

Net Nitrogen Mineralization and Nitrification at Different Landscape Positions in a Lowland Subtropical Rain Forest in Taiwan

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Abstract

Although soil N transformation rate measurements are needed to assess plant availability and N losses in a forest ecosystem, little data is available on lowland subtropical rain forests. The objective of this study is to determine the rates of N mineralization and nitrification in different seasons (January and August in 2006) and at different landscape positions (footslope and summit) in the Nanjenshan forest of southern Taiwan, where the vegetation types and soil properties vary among the different landscape positions. According to our 28-d *in situ* incubation experiments, although there were larger soil C, soil N, and microbial N pools at the summit position, the footslope soils showed higher net N mineralization and nitrification rates, as expressed on a per unit C or N basis. Laboratory incubation results indicated that the N mineralization was more responsive to temperature change than to moisture change in the Nanjenshan forest soils. Our results suggested that the substrate properties at the footslope position contributed to a higher net N mineralization and nitrification rate and that the differences between the N transformation rates at different landscape positions might be related to the types of vegetation.

Key Words

Subtropical rain forest, Net N mineralization and nitrification, Nanjenshan Nature Reserve, Landscape position, Vegetation.

Introduction

Soil N mineralization and nitrification rates often differ with the forest type, elevation, and landscape position (Finzi *et al.* 1998; Knoepp and Swank 1998; Venterea *et al.* 2003). The need to gain a deeper understanding of tropical rain forests is well documented; however, subtropical rain forests have not attracted the same level of attention. The Nanjenshan Nature Reserve in Kenting National Park contains the last native lowland subtropical rain forest in Taiwan. It is worth noting that most of the lowland plant species found in Taiwan are present in the Nanjenshan forest, which also contains numerous rare and locally endemic species of Hengchun flora (Sun *et al.* 1998). Despite the low elevation, it is surprising that temperate-zone tree taxa are also present in the subtropics (Liao 1995; Sun *et al.* 1998). The objective of this study is to examine the rates of soil nitrogen mineralization and nitrification in different seasons (summer and winter) and at different landscape positions (footslope and summit) on Mt. Nanjenshan in southern Taiwan.

Methods

Study site

The study site (22°37'N, 120°10'E) is located in the Nanjenshan Nature Reserve of Kenting National Park on the Hengchun Peninsula at the southern end of Taiwan (Figure 1). The annual precipitation in this area is about 3000 mm, and the mean monthly air temperatures are highest in July (28°C) and lowest in January (18°C). Typhoons are very common during summer; northeastern monsoon winds usually begin to blow in late October and last until late March of the following year. An experimental transect having a length of 450 m and width of 10–40 m was established on the northwestern ridge of Mt. Nanjenshan in 1994 (Figure 1). The vegetation along this 1-ha transect can be divided into three distinct vegetation types, and there is a vegetation compression phenomenon, with great richness in plant species richness within a short elevation range of 200–400 m (Liao 1995). The soils located at the summit position are classified as Typic Paleudults, which have an argillic horizon resulting from strong leaching and illuvial processes. The soils located at the unstable backslope position are associated with steep slopes and those at the footslope position are classified as Typic Dystrudepts, which have a cambic horizon resulting from weak leaching processes.

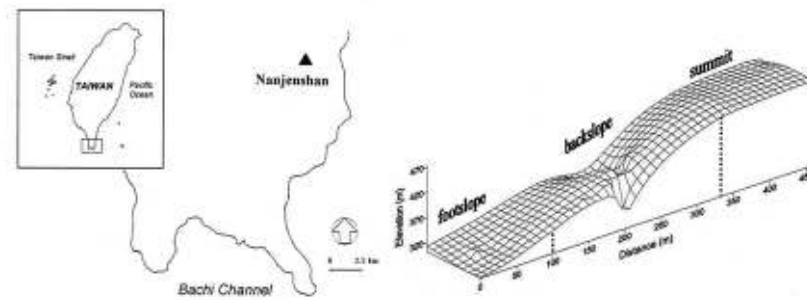


Figure 1. Geographical location of the long-term ecological research site in Nanjenshan Mountain in southern Taiwan.

In-situ incubations

Two sets of three 2 m × 2 m plots were established at the summit and footslope positions in December 2005. All six plots were well covered by a canopy of the dominant tree species. In January and August of 2006, the *in situ* soil net N mineralization and nitrification were measured using 28-d capped cores incubations. Duplicate field-moist soil samples (<5.66 mm) of 20 g were shaken with 100 ml of 2 M KCl for 1-h, filtered, and determined the inorganic N concentrations. The net N mineralization and net nitrification were determined by the differences of ammonium plus nitrate (mineralization) or nitrate-N (nitrification) between the 0-d and 28-d of incubation. The soil microbial biomass carbon (C_{mic}) and nitrogen (N_{mic}) were measured using the chloroform-fumigation incubation method (Jenkinson and Powlson 1976). The spare soils were air-dried, ground, sieved to less than 2 mm, and determined the soil N (TN) and the soil organic carbon (OC) by the total Kjeldahl nitrogen procedure and by the modified Walkley-Black method, respectively.

Laboratory incubations

To determine the potential N mineralization and nitrification and to examine the effects of moisture and temperature condition, bulk soil samples at time zero in January and August in 2006 were also collected for laboratory incubation. After transported to the lab and sieved (< 5.66 mm), soil was air-dried at dark room (< 20°C) overnight and soil water content (105°C) were determined. Eight soils per plot were weighed to the equivalent of 10 g oven-dry in plastic bottles, rewetted to 20 % or 40 % of gravimetric water contents, and incubated under 15°C or 30°C in incubators. After 0, 0.5, 1, 2, 3, and 4 mo of incubation, the soils samples were extracted with KCl as described above and the inorganic N concentration determined. We assumed that the net N production rate during the incubation follows first-order kinetics:

$$np = N_0 (1 - e^{-kt}) \quad (1)$$

where np is the amount of inorganic N produced by time t (days), N_0 is the potentially mineralizable N, and k is the rate constant. Equation (1) was fitted with the Fit Curve procedures of SigmaPlot 5.0 (SPSS Inc., IL).

Results

C and N concentrations of soil and litter, and soil microbial biomass before incubations

Although the litter C and N concentrations did not show any differences between the summit and footslope positions in our collected samples, the concentrations of soil OC and TN at the summit position were significantly higher than those at the footslope position before the incubations (Table 1). The vegetation type and tree species have a considerable effect on the surface soil C and N dynamics (Finzi *et al.* 1998; Hobbie *et al.* 2007). In our study site, the species composition of the summit forest can be distinguished from that of the footslope forest, despite the fact that the elevation difference between the summit and the footslope is small (Liao 1995; Wu *et al.* 2007). We suggest that the leaf litter from the summit tree species is comparably less decomposable than that from the footslope species, and the difference in litter decomposability probably resulted in the higher OC accumulation in the summit soils. The mean values of the microbial biomass C and N concentrations in the footslope soils were lower than those in the summit soils, however, the $C_{mic}:N_{mic}$ and $C_{mic}:OC$ ratios of the footslope soils were significantly higher than those of the summit soils (Table 1). Large $C_{mic}:N_{mic}$ ratios are caused by increased fungal-to-microbial biomass ratios (Joergensen *et al.* 1995), we suggest that there was a larger proportion of fungi distributed in the microbial communities of the footslope soils than those of the summit soils, i.e., the soil microbial populations were different between the landscape positions. Higher $C_{mic}:OC$ ratios in the footslope soils suggests that (a) the C bioavailability of the footslope soils is higher than that of the summit soils and (b) a relatively larger portion of the soil's organic matter is resistant to decomposition at the summit position, as we previously suggested.

Table 1. C and N concentrations of soil and litter, and soil microbial biomass C and N before incubations.

	Soil OC (g/kg)	Soil TN (g/kg)	Soil C:N ratio	Litter C (g/kg)	Litter N (g/kg)	Litter C:N ratio	C _{mic} (mg C/kg)	N _{mic} (mg N/kg)	C _{mic} :N _{mic} ratio	C _{mic} :OC (%)	N _{mic} :TN (%)
January 2006											
Footslope	12.3b	1.11b	10.5b	376a	12.8a	29.3b	863b	32b	29.3a	7.0a	2.9b
Summit	23.4a	1.61a	14.7a	417a	10.7a	39.2a	1158a	102a	11.6a	4.9a	6.3a
August 2006											
Footslope	13.2b	0.95b	13.9a	402a	10.2a	40.1a	962b	71a	13.7a	7.3a	7.5a
Summit	27.1a	1.84a	14.8a	418a	11.0a	38.3a	1259a	140a	9.2b	4.6b	7.6a

Data with different letters between footslope and summit are statistically significant at $P < 0.05$ (Student's *t* test).

In-situ net N mineralization and nitrification rate

In January 2006, the amount ($\text{mg N m}^{-2} 28 \text{ d}^{-1}$) of mineralized and nitrified N and the N transformation rate ($\text{mg N m}^{-2} \text{ d}^{-1}$) of the footslope were similar to those of the summit (Table 2). The net rates and amounts of mineralization and nitrification in August were 1.3- and 2.1-fold higher than those in January on the footslope and 2.29- and 2.46-fold higher on the summit, respectively, both due to significantly higher concentrations in August (data not shown). In addition to the seasonal variation at a given landscape position, the differences in the N transformation rates ($\text{mg N m}^{-2} \text{ d}^{-1}$) between the footslope and summit positions were greater in August, and the net N mineralization rates and net nitrification rates at the summit position were 1.8- and 1.3-fold higher than those at the footslope position, respectively. In addition to the substrate concentration (soil C and N), the SOM composition also plays a role in regulating N mineralization, and the differences in the N mineralization rates among different ecosystem types reflect the importance of the SOM composition (Booth *et al.* 2005). On a per gram organic carbon basis ($\text{mg N g OC}^{-1} \text{ d}^{-1}$) and per gram nitrogen basis ($\text{mg N g N}^{-1} \text{ d}^{-1}$), the net N mineralization and net nitrification rates of the footslope were both higher than those of the summit in January and August (Table 2). It revealed that the differences in the N transformation rates between landscape positions were influenced by the substrate quality, which is directly linked to the vegetation type (Knoepp and Swank 1998) or tree species (Hobbie *et al.* 2007).

Table 2. Net rates and amounts of mineralization and nitrification of the Nanjenshan transect Site.

	January 2006		August 2006	
	Footslope	Summit	Footslope	Summit
Net amount of N mineralization ($\text{mg N m}^{-2} 28 \text{ d}^{-1}$)	844	868	1130	1990
Net rate of N mineralization ($\text{mg N m}^{-2} \text{ d}^{-1}$)	30.1	31.0	40.2	71.3
($\text{mg N g C}^{-1} \text{ d}^{-1}$)	0.018	0.010	0.023	0.019
($\text{mg N g N}^{-1} \text{ d}^{-1}$)	0.201	0.143	0.313	0.287
Net amount of nitrification ($\text{mg N m}^{-2} 28 \text{ d}^{-1}$)	691	737	1440	1810
Net rate of nitrification ($\text{mg N m}^{-2} \text{ d}^{-1}$)	24.7	26.3	51.5	64.6
($\text{mg N g C}^{-1} \text{ d}^{-1}$)	0.015	0.008	0.029	0.018
($\text{mg N g N}^{-1} \text{ d}^{-1}$)	0.165	0.121	0.402	0.260

Table 3. Influences of temperature and moisture on the values of potentially mineralizable N (N_0) and the mineralization rate constant (k) as estimated with non-linear regression of the cumulative net N mineralization during a 4-month incubation of Transect Site soils

Sampling time	Landscape position	Moisture (% w/w)	Temperature			
			15°C		30°C	
			N_0 (mg N kg^{-1})	N_0 (mg N kg^{-1})	k (day^{-1})	k (day^{-1})
January 2006	Footslope	20	18.9***	51.7***	0.0187*	0.0240***
		40	25.0***	52.8***	0.0134*	0.0222***
	Summit	20	23.6***	86.2***	0.0150*	0.0192***
		40	29.8***	151.0***	0.0158**	0.0112***
August 2006	Footslope	20	29.4***	86.7***	0.0138***	0.0113**
		40	39.1***	126.4***	0.0116**	0.0059**
	Summit	20	32.4***	140.1***	0.0243***	0.0100***
		40	32.4***	148.7***	0.0295***	0.085**

(* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$)

Moisture and temperature effects on the potentially mineralizable N (N_0)

In our study, the effects of changing soil moisture condition on N_0 varied with different seasons or landscape positions at a given temperature. On the other hand, the N_0 increased by approximately two- to five-fold when the incubation temperature raised from 15°C to 30°C at a given moisture condition (Table 3). The N_0 represents not only the quantity, but also the quality of substrates and their interaction with the soil matrix (Wang *et al.* 2003). At the summit position, there were larger soil and microbial N pools than those at the footslope position (Table 1), and they could serve as a nutrient pool that are gradually released under appropriate condition for soil microbes. According to the results of *in situ*

and laboratory incubation experiments, it appeared that at a specific landscape position, the seasonal variation in N transformation was mainly affected by the temperature regime, with the soil moisture regime having less effect at the Nanjenshan transect site. This result confirmed the reports of some laboratory incubations that N mineralization was more responsive to temperature change than to moisture change (Knoepp and Swank 2002; Wang *et al.* 2003).

Conclusion

In general, the net N mineralization and nitrification rates at the Nanjenshan transect site varied with the landscape position. Despite the fact that the elevation difference was small, the soil properties and vegetation compositions differed significantly between the summit and footslope positions due to the special geographic location of the Hengchun Peninsula. Although there were larger soil C, soil N, and microbial N pools at the summit position, the footslope soils showed higher net N mineralization and nitrification rates when expressed on a per unit C or per unit N basis. This suggested that the substrate properties at the footslope position contributed to the higher net N mineralization and nitrification rate and that the differences in the N transformation rates between different landscape positions seemed to be related to the vegetation type.

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