characterized by rapid natural afforestation with fast growing pioneer tree species, mainly by grey alder (*Alnus incana* (L.) Moench) and silver birch (*Betula pendula* Roth). In 1975, grey alder forests accounted for 4.0% of all woodlands, while in 2000 their proportion was already 7.8% (Yearbook Forest 2001).

Grey alder is a fast-growing deciduous tree species both on mineral and organic soils (Granhall and Verwjist 1994, Saarsalmi 1995, Telenius 1999). In Estonia, the current increment of grey alder is larger than that of other deciduous tree species, being 7.6 $m^3ha^{-1}yr^{-1}$ (Yearbook Forest 2001). Also, 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 as a source of bioenergy. Grey alder as an actinorhizal N_2-fixing tree species can be used effectively for biological fertilization of the soil with nitrogen (Granhall 1994) and the potential of alder stands to increase the soil nitrogen pool is high (Šlapokas 1991). Alder species have a positive impact on the diversity and activity of soil microbial communities, which has also been reported in relation to increased soil phosphorus availability under alder species (Giardina *et al.* 1995, Binkley 1984). Microbial communities affecting soil processes and the dynamics of the nitrogen pools 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.

In elucidating the impact of increase in the area of grey alder stands on abandoned agricultural lands, concerning nitrogen cycling, nitrogen budgeting proves a useful tool. Since grey alder has not been cultivated in Estonia earlier, this pilot study is expected to provide an assessment of the influence of grey alder on soil nitrogen status.

The aim of the study was to compile a preliminary budget of the nitrogen demand of the grey alder plantation growing on abandoned agricultural land in order to quantify the impact of alders on the soil nitrogen pool.

Materials and methods

Plantation

The grey alder plantation was established on abandoned farm-land in the spring of 1995, in the southeastern part of Estonia, 58^0 3' N and 27^0 12' E. According to the data of the Võru meteorological station, closest to the study area, mean annual temperature, amount of precipitation and length of the vegetation period are 6^0 C, 653 mm and 191 days, respectively. 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 two years. The transplants of natural origin aged 1-2 years were used for planting. The survival and growth of the plantation has been described earlier (Uri and Tullus 1999, Uri *et al.* 2002). The total area of the plantation was 0.08 ha. The 0.7 x 1.0 m planting arrangement was employed.

The dynamics of main stand characteristics of the experimental plantation are presented in Table 1. The soil characteristics of the upper 0-20 cm soil layer at the beginning of the experiment were the following: the N pool formed 2.64 t ha^{-1}; bulk density, pH (KCl) and the C/N ratio for the soil layer were 1.27 g cm^{-3}, 5.5, and 13-15, respectively.

Table 1. The dynamics of main stand characteristics of the grey alder plantation (average ±standard error)

Year	Trees ha^{-1}	Mean height, m	$D_{1.3}$, cm	Basal area, $m^2 ha^{-1}$
1995	15, 750	0.99±0.01	-	-
1996	14, 025	2.13±0.02	-	-
1997	13, 112	3.54±0.02	1.9±0.02	4.19±0.06
1998	12, 662	4.62±0.03	2.6±0.03	7.49±0.12
1999	11, 912	5.22±0.04	3.1±0.04	9.65±0.15
2000	9, 850	6.12±0.05	3.9±0.04	12.96±0.27

Soil and biomass sampling and analysing

Soil investigations were carried out annually (1995-2000) with the aim to estimate the effect of alders on soil fertility. At ten points over the whole area, successive soil samples were taken from a depth of up to 50 cm for the determination of soil. From ten points over the whole area, successive soil samples were taken to a depth of 50 cm (layers: 0-10, 10-20, 20-30, 30-40 and 40-50 cm) for determination of soil pH (KCl) and the concentration of nitrogen and organic matter. The subsamples of a layer were merged in a composite soil sample. Soil bulk density was determined to evaluate the pool of soil nitrogen.

To estimate the above-ground biomass and productivity of alders, dimension analysis techniques (Bormann and Gordon 1984) were used. In August when leaf mass was the largest, 7 sample trees were felled. The stems of the sample trees were divided into three sections so that the base as well as the middle and the upper parts of the tree were represented. Within the sections, the tree was divided into fractions: leaves, primary growth of branches, old branches and stem (wood+bark). From every fraction, a subsample was taken for the estimation of dry matter content as well as for chemical analysis. The annual production of the stemwood, bark and old branches was calculated as the difference between the masses of the respective fractions for the studied year and for the previous year.

The below-ground biomass of the plantation was estimated in October 1998. Two methods were used: excavation of the root system of the sample trees for the estimation of the biomass of the stump and the coarse roots (d ≥ 2 mm), and soil coring to the depth of 40 cm for the estimation of the biomass of the fine roots (d < 2 mm) and nodules (Uri *et al.* 2002).

The concentrations of main nutrients (NPK) were determined from different fractions of model trees. The contents of NPK in different fractions of model trees were calculated as weighed averages considering the share of a particular section in the biomass of the respective fraction of the whole tree as well as the concentration of nutrients in the respective fraction of this tree section. Both the pool and annual demand for nutrients in the above-ground and below-ground part of the plantation were calculated; the biomass or annual increment of a fraction was multiplied by the respective nutrient concentration.

For the estimation of the above-ground biomass of the ground vegetation, samples were taken at the end of June when biomass was at maximum. The aboveground part of all herbaceous plants was collected from a 1 m^2 quadrat at ten randomly chosen points over the whole plantation. The samples were weighed fresh, dried at 70^0 C to constant weight and reweighed to 0.01g.

For the estimation of the below-ground biomass of the ground vegetation, soil coring was employed.

Ten soil cores were taken from a depth of 30 cm in the same squares using a soil auger (d = 80 mm). The core was divided into three 10 cm layers and the plant roots were washed out of each layer. For every fraction, dry mass and the nitrogen content were determined. Total nitrogen concentration in dried biomass was analysed at the laboratory of the Estonian Agricultural University.

Estimation of nitrogen fluxes

Net N mineralization was estimated *in situ* in the upper 10 cm soil, where about 50% of the fine roots (d < 2 mm) are located, between June 1998 and July 1999. The experiment was performed using the method with incubated polyethylene bags (Hart *et al.* 1994), based on measurement of mineral nitrogen in an environment where the impact of intact roots is excluded. For the assessment of net nitrogen mineralization in the deeper soil layer (10-20 cm), a monthly repeated experiment was carried out in May 2001. Denitrification flux was not prevented, as the thickness of the polyethylene film was 18 ģm which guarantees gas permeability (O_2, CO_2, N_2, etc) and avoids leaching or addition of the soil solution (Eno 1960). Net nitrogen mineralization was calculated as the difference between the concentrations of inorganic N in the incubated and initial samples.

Retranslocation of N in alders was estimated using the differences in nitrogen concentrations between the fresh leaves and leaf litter. Leaf litter was gathered from 10 litter traps and sorted into leaves and twigs. Annual retranslocation of N was calculated on the basis of leaf mass and the differences in the nitrogen concentrations.

To estimate the autumn retranslocation of N in the ground vegetation, N concentration was determined in the period of maximum biomass (June) and in October (in the below-ground part). In October too ten soil cores were taken from a depth of 30 cm in the same squares as in June using a soil auger (d = 80 mm). The core was divided into three 10 cm layers and the plant roots were washed out of each layer. For every fraction, dry mass and the nitrogen content were determined. The amount of nutrients accumulated in the below-ground part of the ground vegetation in autumn covers part of the nitrogen demand of the following year.

Nitrogen release from decomposing leaf litter was estimated on the basis of a litter decomposition experiment carried out in the period 1996-1999. Nylon litter bags with 2 mm mesh size were used. Nitrogen leaching from decomposing leaf litter was calculated as the difference in N content between initial material and the decomposing material in the litter bags. One litter bag contained about 1,00 g of alder leaves and 80 litter bags were incubated at 5 different points of the plantation.

Nitrogen deposition was estimated on the basis of literature data (Mander *et al.* 1997).

The amount of symbiotically fixed nitrogen used in the production of alders in the experimental area was estimated on the basis of the nitrogen budget. After estimating the amount of N utilized by plants it was assumed that the budget deficit was covered by symbiotic nitrogen fixation, and the annual budget of nitrogen demand of the grey alder stand (1), growing on former agricultural land, was the following:

Demand (alders + ground vegetation)^a =
Net mineralization of soil N^a + Leaching from decomposing leaf litter^a + Retranslocation in alder^a + Initial N pool of herbs^a + Deposition^b + Symbiotic N_2 fixation^c

^{a} – determined
^{b} – estimated on the basis of literature
^{c} – calculated by balancing the other values

Laboratory analysis

The plant samples were analysed for total nitrogen by the Kjeldahl method using a “Kjeltec Auto 1030” analyzer and Cu/K_2SO_4 as the catalyst. For testing the soil samples for nitrogen according to Kjeldahl, Tecator ASN 3313 was used. Determination of NO_3^--N and NH_4^+-N in the soil was performed by flow injection analysis with the use of Tecator ASN 65-32/84 and Tecator ASN 65-31/84, respectively. The analyses were performed at the Laboratory of Biochemistry of the Estonian Agricultural University.

Statistical methods

Normality of the diameter and height distribution of all trees in the plantation was checked by χ^2 test. For the N,P,K concentrations of the model trees, the Kolmogorov – Smirnov test was used. To analyse the effect of the tree section or height class on N,P,K concentrations in the leaves, stemwood and stembark, one-way ANOVA was applied. When the data did not follow the normal distribution, or when there occurred an inhomogeneity of group variance the nonparametric Kruskal-Wallis analysis of variance was used. Linear and allometric models were employed for estimating the relationships. In all cases the level of significance α=0.05 was accepted.

Results

Annual plant demand

The annual nitrogen demand of the stand was estimated proceeding from the amount of the nitrogen bound in produced biomass.

The annual amount of nitrogen bound in the biomass production of the above-ground part of the stand was 100.2 kg $ha^{-1}yr^{-1}$. As the below-ground part accounted for 18% of the total biomass of the stand (2.68 t ha^{-1}) and the nitrogen pool stored in the below-ground part made up 18.6% of the total nitrogen pool of the biomass, it was assumed that also the share of annual production and the share of nitrogen demand are proportional. Hence the demand of the below-ground part of the grey alder stand was estimated as 21.8 kg $ha^{-1}yr^{-1}$ and the total annual nitrogen demand of the alders as 122.0 kg ha^{-1} yr^{-1}.

The demand of the above-ground part of the understorey was 64.3 kg ha^{-1} yr^{-1} and the demand of the below-ground part was 39.9 kg ha^{-1} yr^{-1}, hence the total annual demand of the understorey for nitrogen was 104.2 kg ha^{-1} yr^{-1} (Fig. 1).

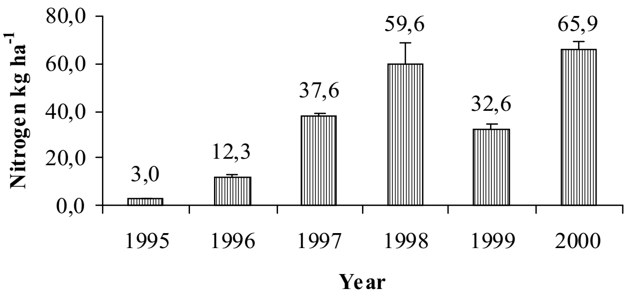

Figure 1. The amount of nitrogen introduced in the soil with leaf litter (with 95% confidence intervals)

Nitrogen pool in soil

In the experimental area, the pool of total nitrogen in the upper 10 cm layer was 1.39 t ha^{-1} and in the 20 cm layer 2.64 t ha^{-1}. During the first six growing years 211 kg ha^{-1} of nitrogen reached the soil with leaf litter (Figure 1). In the present study the amount of nitrogen added to the soil with leaf litter in the fourth growing season was 60 kg ha^{-1} and in the fifth growing season 33 kg ha^{-1}. A decrease in the amount of nitrogen in 1999 is related to unfavourable weather conditions during the growing season. Since the increase in soil Kjeldahl nitrogen during six years was statistically significant ($P < 0.05$) (Table 2), the effect of alders to enrich the soil with nitrogen is revealed already in the young age of stand. Recalculation of the change of nitrogen concentration into the soil nitrogen pool yielded an increase of 360 kg ha^{-1} in the total soil nitrogen pool during six years after planting.

Table 2. The dynamics of nitrogen concentration in the upper 20 cm soil layer in the grey alder plantation

Year	N mg kg^{-1}	Org. matter %	pH $_{KCl}$
1995	1050	2.40	5.93
1996	1010	2.77	5.68
1997	1050	2.51	5.47
1998	1040	2.65	5.41
1999	1150	2.68	5.72
2000	1190	2.60	5.18

Nitrogen fluxes

Annual net mineralization in the studied stand in the fourth year after planting was 141.2 kg ha^{-1} in the upper 0-20 cm layer, which covered 62.4% of the annual demand of the vegetation (alders and herbs) (Uri *et al*. 2003). Decomposition of root litter and leaf litter residues was included through the use of intact unsieved cores.

In 1998, nitrogen retranslocation from grey alder leaves was estimated at 2.4 kg $ha^{-1}yr^{-1}$ and in 1999 at 6.4 kg $ha^{-1}yr^{-1}$. The calculations were based on the average retranslocation for two years, i.e. 4.4 kg $ha^{-1}yr^{-1}$.

The initial N pool of herbs (amount of nitrogen stored in the roots of herbaceous plants in late autumn) was 19.5 kg ha^{-1}.

Deposition was estimated on the basis of literature data. The share of this flux in the studied area is relatively small, at 35 km from the experimental area, deposition was 6.4 kg ha^{-1} yr^{-1} (Mander *et al.* 1997). In the present investigation deposition in the study area was assumed to be of the same order of magnitude.

An experiment of litter decomposition in the grey alder stand showed that 28.2% of litter nitrogen content is leached in the first year. On the basis of this percentage and the average amount of litter for two years (1998-1999), leaching from litter decomposition can be estimated at 13.0 kg ha^{-1}. In natural conditions alder litter disappeared already in July most probably due to the activity of abundant earthworms. Hence leaf litter had been fragmented and transformed and formed part of soil organic matter (see net N mineralization).

The total flux of symbiotic nitrogen fixation was not estimated in this study. The annual nitrogen demand of the whole vegetation was 226.2 kg ha^{-1} and the sum of all studied fluxes was 171.5 kg ha^{-1}. Hence the minimum amount of the nitrogen, fixed from the air, in the grey alder stand on abandoned agricultural land in the fourth year after planting was assumed to be 41.7 kg ha^{-1} (Figure 2).

clay soils and 30 kg ha^{-1}yr^{-1} in originally nutrient poor peat bogs with alder (Granhall 1994). In Estonia, in the 14-year-old natural riparian grey alder stand, net N mineralization amounted to 43 kg ha^{-1} yr^{-1} and in a 40-year–old heavily polluted mature riparian grey alder stand, to 188 kg ha^{-1} yr^{-1} (Lõhmus *et al.* 2002). Hence, the possible impact of previous land use as agricultural land on nitrogen transformation processes in the soil is not excluded.

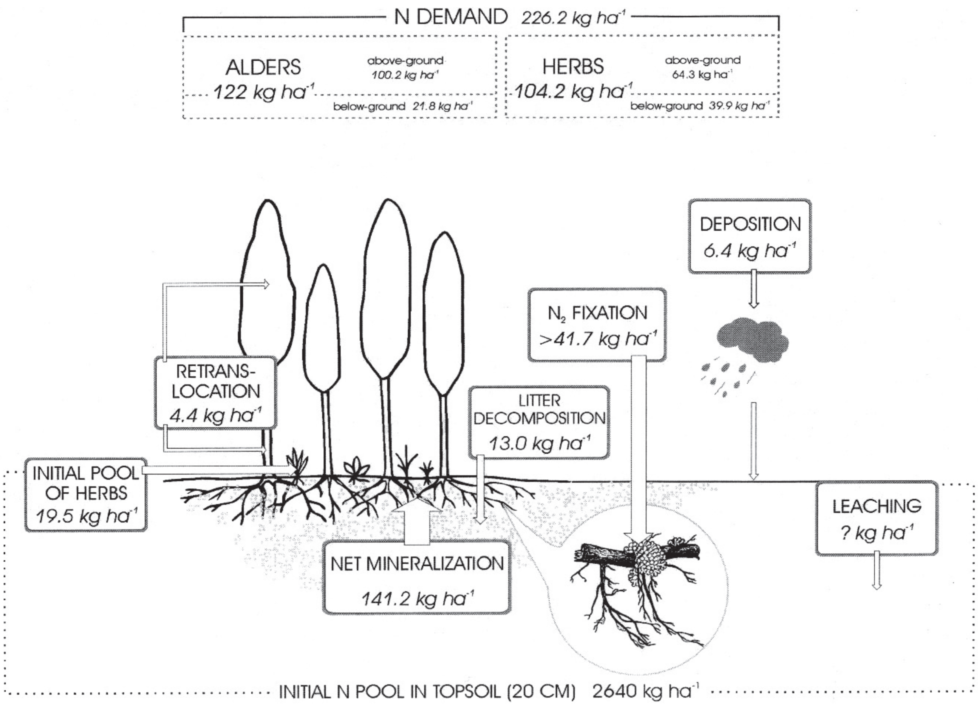

Figure 2. The budget of nitrogen demand of grey alder plantation on abandoned agricultural land

Discussion

In the experimental area, the pool of total nitrogen was 2.64 t ha^{-1} in the upper 20 cm layer, 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 in boreal forest is bound to soil organic material, while only about 0.1 – 1% is available to plants in the form of inorganic nitrogen (Helmisaari 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. 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 – 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}yr^{-1} on highly fertile

Since alders fix nitrogen, a large part of annual nitrogen demand is covered from atmospheric nitrogen. According to the data obtained in the literature the amount of symbiotically fixed nitrogen in the 30-year-old grey alder stand can be as large as 43 kg N ha^{-1} yr^{-1} (Johnsrud 1978). In a young, 4-year-old, *Alnus rubra* stand up to 70% of the accumulated nitrogen can originate from symbiotic fixation (62 kg N ha^{-1} yr^{-1}) (Tripp *et al.* 1979). In some cases up to half of the nitrogen amount accumulated in the above-ground part can originate from symbiotic fixation (Rytter *et al.* 1991). In Estonia, the 14-year-old natural riparian grey alder stand can fix up to 185 kg N ha^{-1} from the air and the 40-year–old heavily polluted mature riparian grey alder stand can fix 28 kg N ha^{-1} (Lõhmus *et al.* 2002). According to Šlapokas (1991) even up to 81% N used by a 7-year-old alder plantation may originate from symbiotic fixation.

Thus the data in the literature vary in a broad range. Nitrogen fixing capacity may depend on the stand, on soil nutrient content, etc. The amount of symbiotically fixed nitrogen in the experimental area was estimated on the basis of the nitrogen budget (Equation 1 and Figure 2). As the demand of N and the other nitrogen fluxes were estimated, then it was assumed that the budget deficit was covered by symbiotic nitrogen fixation. Nitrogen leaching is not excluded and although one can assume that possible nitrogen leaching from grey alder stand on agricultural land is low or insignificant, this can not be claimed definitely. According to the data obtained in the literature nitrogen can indeed be leached from natural grey alder stand (Binkley *et al.* 1992). In a fertilized grey alder stand growing on peaty soil nitrogen leaching can be as high as 10 kg ha^{-1} (Šlapokas 1991). In Estonia, nitrogen leaching of 9-13 kg $ha^{-1}yr^{-1}$ was observed in riparian grey alder stands functioning as buffering zones (Kuusemets 1999). During six study years the soil nitrogen pool increased significantly, the annual average increase being 60 kg $ha^{-1}yr^{-1}$. 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 for N use of alders growing on abandoned agricultural land and symbiotic fixation forms 34% of annual alder demand (18% of all vegetation). Although a large part of the annual nitrogen demand of alders is usually covered through symbiotic fixation, the annual net N mineralization was the largest flux in the N budget in this study. After that first period main N source for alders should be symbiotic fixation.

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БАЛАНС ПОТРЕБНОСТИ В АЗОТЕ ПЛАНТАЦИИ СЕРОЙ ОЛЬХИ *ALNUS INCANA* L., ПРОИЗРАСТАЮЩЕЙ НА ЗАБРОШЕННОЙ ПАХОТНОЙ ЗЕМЛЕ

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Резюме

Составлен баланс потребности в азоте в 5-летнем сероольшанике, произрастающем на пахотной земле. Годовую потребность насаждения в азоте оценили на основании количества связанного азота в надземной и подземной продукции, которое составило на четвертом году после посадки 226,2 кг $га^{-1}г^{-1}$. Нетто-минерализация азота в верхнем 20-саниметровом слое почвы составляла 141,2 кг $га^{-1}г^{-1}$, что покрывало 62,4 % годовой потребности в азоте всей растительности (насаждение и травянистая растительность).

Другие азотные потоки покрывали 1,9-8,6% годовой потребности в азоте: ретранслокация из подземной части травянистых растений 19,5 кг $га^{-1}г^{-1}$, разложение опавших листьев 13,0 кг $га^{-1}г^{-1}$, депозиция 6,4 кг кг $га^{-1}г^{-1}$ и ретранслокация ольхи 4,4 кг $га^{-1}г^{-1}$. Симбиотическую фиксацию азота (41,7 кг $га^{-1}г^{-1}$) оценивали на основании баланса, и она покрывала 18% годовой потребности насаждения и 34 % годовой потребности ольхи в азоте. За шесть рассматриваемых лет содержание азота в почве увеличилось (360 кг $га^{-1}$), и, тем самым, действительное годовое количество симбиотически фиксированного азота больше.

Ключевые слова: ольха серая, азотный баланс, бросовая пахотная земля, потребность в азоте, симбиотическая фиксация азота.