Natural ^{15}N abundance in two nitrogen saturated forest ecosystems at Solling, Germany

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ABSTRACT: This research deals with a comparative study of two different N-saturated forests: 1. beech forest and 2. spruce forest at the same locality of Solling, Central Germany. The present results show that ^{15}N natural occurrence in the rainfall (both above and below canopy) at Solling site is similar ($\delta^{15}N$ = –15‰ to +19‰) to other sites of the world (such as NITREX sites, USA etc.). Furthermore, ^{15}N values in the soil water ranged from –4.32 (±2.09) to +5‰ (±1.47), which also corresponds to NITREX sites and other sites of Europe and USA. In both forests, $\delta^{15}N$ enrichment of both NH_4-N and NO_3-N showed a decreasing trend of their values from bulk precipitation to the upper soil layer, but increasing in the deeper soil layer again. An increase in the ^{15}N enrichment of soil water from upper soil depth to lower soil depth was observed in our study and it is assumed to be due to the strong net nitrification taking place in the upper layer (organic surface layer) of soil. The soils at both sites showed characteristic low (negative) $\delta^{15}N$ values in the upper organic layers, strongly increasing to positive $\delta^{15}N$ values in the mineral soil. In the lower depths of mineral soil horizons of both stands, an increase in $\delta^{15}N$ values was found to culminate at +3 to +5‰. In contrast to the mineral soil horizon, in the organic soil horizon (0 to 6 cm depth) of both sites there was almost a similar or slight decrease in $\delta^{15}N$ values with depth. This is attributed to the high nitrification rate in the organic soil horizon, resulting in excessive seepage water NO_3-output at both sites (especially at the spruce site).

Keywords: beech forest; spruce forest; ^{15}N; isotopes; precipitation; soil

The use of natural abundance of stable isotopes to elucidate physiological processes in plants is one of the most common applications in ecology. The characteristics of the isotopic compositions of pollutants can provide useful information on their source and quantity in the environment. The use of ^{15}N abundance values of ecosystem pools offers possibilities of checking and improving estimates of nitrogen fluxes and nitrogen losses from forest ecosystems (NADELHOFFER, FRY 1994). Several ecosystem researchers predicted that ^{15}N natural abundance values would increase for systems approaching N-saturation (GARTEN 1993; NADELHOFFER, FRY 1994). So the natural ^{15}N abundance values could identify the position of forests along the gradient for N deficiencies to N saturation.

Over decades, N deposition has affected forest areas of Europe and N. America. Nitrogen saturation is associated with the increased rates of N cycling and losses of NO_3 to percolation water (ABER et al. 1989; DIESE, WRIGHT 1995; LAJTHA et al. 1995). As nitrogen cycles through the ecosystem, slight fractionation or discrimination against the heavier isotope ^{15}N is usually observed (NADELHOFFER, FRY 1994). As the fractionation of N in favor of lighter ^{14}N occurs during various transformation processes associated with N enrichment and N loss (SHEARER et al. 1974), the ^{15}N signal of vegetation can provide an useful tool for evaluating the past and present N status of forested ecosystems (GARTEN 1993; HÖGBERG, JOHANNISSON 1993). For example, relatively low $\delta^{15}N$ values in vegetation or in both vegetation and soil could indicate that the rates of N losses from the compartments are low. In contrast, relatively high N-exports from a compartment lead to higher $\delta^{15}N$ values in vegetation and surface soils. Reports on the forest sites across N. America (The Long Term Ecological Research, LTER Project) and Europe (NITREX, Nitrogen Saturation Experiments on Forest Ecosystems Project) illustrate the overall pattern of ^{15}N enrichment resulting in the order of increasing enrichment as follows: plant < litter < organic soil < mineral soil (a review of EMMETT et al. 1998).

Recently, the uptake of N from atmospheric deposition by aboveground parts of trees was hypothesized to be involved in the complex phenomenon of forest decline (EILERS et al. 1992; SCHULZE et al. 1987; NIHLGARD 1985). The ^{15}N natural abundance technique was recently used in forest ecosystem health studies by GEBAUER and SCHULZE (1991) and GEBAUER et al. (1994). They reported that needles from a healthy Norway spruce stand

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were more depleted of ^{15}N than those from a declining stand receiving increased N and S depositions.

This study is concerned with the comparative study of two highly N-saturated beech [*Fagus sylvatica* (L.)] and spruce forests [*Picea abies* (L.) Karst.] at the same locality of Solling, Germany. Both ecosystems are under the same bulk precipitation deposition of N, but differ in their total atmospheric N-deposition and degree of podzolization. The spruce site receives about 33% higher N-input than that found at the beech site. The beech forest site is slightly podzolized (formation of Ahe and Aeh horizons) and the spruce site shows the strongest signs of podzolization. Organic layers are moder in beech stand and mor/moder in spruce stand. This study aims to investigate the changes in isotope ratios within ecosystem pools resulting from N-deposition and isotopic fractionation of N in all major ecosystem compartments, including vegetation, soil, bulk precipitation, throughfall and soil water of the above mentioned forests. The study hypothesizes that the isotopic N composition of both ecosystems will act as an environmental indicator of N saturation.

MATERIALS AND METHODS

Site selection and their description

Two long-term forest research stands at Solling, beech forest (B1) and spruce forest (F1), were selected for the present study. The purpose of selection was to compare the natural abundance of the above-mentioned two different types of forests at the same locality, i.e. under the same environmental conditions. Both forests are located in the mountainous Solling area of Germany at 51°46´N, 9°34´E, and are just 100 m away from each other. The Solling area is a part of the Weser river mountain range. The soil is strongly acidified dystric Cambisol (FAO Classification), which has developed in a loess solifluction layer overlying the sandstone bedrock. Both forests B1 (145 years old) and F1 (110 years old) are situated at 504 m altitude and the vegetation mainly consists of beech [*Fagus sylvatica* (L.)] and spruce [*Picea abies* (L.) Karst.], respectively. Both sites have the average annual precipitation of 1,142 mm and the mean annual air temperature of 6.4°C. The nitrogen deposition (in throughfall between 1969–1985) of the spruce forest (40.8 kg/ha/yr) was found slightly higher than that of the beech stand (34.8 kg N/ha/yr). The open field precipitation deposition (between 1981 to 1994) of total nitrogen was 20 kg N/ha/yr (MESSENBURG et al. 1995). The nitrogen leaching from seepage water is strongly higher in the spruce stand (14.9 kg N/ha/yr) as compared to the beech stand (4.7 kg N/ha/yr).

Sampling

Bulk precipitation was collected by standard rain gauges using the method described by MEIWES et al. (1984), KÖNIG and FORTMANN (1996). 15 and 6 rain gauges on the plot were used for the collection of throughfall and bulk precipitation, respectively, for the year 2000. The precipitation water samples were collected weekly and 5 samples of throughfall and 2 of bulk precipitation were bulked to a monthly sample. Soil water was collected biweekly from ceramic lysimeter and plates installed at the soil depths just below the O_L-horizon (0 cm) and 80 cm. Samples were bulked to a monthly sample. After the collection of water samples, they were immediately filtered and stored at 4°C prior to bulking and analysis.

Samples of needles, leaves and litter were collected from the selected sites in the spring season. Litter fall was collected weekly in 15 litter traps in the autumn season (September to November, 1986–1994) and was mixed to one sample for each month. All plant samples were dried at 60–80°C and milled using planetary mills.

In order to assess the vertical distribution of stable isotopes in the soil, an undisturbed soil core (in 4 replications) was extracted with a steel soil core sampler (30 cm long and 8 cm diameter) to the soil depth of 14 cm randomly from the plot. The extraction of samples followed in 2001. The soil cores were cut into 0.5–2 cm slices for the laboratory analysis.

Analytical methods

All the solid samples were dried (plant samples at 40°C and soil samples at 70°C) and ground into a fine powder in a planetary mill. ^{15}N was measured on a Finnigan MAT Delta Plus stable isotopic ratio mass spectrometer (IRMS) equipped with an elemental analyzer for conversion of N into N_2, C into CO_2. For the N-isotope determination in water samples, the diffusion method was used (SORENSEN, JENSEN 1991). The results of IRMS measurements were given in δ notation. The δ values of N-isotopes are expressed as parts per 1,000 differences from standard atmospheric isotopes (SHEARER, KOHL 1993):

$$\delta^{15}N(‰) = \{[(^{15}N/^{14}N_{sample})/(^{15}N/^{14}N_{air})] - 1\} \cdot 1,000$$

where: air – reference standard gas.

RESULTS

Trend of natural abundance of ^{15}N in bulk precipitation, throughfall and soil water

In general, the $\delta^{15}N$ values of NH_4-N and NO_3-N in bulk precipitation, throughfall and soil percolation water ranged between –20‰ and +19‰ (Table 1). The range of the values $\delta^{15}N$ (both ammonium and nitrate isotopes) is similar in both forests. ^{15}N in NH_4-N in the soil water could not be measured due to its insufficient amount present in the sample. In both studied forests, $\delta^{15}N$ enrichment of both NH_4-N (only in bulk precipitation and throughfall) and NO_3-N shows a decreasing trend from bulk precipitation to throughfall and increasing with soil depth again (Fig. 1).

Table 1. Range (minimum and maximum) of $\delta^{15}N$ abundance of NH_4-N and NO_3-N in bulk precipitation, throughfall and soil water of beech and spruce forests of Solling, Germany (*n* = 12), B1 = beech forest, F1 = spruce forest

Site		Bulk precipitation		Throughfall		Soil solution	
						0 cm	80 cm
		δ^{15} NH_4-N	δ^{15} NO_3-N	δ^{15} NH_4-N	δ^{15} NO_3-N	$\delta^{15}NO_3$-N	$\delta^{15}NO_3$-N
B1	min.	–12.5	–3.70	–15.8	–17.00	–12.00	–8.91
	max.	+12.6	+2.50	+10.1	–0.55	+0.35	+7.38
F1	min.	–12.5	–3.70	–12.5	–20.00	–10.10	–16.30
	max.	+12.6	+2.50	+19.3	–4.48	–3.96	+8.31

Fig. 1 also illustrates that for both forest ecosystems, NH_4-N in bulk precipitation (–0.56‰, ±2.76 ‰) and throughfall (beech forest, –2.26‰, ±1.94‰ and spruce forest +1.79‰, ±3.55‰) is slightly enriched with ^{15}N in comparison with NO_3-N of bulk precipitation (–1.54‰, ±0.44‰) and throughfall (beech forest, –6.26‰, ±1.33‰ and spruce forest –10.7‰, ±1.6‰). After passing through the canopy, both NO_3-N and NH_4-N in throughfall were depleted of ^{15}N compared to the bulk precipitation, except for NH_4-N in the spruce forest where a slight increase in $\delta^{15}N$ values was observed.

The mean $\delta^{15}NO_3$-N values of soil water at the spruce and beech forest sites ranged from –4.92‰ (±1.30) to –7.89‰ (±0.86). After passing through the O-horizon (below 0 cm), the $\delta^{15}N$ abundance of nitrate was increased in the 80 cm soil depth from –6.76‰ to –2.61‰ in the beech forest and from –7.89‰ to –4.92‰ in the spruce forest.

Natural ^{15}N abundance in the vegetation and soil

Natural ^{15}N abundance of the green needles of spruce forest was slightly lower compared to the leaves of beech stand (Table 2). Natural ^{15}N abundance of the green foliage of spruce forest was in the range of –2.61‰ to –0.72‰ and in the beech forest trees from –1.25‰ to +3.29‰ (Ta-

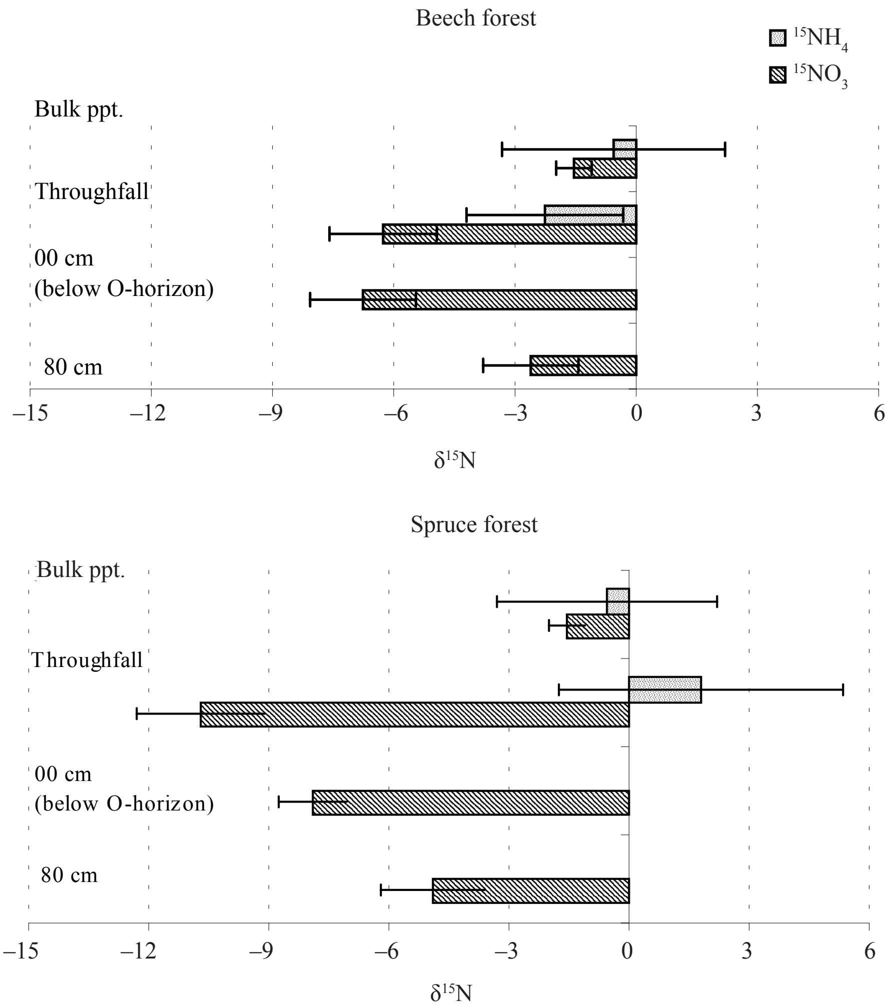

Fig. 1. $\delta^{15}N$ values of NH_4-N and NO_3-N in bulk precipitation, throughfall and soil percolation water of both beech and spruce forests (*n* = 9, ± = standard error of the means)

Table 2. %N and δ15N in the green foliage and litter of beech and spruce forests (*n* = 16, ± SE)

	Spruce (F1)		Beech (B1)	
	(%N)	(δ15N)	(%N)	(δ15N)
1. Green leaves	1.53 (±0.20)	–1.70 (±0.56)	2.48 (±0.26)	1.74 (±1.39)
2. Litter fall	1.00 (±0.06)	–3.46 (±1.03)	1.34 (±0.43)	–3.92 (±0.52)

ble 2). The range of $\delta^{15}N$ values of spruce needle litter fall was –5.24‰ to –2.41‰, slightly lower than the litter fall of beech trees (–4.65‰ to –3.09‰). The mean values of $\delta^{15}N$ in the green foliage of beech were higher (+1.74‰) than in the green needles of spruce trees (–1.70‰), i.e. the beech green foliage nitrogen is much more enriched with ^{15}N than the spruce needles. The litter fall of both forests showed a slight depletion of ^{15}N compared to their green leaves.

Soils at both sites showed characteristic lower (negative) $\delta^{15}N$ values in the O-horizon and the upper mineral soil layer and strongly increased with increasing soil depth up to +3 to +5‰ in the lower mineral soil depth (Fig. 2). At both sites, the increase in ^{15}N in soil with the depth corresponds to a decrease in nitrogen and carbon concentrations. However, within the 0 to 6 cm thick O-horizon in both stands, there is almost a constant ^{15}N value or even a trend of slight ^{15}N-depletion. This observation is different from the other studies.

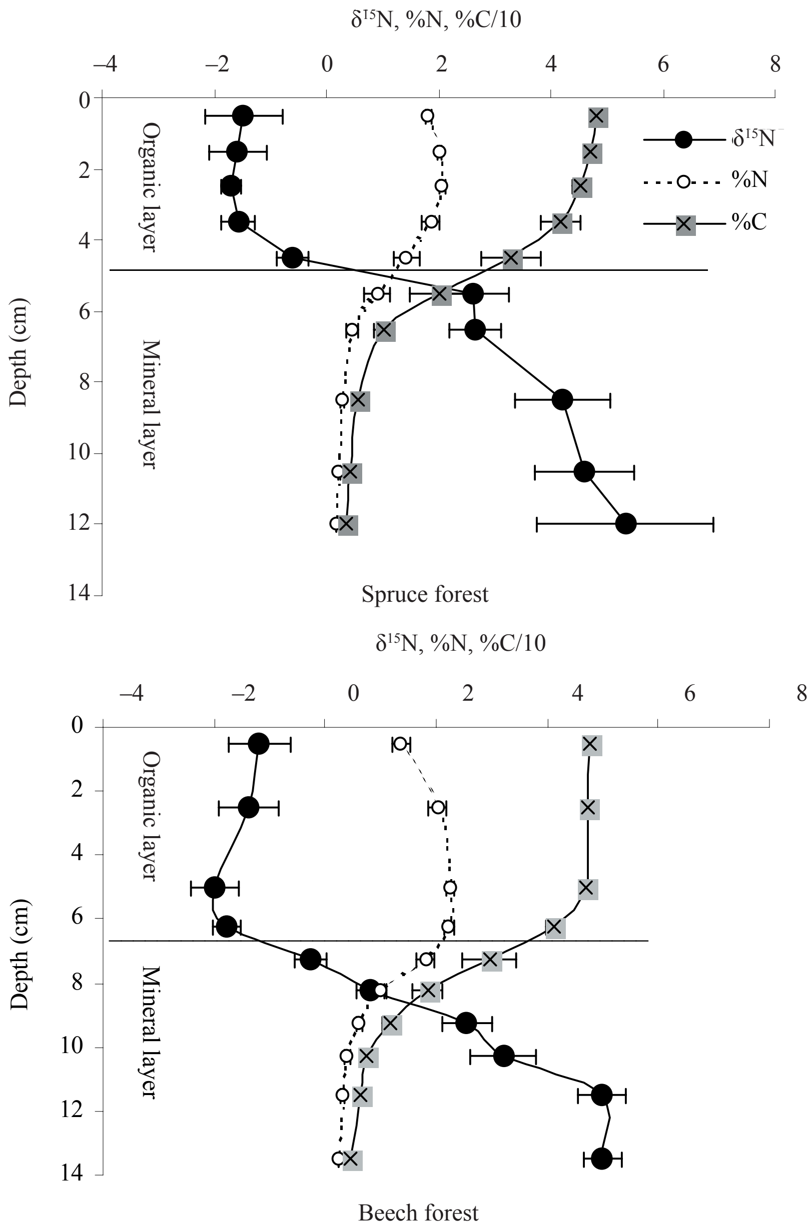

Fig. 2. $\delta^{15}N$ variations and N- and C-concentrations at the different soil depths of both beech and spruce forests (*n* = 4, ± = standard error of the means)

DISCUSSION

Natural abundance of ^{15}N in bulk precipitation, throughfall and soil water

Ammonium and nitrate in bulk precipitation showed almost similar enrichment for $\delta^{15}N$ in both forests at Solling and were in the range reported by other studies (–17 to +17‰) (EMMET et al. 1998; GUNDESSON, RASMUSSEN 1995; MOLDAN et al. 1995; BOXMAN et al. 1998). Less positive values of $\delta^{15}N$ were reported from the USA (MOORE 1977), Japan (WADA et al. 1975) and Africa (HEATON 1987) ranging from –14 to +5 ‰. Ammonium is slightly more enriched with ^{15}N than nitrate in bulk precipitation at Solling. Other studies reported even much higher ^{15}N abundance in ammonium than nitrate (HOERING 1957; MOORE 1977; HEATON 1986; KOOPMANS et al. 1997). On the basis of their studies in the Netherlands, KOOPMANS et al. (1997) found a much higher $\delta^{15}NH_4$-N value up to +10.8‰, compared to $\delta^{15}NO_3$-N of only –12.1‰ in a stand (in Ysselsteyn forest) closer to emission sources compared to a stand (in Speued forest) relatively far away from emission sources, where $\delta^{15}NH_4$-N and $\delta^{15}NO_3$-N were only –0.6‰ and –3.3‰, respectively. They explained these differences by the presence of dry deposition and by the high intensity of animal stock breeding in the proximate surroundings of the studied sites. Solling has similar $\delta^{15}N$ values like in Speued (far from emission sources) in the Netherlands, and it could be attributed to the location of Solling, also relatively far away from emission sources. MOORE (1977) reported the $\delta^{15}N$ values for NH_3-gas, sampled in the proximity of an emission source in barnyards, of more than 20‰. However, most studies also reported higher ^{15}N enrichment of nitrate in bulk precipitation than of the coexisting ammonium (a review by KENDALL 1998), and it was explained by a washout of ^{15}N depleted atmospheric NH_3 and the higher NO_3-values by a washout of NO and NO_2 (FREYER 1978).

The pathway through the canopy did not significantly influence the ^{15}N abundance of ammonium whereas nitrate in throughfall in the beech stand was depleted of ^{15}N compared to bulk precipitation. However, nitrate in throughfall in the spruce stand was slightly enriched with ^{15}N but not significantly (having a large standard error) compared to bulk rainfall. The higher ^{15}N abundance in throughfall relative to bulk precipitation was reported from the NITREX sites and other studies (KOOPMANS et al. 1997; EMMET et al. 1998; GARTEN 1992). It was attributed to a higher rate of dry deposition. The dry deposition at these sites was found to be more enriched with ^{15}N. The observed lower ^{15}N abundance of nitrate in throughfall in our studies could not be explained through dry deposition but probably by nitrification of atmospheric ammonium to nitrate in the canopy leaves. Nitrification process results in the ^{15}N enrichment of ammonium and ^{15}N depletion of nitrate (HÖGBERG 1997).

Nitrate in the soil solution increased in its ^{15}N enrichment from 0 to 80 cm soil depth at both studied sites of Solling. This finding is similar to most findings of other studies (EMMETT et al. 1998; KOOPMANS et al. 1997) and was explained by the sum of transformation processes in the soil. Among these processes only mineralization and nitrification are quantitatively important at our sites. Other processes such as denitrification and N assimilation are very low at both sites (BRUMME et al. 1999). In both forest ecosystems, throughfall water is highly depleted of ^{15}N compared to the upper (beech, –1.10‰ and spruce, –1.96‰) and lower mineral soil layers (beech, +4.21‰; spruce, +5.28‰). Although mineralization leads to the production of ^{15}N depleted NO_3-N in the mineral soil, it still remains relatively much more enriched with ^{15}N compared to the throughfall ^{15}N. As the relatively ^{15}N depleted throughfall water passes through the ^{15}N enriched upper soil and lower mineral soil layer, it results in the enrichment of $^{15}NO_3$-N of soil percolation water with the depth.

Vegetation and soil

The range of natural ^{15}N abundance in the green foliage in our studies corresponds to the studies of other authors ranging from –5 to +4.1‰ (GARTEN, MIGROET 1994; EMMETT et al. 1998). Much more negative $\delta^{15}N$ values (–2.4 to –3.3‰) in the green foliage of deciduous tree species (oak and maple trees) were reported by GARTEN (1993). Similarly to our results, GARTEN and MIGROET (1994) also reported higher values of $\delta^{15}N$ (–0.8‰) in the beech green foliage compared to the green needles of spruce forest in the USA (–2.2‰). The high positive values of $\delta^{15}N$ in the needles of conifer species were reported by KOOPMANS et al. (1997) from N-saturated forests and this corresponds to our study. Litter fall is often enriched with ^{15}N compared to green foliage; it was attributed to the redistribution of N from the needles before needle fall (GEBAUER, SCHULZE 1991; GEBAUER et al. 1994; NASHOLM 1994). However, in our study the litter fall of both forest tree species showed a slight depletion of ^{15}N compared to their green leaves. The observed depletion of ^{15}N in litter fall in our study remains mostly unexplained.

The ^{15}N enrichment of nitrogen in the mineral soil increased from –1‰ at 0 cm to +5‰ at 14 cm depth at both sites of Solling. Similar values of enrichment with ^{15}N at lower soil depths (+5 and +10‰) were reported by most studies (EMMET et al. 1998; SHEARER et al. 1974; NADELHOFFER, FRY 1988, 1994; GEBAUER, SCHULZE 1991; HÖGBERG et al. 1996; KOOPMANS 1996; KOOPMANS et al. 1997; GARTEN, MIGROET 1994). The mechanistic level is still controversial. ^{15}N discrimination during microbial decomposition and leaching of depleted nitrate can be the most important processes that result in the gradual ^{15}N enrichment of residual organic matter (MELILLO et al. 1989). NADELHOFFER and FRY (1988) concluded that the increase in ^{15}N in the deep soil layer of forests was solely due to fractionation during net mineralization, as indicated by the decrease in total soil nitrogen, and not to differential preservation of litter components with higher $\delta^{15}N$ values. This increase in $\delta^{15}N$ with depth and age was considered mainly as the result of excreting ^{15}N-depleted microbial waste (NADEHOFFER, FRY 1994). In contrast to the above-mentioned arguments, they suggested that the enrichments observed in litter $\delta^{13}C$ were not due to a selective loss of ^{13}C through microbial respiration (MELILLO et al. 1989) but instead, they were caused by immigration of carbon to decaying organic matter, possibly via fungal hyphae and other microbes. This new information makes us think how much of the observed ^{15}N enrichment in decaying organic matter and soil profiles can be due to mineralization processes *per se* and how much can be caused by a similar pattern of immigrating external N.

In contrast to the mineral soil, no increase in the ^{15}N abundance was observed in the O-horizon of soil with depth at Solling. The ^{15}N abundance is constant or even slightly decreases with increasing depth within the O-horizon in both stands (Fig. 2). This observation is not in agreement with the majority of other studies where an increase in the O-horizon was found similarly like for the mineral soil. Only in forests with higher N-deposition in the Netherlands (KOOPMANS et al. 1997) and Sweden with nitrate leaching >1 mg N/L (HÖGBERG et al. 1996) the ^{15}N abundance did not change or slightly decreased with increasing depth within the O-horizon. A similar pattern was observed in forests with high fertilization in Sweden (HÖGBERG et al. 1996). These observations indicate that N-deposition in combination with nitrate leaching in N-saturated forests increases the natural ^{15}N abundance in the O-horizon. HÖGBERG (1997) postulated that a high N-input promotes nitrification, and thus ^{15}N-enriched ammonium production; plants preferentially using ammonium as an N source will progressively enrich the soil surface. This will occur only in N-saturated forests with the open N-cycle. These forests lose depleted nitrate through seepage water. Both forest ecosystems at our sites, especially at the spruce site, are under the high N-input load. The high N-input promotes nitrification and thus $\delta^{15}N$ enriched NH_4-N and ^{15}N depleted NO_3-N are produced. The NO_3-N, depleted of ^{15}N, is lost from the upper part of soil profile, but could partly be retained further down. If ^{15}N depleted NO_3-N remained in the horizon where nitrification occurred, the isotopic mass balance would not change, and there would not be a shift in the isotopic composition. This process can explain why the increase in $\delta^{15}N$ with depth, near the soil surface, can have either no shift in the isotopic composition or turn into a decrease further down in the soil (HÖGBERG 1997).

CONCLUSIONS

As expected, in our study the natural abundance of ^{15}N was found to be an indicator of N-deposition in the forest ecosystems. The deciduous trees showed a comparatively more efficient N cycling than the conifer tree species based on their higher abundance of ^{15}N in green leaves. The observed lower ^{15}N abundance of nitrate in the throughfall of beech forest stands indicates the nitrification of atmospheric ammonium to nitrate in the canopy leaves. A slightly higher $\delta^{15}N$ value in the throughfall of spruce stand can be attributed to the higher deposition rate at this site compared to the beech stand.

In both forest ecosystems, typical ^{15}N enrichment of mineral soil with depth (7–14 cm soil depth) reflected different rates of mineralization at the different soil depths. In contrast to the mineral soil layer, an almost similar or a slight decrease in $\delta^{15}N$ values within the organic soil layer with increasing depth to 6 cm in organic soil at both sites indicates the high nitrification rate in this layer, resulting in excessive seepage water NO_3-output at both sites (especially at the spruce site). In spite of the huge NO_3-N leaching from soil, the N-balance of both ecosystems is in equilibrium due to the atmospheric deposition of nitrogen, not to the reduced organic matter decomposition in soil. Therefore, the trend of natural abundance of ^{15}N in seepage water does not differ very much in both ecosystems although one system (spruce) has the relatively higher rate of NO_3-N leaching with seepage water.

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Přirozené zastoupení izotopu ^{15}N ve dvou lesních ekosystémech saturovaných dusíkem na lokalitě Solling v Německu

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ABSTRAKT: Předmětem výzkumu je srovnávací studie dvou rozdílných ekosystémů saturovaných dusíkem: 1. bukový porost a 2. smrkový porost na stejné lokalitě Solling ve středním Německu. Prezentované výsledky ukazují, že přirozený výskyt izotopu ^{15}N ve srážkách (jak na volné ploše, tak pod korunami) na lokalitě Solling je podobný ($\delta^{15}N$ = –15 ‰ až +19 ‰) jako na jiných lokalitách ve světě (tj. na stanovištích projektu NITREX, v USA atd.). Také zjištěné hodnoty obsahu ^{15}N v půdním roztoku v rozmezí –4,32 ‰ (±2,09) až 5 ‰ (±1,47) korespondují s údaji ze stanovišť projektu NITREX a dalšími v Evropě a USA. V obou sledovaných porostech bylo zjištěno, že obohacení $\delta^{15}N$ v NH_4-N a NO_3-N vykazuje jednak klesající trend směrem od obsahu v celkových srážkách k obsahu ve svrchní půdní vrstvě, jednak vzrůstající trend v hlubších půdních vrstvách. Podle výsledků studie se zvyšuje obohacení izotopem ^{15}N v půdním roztoku směrem od svrchní půdní vrstvy k hlubším horizontům. Dá se předpokládat, že je to způsobeno výraznější nitrifikací, nastupující v horních půdních vrstvách (povrchová organická vrstva). Půdy na obou stanovištích vykazují ve svrchních organických vrstvách charakteristicky nízké (negativní) hodnoty $\delta^{15}N$, které se v minerální vrstvě výrazně zvyšují na pozitivní hodnoty $\delta^{15}N$. V hlubších minerálních horizontech na obou sledovaných stanovištích kulminovaly zvýšené hodnoty $\delta^{15}N$ na 3–5 ‰. Naopak v organických půdních horizontech (hloubka 0–6 cm) byly s postupující hloubkou zaznamenány téměř shodné nebo nepatrně snížené hodnoty $\delta^{15}N$, a to na obou stanovištích. Důvodem je zřejmě vyšší stupeň nitrifikace v organických půdních horizontech, způsobující nadměrné vymývání NO_3 vodou na obou stanovištích (především na smrkovém stanovišti).

Klíčová slova: bukové porosty; smrkové porosty; ^{15}N; izotopy; srážky; půda

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