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NH_4^+ Mineralization and Nitrification in Alder Stand Established on Mt. Showa-Shinzan

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昭和新山의 火山噴火後에 成立한 두메오리나무 林分의 窒素無機化와 窒化作用

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ABSTRACT

Nitrogen dynamics in mineral soils of an alder (*Alnus maximowiczii*) stand established on volcano Mt. Showa-Shinzan were measured by laboratory incubation method in order to clarify characteristics of NH_4^+ mineralization and nitrification rate, from August 1994 to July 1996. Contents of total N and organic matter were relatively low, but increased in May-July. Extractable NH_4^+ concentrations and NH_4^+ mineralization were high in June and July, and decreased in midsummer and fall. Extractable NO_3^- concentrations did not vary seasonally. Negative values at NH_4^+ mineralization and nitrification rate were observed in August and September. NH_4^+ mineralization was positively correlated with soil organic matter, and nitrification rates were influenced by extractable NH_4^+ concentration and NH_4^+ mineralization.

Key words: *Alnus maximowiczii*, NH_4^+ mineralization, Nitrification, Vegetation recovery, Volcano.

INTRODUCTION

Over the past few decades there have been many studies of vegetation recovery after volcanic activity (Tezuka 1961, Tsuyuzaki 1994, Whittaker *et al.* 1989, Wood and Del Moral 1987), but most have been concerned with describing the successional changes that occur in the species composition of plant communities. Specific competition for limited resource is a major factor in determining species composition and the diversity of plant communities, and therefore successional dynamics (Parrish and Bazzaz 1985, Walker and Chapin 1986). Robertson *et al.* (1988) suggested that small-scale patterns of N availability within an old-field may significantly influence community structure. Furthermore, McLendon and Redente (1991) concluded that dominance by annuals in early stages of secondary succession is related to high nutrient availability.

Nitrogen (N) within forest ecosystems may limit plant primary productivity, species composition and species diversity. However, early stages of vegetation recovery after a volcanic eruption start with a N-poor site followed by subsequent increases in the total N pool size as a result of N fixation (Halvorson *et al.* 1992, Vitousek and Walker 1989, Walker and Vitousek 1991), since N-fixing species grow fast, accumulate high tissue concentrations of macronutrients, accelerate accretion of N and organic matter (Turner *et al.* 1976, Youngberg and Wollum 1976) and increase N availability in the ecosystem (Binkley *et al.* 1982). Consequently, it may be expected that rates of N mineralization and nitrification in an alder stand should progressively increase over time, with consequent benefits for other invading species.

This study aimed to determine potential NH_4^+ mineralization and nitrification rate in mineral soils in an alder stand, to identify the factors limiting these processes, and to estimate the effects of alder stand on early vegetation recovery after volcanic eruptions.

MATERIALS AND METHODS

Study site

This study was conducted on Mt. Showa-Shinzan (407 m in alt., 42°33′N, 140°52′E) which was created by volcanic eruptions in the period 1944-45. Annual precipitation is about 987 mm, about half falling in the summer months. Mean annual temperature is 8.6℃; temperature fluctuates monthly, with mean monthly temperatures ranging from −6.2℃ in January to 23.2℃ in August. The study area was covered by snow for 4 months between late December to early April.

The study site was located at an elevation of about 300 m. The slope is 8~12 degrees, and faces a northeasterly direction. The tree age estimated by increment cores was approximately 30 years old. The maximum height of tree was 9 m and the basal area was 19.28 m^2/ha. The alder stand consisted of a pure stand of *Alnus maximowiczii* with well-nodulated roots, and the density within 400 m^2 was 44 stems with lagwort (*Petasites japonicus* var. *giganteus*) covering most of the forest floor. The lagwort was 2 m tall in the growing season.

Soil sampling

Soil samples were randomly collected from 0~10 cm soil layer. Surface litter and roots were removed from soil samples. Collected samples were refrigerated at 4℃. Sampling was carried out monthly from August 1994 to July 1996, except periods covered by snow for 4 months, from late December to early April. For each sampling time, seven soil samples were taken. Soil temperature was measured hourly with a thermo recorder (TR-71, T AND D) throughout the study period.

Soil analysis

The soil samples were sieved (<2 mm) and soil moisture content was determined by drying to constant weight at 105℃. Soil pH (H_2O) was measured in a 1:2.5 mixture of soil:deionized water using a glass electrode. Organic matter content was estimated by ignition loss at 450℃ for 4h. Throughout the study period, total C and N contents were measured at three months interval using a C-N Corder (MT-1600, YANACO), and the C/N ratios were calculated. Exchangeable Ca^{2+}, Mg^{2+}, and Na^+ were determined by atomic absorption spectrophotometry, and K^+ by flame-photometry (SPCA-626D, SHIMADZU). Available P concentration in soil was extracted by 0.002 N H_2SO_4 and determined colorimetrically by molybdate blue method (Murphy and Riley 1962). Exchangeable cations and available P were determined in May, August and November during the study period.

Initial concentrations of NH_4^+- and NO_3^--N were determined. Seven 20 g soil samples were extracted by shaking with 80 ml of 2 N KCl. The extracts were filtered and stored. Color development with Na-phenolate was used to determine NH_4^+, and Cd reduction followed by color development with n-napthylethylene diamine was used to determine NO_3^- (UV-260, SHIMADZU). Concentrations of extractable NH_4^+ and NO_3^- were expressed as N mg/kg dry soil. NH_4^+ mineralization and nitrification rates were also determined. Soil samples were incubated for 30 days under aerobic conditions (Keeney 1982). Temperature and moisture content were kept with 25℃ and 60% of field capacity throughout the incubation period, respectively. The moisture content was checked weekly by weighing and moisture losses were refilled with deionized water. At the end of the incubation period the samples were extracted and analyzed for NH_4^+ and NO_3^- as described above. NH_4^+ mineralization was determined as the difference in the concentration of NH_4^+ between the initial and incubated sample. Nitrification rate was determined in a similar fashion by subtracting the initial NO_3^- concentrations from the concentration observed after incubation. N availability is the sum of NH_4^+ mineralization plus the nitrification rate.

RESULTS

Soil properties

Moisture content in the alder stand was approximately 25%, and remained fairly stable during the experimental period (Table 1). Soil pH for the alder stand ranged from 5.4 in October and September 1994 to 6.9 in November 1995. Soil organic matter content was greatest in July 1995 and lowest in November 1994.

Total N content of soil was greatest in May 1996 (0.17%) and decreased in both summer and fall (Table 2). The C/N ratio of 10 was more or less constant. Available P concentrations ranged from 6

Table 1. Soil temperature, pH, moisture and organic matter content for mineral soils of the alder stand on volcano Mt. Showa-Shinzan. The data are mean values with standard deviations shown in parenthesis

Sampling month	Temp.* (℃)	pH (H_2O)	Moisture (%)	Organic matter (%)
'94 Aug.	20.9	5.7 (0.3)	19.4 (4.0)	2.5 (0.5)
Sep.	18.6	5.4 (0.3)	22.3 (1.8)	2.6 (0.2)
Oct.	12.2	5.4 (0.3)	29.0 (5.6)	2.3 (0.4)
Nov.	3.5	6.3 (0.4)	27.7 (4.6)	2.2 (0.5)
'95 May	8.6	6.4 (0.2)	22.7 (2.4)	2.8 (0.5)
Jun.	10.3	5.6 (0.2)	30.9 (4.1)	3.9 (0.3)
Jul.	14.1	6.4 (0.4)	27.6 (3.8)	4.4 (0.6)
Aug.	16.7	6.4 (0.3)	21.1 (3.2)	2.7 (0.3)
Sep.	16	6.6 (0.3)	22.8 (1.9)	2.6 (0.3)
Oct.	9.7	6.8 (0.3)	23.5 (1.8)	2.4 (0.3)
Nov.	7.8	6.9 (0.4)	23.4 (1.6)	2.4 (0.4)
'96 May	4.6	6.3 (0.4)	26.0 (2.9)	2.6 (0.4)
Jun.	11.8	6.5 (0.2)	26.7 (3.8)	3.8 (0.8)
Jul.	16.9	5.9 (0.2)	27.4 (1.7)	3.7 (0.4)

* Temperature (℃) are daily mean soil temperature over 24 hr of sampling date at depths of 10 cm.

Table 2. Selected chemical properties of the surface 10 cm for mineral soils of the alder stand on volcano Mt. Showa-Shinzan. The data are mean values with standard deviations shown in parenthesis

Sampling month	C (%)	N (%)	C/N ratio	Available P (mg/100 g)	Exchangeable (me/100 g)			
					Ca	Mg	K	Na
'94 Aug.	0.72 (0.12)	0.08 (0.01)	9.5 (0.73)	15.1 (3.5)	9.2 (1.93)	1.79 (0.39)	1.1 (0.21)	0.14 (0.04)
Nov.	1 (0.14)	0.09 (0.02)	11 (1.15)	20.5 (3.1)	14.7 (3.27)	2.56 (0.79)	1.95 (0.28)	0.19 (0.08)
'95 May	1.52 (0.31)	0.15 (0.03)	10.1 (0.63)	8.6 (2.4)	8.5 (1.22)	2.09 (0.41)	1.29 (0.22)	0.26 (0.08)
Aug.	0.74 (0.16)	0.07 (0.02)	10.2 (0.99)	6 (1.3)	7.8 (2.10)	1.97 (0.42)	1.42 (0.25)	0.25 (0.09)
Nov.	1.06 (0.36)	0.1 (0.04)	10.7 (0.47)	15.2 (3.5)	9.2 (3.51)	2.14 (0.36)	2.36 (0.25)	0.18 (0.02)
'96 May.	1.85 (0.21)	0.17 (0.01)	10.8 (0.46)	8.7 (3.3)	11.5 (3.65)	1.54 (0.27)	1.56 (0.23)	0.15 (0.02)

to 21 P mg/100 g, and did not vary seasonally. Exchangeable Ca^{2+} concentrations ranged from 7.8 (me/100 g) in August 1995 to 14.7 in November 1994, the order of concentration of exchangeable cations was $Ca^{2+} > Mg^{2+} > K^{+} > Na^{+}$ (Table 2).

Extractable NH_4^+ and NO_3^-concentration

Extractable NH_4^+ concentrations ranged from 2.3 to 12 N mg/kg with maxima in June and July 1995 (Fig. 1). The lowest concentration of extractable NH_4^+ was in November 1995. Extractable NO_3^- concentrations ranged from 2.1 in November 1995 to 9.6 N mg/kg in July 1996. Average extractable NO_3^- concentrations throughout the experimental period were greater than average extractable NH^{4+} concentrations except in June and July. Extractable NO^{3-} concentrations did not vary seasonally. Extractable N ($NH_4^+ + NO_3^-$) to total N content ranged from 0.45% to 1.41%. And, the ratio of extractable NO_3^- concentrations to extractable N contents was comparatively high, and ranged from 48% to 68%. (Fig. 1).

NH_4^+ mineralization and nitrification rate

The rate of NH_4^+ mineralization generally reflects the amount of organic N for mineralization. Greatest rates of net NH_4^+ mineralization were in June and July, decreasing in the summer and fall (Fig. 2). Negative values of NH_4^+ mineralization and nitrification rate were observed in August and September. Negative values during the late summer are due to immobilization of NH_4^+ and NO_3^- during incubation. The percentage of nitrification rate to N availability ranged from 45% to 58% (Fig. 2).

Correlation between soil N dynamics and soil properties

Soil pH ranging from 5.39 to 6.86 had no significant effect on soil properties and soil N dynamics (Table 3). Extractable NH_4^+ concentration was positively correlated with organic matter ($r=0.80$, $p<0.001$) and moisture content ($r=0.48$, $p<0.001$) (Table 3). The production of NH_4^+ during the incubation period was affected by the concentrations of organic matter ($r=0.55$, $p<0.001$). Although the concentration of extractable NH_4^+ was significantly correlated with NH_4^+ mineralization ($r=0.63$, $p<0.001$), that of ex-

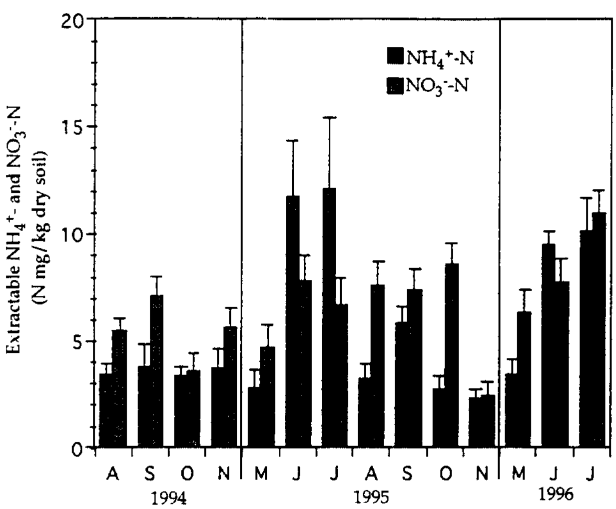

Fig. 1. Seasonal patterns and amounts of concentration of extractable NH_4^+- and NO_3^--N at the time of sampling for mineral soils of the alder stand established on volcano Mt. Showa-Shinzan. The data are mean values with standard deviations.

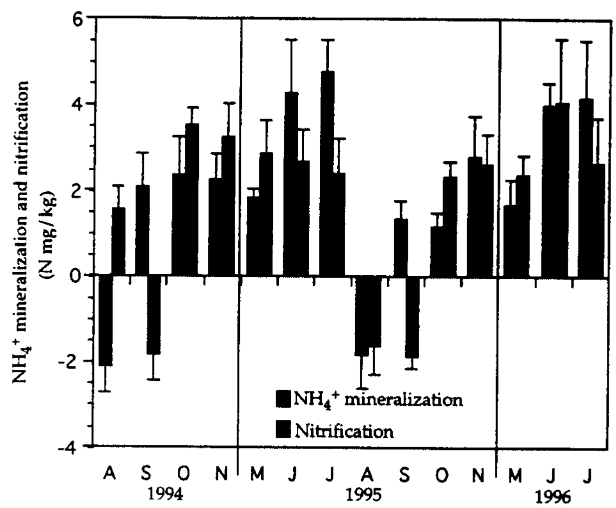

Fig. 2. Seasonal patterns of NH_4^+ mineralization and nitrification rate during incubation period for mineral soils of the alder stand established on volcano Mt. Showa-Shinzan. The data are mean values with standard deviations.

Table 3. Correlation coefficient between soil N dynamics and soil properties for mineral soils of the alder stand established on volcano Mt. Showa-Shinzan

Paremater	pH	Moisture	Organic matter	Extractable		NH_4^+ mineralization
				NH_4^+	NO_3^-	
pH						
Moisture	-0.25^{ns}					
Organic matter	-0.19^{ns}	0.34^{*}				
Ext. NH_4^+	-0.16^{ns}	0.48^{***}	0.80^{***}			
Ext. NO_3^-	-0.05^{ns}	0.22^{ns}	0.37^{**}	0.46^{***}		
NH_4^+ mineralization	-0.02^{ns}	–	0.55^{***}	0.63^{***}	0.15^{ns}	
Nitrification	0.06^{ns}	–	0.18^{ns}	0.22^{ns}	-0.27^{*}	0.45^{***}

Statistics: Pearson's test, n=70, ^{ns}:not significant, *:$p<0.05$, **:$p<0.01$, ***:$p<0.001$

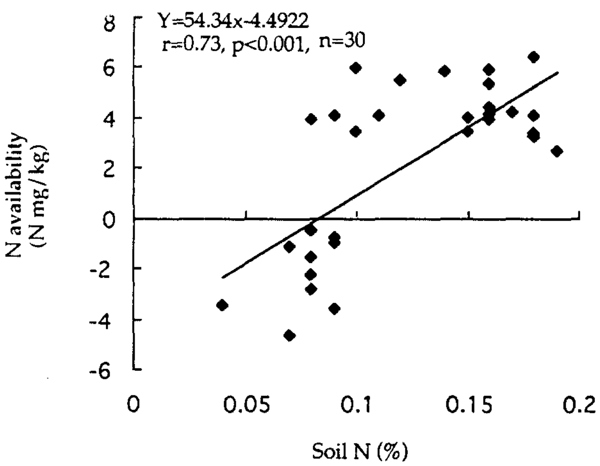

Fig. 3. The relationships between N availability (NH_4^+ mineralization plus nitrification rate) and soil total N content for mineral soils of the alder stand established on volcano Mt. Showa-Shinzan.

tractable NO_3^- was negatively correlated with nitrification rate ($r=-0.27$, $p<0.05$). Nitrification rates were highly correlated with net NH_4^+ mineralization ($r=0.45$, $p<0.001$). There were also significant positive correlations between N availability and soil total N content ($r=0.73$, $P<0.001$) (Fig. 3).

DISCUSSION

There have been many studies on the relationship between succession and N mineralization in forest ecosystems with the conclusion that rates of nitrification are dependent on the rate of N mineralization in primary and secondary succession (Montes and Christensen 1979, Robertson and Vitousek 1981, Robertson 1982). However, the dynamics of N transformations are difficult to understand completely, because of the continuous flux between soil, vegetation and atmosphere in forest ecosystems.

Contents of organic matter and total N for mineral soils in alder stand were low compared with the adjacent deciduous broad-leaved (unpublished, Table 1, 2). Although decomposition rates of litter in alder were not investigated in the present study, it is thought that litter of alder is suitable for microbial decomposition with high N content (low C/N ratio) in litter (Moon 1998). The rates of N mineralization generally reflected the amount of organic N and the quality of matter available for mineralization. Concentrations of extractable NH_4^+- and NO_3^--N were high, as shown in Fig. 1. And, rates of nitrification throughout the year were relatively high (Fig. 2). Bollen and Lu (1968) and Hendrickson and Chatarpaul (1984) found that high concentrations of mineral N (especially NO_3^--N) and high nitrification rates under alder stand, respectively. Furthermore, Beaupied *et al.* (1990) concluded that alder species can satisfy most of their N requirements from an atmospheric origin (94%), even though mineral N is plentiful in the soil. To some extent advanced stages of soil formation, the soil becomes increasingly influenced by vegetation, resulting in modifications of the microbial populations. Therefore, the high nitrification rates and extractable NO_3^- concentrations in alder stand suggest that the return of organic matter to the forest floor presumably provided favorable conditions for microbial decomposition, resulting in rapid and efficient uptake by the soil microbes and plants of mineral N. Extractable NH_4^+ concentrations and greater rates of NH_4^+ mineralization in June to July suggest that litter from the previous fall provided a suitable substrate for microbial decomposition with the approach of warmer weather and consequent increase in soil temperature (Van Cleve *et al.* 1993). Observed negative values in rates of both NH_4^+ mineralization and nitrification rate in August and September resulted from immobilization of NH_4^+ and NO_3^- by soil microbes during incubation (Nadelhoffer *et al.* 1984, Van Cleve *et al.* 1993) (Fig. 3). This suggests that N immobilization by soil microbes exceed N mineralization during incubation period. As shown in Fig. 3, when organic N content is relatively higher than 0.1%, soil microbes decompose organic materials and provide mineral N for soil and plant, while when organic N content is lower than 0.1%, soil microbes take organic N for reproduction of itself.

Substantial rates of N fixation have been documented for alder species (Binkley 1981, Tsutsumi *et al.* 1993), and N fixation by alder species contributes to the growth of other species. N fixation at a rate of 20～50 $kg \cdot ha^{-1} \cdot yr^{-1}$ by sitka alder might be sufficient to alleviate N competition as a growth (Miller and Murray 1979). In the present study, it appears certain that alder species contribute efficiently to nutrient accumulation within forest ecosystems, resulting in more N in litterfall and higher root and nodule turnover compared with trees in the other broad-leaved stands, but we found some dead trees of willow (*Salix* spp.) in the alder stand.

Alder (*Alnus maximowiczii* C.) stand is well-adapted to N-poor sites such as those that occur after volcanic eruptions, because of its N fixation properties. Alder accumulates litter of high N content which, after its rapid decomposition (Gessel and Turner 1974), provides a plentiful supply of N for other species. Although some alder species may inhibit the growth of other trees through shading, the overall benefits resulting from increased N availability probably facilitate the growth and invasion by a wide range of plants on otherwise poor soils.

적 요

이 연구는 소화신산의 화산분화후에 성립한 두메오리나무 임분의 무기질토양에서의 질소무기화와 질화작용의 특성을 파악하기 위하여 조사한 연구 결과이다. 토양상층부 10 cm의 토양을 채취, 실험실에서 배양하는 방법으로 1994년 8월부터 1996년 7월까지 2년간 조사하였다. 토양유기물 함량과 전질소량은 대체로 낮았지만, 5월～7월의 초기생장기에는 증가하는 경향이었다. 암모니아태질소와 질소무기화율은 매년 6월-7월에 높아지고, 그 이후에는 감소하는 경향을 나타내었다. 질산태질소은 명료한 계절변화는 보이지 않았다. 질소무기화율과 질화작용은 8, 9월에 마이너스의 수치를 나타내었다. 질소무기화는 토양유기물 함량과 정의 상관을, 질화작용은 암모니아태질소 함량과 질소무기화율의 영향을 받는다는 것을 알 수 있었다.

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