Soil Inorganic Nitrogen and Microbial Biomass Carbon and Nitrogen Under Pine Plantations in Zhanggutai Sandy Soil

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ABSTRACT

The dynamics of soil inorganic nitrogen (NH4+-N and NO3−-N) and microbial biomass carbon (Cmic) and nitrogen (Nmic) under 30-year-old fenced Pinus sylvestris L. var. mongolica Litvin (SF), unfenced P. sylvestris L. var. mongolica Litvin (SUF), and unfenced Pinus densiflora Siebold et Zucc. (DUF) plantations in the Zhanggutai sandy soil of China were studied during Apr. to Oct. 2004 by the in situ closed-top core incubation method. All mentioned C and N indices in each stand type fluctuated over time. The ranges of inorganic N, Cmic, and Nmic contents in the three stand types were 0.7–2.6, 40.0–128.9, and 5.4–15.2 μg g−1, respectively. The average contents of soil NH4+-N and Cmic under the three 30-year-old pine plantations were not different. However, soil NO3−-N and total inorganic N contents decreased in the order of SUF ≥ SF ≥ DUF, the Nmic content was in the order of SF = SUF > DUF, and the Cmic:Nmic ratio was in the order of SF = SUF > SF. Seasonal variations were observed in soil inorganic N, microbial biomass, and plant growth. These seasonal variations had certain correlations with microbe and plant N use in the soil, and their competition for NH4+-N was mostly regulated by soil N availability. The influence of tree species on inorganic N and Nmic were mainly because of differences in litter quality. Lack of grazing decreased the Cmic:Nmic ratio owing to decreased carbon output and increased the ability of soil to supply N. The soil N supply under the P. sylvestris var. mongolica plantation was lower than under the P. densiflora plantation.

Key Words: ecosystem management, Horqin sandy land, soil nitrogen availability, Pinus densiflora, Pinus sylvestris var. mongolica


Nitrogen (N) is considered to be the most limiting nutrient to plant growth in most forest ecosystems (Vitousek et al., 1982; Ferris et al., 1998), especially in arid and semiarid regions (Sharifi et al., 1988; Lajtha and Whitford, 1989). Soil N generally contains 85%–90% of the total N in terrestrial ecosystems (Kaye et al., 2003). Less than 5% of the soil N pool, regarded as minerizable N, is biologically active and is the source of available N in soil (Binkley and Hart, 1989). In forest ecosystems, soluble organic N and inorganic N (i.e., NH4+-N and NO3−-N) are the major sources available to plants for uptake during growth (Binkley and Hart, 1989; Chapin et al., 1993). Because the plant that grows on mineral soils in temperate zone does not efficiently utilize soluble organic N (amino acids) for growth (Chapin et al., 1993), soluble organic N was rarely reported in sandy land ecosystem. Although NH4+-N and NO3−-N represent the available inorganic forms of N in soils, the sizes of these pools are generally small. A small pool of NO3−-N may indicate either a low nitrification rate, a high rate of NO3−-N uptake by plants or rapid denitrification. In addition, soil microbial biomass is an agent of transformation of organic matter.
and serves as a labile reservoir for plant-available N, phosphorus (P), and sulfur (S) (Jenkinson and Ladd, 1981; Wardle, 1992; Tracy and Frank, 1998). Microbial biomass activity is commonly used to characterize the status of soils (Fisk and Fahy, 2001) and to evaluate the effects of plant composition and management practices (Beyer et al., 1991; Anderson and Domsch, 1993). Organic matter inputs are both a source and a sink of carbon (C), N, P, and S. Organic matter is the center of the majority of biological activity in the soil system. It is generally agreed that soil N availability limits N use efficiency and directly influences net primary production in terrestrial ecosystems as well as feedback relationships that impact plant biodiversity and ecosystem sustainability (Reich et al., 1997). Thus, the study of soil inorganic N and microbial biomass N can be advantageous to understanding N biogeochemical cycling and assessing forest ecosystem stability and function.

The Horqin Sand Lands in North China are seriously affected by desertification. During the revegetation projects of the 1950’s, Mongolian pines (Pinus sylvestris L. var. mongolica Litvin) were planted in the Zhanggutai region located in the southeastern part of the Horqin Sand Lands (Jiang and Zhu, 2002). In the past 50 years, the encouragement of the national afforestation policies has resulted in planting large quantities of Mongolian pines in three areas of North China (Jiang and Zhu, 2002). Grazing has severely disturbed pine plantation ecosystems in the Zhanggutai region. Generally, grazing can impact N availability and terrestrial ecosystem stability. Unfortunately, the effects of grazing on available soil N in pine plantations on sandy soils in China are largely unknown. The study described the temporal changes in soil inorganic N, C_{mic}, and N_{mic} in different 30-year-old pine plantations. The influence of tree species and grazing on the soil N pools within these plantations were also assessed.

MATERIALS AND METHODS

Site descriptions and experimental design

The study was conducted near the town of Zhanggutai (42° 43′ N, 122° 22′ E; altitude 226.5 m) located in Zhangwu County, Liaoning Province, southeastern Horqin Sandy Land, China. Historically, southeastern Horqin Sandy Land was a typical ecotone of silvapasture, but now it exhibits a mixed land use pattern that is semi-agriculture and semi-pasture. Much of the local ecosystems are currently degraded because of excessive cultivation and overgrazing. This area is viewed as a semi-arid region with sandy soil, low precipitation, and high evaporation (Jiang and Zhu, 2002). The annual precipitation averages 450 mm with most rainfall occurring between Jun. and Aug.; the mean annual evaporation capacity is 1300–1800 mm. The average annual wind speed ranges from 4.5 to 5.0 m s\(^{-1}\) and is prevalent in winter and spring. The mean annual temperature is 6.2 °C with a mean relative air humidity of 59%. The mean annual frost-free period is 150 days. Soils in this region were developed from wind-deposited sand and are characterized by coarse texture and loose structure with a greater proportion of sand; thus, the concentrations of soil C, N, and P are rather low. In Apr. 2004, three stands (30 m × 20 m) were selected in two 30-year-old Mongolian pine plantations and one 30-year-old Japanese red pine (Pinus densiflora Siebold et Zucc.) plantation. These three stands were evenly thinned by one third in the winter of 1999. One Mongolian pine stand (SF) was fenced after thinning to prevent human disturbance (e.g., grazing and litter raking); the other Mongolian pine stand (SUF) and the Japanese red pine stand (DUF) were unfenced and exposed to grazing and litter raking during the study. The topography is flat and there are 50 m buffer strips between the three stand types.

Sampling and analysis

Each stand was divided into six equal size plots (10 m × 10 m). Number and diameter at breast height (1.3 m) of all trees in each stand were measured. In addition, one average sized tree was selected in Apr. 2004 from each plot and its height was measured.

Forest floor samples, including standing understory, litter layer, and organic layer of soil, were collected from each plot in the fall of 2004. A 50 cm × 50 cm frame was randomly located within each
plot; the forest floor inside the frame was cut with scissors, carefully separated from the mineral soil, and placed in plastic bags. Samples were brought to the laboratory and sorted into litter (grass/forb, shrub, and pine) and duff. The pine fraction consisted of pine needles, cones, and twigs. All samples were dried at 70 °C for 48 h and weighed to estimate the forest floor mass and the standing understory. Stand characteristics of the three pine plantations are summarized in Table I.

**TABLE I**

Basic stand characteristics of three 30-year-old pine plantations in Zhanggutai sandy soil

<table>
<thead>
<tr>
<th>Stand</th>
<th>Species</th>
<th>Density</th>
<th>DBH(b)</th>
<th>Height</th>
<th>Biomass of floor</th>
<th>Management practice</th>
</tr>
</thead>
<tbody>
<tr>
<td>SF</td>
<td><em>Pinus sylvestris</em> var. <em>mongolica</em></td>
<td>850</td>
<td>14.35</td>
<td>8.01</td>
<td>8 000</td>
<td>Non-grazing</td>
</tr>
<tr>
<td>SUF</td>
<td><em>P. sylvestris</em> var. <em>mongolica</em></td>
<td>825</td>
<td>14.15</td>
<td>7.93</td>
<td>3 500</td>
<td>Free-grazing</td>
</tr>
<tr>
<td>DUF</td>
<td><em>P. densiflora</em></td>
<td>950</td>
<td>13.80</td>
<td>8.26</td>
<td>3 500</td>
<td>Free-grazing</td>
</tr>
</tbody>
</table>

a) SF = fenced Mongolian pine plantation; SUF = unfenced Mongolian pine plantation; DUF = unfenced Japanese red pine plantation.
b) Diameter at breast height.

Soil samples were randomly collected from each plot in the SF, SUF, and DUF stands. Sampling was conducted using polyvinyl chloride (PVC) tubes (4 cm inner diameter and 15 cm height) once a month from Apr. 16 to Oct. 16, 2004; soil sampling during the winter was not possible because soil was frozen. Soil samples were immediately brought to the laboratory, sieved (2 mm mesh screen), and stored at 4 °C in a refrigerator. Each soil sample was divided into two parts. One part under the field-moist condition was used for the measurement of inorganic N (NH$_4^+$-N plus NO$_3^-$-N), C$_{mic}$, and N$_{mic}$. The second part was oven-dried and used for the determination of pH, total N, organic matter, and soil dry weight.

Soil moisture was determined by the oven-dry method at 105 °C for 24 h. Soil pH was measured in a 1:2.5 mixture of soil and deionized water using a glass electrode. Bulk density was expressed in g cm$^{-3}$ using the weight of dry soil in a unit volume to a depth of 10 cm based on the soil cores. Soil organic C in samples was determined by dry combustion technique using a TOC-analyzer (TOC 5000A, Dimatec, Germany). Total N was determined by an automatic procedure using a rapid flow analyzer (AutoAnalyzer-3, manufacturer, Place) and NH$_4^+$-N was extracted by 2 mol L$^{-1}$ KCl and analyzed by the phenate method. Nitrate-N was measured by the phenoldisulphonic acid (PDSA) method, using 2 mol L$^{-1}$ KCl as the extractor. Inorganic N was calculated by the addition of NH$_4^+$-N and NO$_3^-$-N. Total P was determined by the molybdenum blue method following H$_2$SO$_4$-HClO$_4$ digestion. Soil C$_{mic}$ and N$_{mic}$ were determined by the chloroform fumigation extraction method (Brookes *et al.*, 1985; Vance *et al.*, 1987). Organic C in extracts was measured by dry or liquid combustion in a TOC-analyzer (TOC 5000A, Dimatec, Germany). C$_{mic}$ was calculated from the flush in K$_2$SO$_4$-extractable organic C following CHCl$_3$-fumigation with a proportionality factor of 0.38. Total N in the extracts was determined by an automatic procedure using a rapid flow analyzer (AutoAnalyzer-3) and N$_{mic}$ was calculated from the flush in K$_2$SO$_4$-extractable total N following CHCl$_3$-fumigation with a proportionality factor of 0.54.

A two-way analysis of variance (ANOVA) was conducted to test spatial and temporal effects. Differences between mean values were tested for significance by Tukey’s test ($P < 0.05$). All statistical analyses were done with SPSS 11.0 for Windows.

**RESULTS**

Soil properties

Physico-chemical characteristics of the three plantation stands indicated a high bulk density, neutral pH, and poor soil nutrient level (Table II). Soil bulk density, organic C, and C:N ratio in the Japanese
red pine plantation were higher than those in the Mongolian pine plantations, whereas, the reverse was true for total N. No differences in soil pH, total phosphorus, and N:P ratio among the three stands were found \((P < 0.05)\) (Table II).

### TABLE II

Soil properties of three 30-year-old pine plantations in Zhanggutai sandy soil

<table>
<thead>
<tr>
<th>Stand</th>
<th>Bulk density ((g \text{ cm}^{-3}))</th>
<th>pH</th>
<th>Organic C ((g \text{ kg}^{-1}))</th>
<th>Total N ((g \text{ kg}^{-1}))</th>
<th>Total P ((g \text{ kg}^{-1}))</th>
<th>C:N</th>
<th>N:P</th>
</tr>
</thead>
<tbody>
<tr>
<td>SF</td>
<td>1.62±0.01a,b,c</td>
<td>6.37±0.07a</td>
<td>3.90±0.14a</td>
<td>0.395±0.038a</td>
<td>0.101±0.007a</td>
<td>9.87±1.94a</td>
<td>3.91±0.98a</td>
</tr>
<tr>
<td>SUF</td>
<td>1.65±0.01a</td>
<td>6.67±0.05a</td>
<td>3.97±0.08a</td>
<td>0.415±0.006a</td>
<td>0.111±0.002a</td>
<td>9.57±2.17a</td>
<td>3.74±0.98a</td>
</tr>
<tr>
<td>DUF</td>
<td>1.68±0.02b</td>
<td>6.62±0.08a</td>
<td>4.73±0.57b</td>
<td>0.327±0.004b</td>
<td>0.082±0.005a</td>
<td>14.46±4.87b</td>
<td>3.99±0.54a</td>
</tr>
</tbody>
</table>

\(a)\) See Table I for the descriptions of SF, SUF, and DUF.

\(b)\) Mean±standard error \((n = 6)\).

\(c)\) Values followed by the same letter within a column are not significantly different at \(P < 0.05\), based on one-way analysis of variance and Tukey’s test.

**Ammonium-N**

The seasonal dynamics of \(\text{NH}_4^+\)-N (range from 0.11 to 0.99 \(\mu g \text{ g}^{-1}\)) in each stand followed a “low-high-low” trend during the period of Apr. to Oct. (Fig. 1, Table III). The tree species had no significant difference throughout the growing season (Tables III and IV). However, significant temporal differences in \(\text{NH}_4^+\)-N content among stands were observed from Apr. to Oct. \((P < 0.05, \text{Table III})\), i.e., SUF > SF = DUF from Apr. to Jul., SF > SUF = DUF in Aug., SUF > SF = DUF in Sep., and DUF = SUF > SF in Oct. (Fig. 1).

### TABLE III

ANOVA results for effects of stand and month on soil \(\text{NH}_4^+\)-N, \(\text{NO}_3^-\)-N, inorganic N, microbial biomass C (C\(_{\text{mic}}\)) and N (N\(_{\text{mic}}\)), and C\(_{\text{mic}}\):N\(_{\text{mic}}\) ratio for three 30-year-old pine plantations in Zhanggutai sandy soil

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>(\text{NH}_4^+)-N</th>
<th>(\text{NO}_3^-)-N</th>
<th>Inorganic N</th>
<th>C(_{\text{mic}})</th>
<th>N(_{\text{mic}})</th>
<th>C(<em>{\text{mic}}):N(</em>{\text{mic}})</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(F)</td>
<td>(P)</td>
<td>(F)</td>
<td>(P)</td>
<td>(F)</td>
<td>(P)</td>
</tr>
<tr>
<td>Stand</td>
<td>2</td>
<td>2.02</td>
<td>0.138</td>
<td>21.26</td>
<td>0.000</td>
<td>15.32</td>
<td>0.000</td>
</tr>
<tr>
<td>Month</td>
<td>6</td>
<td>16.28</td>
<td>0.000</td>
<td>31.06</td>
<td>0.000</td>
<td>12.99</td>
<td>0.000</td>
</tr>
<tr>
<td>S × M</td>
<td>12</td>
<td>2.64</td>
<td>0.004</td>
<td>1.88</td>
<td>0.046</td>
<td>2.06</td>
<td>0.026</td>
</tr>
</tbody>
</table>

**Nitrate-N**

The dynamics of \(\text{NO}_3^-\)-N (range from 0.17 to 1.87 \(\mu g \text{ g}^{-1}\)) in each stand fluctuated in a “high-low-high” pattern during the growing season (Fig. 1, Table III). There were significant temporal differences among stands.

### TABLE IV

Status of soil \(\text{NH}_4^+\)-N, \(\text{NO}_3^-\)-N, inorganic N, microbial biomass C (C\(_{\text{mic}}\)) and N (N\(_{\text{mic}}\)), and C\(_{\text{mic}}\):N\(_{\text{mic}}\) ratio for three 30-year-old pine plantations in Zhanggutai sandy soil over the whole growth season (from Apr. to Oct. 2004)

<table>
<thead>
<tr>
<th>Stand</th>
<th>(\text{NH}_4^+)-N</th>
<th>(\text{NO}_3^-)-N</th>
<th>Inorganic N</th>
<th>C(_{\text{mic}})</th>
<th>N(_{\text{mic}})</th>
<th>C(<em>{\text{mic}}):N(</em>{\text{mic}})</th>
</tr>
</thead>
<tbody>
<tr>
<td>SF</td>
<td>0.51±0.29a,b,c</td>
<td>0.74±0.51ab</td>
<td>1.25±0.51ab</td>
<td>82.09±5.07a</td>
<td>10.59±0.59a</td>
<td>7.70±0.14a</td>
</tr>
<tr>
<td>SUF</td>
<td>0.61±0.03a</td>
<td>0.93±0.06a</td>
<td>1.55±0.07a</td>
<td>82.04±4.93a</td>
<td>9.86±0.56a</td>
<td>8.27±0.17b</td>
</tr>
<tr>
<td>DUF</td>
<td>0.57±0.04a</td>
<td>0.47±0.06b</td>
<td>1.04±0.06b</td>
<td>73.77±4.09a</td>
<td>8.94±0.46b</td>
<td>8.22±0.15b</td>
</tr>
</tbody>
</table>

\(a)\) See Table I for the descriptions of SF, SUF, and DUF.

\(b)\) Mean±standard error \((n = 42)\).

\(c)\) Values followed by the same letter within a column are not significantly different at \(P < 0.05\), based on one-way analysis of variance and Tukey’s test.
in NO$_3^-$-N among the stands (Table III). The average NO$_3^-$-N content in growing season was in the order of SUF $\geq$ SF $\geq$ DUF (Table IV). No similar trends were observed in May and Oct. (Fig. 1).

Inorganic nitrogen

The dynamics of inorganic N (range from 0.70 to 2.59 $\mu$g g$^{-1}$) in each stand exhibited a similar “low-high-low” pattern during the growing season (Fig. 1, Table III). Like NO$_3^-$-N, there were significant temporal differences in inorganic N content among the stands (Table III). The average inorganic N value in growing season was in the order of SUF $\geq$ SF $\geq$ DUF (Table IV), whereas no similar trends among stands were found in May, Sep., and Oct. (Fig. 1).

In addition, NO$_3^-$-N was found to be the dominant form of inorganic N in the Mongolian pine plantations, whereas NH$_4^+$-N dominated in the Japanese red pine plantation according to the NH$_4^+$-N:NO$_3^-$-N ratio (0.69, 0.66 and 1.21 in SF, SUF, and DUF, respectively; Table IV).

Microbial biomass C

The dynamics of C$_{mic}$ (range from 40.02 to 128.86 $\mu$g g$^{-1}$) in the SUF and DUF showed a “low-high-low-high” trend, whereas the SF exhibited a “low-high-low” pattern from Apr. to Oct. (Fig. 1, Table III). Tree species had no significant difference through the growing season (Tables III and IV); however,
there appeared to be differences among stands in each month (Fig. 1). Further, ANOVA analysis showed insignificant temporal variations in C\textsubscript{mic} among the stands throughout the growing season (Table III).

**Microbial biomass N**

The dynamics of N\textsubscript{mic} (range from 5.42 to 15.20 μg g\textsuperscript{-1}) in each stand showed a “low-high-low-high” pattern from Apr. to Oct. (Fig. 1, Table III). Tree species had a significant effect on N\textsubscript{mic} throughout the growing season (Table III), and the average value from Apr. to Oct. was in the order of SF = SUF > DUF (Table IV), in spite of an inconsistent order for each month (Fig. 1). Stand-month interaction had an insignificant effect on N\textsubscript{mic} (Table III).

**The ratio of microbial biomass C to N**

Soil C\textsubscript{mic}:N\textsubscript{mic} was an important index reflecting N supply ability. The ranges of the C\textsubscript{mic}:N\textsubscript{mic} ratios for the SF, SUF, and DUF stands were 6.60–8.23, 7.01–9.56, and 7.00–9.28, respectively (Fig. 1). In general, the ratios in Apr. and Oct. for the three stands were low, moderate in May, Jul., and Sep., and high in Jun. and Aug. (Fig. 1). Tree species had a significant effect on the C\textsubscript{mic}:N\textsubscript{mic} ratio throughout the growing season (Table III). For C\textsubscript{mic}:N\textsubscript{mic} of each month, there were no differences in Apr., but, it was in the order of DUF ≥ SUF ≥ SF in May and Jul., and SUF = DUF > SF in Jun., Aug., Sep., and Oct. (Fig. 1). The average C\textsubscript{mic}:N\textsubscript{mic} ratio value from Apr. to Oct. decreased in the order of SUF = DUF > SF (Table IV). The stand-month interaction was not significant for the C\textsubscript{mic}:N\textsubscript{mic} ratio as well as for C\textsubscript{mic} and N\textsubscript{mic} (Table III).

**DISCUSSION**

**Interrelations among soil inorganic nitrogen, microbial biomass, and plants**

Information on available nutrient pools in soils, microbes, and plants is important for understanding nutrient cycling and ecosystem function. There have been many reports on the relationship between available soil N and N\textsubscript{mic}, especially in agricultural soils. Generally, soil N\textsubscript{mic} precedes NH\textsubscript{4}+\textsuperscript{-N} to NO\textsubscript{3}−\textsuperscript{-N} (Jackson et al., 1989; Recous et al., 1990). For example, Jansson et al. (1985) found that N\textsubscript{mic} primarily came from NH\textsubscript{4}+\textsuperscript{-N} and not from NO\textsubscript{3}−\textsuperscript{-N} during a straw decomposition study. Wickramasinghe et al. (1985) found that NH\textsubscript{4}+\textsuperscript{-N} restrained microbes from absorbing NO\textsubscript{3}−\textsuperscript{-N} and that few utilized NO\textsubscript{3}−\textsuperscript{-N} because microbes require energy for NO\textsubscript{3}−\textsuperscript{-N} absorption. Nevertheless, contradictory reports exist. For example, Bjarnason (1987) reported no difference in immobilization for NH\textsubscript{4}+\textsuperscript{-N} and NO\textsubscript{3}−\textsuperscript{-N}. It was deduced that the competition for NH\textsubscript{4}+\textsuperscript{-N} between microbes and plants depends on inorganic N content. This deduction is supported by the observation of a significant positive relationship between NO\textsubscript{3}−\textsuperscript{-N} and inorganic N (r = 0.87, P < 0.01, n = 21) (Table V).

Results from this study showed that NO\textsubscript{3}−\textsuperscript{-N} was the dominant form of inorganic N in the Mongolian pine plantations, whereas NH\textsubscript{4}+\textsuperscript{-N} dominated in the Japanese red pine plantation. The difference in nitrification inhibition is possibly because of the difference in content of phenolics in plant residues (Baldwin et al., 1983). Phenolic acids are very common compounds in the pedosphere. Phenolic acids desorbed from soil particle surfaces and remaining in solution phase can be utilized by microbes as carbon sources and absorbed by plants. However, Castells et al. (2004) discovered that although phenolic compounds leached from the canopy could change gross N mineralization and NO\textsubscript{3}−\textsuperscript{-N} immobilization, these effects did not seem relevant when considering the whole-plant effect on soil. Similar effects of
nonphenolic compounds and *Cistus* presence on soil N transformations suggest that nonphenolic rather than phenolic compounds are more important in soil N cycling.

The soil-microbe-plant relationship is generally considered as a whole system. Researchers have shown a good balance of N use between soils, microbes, and plants; that is, high inorganic N concentration during rapid plant growth and low inorganic N concentration and high microbial immobilization N during non-growing seasons (Fisk and Schmidt, 1996). Singh *et al.* (1989) studied the seasonal dynamics of soil N$_{\text{mic}}$ in an Indian tropical forest and grassland. They reported that soil N$_{\text{mic}}$ was high during droughts and hot summers because plant growth was limited, but microbial growth could still occur under limited water conditions, thereby still immobilizing N. Soil N$_{\text{mic}}$ was low during the rainy season (fall and winter) because of rapid plant growth and N uptake from soil. They suggested that temperature and plant growth were the major factors influencing soil N$_{\text{mic}}$ status. Garcia and Rice (1994) reported that soil N$_{\text{mic}}$ was high in a tall grass prairie during early spring, decreased when plant growth increased, and returned to high levels at the end of the growing season. However, Holmes and

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**TABLE V**

Pearson correlations (n = 21) among soil NH$_4^+$-N, NO$_3^-$-N, inorganic N, microbial biomass C (C$_{\text{mic}}$) and N (N$_{\text{mic}}$), and C$_{\text{mic}}$:N$_{\text{mic}}$ ratio for three 30-year-old pine plantations in Zhanggutai sandy soil over the whole growth season (from Apr. to Oct. 2004)

| Parameter        | NH$_4^+$-N | NO$_3^-$-N | Inorganic N | C$_{\text{mic}}$ | N$_{\text{mic}}$ | C$_{\text{mic}}$:N$_{\text{mic}}$
<table>
<thead>
<tr>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>NH$_4^+$-N</td>
<td>1.00</td>
<td>0.37</td>
<td>0.13</td>
<td>0.75**</td>
<td>0.64**</td>
<td>0.50*</td>
</tr>
<tr>
<td>NO$_3^-$-N</td>
<td>1.00</td>
<td>0.87**</td>
<td>0.13</td>
<td>0.53**</td>
<td>0.23*</td>
<td>0.42</td>
</tr>
<tr>
<td>Inorganic N</td>
<td>1.00</td>
<td>0.87**</td>
<td>1.00</td>
<td>0.53**</td>
<td>-0.18</td>
<td>0.23*</td>
</tr>
<tr>
<td>C$_{\text{mic}}$</td>
<td>1.00</td>
<td>1.00</td>
<td>0.95**</td>
<td>0.50*</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>N$_{\text{mic}}$</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>0.50*</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>C$<em>{\text{mic}}$:N$</em>{\text{mic}}$</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
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</tbody>
</table>

*, **Significant at $P = 0.05$ and $P = 0.01$, respectively.
Zak (1994) found soil $N_{mic}$ was stable throughout the entire year in a North American larch forest. In this study, both $C_{mic}$ and $N_{mic}$ increased from Sep. to Oct. (Fig. 1), although there was no cooperation of $N$ use among soils, microbes, and plants as described by others (Fisk and Schmidt, 1996). In addition, although the variation of $C_{mic}:N_{mic}$ ratio in the three stands was small, the ratio was high during the growing season and low during the non-growing season (Fig. 1). Further, there was a significant positive relationship between $NH_4^+$ and $C_{mic}:N_{mic}$ ratio ($r = 0.50$, $P < 0.05$, $n = 21$).

**Effects of tree species and grazing on soil inorganic $N$ and microbial biomass**

Plants affect ecosystem processes, including nutrient cycling, through a combination of morphological, phenological, physiological, and biochemical traits (Hobbie, 1992; Ehrenfeld and Scott, 2001). The growth form, residue quantity, residue chemical quality, and timing of both above-ground and below-ground plant growth influence the input of organic matter to the soil. Thus, activities of soil biota are responsible for $C$ and nutrient dynamics (Wedin and Tilman, 1990; Ehrenfeld and Scott, 2001). In this study, SUF was compared with DUF under similar management schemes (i.e., free-grazing). This comparison revealed that the means of soil NO$_3^-$-N, inorganic $N$, and $N_{mic}$ in SUF were higher than those in DUF, whereas no differences were found for soil $NH_4^+$-N, $C_{mic}$, and $C_{mic}:N_{mic}$ ratio (Table IV).

There are several reports on the effects of grazing on soil $N$ cycling in grasslands, but little information exists for plantation type ecosystems. Herbivores are an integral component of grasslands and at the ecosystem level influence nutrient transformation and translocation, nutrient flow rates, and nutrient availability because of feedbacks between plant responses to grazing and $N$ cycling (Holland et al., 1992; McNeil and Cushman, 2005). Grazing may also increase nutrient availability by maintaining a pool of readily mineralizable organic nutrients near the soil surface where it is more accessible to plants and microbes (Pastor and Naiman, 1992; Shariff et al., 1994; Ritchie and Tilman, 1995). Two major theories exist. Some researchers think that herbivores accelerate nutrient cycling (Ruess and McNaughton, 1987; Day and Detling, 1990; Holland et al., 1992; Steinauer and Collins, 1995), whereas, others think that herbivores have a decelerating effect on nutrient cycling (Bryant et al., 1991; Pastor and Naiman, 1992). These conflicting results suggest that the type of resource limiting plant growth may determine the effects of herbivores on $N$ cycling. If plant productivity is $N$-limited and dominant species are likely to have lower tissue $N$ (Hobbie, 1992), then herbivores may slow $N$ cycling. If dominant plants have high tissue $N$ to maintain efficiency in using other resources (e.g., water, light) and/or to tolerate herbivore activity in ways unrelated to tissue chemistry, then herbivores may accelerate $N$ cycling. In this study, soil $C_{mic}:N_{mic}$ ratio in SUF was greater than that in SF, although no differences in other indices were observed.

Coupling the two aforementioned aspects, it was concluded that the influence of tree species on inorganic $N$ and $N_{mic}$ were evident, in addition to the influence of gazing on soil microbial biomass characteristics. The tree species differences were most likely because of the differences in litter quality. Litterfall C:N ratio of *P. sylvestris* var. *mongolica* and *P. densiflora* was 80 and 110, respectively (data not shown). Whereas the differences because of management practices was predominantly the result of litter quantity. Grazing removed 50%–60% of the litterfall from the plantation.

**Ecological assessment of nutrient supply ability**

Soil physicochemical characteristics influence the level of microbial biomass and the activity of microorganisms. Seasonal changes in soil moisture, soil temperature, and C input from crop roots, rhizosphere products (i.e., root exudates, mucilage, sloughed cells, etc.), and crop residues can have a large effect on soil microbial biomass and its activity (Ross, 1987), which in turn, affect the ability of soil to supply nutrients to plants through soil organic matter turnover (Bonde and Roswall, 1987).

The ratio of $C_{mic}$ to organic carbon ($C_{mic}:OC$), which represents microbial biomass per organic carbon, was considered an important index that reflects soil microbial activity. The $C_{mic}:OC$ ratio in the SF, SUF, and DUF were 2.10%, 2.07%, and 1.56%, respectively. These results suggested that *P. 
densiflora improved soil quality more than *P. sylvestris* var. *mongolica*.

In addition, the ratio of N$_{\text{mic}}$ to total nitrogen (N$_{\text{mic}}$:TN) was considered to be an index that reflects the ability of the soil to supply N. A high N$_{\text{mic}}$:TN ratio represents a rapid N transformation and a high N supply ability. For example, Anderson and Domsch (1980) found that the N$_{\text{mic}}$:TN ratio ranged from 0.5% to 15.3%, with an average value of about 5%, in 26 types of agricultural soils. Azam et al. (1989) reported that the range of N$_{\text{mic}}$:TN ratio was 2.6% to 14.8% with an average value of 3.36%. The range of N$_{\text{mic}}$:TN ratio was 0.20% to 5.65% with an average value of 3.36% in a Loess Plateau (Zhou and Li, 1985). In this study, the N$_{\text{mic}}$:TN ratio in the SF, SUF, and DUF were 2.68%, 2.38%, and 2.73%, respectively. This indicated that the soil N supply ability was low in this study area. Furthermore, prohibition of grazing was advantageous to the improvement of soil N supply ability. The soil N supply ability in the *P. sylvestris* var. *mongolica* system was lower than that in the *P. densiflora* system.

To improve ecosystem stability and health in pine plantations, further study of soil N transformation processes and its regulating factors are required.

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