[Turkish Journal of Botany](https://journals.tubitak.gov.tr/botany)

Volume 31 | Number 4 Article 1

1-1-2007

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Recommended Citation

GÜLERYÜZ, GÜRCAN; KIRMIZI, SERAP; and ARSLAN, HÜLYA (2007) "Nitrogen Mineralisation in the Soils of Alpine Mat Communities: An Incubation Experiment under Laboratory Conditions," *Turkish Journal of Botany*: Vol. 31: No. 4, Article 1. Available at: https://journals.tubitak.gov.tr/botany/vol31/iss4/1

Turk J Bot
31 (2007) 277-286


**Research Article**

# Nitrogen Mineralisation in the Soils of Alpine Mat Communities: An Incubation Experiment under Laboratory Conditions

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Received: 03.05.2006
Accepted: 04.04.2007

**Abstract:** *Plantago holosteum* Scop. and *P. atrata* Hoppe plant communities contribute to the vegetation mosaic in the humid places on different substrata in the sub-alpine and alpine belts of Uludağ Mountain, Bursa, Turkey. Nitrogen mineralisation in the soils of these 2 mat communities was investigated under controlled conditions (60% WHC, 20 °C). Different N mineralisation rates in the soils of the communities were found. This difference was clearer in the upper layer (0-5 cm) of soil, in which the organic matter accumulation was high. We found that nitrification occurred in the soils of both communities, but it was dominant in the soils of the *P. atrata* Hoppe mat community. Our results support the general opinion that plant diversity and composition exert control over N cycling, affecting inorganic N in soils.

Key Words: Mat community, grassland, N mineralisation, nitrification, alpine

## Alpin Keçemsi Toplulukların Toprağında Azot Mineralleşmesi: Laboratuar Koşullarında İnkübasyon Denemesi

**Özet:** *Plantago holosteum* Scop. ve *P. atrata* Hoppe bitki toplulukları Uludağ'ın subalpin ve alpin kuşağındaki farklı ana materyeller üzerindeki nemli alanlarda vejetasyon mozaiğine katılmaktadırlar. Bu iki keçemsi bitki topluluğunun toprağında azot mineralleşmesi kontrollü koşullarda (% 60 Maksimum Su Tutma Kapasitesi ve 20 °C) araştırıldı. Toplulukların topraklarındaki farklı azot mineralleşme oranları saptandı. Bu farklılık, organik maddenin birikiminin yüksek olduğu üst toprak katmanında (0-5 cm) daha belirgindi. Her iki topluluğun toprağında nitrifikasyonun meydana geldiği ancak *P. atrata* Hoppe topluluğunda nitrifikasyonun baskın olduğunu saptadık. Sonuçlarımız, bitki çeşitliliği ve kompozisyonun azot döngüsünü kontrol ettiğini ve topraklardaki inorganik azotu etkilediğini gösteren genel görüşü desteklemektedir.

Anahtar Sözcükler: Keçemsi topluluk, otlakalan, azot mineralleşmesi, nitrifikasyon, alpin

## Introduction

There is a connection between plant characteristics and availability of nutrients in terrestrial ecosystems (Chapin, 1980; Vitousek, 1982; Pastor et al., 1984; Wedin & Tilman, 1990). Nitrogen is the most limiting nutrient for plants. The composition and diversity of plants have controlling effects on nitrogen cycling, affecting inorganic nitrogen levels in soil (Naeem et al., 1994; Hooper & Vitousek, 1997; Reynolds et al., 1997; Tilman et al., 1997; Epstein et al., 1998; Steltzer & Bowman, 1998; Knops et al., 2002). However, nitrogen availability can influence plant community structures (Ellenberg, 1964; Aerts & de Caluwe, 1994; Inouye & Tilman, 1995). Reciprocal effects between N availability and plant community structure result in positive feedbacks, leading to the persistence of certain plant communities (Pastor et al., 1987; Aerts & Berendse, 1989; Wedin & Tilman, 1990). Since assimilation of inorganic nitrogen into plant and soil microbial biomass is essential for the maintenance of fertility and production in terrestrial ecosystems (Runge, 1983; Jaeger et al., 1999), the mineralisation rate of nitrogen is usually

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considered a key process in these ecosystems (Ellenberg, 1977; Gökçeoğlu & Rehder, 1977; Rehder, 1982; Gökçeoğlu, 1988; Güleryüz & Gökçeoğlu, 1994; Epstein et al., 1998; Lovett et al., 2004; Ross et al., 2004). Ellenberg (1977) pointed out that the mineralisation rates of organic nitrogen compounds in soils vary from nearly zero in waterlogged swamps and bogs to up to 300 kg N ha/year in wasteland sites.

Not much work has been done on the N mineralisation by field incubation or by standard incubation for *Plantago* L. mat vegetation types. For this reason, we investigated the alpine mat community. In this study, N transformations in the soils of 2 mat communities (*Plantago holosteum* Scop. and *Plantago atrata* Hoppe) distributed on the alpine belt of Uludağ Mountain, Bursa, Turkey, were investigated under controlled conditions (20 ºC and 60% WHC). An attempt was made to establish relationships between mineral N production and soil characteristics (organic C, total N, C/N ratio, %WHC, pH) for these communities.

### Study Area

Uludağ Mountain is a western extension of the Pontic mountain ranges, lying at the intersection of 40 °N with 29 °E, and has one of the highest peaks (2543 m) in the far north-west part of the Anatolian peninsula (Asia Minor). Phytogeographically, it lies in the Eastern Mediterranean. The mountain has an interesting geomorphological structure, with very steep southern slopes of calcareous and north-western parts made up of granite. The climate of the mountain varies from base to top, being of Mediterranean type in the lower parts (near the city of Bursa at the NW side of the mountain), to rainy, partially mild microthermic, with icy winters at higher altitudes. Annual mean number of snow days at the top of Uludağ is 66.7, total number of snow covered days is 179.2, and maximum snow depth is 430 cm. According to the meteorological station at altitude 1877 m, the approximate yearly amount of rain is 1484 mm, the minimum temperature is 22.2 °C, and the maximum temperature is 29.5 °C (Güleryüz & Gökçeoğlu, 1994). The mountain is unusual because of its plants. For this reason, it is one of the Important Plant Areas (IPAs) in Turkey (Uludağ, IPA 18) (Güleryüz et al., 2005). Uludağ Mountain is endowed with a rich flora containing numerous endemic species and forming several well-distinguished vegetation types. Due to its natural plant communities and various geomorphologic structures, in 1961 an area of 11,338 ha was declared a national park; this area was enlarged to 12,762 ha in 1998. Uludağ has been one of the most important winter sport centres in Turkey since the 1940s.

*P. holosteum* and *P. atrata* plant communities contribute to the vegetation mosaic in the humid places of the sub-alpine and alpine belts of Uludağ Mountain. Rehder et al. (1994) has defined 3 main plant communities in the vegetation mosaic of this area: *Juniperus communis* L. dwarf shrub, *Nardus stricta* L. meadow, and *Festuca* L. hard cushions. They reported that *Plantago* mats are related to the *Nardus stricta* meadow community. Similarly, Tomaselli et al. (2003) found that the *P. atrata* community was closely related to the *Nardus stricta* community in snow-beds in the Southern Apennines (S Italy). The *P. atrata* community is spread over the upper parts of the alpine belt (over 1900 m) where snow stays longer, and humid areas of plateaus on the northern slopes. *P. atrata* is spread on the calcareous-silicate substratum. The *P. holosteum* community is spread on humid areas among dwarf shrub communities in the sub-alpine belt but covers a wider area compared to *P. atrata*. *P. holosteum* is widespread on the silicate soils. The communities have similar aspects (Rehder et al., 1994). In addition to *P. holosteum* and *P. atrata*, which are dominating species, *Alopecurus vaginatus* (Willd.) Boiss. and *Gnaphalium supinum* L. are characteristic species in these communities. *Trifolium repens* L. var. *orphanideum* (Boiss.) Boiss., *Poa supina* Schrader, *Cerastium cerastioides* (L.) Britt., *Potentilla aurea* L., *Festuca punctoria* Sm., *Achillea multifida* (DC.) Boiss., *Crepis alpestris* (Jacq.) Tausch, *Minuartia erythrocephala* (Boiss.) Hand.-Mazz., and *Leontodon crispus* Vill. contribute to the composition of communities with different abundances. The cover degree of *P. holosteum* (50%-80%) is lower than that of *P. atrata* (81%-100%).

## Materials and Methods

### Sampling

Soil samples taken from 2 depths of soils (0-5 cm and 5-15 cm) of 2 mat communities (*Plantago atrata* and *P. holosteum*) spread in the alpine belt of Uludağ were used for this study. Plots (5 x 6 m) were determined at 2000-2200 m altitudes, since plant communities are close to each other in this belt. Two plots were selected for each community. Soil samples were taken from the surface below undecomposed litter down to 15 cm depth. Sampling was done on 3 different parts from each plot. Volumetric soil samples were taken from the surface down to 15 cm depth with a container of 20 x 20 x 15 cm and soil cores were divided into 2 layers (0-5 and 5-15 cm). The subsamples were mixed, sieved (4 mm), and weighed (wet mass). One portion of (~300-400 g) sieved soil was put into plastic bags and transported to the laboratory.

### Soil Water Content (%) and Water Holding Capacity (WHC %)

Soil samples (40 g) were dried in an oven (80 °C, 24 h) until constant weight, and the difference between fresh and dried values gave the water content of soil. This was used to calculate the relative soil moisture (%). Volumetric dry weights of soil cores in the container were determined using soil moisture values. All subsamples dried in air were stored in paper bags. The water holding capacity (WHC) %, pH, organic C, and total N analyses, and standard incubation experiments were carried out with these air-dried soil samples.

The WHC% of the soil samples was calculated using the differences between the fresh and dry weights of materials, which were saturated and then dried at 80 °C until constant weight.

### Incubation Procedure

Air-dried soil samples (100 g) were put into polyethylene bags, and moistened with distilled water until the WHC was 60%. These bags prevent leaching of mineral nitrogen and water (and moisture), but permit the passage of $CO_2$ and $O_2$ (Runge, 1970). Soil samples were incubated in an incubator at 20 °C for 9 weeks (63 days).

### Analysis Procedures and Calculation of Net Nitrogen Mineralisation Production

Total nitrogen (%) in the soil was determined by a Kjeldahl method using salicylic-sulphuric acid and selenium reagent (Steubing, 1965). Organic carbon (%) content was determined by the wet incineration method (digestion with concentrated sulphuric acid and titration by $K_2Cr_2O_7$) (Steubing, 1965). Soil pH was determined in the mud saturated by distilled water (20 g soil sample, 50 ml water).

The mineral nitrogen of the soil was determined by micro-distillation (Bremner & Keeney, 1965; Gerlach, 1973). The incubation period was divided into 2 main periods: 21 days (between the start and day 21) and 42 days (between day 21 and day 63). The mineral nitrogen ($NH_4^+$-N and $NO_3^-$-N) was analysed 3 times: at the beginning of the incubation period, on day 21, and on day 63. Net mineral nitrogen accumulations were calculated for 21 days (kg ha 21 day) and 42 days (kg ha 42 day). Then 63-day mineral nitrogen production levels expressed as total nitrogen mineralisation rates were calculated by the difference between the start and day 63.

### Statistical Analysis

The differences among the sampling sites related to the mineral nitrogen values and the net mineralisation production were tested by analyses of variance (one-way ANOVA). Correlations between net mineral nitrogen production at the end of 63 days (kg ha 63 days) and some soil factors (pH, C%, N%, C/N ratio) were tested. All of the tests were performed at the significance level of $\alpha = 0.05$, with the Statistica version 6.0 (StatSoft Inc. 1984-1995) program.

## Results

Soil characteristics of the 2 mat communities are shown in Table 1. Among the soil layers, while total N %, organic C %, C:N, and WHC % values were higher at 0-5 cm depth than at 5-15 cm, the pH was higher at the latter. Differences among communities in terms of soil characteristics, except organic C (C % and kg ha in 0-5 cm and C % in 5-15 cm), in both soil layers were significant ($P < 0.05$). Total N in the soils of the *P. atrata* community was double that of *P. holosteum*. Organic C % in the communities was similar. Mean C values varied between 2.17% and 2.66%. While organic C rates were similar, a significant difference in C/N ratio was found between the plant communities ($P < 0.05$) because of different total N values. C/N ratio in *P. holosteum* was found to be about double that of *P. atrata*. The soil pH of *P. holosteum* is more acidic than that of *P. atrata*. A significant difference between the 2 communities was found in both soil layers for WHC% (Table 1).

There was a different Nmin model in both layers of plant communities (Figure 1). At the end of day 21, there was a significant difference between the communities regarding the whole, except for $NH_4^+$-N in the 0-5 cm

Table 1. Average values of some soil properties in soil of 2 mat communities and the significance levels for differences among communities (mean ± standard deviation; n = 12; $F_{\alpha;0.05\ (1)10} = 4.96$).

| Soil Layers | Soil Properties | Community | | F | P |
|---|---|---|---|---|---|
| | | *P. holosteum* | *P. atrata* | | |
| 0-5 cm | | | | | |
| Total N | % | 0.15 ± 0.03 | 0.31 ± 0.05 | 37.337 | 0.000114 |
| | kg/ha | 1077 ± 244 | 2143 ± 299 | 45.637 | 0.000050 |
| Organic C | % | 2.46 ± 0.46 | 2.66 ± 0.43 | 0.622 | 0.448709 |
| | kg/ha | 18,014 ± 2989 | 18,851 ± 3751 | 0.183 | 0.678006 |
| C/N ratio | | 17.1 ± 2.3 | 8.8 ± 1.6 | 50.228 | 0.000033 |
| pH | | 4.65 ± 0.16 | 5.22 ± 0.49 | 7.332 | 0.022020 |
| WHC | % | 52.2 ± 4.4 | 77.6 ± 13.9 | 18.158 | 0.001660 |
| 5-15 cm | | | | | |
| Total N | % | 0.09 ± 0.03 | 0.23 ± 0.06 | 26.688 | 0.000422 |
| | kg/ha | 1629 ± 445 | 2900 ± 783 | 11.933 | 0.006180 |
| Organic C | % | 2.17 ± 0.37 | 2.29 ± 0.40 | 0.289 | 0.602392 |
| | kg/ha | 40,062 ± 7302 | 28,529 ± 3379 | 12.327 | 0.005623 |
| C/N Ratio | | 25.7 ± 5.8 | 10.5 ± 3.0 | 32.550 | 0.000197 |
| pH | | 4.88 ± 0.16 | 5.47 ± 0.50 | 4.595 | 0.057676 |
| WHC | % | 50.1 ± 2.6 | 68.2 ± 6.3 | 41.763 | 0.000072 |

P < 0.05, significantly different

layer (P < 0.05). $NH_4^+$-N production in soil layer of 0-5 cm of communities increased from the start to day 21 and then the increase continued in *P. holosteum*, but decreased towards day 63 in *P. atrata* (Figure 1). Initial $NO_3^-$-N values indicated a similar model for all situations. While there was rapid $NO_3^-$-N production in the *P. atrata* community until day 21, this trend was slower in *P. holosteum* (Figure 1). Significant differences between communities in terms of $NO_3^-$-N production in all soil layers were found (P < 0.05). A significant difference (P < 0.05) between communities for all situations (except initial $NO_3^-$-N) in the soil layer of 5-15 cm was determined. Although there are significant differences between the 2 communities, mineral nitrogen production during the incubation period showed a similar model in both communities. $NH_4^+$-N production increased in the soils of both communities until day 21, and then decreased during the subsequent period. $NO_3^-$-N also showed a similar model in these communities. $NO_3^-$-N increased very slowly from the start to day 21, but the increase was higher after day 21 (Figure 1).

The difference between *P. holosteum* and *P. atrata* communities regarding the net Nmin for 21-day and 42-day periods was found to be significant (P < 0.05; Figure 2). While the highest $NO_3^-$-N accumulation was in the *P. atrata* community, the highest $NH_4^+$-N was in the *P. holosteum* community in 21-day incubation in 0-5 cm depth of soils. In addition, both ammonification and nitrification were higher in the *P. holosteum* community at 5-15 cm depth of soils in this period. The nitrogen transformation model at 0-15 cm depth was similar to that at 0-5 cm depth (Figure 2). $NH_4^+$-N accumulation was positive at 0-5 cm depth of the soils of *P. holosteum* at the end of the second period (42 days), whereas it was negative in 5-15 cm depth of soil. $NH_4^+$-N accumulation in *P. atrata* was negative in the 2 layers of soils. $NO_3^-$-N accumulation is positive in the 2 depths of soils in both communities but it was higher in *P. atrata* (Figure 2).

Net mineral nitrogen production for 63 days in the soil layers of the *P. holosteum* and *P. atrata* communities is shown in Table 2. Significant differences between *P. holosteum* and *P. atrata* in terms of all situations except

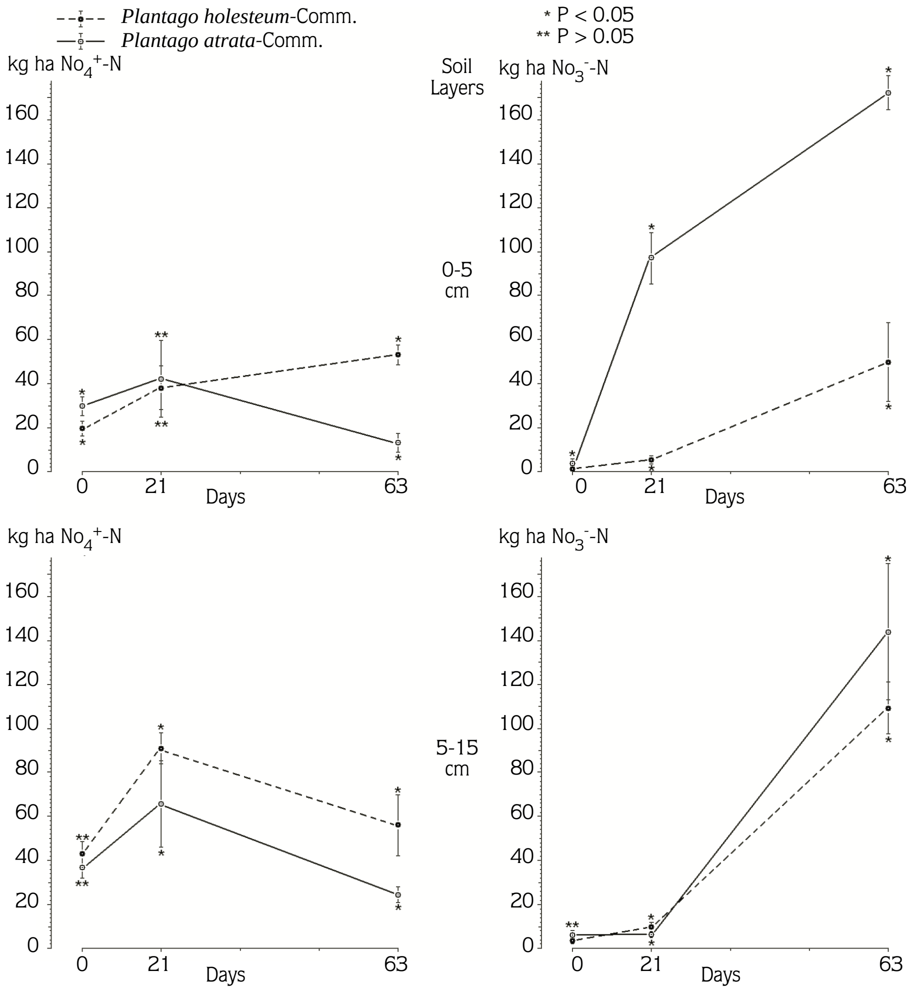


Figure 1. Nitrogen mineralisation in the soil of *P. holosteum* and *P. atrata* communities. Values are means ± standard deviations (n = 6). Asterisks above sets of bars indicate statistical differences between the 2 mat communities for each date; *P < 0.05 significant difference; **P > 0.05 non-significant difference.

total Nmin ($NH_4^+$+$NO_3^-$-N) at the 5-15 cm soil layer depths were found ($P < 0.05$). Net $NH_4^+$-N production was positive in *P. holosteum*, but it was negative in *P. atrata*. Although $NH_4^+$-N production showed a negative value, total Nmin ($NH_4^+$+$NO_3^-$-N) production of *P. atrata* was higher than that of *P. holosteum* (Table 2).

There was no significant correlation between organic C and $NH_4^+$-N and $NO_3^-$-N ($P > 0.05$) (Table 3). The correlation between other factors and $NH_4^+$-N and $NO_3^-$-N was significant ($P < 0.05$). This significant correlation except for C/N ratio was positive for $NO_3^-$-N, while it was negative for $NH_4^+$-N. In contrast, the significant correlation between $NH_4^+$-N and C/N ratio was positive and negative for $NO_3^-$-N (Table 3).

## Discussion

Nitrogen content of soil, nitrogen mineralisation, and nitrification potential are suggested as main soil quality indicators (Zöttl, 1958; Runge, 1974; McCarty & Meisinger, 1997; Knoepp et al., 2000). N mineralisation rates of soil are measured in laboratory and field conditions (in situ) and they are used as available nitrogen indices of soil (Knoepp et al., 2000).

Nitrogen mineralisation rates in the soils of 2 alpine *Plantago* communities belonging to the same vegetation type are different due to different soil characteristics. This difference is clearer in the upper layer (0-5 cm) of soil, on which the organic matter accumulation is high (Figure 2). Although nitrification occurred in the soils of

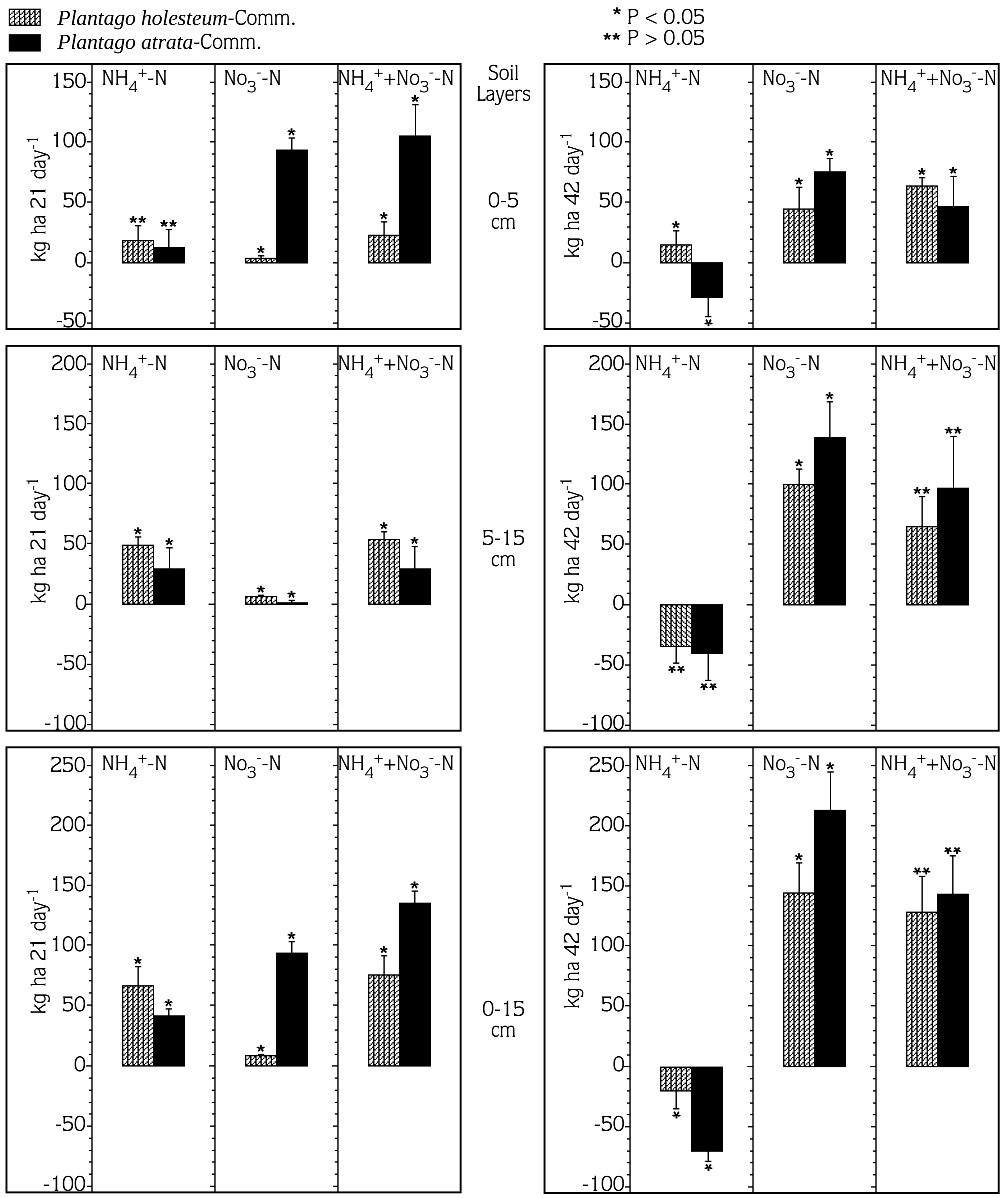


Figure 2. Net mineral nitrogen accumulation rates during incubation periods of 21 and 42 days in the soil of *P. holosteum* and *P. atrata* communities. Values are means ± standard deviations (n = 6). Asterisks above sets of bars indicate statistical differences between the 2 mat communities for each date; *P < 0.05 significant difference; **P > 0.05 non-significant difference.

both communities, it was high in the soils of *P. atrata* (Figure 2). On the other hand, net ammonium accumulation was observed in the soils of *P. holosteum* whereas it was negative in *P. atrata* because the ammonium produced is converted to nitrate.

It is reported that net mineralisation is related to organic N and, it is negatively correlated with C/N ratio (Harmsen & Van Schreven, 1955; Zöttl, 1960a). C/N ratio of litter is regarded as one of the main factors affecting organic matter decomposition (Runge, 1983; Köhler et al., 1995; Paul & Clark, 1996; Chapin, 2003). Organic C contents in the soils of investigated communities were similar, whereas the N contents were different, and N contents in soil of the *P. atrata*

Table 2. Average mineral nitrogen production for 63-day incubation periods and the significance levels for differences among communities (mean ± standard deviation; n = 12; $F_{\alpha;\ 0.05\ (1)10} = 4.96$).

| $N_{min}$ (kg ha 63 $d^{-1}$) | Soil Layers | Community *P. holosteum* | Community *P. atrata* | F | P |
|---|---|---|---|---|---|
| $NH_4^+$-N | 0-5 cm | 33.6 ± 6.2 | -16.5 ± 4.8 | 246.243 | 0.000000 |
| | 5-15 cm | 13.0 ± 18.3 | -12.5 ± 8.5 | 9.616 | 0.011232 |
| | 0-15 cm | 46.6 ± 20.7 | -29.0 ± 10.9 | 63.018 | 0.000013 |
| $NO_3^-$-N | 0-5 cm | 47.7 ± 18.5 | 168.5 ± 6.9 | 224.065 | 0.000000 |
| | 5-15 cm | 105.0 ± 12.5 | 137.9 ± 30.5 | 5.981 | 0.034517 |
| | 0-15 cm | 152.7 ± 25.2 | 306.4 ± 32.4 | 84.195 | 0.000003 |
| Total-Nmin | 0-5 cm | 81.4 ± 21.7 | 151.9 ± 8.6 | 54.661 | 0.000023 |
| | 5-15 cm | 118.0 ± 28.8 | 125.4 ± 34.1 | 0.162 | 0.695409 |
| | 0-15 cm | 199.4 ± 44.4 | 277.3 ± 34.7 | 11.455 | 0.006949 |

P < 0.05, significantly different

Table 3. Simple correlation coefficients between mineral nitrogen production ($NH_4^+$-N and $NO_3^-$-N kg ha 63 $d^{-1}$) and soil factors in the soil layer of 0-5 cm, and linear regression equations (n = 12, $r_{\alpha;\ 0.05\ (1)10}$: 0.497; P < 0.05 significant correlation).

| Parameters | r | P | Y = α + bx |
|---|---|---|---|
| $NH_4^+$-N (kg ha 63 $d^{-1}$) | | | |
| pH ($H_2O$) | -0.617 | 0.033 | $NH_4^+$-N = 186.88 – 36.12 xpH |
| Organic C (kg ha) | -0.094 | 0.772 | $NH_4^+$-N = 22.742 – 0.0008 xOrgC |
| Total N (kg ha) | -0.901 | 0.000 | $NH_4^+$-N = 71.686 – 0.0392 xTotalN |
| C/N Ratio | 0.945 | 0.000 | $NH_4^+$-N = 60.91 + 5.365 xC / N |
| WHC (%) | -0.851 | 0.000 | $NH_4^+$-N = 97.871 – 1.376 xWHC(%) |
| $NO_3^-$-N (kg ha 63 $d^{-1}$) | | | |
| pH ($H_2O$) | 0.671 | 0.017 | $NO_3^-$-N = 359.3 + 94.698 xpH |
| Organic C (kg ha) | 0.189 | 0.556 | $NO_3^-$-N = 39.253 + 0.00374 xOrgC |
| Total N (kg ha) | 0.895 | 0.000 | $NO_3^-$-N = 43.10 + 0.09392 xTotalN |
| C/N ratio | -0.869 | 0.000 | $NO_3^-$-N = 262.1 – 11.89 xC / N |
| WHC (%) | 0.775 | 0.003 | $NO_3^-$-N = 88.253 + 3.023 xWCH(%) |

community were higher than those of the *P. holosteum* community. The difference between communities in terms of N contents in soil was also reflected by C/N ratio (Table 1). No significant correlation was found between net Nmin production and organic C, but the correlation between total N content and $NH_4^+$-N and $NO_3^-$-N was significant. This correlation is negative for $NH_4^+$-N and positive for $NO_3^-$-N (Table 3). This result shows that N mineralisation increases with the increasing N contents in soils. Our results fully agree with the general approach that higher nitrogen content in litter provides greater net mineralisation of nitrogen than that of lower ones (Chapin, 2003).

The soil of *P. holosteum* was more acidic than that of *P. atrata*. As a general rule, increasing acidity leads to the predominance of $NH_4^+$-N, whereas increasing alkalinity favours the formation of $NO_3^-$-N (pH 6.0-8.0) (Runge,

Table 4. Nitrification degrees regarding $NO_3^-$ / $NH_4^+$ ratio (Runge, 1983) and percent $NO_3^-$-N in total N mineralisation (Ellenberg, 1977) in the soil layers of both communities.

| | Soil Layers | *P. holosteum* | *P. atrata* |
|---|---|---|---|
| $NO_3^-$ / $NH_4^+$ | 0-5 cm | 1.4 | 168.5 |
| Ratio | 5-15 cm | 8.1 | 137.9 |
| | 0-15 cm | 3.3 | 306.4 |
| $NO_3^-$ / Total-Nmin | 0-5 cm | 59 | 100 |
| (% Ratio) | 5-15 cm | 89 | 100 |
| | 0-15 cm | 77 | 100 |

1983). However, some researchers demonstrated that nitrate production occurred in acidic soils (Zötll, 1960b; Runge, 1974). Similar results were obtained in our study. Although the soils of both communities were relatively acidic, nitrification occurred.

Güleryüz & Gökçeoğlu (1994) investigated the N mineralisation and annual net Nmin production in the soils of *Juniperus communis* dwarf shrub, *Nardus stricta* meadow, and *Festuca* hard cushion communities in the same belt. They determined the highest $NO_3^-$-N accumulation in the soils of the *Festuca* community and the highest $NH_4^+$-N accumulation in the soils of *Nardus stricta*. In addition, Güleryüz (1998) compared the soils of *Festuca* and *Nardus stricta* communities on the basis of Nmin production under laboratory conditions. He obtained similar results. *Plantago* mat communities were related to the *Nardus stricta* meadow community (Rehder et al., 1994). However, the *P. holosteum* and *P. atrata* communities were similar to the *Festuca* community where nitrification was dominant.

Two parameters are used to determine the nitrification degree: $NO_3^-/NH_4^+$ rate (Runge, 1983) and percent $NO_3^-$-N in total N mineralisation (Ellenberg, 1977). When the 2 communities were compared, the nitrification degree in the *P. atrata* community was higher than that in the *P. holosteum* community (Table 4).

In this study, it is concluded that N mineralisation differed between the soils of *Plantago holosteum* and *P. atrata*. Our results support the general opinion, which indicates that the plant diversity and composition exert control over N cycling, affecting inorganic N in soils (Naeem et al., 1994; Hooper & Vitousek, 1997; Reynolds et al., 1997; Tilman et al., 1997; Steltzer & Bowman, 1998; Knops et al., 2002). Some researchers suggest that nitrification occurs in alkaline soils of arctic ecosystems (Nadelhoffer et al., 1991; Robinson et al., 1995) and others suggest that the ammonium is dominant in inorganic N form in the cold and humid tundra soils (Giblin et al., 1991; Jonasson et al., 1993; Robinson, 2002). However, our results indicate that these conclusions are not observed in every case, as nitrification was dominant in *Plantago* communities, which are meadow grasslands and have slightly acidic soil pH.

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