

Original article

## Soil nitrogen mineralization in adjacent stands of larch, pine and oak in central Korea

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(Received 3 January 1996; accepted 23 May 1996)

**Summary** – To examine the effects of tree species on soil nitrogen (N) mineralization we monitored rates of soil nitrogen mineralization and nitrification using the buried bag incubation method in 37-year-old Japanese larch (*Larix leptolepis* Gordon), pitch pine (*Pinus rigida* Mill), and oak (*Quercus serrata* Thunb) stands on a similar soil in central Korea. Litter and mineral soil (0–15 cm) were incubated for 45 day intervals from 1 September 1994 to 31 August 1995. Mean daily N mineralization rates were significantly different among sampling dates and the tree species. Annual net N mineralization and nitrification were also significantly different among the tree species; the annual N mineralization being 44 kg/ha/year for *P rigida*, 92 for *L leptolepis* and 112 for *Q serrata*, and percent nitrification ranging from 45% for *P rigida* to 90% for *L leptolepis*. Litterfall N inputs seemed to influence soil N mineralization. This study indicates that under a similar environment and soil type, N mineralization may differ by several-fold under the influence of different species.

**larch / central Korea / oak / pine / soil N mineralization**

**Résumé – Minéralisation de l'azote du sol dans des peuplements adjacents de mélèze, pin et chêne en Corée centrale.** Afin d'examiner les effets de trois espèces forestières sur la minéralisation de l'azote du sol, nous avons mesuré la vitesse de minéralisation de l'azote et de la nitrification dans les sols par la technique des sacs in situ dans des peuplements de mélèze du Japon (*Larix leptolepis* Gordon), de pitchpin (*Pinus rigida* Mill) et de chêne (*Quercus serrata* Thunb), âgés de 37 ans et situés sur des sols similaires de Corée centrale. Litière et sol minéral (0–15 cm) ont été incubés pendant des périodes de 45 jours du 1<sup>er</sup> septembre 1994 au 31 août 1995. Les moyennes journalières de minéralisation de l'azote étaient significativement différentes entre les trois espèces forestières. La minéralisation azotée annuelle a été estimée à 44 kg/ha/an pour *P rigida*, à 92 pour *L leptolepis* et à 112 pour *Q serrata*. Le pourcentage de nitrification varie de 45 % pour *P rigida* à 90 % pour *L leptolepis*. La quantité d'azote apportée par la chute des litières semble influencer la minéralisation de l'azote au sol. Cette étude montre que, dans des conditions stationnelles équivalentes, la minéralisation de l'azote peut varier, dans des rapports supérieurs à un, sous l'effet de l'espèce.

**mélèze / Corée centrale / chêne / pin / minéralisation de l'azote**

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## INTRODUCTION

Species-specific effects of plants on soil properties have been noted in various forest ecosystems (Alban et al, 1978; France et al, 1989; Boettcher and Kalisz, 1990; Binkley and Valentine, 1991; Son and Gower, 1992), and are of interest for understanding nutrient cycling and the importance of individual species in ecosystem-scale biogeochemistry (Wedin and Tilman, 1990; Gower and Son, 1992). Net nitrogen (N) mineralization, the rate at which mineral N becomes available in soil for plant growth through the decomposition of organic matter, is an important factor limiting production in forest ecosystems. Feedback effects of a species on N supply may be a key mechanism in interaction between tree species (Pastor et al, 1984; Pastor and Naiman, 1992). Demonstration of species effects on soil N mineralization requires a common experimental study, which minimizes differences in historical and environmental factors among species.

We established adjacent stands of *Larix leptolepis* Gordon, *Pinus rigida* Mill and *Quercus serrata* Thunb on a similar site (soil texture, aspect, slope and elevation) at the same time at the Korea University Experimental Forest; these stands provide the opportunity to study species-specific influence on soil characteristics and nutrient cycling. A previous study in the same forest revealed that biomass and nutrient accumulation and litterfall inputs differed significantly among the three tree species (Kim,

1995), and raised an interesting question about the influence of tree species on soil N mineralization. *L leptolepis* and *P rigida* are common conifers in central and southern Korea; these two species were imported in the early 1900s and have been planted extensively throughout the region because they have rapid early growth rates. *Q serrata* is a widely distributed native oak in Korea. Studies on nutrient cycling and productivity for these three species are very limited, and the influence of these species on soils is largely unknown.

The objectives of this study were to quantify soil net N mineralization and nitrification and examine the effect of tree species on soil N mineralization for the three tree species on a similar site in Yangpyeong, Korea.

## MATERIALS AND METHODS

### Site characteristics

The study was conducted at the Korea University Yangpyeong Experimental Forest in central Korea (37°30'N, 127°42'E, elevation 160 m). The experimental forest contains 558 ha of natural and plantation forests. The study area was dominated by *Pinus densiflora* Sieb et Zucc and *Quercus* spp (*Q variabilis* B1, *Q mongolica* Fisch and *Q acutissima* Carruth) before harvesting. For this study we selected three adjacent stands; one natural stand of *Q serrata* and two plantations of *P rigida* and *L leptolepis* (table I). The stands were within 500 m of each other,

**Table I.** Stand and soil characteristics of the study site (from Kim, 1995).

	L leptolepis	P rigida	Q serrata
dbh (cm)	24.0	23.6	14.6
Basal area (m <sup>2</sup> )	55.5	64.8	29.2
No of stems/ha	548	667	682
Soil texture	Sandy clay loam	Sandy clay loam	Sandy clay loam
pH	4.9	4.9	5.1
Total N (%)	0.28	0.18	0.19
Available P (ppm)	18.5	15.3	13.6
Exchangeable (me/100 g)			
K	0.10	0.19	0.15
Ca	1.31	2.03	2.19
Mg	0.19	0.22	0.45
Na	0.06	0.08	0.01

dbh: stem diameter at breast height.

and were established on a relatively homogeneous slope, aspect and soils in 1956. We established three 15 x 15 m replicate plots for each study species, and the distance among plots within a species was at least 10 m. As there was only a short distance between plots and stands within the study site, differences in microclimate conditions should have been minimal, and we assumed that differences in soil characteristics among species were due to species-specific influences.

Characteristic understory species were *Q. mongolica*, *Q. aliena*, *Q. serrata*, *Q. acutissima*, *Rhus trichocarpa* Miq, *Corylus heterophylla* Fisch, *Symplocos chinensis* for *pilosa* Ohwi and *Lindera obtusiloba* Bl. There were no nitrogen-fixing species in the understory vegetation. At each stand the dominant tree species made up more than 98% of the total above-ground biomass (Kim, 1995). Weather data obtained from a station located in Yangpyeong (15 km from the study site) show mean January and July temperatures of -7.9 and 24.1 °C, respectively, and the average annual precipitation was 1 365 mm (based on the 1984–1993 records; KMA, 1984–1993). The soils were classified as slightly dry brown forest soils, and a detailed stand and soil description of the study site was provided by Kim (1995) and colleagues (Kim et al, 1995).

### Nitrogen mineralization measurements

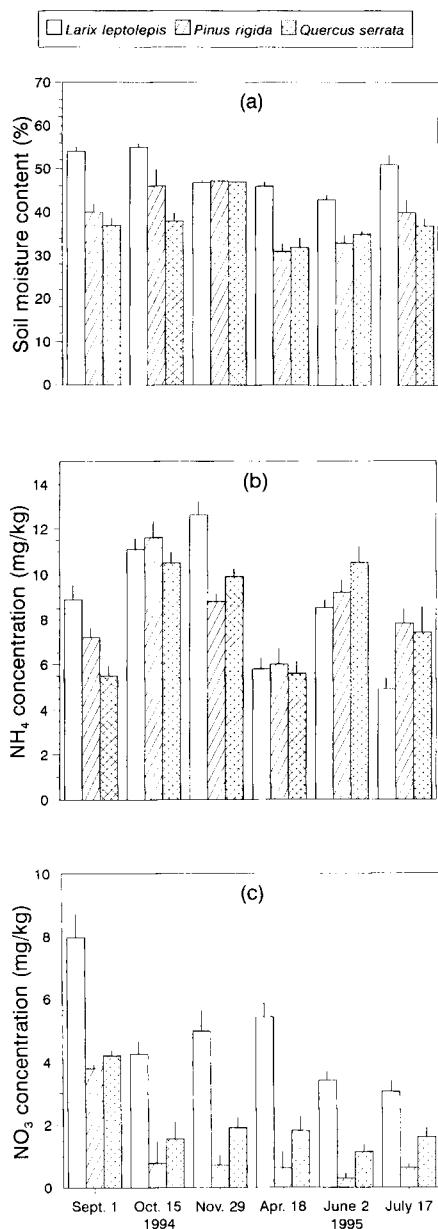
Soil N mineralization and nitrification was determined from 1 September 1994 to 31 August 1995 by the in situ buried bag incubation method (Eno, 1960). This method is widely used to investigate N cycling in different ecosystems (Nadelhoffer et al, 1983; Pastor et al, 1984, 1987; Gower and Son, 1992) because of its sensitivity to differences in on-site soil temperature and moisture (Binkley and Hart, 1989). Two cores were taken at five random locations in each stand for each of the three plots from the forest floor and the upper 15 cm of soil; one core was placed in two layers of a 10 µm thick polyethylene bag, reinserted into the soil and incubated for five periods of 45 days and one period of 140 days (in winter). Sampling dates were 1 September, 15 October, 29

November 1994, 18 April, 2 June and 17 July 1995. The other soil core was returned to the laboratory for analysis of water content, and ammonium and nitrate concentrations. At the end of each incubation period the incubated samples were retrieved and taken to the laboratory and a new pair of samples was taken.

In the laboratory, field-moist soil samples were extracted with 2 M KCl (15 g soil:100 mL KCl) for 24 h and filtered through Whatman no 42 filter paper. The extracts were frozen until time of analysis, and analyzed for ammonium by the indophenol blue reaction and nitrate with an Alpkem autoanalyzer (Keeney and Nelson, 1982). Additional 15 g soil samples were dried at 105 °C to determine field soil moisture content. Data were adjusted to an oven-dry basis. Net N mineralization was calculated as the difference between ammonium and nitrate concentrations of the incubated and initial soil samples. Net nitrification was calculated as the difference between nitrate concentration of the incubated and initial soil samples (Nadelhoffer et al, 1984). Conversion of net N mineralization and nitrification from mg per dry soil to kg/ha was based on the bulk density of the soil in each plot, which was measured in four soil samples per plots. Annual net N mineralization and nitrification were calculated as the sum of net N mineralization and nitrification over the six incubation periods. Percent nitrification was calculated as net nitrification divided by net N mineralization.

### Statistical analysis

The statistical analyses used in all comparisons assumed a split-plot design. ANOVA was used to test differences in annual net N mineralization and nitrification among the three species. When the ANOVA was significant, Tukey's studentized range tests were performed to test for significant differences among means. A repeated measures of variance was used to investigate seasonal patterns of soil moisture content, ammonium and nitrate concentrations, net N mineralization and nitrification. Linear regression analysis was used to relate net N mineralization and nitrification to initial soil moisture content, and ammonium and nitrate concentra-



**Fig 1.** Initial soil moisture content (a), ammonium (b) and nitrate (c) concentrations for 37-year-old *L. leptolepis*, *P. rigida* and *Q. serrata* stands in central Korea. Vertical lines are one standard error of means.

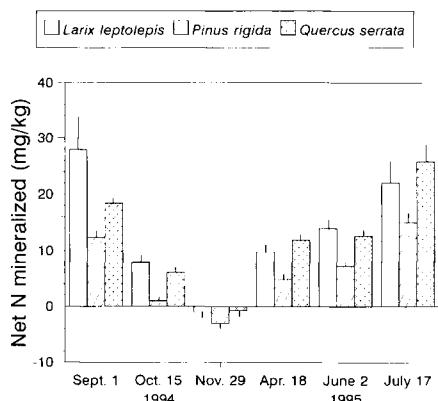
tions. Regression analysis was also used to explore the association between rates of net N mineralization and nitrification and previously measured soil chemical properties and above-ground litterfall inputs in the same study site. All statistical analyses were conducted using SAS (1988).

## RESULTS AND DISCUSSION

### Seasonal patterns of soil moisture content and soil N concentration

Initial soil moisture content, and ammonium and nitrate concentrations were significantly different among sampling dates and tree species ( $P < 0.001$ ). Throughout the year, the average soil moisture content of the initial samples varied between 31 to 55% for the three species (fig 1a). Initial soil ammonium and nitrate concentrations were generally low (< 10 mg/kg) with occasional pulses. The highest ammonium level observed (12.6 mg/kg) was for *L. leptolepis* in November while the highest nitrate level (8.0 mg/kg) was for *L. leptolepis* in September 1994. In general, soil ammonium pools were larger (4.9–12.6 mg/kg) than nitrate pools (0.3–8.0 mg/kg) (fig 1b, c). The average initial soil ammonium and nitrate concentrations (mg/kg) were 8.6 and 4.9 for *L. leptolepis*, 8.4 and 1.1 for *P. rigida* and 8.2 and 2.0 for *Q. serrata*, respectively. These values are similar to the concentrations measured for other coniferous forests in central Korea (Son et al., 1995). However, average nitrate concentrations were generally lower than those reported for other forest soils in temperate regions (Nadelhoffer et al., 1983; Gower and Son, 1992).

Low nitrate levels in soils have been attributed to low soil pH, low ammonium availability, allelopathic inhibition, nitrate leaching loss, plant uptake and microbial immobilization (Donaldson and Henderson, 1990a, b; Wedin and Tilman, 1990; Hart et al., 1994). It seemed that low soil pH in the study site (4.9, 4.9 and 5.1 for *L. leptolepis*, *P. rigida* and *Q. serrata*, respectively [Kim, 1995]) may have been related to low initial nitrate concentrations for the three species. Except for *P. rigida*, initial in soil inorganic N (ammonium plus nitrate) concentrations were



**Fig. 2.** Seasonal net N mineralization for 37-year-old *L. leptolepis*, *P. rigida* and *Q. serrata* stands in central Korea. Vertical lines are one standard error of means.

significantly higher in October than in other sampling dates ( $P < 0.05$ ). Heavy leaf litterfall occurs from late September through late October in the study region (Kim, 1995), and high soil inorganic N concentrations in October might be related to litterfall inputs.

### Seasonal patterns of N mineralization

Mean net N mineralization (mg/kg/d) differed significantly among incubation dates and tree species ( $P < 0.001$ ) (data not shown). Net N mineralization showed a clear seasonal pattern for the three species; rates were greatest in the mid-summer and early fall (fig 2). More than 60% of the annual net N mineralization occurred during the two incubation periods from July through September. Seasonal fluctuations in the soil moisture contents and litterfall inputs may

be responsible for the pattern (Van Vuuren et al, 1992). Peak rates of net N mineralization were associated with high soil moisture. A significant correlation ( $P < 0.001$ ) between net N mineralization and initial soil moisture content supports the previous finding that the latter plays an important role in controlling soil N mineralization (Nadelhoffer et al, 1991; Gower and Son, 1992; Van Vuuren et al, 1992; see also Turner et al, 1993). Although soil temperature would be the main reason for high seasonal net N mineralization (Van Vuuren et al, 1992), we could not determine the influence of soil temperature in this study because we did not measure it. However, soil moisture and net N mineralization were higher in September than in July, when soil should have been warmer.

Mean net N mineralization (mg/kg) for all three species for fall (September–October), late fall (October–November), winter (November–April), spring (April–June), early summer (June–July) and summer (July–August) were 19.6, 5.0, -1.5, 8.9, 11.3 and 21.0, respectively. These rates are similar to values reported for other three coniferous plantations (*L. decidua*, *P. strobus* and *Thuja occidentalis*) growing on a similar soil (Son et al, 1995) in central Korea. The higher rates of N mineralization in summer than in winter months in this study are consistent with the previous findings for other forest soils (Nadelhoffer et al, 1983; Pastor et al, 1984; Stump and Binkley, 1993). The high N mineralization in July–August and September–October is probably related to soil temperature and timing of aboveground litterfall inputs. Negative net N mineralization occurred for all three species during the winter (November 1994–April 1995); very little or no net N mineralization during the

**Table II.** Annual net N mineralization and percent nitrification calculated for *L. leptolepis*, *P. rigida* and *Q. serrata*.

Species	Ammonium (kg/ha/year)	Nitrate (kg/ha/year)	Total (kg/ha/year)	Nitrification (%)
<i>L. leptolepis</i>	9.1 (1.7) <sup>a</sup>	82.8 (10.3) <sup>a</sup>	91.9 (9.6) <sup>ab</sup>	89.8 <sup>a</sup>
<i>P. rigida</i>	23.7 (7.8) <sup>a</sup>	19.9 (0.1) <sup>b</sup>	43.6 (8.0) <sup>b</sup>	49.5 <sup>b</sup>
<i>Q. serrata</i>	26.5 (7.6) <sup>a</sup>	85.8 (16.1) <sup>a</sup>	112.3 (16.3) <sup>a</sup>	75.9 <sup>ab</sup>

<sup>ab</sup>Means in each column followed by the same letter are not significantly different ( $P > 0.05$ ). The number in parentheses is one standard error of the mean.

winter have been observed for other forest soils (Nadelhoffer et al, 1984; Zak and Grigal, 1991; Gower and Son, 1992). Negative net N mineralization is also observed elsewhere (Aber and Melillo, 1982; Nadelhoffer et al, 1984; Stump and Binkley, 1993).

### **Annual net N mineralization and nitrification**

We found a significant difference in annual net N mineralization between species ( $P < 0.001$ ). Annual net N mineralization (kg/ha/year) in the forest floor and top 15 cm of mineral soil for *L leptolepis*, *P rigida* and *Q serrata* was 92, 44, 112, respectively (table II). These rates were within the range of 50 to 100 kg/ha/year for coniferous forests and 100 to 300 kg/ha/year for deciduous forests suggested by Gosz (1981) and were similar to values reported from other temperate forest ecosystems (reviewed by Binkley, 1995). Annual net nitrification (kg/ha/year) was significantly different between species ( $P < 0.001$ ) and *Q serrata* had the highest annual net nitrification (86) followed by *L leptolepis* (83) and *P rigida* (20). The dramatic divergence of annual net N mineralization and nitrification in initially similar soils but affected by different three tree species demonstrated a potential for strong interactions between the species composition and nutrient cycling.

Values of percent nitrification were 50% or greater for all species, and *L leptolepis* had the highest percent nitrification (90%) followed by *Q serrata* (76%) and *P rigida* (50%) (table II). High nitrification for *Larix* spp was also reported from another study (Gower and Son, 1992). Although initial soil nitrate concentration was low, net nitrification was important for the three species (Nadelhoffer et al, 1984; Pastor et al, 1987). However, there is a possibility that nitrification might be overestimated in soil incubations where root uptake of N was prevented (Zak and Grigal, 1991). *P rigida* had the lowest annual net N mineralization and percent nitrification among the three species; this supports the previous finding that nitrification rates are limited by the supply of ammonium, ie, net N mi-

neralization (Wedin and Tilman, 1990; Van Vuuren et al, 1992).

Various researchers have found that soil chemical characteristics can predict soil N mineralization (Pastor et al, 1987; Nadelhoffer et al, 1991; Zak and Grigal, 1991) (but see Nadelhoffer et al, 1983, 1984; Pastor et al, 1984; Gower and Son, 1992). However, there was no significant correlation ( $P > 0.1$ ) between annual net N mineralization and previously measured soil organic carbon (C) concentration, total soil N concentration, soil organic matter C:N ratio or total soil N content (data from Kim, 1995). Instead we found a significant correlation ( $r^2 = 0.99$ ,  $P < 0.05$ ) between annual net N mineralization and previously measured aboveground litterfall N contents: 28, 16 and 32 kg/ha/year for *L leptolepis*, *P rigida* and *Q serrata*, respectively (Kim, 1995). Pastor et al (1984) also reported a correlation between litterfall N contents and N mineralization (but see Gower and Son, 1992). We cannot assume cause or effect in this association; rather, we expect a positive feedback between litter quality and soil N mineralization provides a circle of cause and effect.

In summary, earlier results of differences in biomass production and nutrient distribution and the present soil N mineralization study strengthen the conclusion that the tree species studied strongly modify soil properties and nutrient cycling. It appeared that aboveground litterfall N contents influenced N mineralization in soils. However, as soil N mineralization depends on environmental factors (soil moisture, temperature and texture) and above- and belowground litter (quantity, quality and timing of inputs) (Aber and Melillo, 1982; Pastor et al, 1987; Wedin and Tilman, 1990; Gower and Son, 1992; Stump and Binkley, 1993; Garten and Van Miegroet, 1994), more detailed studies are necessary to clarify the major factors of regulating soil N mineralization in this forest ecosystem.

### **ACKNOWLEDGMENTS**

This research was supported by Korea Research Foundation (04-G-0054). We thank Dr SE Lee, JY Hong, HW Kim and JH Hwang for help in

the field and laboratory. Dr D Binkley provided a number of very useful suggestions that greatly improved the manuscript.

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