JOURNAL OF FOREST SCIENCE, *57*, 2011 (8): 340–348

Moisture effect on carbon and nitrogen mineralization in topsoil of Changbai Mountain, Northeast China

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ABSTRACT: Changbai Mountain Natural Reserve (1,985 km^2 and 2,734 m a.s.l.) of Northeast China is a typical ecosystem representing the temperate biosphere. The vegetation is vertically divided into 4 dominant zones: broad-leaved Korean pine forest (annual temperature 2.32°, annual precipitation 703.62 mm), dark coniferous forest (annual temperature –1.78°C, annual precipitation 933.67 mm), Erman's birch forest (annual temperature –2.80°C, annual precipitation 1,002.09 mm) and Alpine tundra (annual temperature –3.82°C, annual precipitation 1,075.53 mm). Studies of soil carbon (C) and nitrogen (N) mineralization have attracted wide attention in the context of global climate change. Based on the data of a 42-day laboratory incubation experiment, this paper investigated the relationship between soil moisture and mineralization of C and N in soils with different vegetation types on the northern slope of the Natural Reserve Zone of Changbai Mountain. The elevation influence on soil C and N mineralization was also discussed. The results indicated that for the given vegetation type of Changbai Mountain the C and N mineralization rate, potential mineralizable C (C_0) and potential rate of initial C mineralization (C_0k) all increased as the soil moisture rose. The elevation or vegetation type partially affected the soil C and N mineralization but without a clear pattern. The moisture-elevation interaction significantly affected soil C and NO_3^--N mineralization, but the effect on NH_4^+-N mineralization was not significant. The complex mechanism of their impact on the soil C and N mineralization of Changbai Mountain remains to be studied further based on data of field measurements in the future.

Keywords: soil moisture; soil C and N mineralization; incubation experiment; Changbai Mountain; Northeast China

A great deal of attention has been paid to soil respiration and soil carbon (C) mineralization for their significant impact on the global carbon cycle and terrestrial ecosystem (IPCC 2007; Jenkinson et al. 1991). Soil respiration is one of the largest carbon flux components within terrestrial ecosystems (Houghton, Wooswell 1989; Raich, Schlesinger 1992), as well as the second largest C flux between the atmosphere and the terrestrial biosphere (Schlesinger, Andrews 2000). The amount of carbon dioxide (CO_2) released from soils is 10 times higher than that from the fossil fuel combustion (Raich, Potter 1995). As the global temperature rises, the soil C pool will be stimulated to decompose and soil-to-atmosphere CO_2 will increase, especially in the high northern latitudes (Lee et al. 2006), due to the existence of terrestrial C sequestration of 1–2 Pg C per year in the Northern Hemisphere (Pacala et al. 2001).

Soil nitrogen (N) availability has significant influences on plant growth, thus limiting net primary productivity (Cole et al. 2008) through altering the efficiency of plant N use (Aerts et al. 1994), changing the composition of soil microbial communities, and affecting the biomass of microbial organisms and roots (Hu et al. 2001; Bradley et al. 2006). However, N availability is mainly determined by N mineralization through transforming organic N to inorganic form (Zhou et al. 2009). As the uptake of inorganic N by plants and soil microorganisms is significant for the net primary productivity in terrestrial ecosystems (Jaeger et al. 1999), N miner-

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Supported by National Natural Science Foundation of China, Grants No. 30800139, 40873067 and 30900208, and The Knowledge Innovation Program of the CAS, Project No. KZCX2-YW-Q1-0501.

alization is usually considered as a key process in these ecosystems (Ross et al. 2004).

Previous studies indicated that soil C and N mineralization was regulated by several environmental factors, such as temperature, moisture and oxygen content in soils (Wang et al. 2006; Xu et al. 2007). In recent decades, both field measurements and laboratory incubation data have been employed to illuminate relationships between soil C or N mineralization and soil moisture in different types of land use (Baumann et al. 2009; Zhou et al. 2009). Although studies regarding climate changes have focused on arctic, boreal or temperate ecosystems (Chapin et al. 1995; Dean, Johnson 2010; Deng et al. 2010; Liddle, Lung 2010), our knowledge of the effects of soil moisture on soil C and N mineralization in forests on Changbai Mountain, Northeast China is limited.

The primary objective of this paper was to determine the effect of soil moisture on mineralization of topsoil C and N. Secondly, we estimated potential mineralizable C in the surface layer of soils with different moisture levels in forests and tundra on Changbai Mountain.

METHODS

Study area

The study area is the Changbai Mountain Natural Reserve which is located on the border between China and North Korea (41°41'–42°51'N; 127°43' to 128°16'E). The area of the reserve is about 1,985 km^2 and the highest elevation is 2,734 m a.s.l.. The reserve, established in 1960, is a typical ecosystem representing the temperate biosphere. The vegetation cover displays a vertical pattern and is divided into 4 dominant zones along the elevation gradient, and soils change with altitude accordingly (Table 1).

A broadleaved Korean pine forest underlain by Alfisols is situated at elevations of 500–1,000 m a.s.l. It is primarily dominated by *Pinus koraiensis*, *Quercus mongolica*, *Acer mono*, *Tilia amurensis*, *Tilia manshurica*, *Ulmus propinqua*, *Fraxinus mandshurica*, *Abies holophylla* and *Betula costata*; the dominant shrub species are *Corylus mandshurica*, *Philadelphus schrenkii*, *Deutzia amurensis* and *Eleutherococcus senticosus*; the dominant herbage species are *Brachybotrys paridiformis*, *Cimicifuga simplex*, *Phryma leptostachya*, and *Impatiens nolitangere* (Yang, Xu 2003; Guo et al. 2006).

A dark coniferous forest on Andosols is situated at elevations of 1,100–1,700 m, dominated by the tree species *Picea jezoensis*, *Picea koraiensis* and *Abies nephrolepis*; the dominant shrub species are *Acer ukurunduense*, *Lonicera edulis* and *Evonymus pauciflorus*; and the dominant herbage species are *Maianthemum bifolium*, *Carex callitrichos*, *Solidago virgaaurea* var. *dahurica* and *Linnaea borealis*.

An Erman's birch forest underlain by Andosols is situated at elevations of 1,700–2,000 m, dominated by mountain birch (*Betula ermanii*). The dominant shrub species are *Lonicera edulis*, *Rhododendron chrysanthum*, *Vaccinium uliginosum*, and *Phyllodoce caerulen*. The dominant herbage species are *Cacalia auriculata* and *Sanguisorda tenuifolia* (Wang et al. 2004; Guo et al. 2006).

The Alpine tundra on Changbai Mountain on Andosols is situated across elevations of 1,950 to 2,700 m. It is dominated by *Vaccinium uliginosum*, *Vaccinium koreanum* and *Papaver radicatum* var. *pseudo-radicatum* (Dai et al. 2002; Guo et al. 2006). The physico-chemical properties of soils at the above four sites are shown in Table 1.

Table 1. The properties of soils on Changbai Mountain, NE China (Cheng et al. 1981; Chi et al. 1981; Zheng et al. 1984; Cui 1986; Zhao et al. 1992; Zhou et al. 2001; Wei et al. 2005; Zong 2010)

Elevation (m)	Vegetation type for soil sample	Soil		Annual		C:N ratio ($g \cdot g^{-1}$)	Base saturation (%)	Respiratory quotient	Topsoil water content (%)	pH	Organic matter (%)	Total N	
		type	texture	temperature (°C)	precipitation (mm)							($g \cdot kg^{-1}$)	(%)
800	Broadleaved Korean pine forest	Alfisols	Loam clay	2.32	703.62	11.5	68.17	1.27	60.60	6.70	8.79	1.25	0.075
1,600	Dark coniferous forest	Andosols	Silt loam	–1.78	933.67	16.7	34.87	1.18	60.30	5.80	8.50	0.93	0.063
1,800	Erman's birch forest	Andosols	Sandy loam	–2.80	1002.09	15.5	32.70	1.05	122.9	4.90	10.50	3.00	0.057
2,000	Alpine tundra	Andosols	Sandy loam	–3.82	1075.53	15.9	12.21	1.06	114.62	4.96	10.00	2.80	0.038

Soil incubation experiment

Soil samples were collected from the upper 0.2 m of the topsoil. At each site we took six randomly selected soil samples (approximately 100 g) and mixed them respectively to yield 4 final samples representing soils at different elevations and associated vegetation types. Soils were air dried, crushed, and sieved through a 2-mm sieve to remove small rocks, handpicked to remove fine roots, ground on a ball mill and finally adjusted to different water contents (20%, 40% and 60%, g water·g^{-1} soil) for an incubation experiment.

Soil C mineralization rates were measured by the method of Goyal et al. (1999). Soils with different water contents equivalent to 20 g of air-dried soil were aerobically incubated in 500 ml flasks (with covers) at 20°C for 42 days. We also set up 3 air-dried soil controls during the incubation period. A CO_2 trap with 10 ml of 0.1mol·l^{-1} NaOH was placed in each flask. At day 1, 2, 4, 7, 14, 21, 28, 35 and 42 of incubation, the evolved CO_2 trapped in NaOH was measured by titration with 0.05 mol·l^{-1} HCl after adding 2 ml of 0.25 mol·l^{-1}$BaCl_2$. The air in the flask was renewed with CO_2-free air before the CO_2 traps were replaced inside the flasks. Finally, the released CO_2 (mg·kg^{-1}) was calculated by the equation (1):

$$CO_2 = (V_0 - V) \times C \times 0.0222 \times 10^9/M \qquad (1)$$

where:

V_0 – volume of HCl consumed by air-dried soil controls (ml),

V – volume of HCl consumed by soil samples with different moisture levels (ml),

C – concentration of hydrochloric acid standard solution (mol·l^{-1}),

M – weight of air-dried soil (20 g in this study) (g).

The soil accumulative C mineralization quantity equalled the sum of soil released CO_2-C (g·air-dried soil^{-1}). The first-order decay model was used to simulate the relationship between the accumulative C mineralization quantity and incubation time (2):

$$C_m = C_0\,(1 - \mathrm{Exp}\,(-kt)) \qquad (2)$$

where:

C_m (CO_2-C mg·kg^{-1} soil) – quantity of CO_2-C released in time (days),

C_0 (CO_2-C mg·kg^{-1} soil) – quantity of soil potential mineralizable C,

k (day^{-1}) – constant of C mineralization rate,

C_0k – potential rate of initial C mineralization.

NO_3^--N was measured by the method of ultraviolet spectrophotometry and NH_4^+-N by the indophenol blue method. Indexes of N mineralization were calculated as follows (3)–(7):

$$R_n = R_1 + R_2 \qquad (3)$$

$$R_1 = c_m(NO_3^-\text{-N})/d \qquad (4)$$

$$R_2 = c_m(NH_4^+\text{-N})/d \qquad (5)$$

$$c_m(NO_3^-\text{-N}) = c_1(NO_3^-\text{-N}) - c_0(NO_3^-\text{-N}) \qquad (6)$$

$$c_m(NH_4^+\text{-N}) = c_1(NH_4^+\text{-N}) - c_0(NH_4^+\text{-N}) \qquad (7)$$

where:

R_n – net N mineralization rate (mg g^{-1}·day^{-1}),

R_1 – net nitrification rate (mg·g^{-1}·day^{-1}),

R_2 – net ammonification rate (mg·g^{-1}·day^{-1}),

d – incubation time (days),

$c_m(NO_3^-\text{-N})$ – quantity of mineralized NH_4^+-N (mg·g^{-1}),

$c_1(NO_3^-\text{-N})$, $c_0(NO_3^-\text{-N})$– content of NH_4^+-N (mg·g^{-1}) after and before incubation,

$c_m(NH_4^+\text{-N})$ – quantity of mineralized NH_4^+-N (mg·g^{-1}),

$c_1(NH_4^+\text{-N})$, $c_0(NH_4^+\text{-N})$ – content of NH_4^+-N (mg·g^{-1}) after and before incubation.

The two-way ANOVA followed by multiple comparisons (Duncan's test) was used to compare the differences in C and N mineralization indexes among different moisture and elevation levels, and the effects of interactions among different factors were also analysed. The one-way ANOVA followed by multiple comparisons (Duncan's) was employed to compare the differences in soil accumulative mineralized C of all the 12 treatments. The results were considered significant when $P < 0.05$. All data analyses and equation simulations were performed using SPSS 16.0 and Origin 8.0.

RESULTS

Soil C mineralization rate

Soil C mineralization rates of 6-week incubation were represented as soil CO_2 released every day (Fig. 1). During the second day of incubation, a CO_2 flux maximum was observed, and then the soil C mineralization rates decreased and finally reached a steady state for all treatments.

The significant values of ANOVA analysis (univariate analysis of GLM program) showed that on all days of incubation both the soil moisture and elevation significantly affected the rates of soil C mineralization during the period of incubation

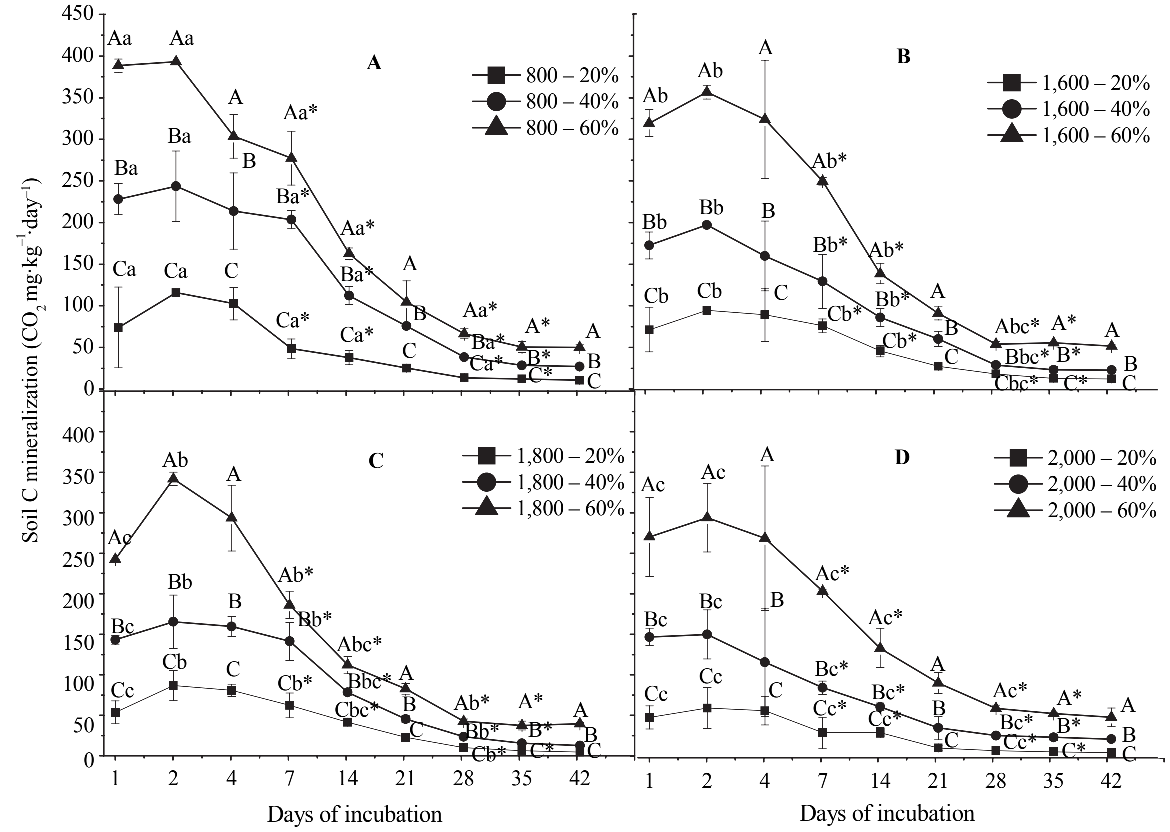

Fig. 1. The effect of soil moisture on rates of soil C mineralization by elevation and soil moisture level on Changbai Mountain in NE China

Elevation (m): A: 800; B: 1,600; C: 1,800; D: 2,000; Soil moisture levels: 20%; 40%; 60%

The error bars represent the standard deviation values of three replications for each treatment; capital letter values are Duncan groups of the factor elevation; small letter values are Duncan groups of the factor soil moisture; the symbol "*" means that the moisture-elevation interaction is significant

experiment, the interaction existed only between moisture and elevation (Table 2).

The results of two-way ANOVA showed that the differences among 3 moisture levels were significant every day, whereas those among 4 elevation levels were significant just at day 1, 2, 7, 14 and 28, and the moisture-elevation interaction existed only at day 7, 14, 28 and 35. GLM results also showed that soil moisture was the most effective factor for daily rates of soil C mineralization, followed by elevation, while the moisture-elevation interaction was the least effective (not shown in this paper). Soil C mineralization rates increased as soil moisture rose within soil water contents of 20–60% (g·g^{-1}). CO_2 flux curves for soil moisture treatments of the same elevation did not cross each other (Fig. 1).

Soil accumulative C mineralization quantity

The results of one-way ANOVA showed that the differences in the quantity of soil accumulative C mineralization among all the 12 treatments were significant. In our incubation experiment, moisture was the key factor controlling soil C mineralization (Fig. 2).

For each of the four soils at different elevations (with their corresponding vegetation types), the treatments with 60% soil water content (g·g^{-1}) ac-

Table 2. Significance of the values of ANOVA analysis for C mineralization

Day	Moisture	Elevation	Day × Moisture	Day × Elevation	Moisture × Elevation	Day × Moisture × Elevation
*	*	*	ns	ns	*	ns

ns – not significant; *significant

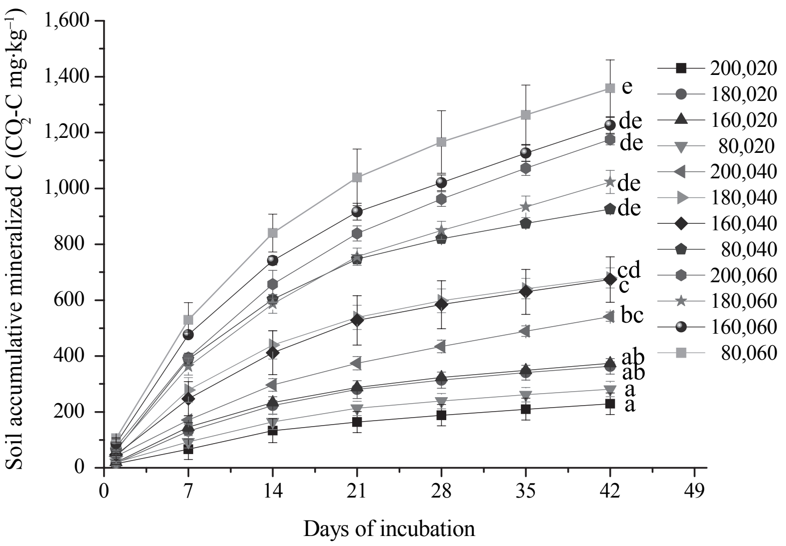

Fig. 2. The effect of soil moisture on the quantities of soil accumulative mineralized C

The error bars represent the standard deviation values of three replications for each treatment; the letters behind each curve are Duncan groups of all the 12 soil accumulative mineralized C curves

cumulated more mineralized C than the others, while those with 20% soil water content ($g\cdot g^{-1}$) accumulated the lowest quantity of mineralized C (Fig. 2). However the trend was not consistent at each moisture level. At soil moisture of 40% ($g\cdot g^{-1}$) and 60% ($g\cdot g^{-1}$), C mineralization quantities of soils from 800 m were higher than those of soils form 2,000 m. But it was not the case when the soil moisture was very low [20% ($g\cdot g^{-1}$)]. The accumulative C mineralization curves of soils form 1,600 m and 1,800 m overlapped partially at moisture levels of 20% ($g\cdot g^{-1}$) and 40% ($g\cdot g^{-1}$), whereas they were clearly separated at soil moisture of 60% ($g\cdot g^{-1}$).

Soil C mineralization simulation

For a given elevation and its associated vegetation type, potential mineralizable C (C_0) increased with an increase in soil water content (Table 3). To some extent, C_0 was also affected by the elevation or vegetation type. For example, C_0 decreased as the elevation increased at soil water content of 40%, while the C_0 difference of soils at the elevation of 1,600 m and 1,800 m was not significant. However, this trend was not suitable for C_0 at water contents of 20% and 60%. At 20% water content, as the elevation increased, C_0 increased initially, then it

Table 3. Results of soil C mineralization simulations

Elevation (m) – soil water content (%)	C_0	k	C_0k	R^2
800 – 20	317.03 ± 15.29^{Aa*}	0.052 ± 0.009^{a*}	16.51 ± 3.45^{Aa*}	0.994 ± 0.003
800 – 40	961.40 ± 16.97^{Ba*}	0.071 ± 0.005^{a*}	68.55 ± 3.66^{Ba*}	0.999 ± 0.001
800 – 60	1,377.17 ± 49.39^{Ca*}	0.063 ± 0.002^{a*}	89.98 ± 10.01^{Ca*}	0.997 ± 0.003
1,600 – 20	396.88 ± 20.57^{Ab*}	0.063 ± 0.008^{a*}	25.03 ± 2.06^{Ab*}	0.997 ± 0.002
1,600 – 40	729.73 ± 60.35^{Bb*}	0.060 ± 0.011^{a*}	43.82 ± 11.46^{Bb*}	0.998 ± 0.001
1,600 – 60	1,293.54 ± 45.24^{Cb*}	0.060 ± 0.002^{a*}	78.04 ± 0.89^{Cb*}	0.995 ± 0.003
1,800 – 20	396.94 ± 11.34^{Ac*}	0.058 ± 0.011^{a*}	23.11 ± 4.85^{Ab*}	0.997 ± 0.0001
1,800 – 40	712.92 ± 14.11^{Bc*}	0.068 ± 0.011^{a*}	48.91 ± 8.58^{Bb*}	0.999 ± 0.001
1,800 – 60	1,124.75 ± 28.17^{Cc*}	0.053 ± 0.002^{a*}	59.37 ± 3.97^{Cb*}	0.997 ± 0.001
2,000 – 20	272.88 ± 11.05^{Ac*}	0.057 ± 0.008^{b*}	15.40 ± 1.60^{Ac*}	0.993 ± 0.001
2,000 – 40	633.74 ± 48.25^{Bc*}	0.044 ± 0.007^{b*}	27.72 ± 2.99^{Bc*}	0.995 ± 0.004
2,000 – 60	1,335.65 ± 26.47^{Cc*}	0.048 ± 0.005^{b*}	63.71 ± 4.91^{Cc*}	0.997 ± 0.001

The values behind "±" are the standard deviations of three replications for each treatment; capital letter values are Duncan groups of the factor elevation (the same values represent a Duncan group); small letter values are Duncan groups of the factor soil moisture (the same values represent a Duncan group); the symbol "*" means that the moisture-elevation interaction is significant

Table 4. The Effect of soil moisture on soil N mineralization

Elevation (m) – soil water content (%)	$c_m(NO_3^-\text{-}N)$	$c_m(NH_4^+\text{-}N)$	R_1	R_2	R_n
	(mg·g^{-1})			(mg·g^{-1}·day^{-1})	
800–20	$0.033 \pm 0.00082^{Aa*}$	1.941 ± 0.038^{Aa}	$0.00076 \pm 1.91E\text{-}5^{Aa*}$	0.046 ± 0.0009^{Aa}	0.046 ± 0.00086^{Aa}
800–40	$0.054 \pm 0.00046^{Ba*}$	2.956 ± 0.152^{Ba}	$0.0012 \pm 1.07E\text{-}5^{Ba*}$	0.067 ± 0.0035^{Ba}	0.070 ± 0.0035^{Ba}
800–60	$0.097 \pm 0.00464^{Ca*}$	4.164 ± 0.252^{Ca}	$0.0023 \pm 0.00011^{Ca*}$	0.097 ± 0.0059^{Ca}	0.099 ± 0.0058^{Ca}
1600–20	$0.026 \pm 0.0075^{Ab*}$	1.985 ± 0.30^{Aa}	$0.00060 \pm 0.00017^{Ab*}$	0.051 ± 0.0070^{Aa}	0.047 ± 0.0068^{Aa}
1600–40	$0.047 \pm 0.0033^{Bb*}$	2.870 ± 0.21^{Ba}	$0.0011 \pm 7.88E\text{-}5^{Bb*}$	0.065 ± 0.0049^{Ba}	0.068 ± 0.0048^{Ba}
1600–60	$0.079 \pm 0.0023^{Cb*}$	4.170 ± 0.49^{Ca}	$0.0018 \pm 5.44E\text{-}5^{Cb*}$	0.096 ± 0.0023^{Ca}	0.099 ± 0.011^{Ca}
1800–20	$0.026 \pm 0.0036^{Ac*}$	2.207 ± 0.039^{Aa}	$0.00060 \pm 8.34E\text{-}5^{Ac*}$	0.029 ± 0.0009^{Aa}	0.052 ± 0.00082^{Aa}
1800–40	$0.032 \pm 0.00015^{Bc*}$	2.782 ± 0.013^{Ba}	$0.00075 \pm 3.40E\text{-}6^{Bc*}$	0.039 ± 0.0003^{Ba}	0.065 ± 0.00030^{Ba}
1800–60	$0.054 \pm 0.0020^{Cc*}$	4.149 ± 0.44^{Ca}	$0.0012 \pm 4.59E\text{-}5^{Cc*}$	0.063 ± 0.010^{Ca}	0.098 ± 0.010^{Ca}
2000–20	$0.037 \pm 0.0014^{Aa*}$	1.257 ± 0.076^{Ab}	$0.00085 \pm 3.31E\text{-}5^{Aa*}$	0.045 ± 0.0018^{Ab}	0.030 ± 0.0018^{Ab}
2000–40	$0.055 \pm 0.0011^{Ba*}$	1.680 ± 0.0082^{Bb}	$0.0013 \pm 2.66E\text{-}5^{Ba*}$	0.069 ± 0.00020^{Bb}	0.040 ± 0.00022^{Bb}
2000–60	$0.090 \pm 0.0059^{Ca*}$	2.724 ± 0.037^{Cb}	$0.0021 \pm 0.00014^{Ca*}$	0.097 ± 0.00086^{Cb}	0.065 ± 0.00073^{Cb}

R_1 – net nitrification rate; R_2 – net ammonification rate; R_3 – net N mineralization rate
The values behind "±" are the standard deviations of three replications for each treatment; capital letter values are Duncan groups of the factor elevation (the same values represent a Duncan group); small letter values are Duncan groups of the factor soil moisture (the same values represent a Duncan group); the symbol "*" means that the moisture-elevation interaction is significant

kept stable and finally it decreased at the elevation of 2,000 m. At 60% water content, the trend was a decrease at first, then it kept stable and increased at the elevation of 2,000 m. Elevations of 800 and 2,000 were the source of differences in C_0, k and C_0k (Table 3).

The change of the potential rate of initial C mineralization (C_0k) was similar to C_0, which is controlled by soil moisture, and affected by elevation or vegetation type to some extent. Although the moisture significantly affected C_0 and C_0k, its effect on the constant of C mineralization rate (k) was not significant, while differences among 4 elevations were significant. C mineralization rates of soils with low moisture changed less than those with high moisture. Based on their effects on k and C_0k, the 4 elevation levels could be divided into 3 groups, i.e. 800 m, 1,600–1,800 m, and 2,000 m. The moisture-elevation interaction existed in C_0, k and C_0k, but its effects were smaller than those of moisture or elevation except for k (Table 3).

Soil N mineralization rate

Net N, NH_4^+-N and NO_3^--N increased as a result of the incubation experiment, which agreed with the results of Li et al. (1995). Generally, both quantities and rates of NH_4^+-N mineralization were higher than those of NO_3^--N for each treatment. Soil moisture affected N mineralization significantly. For a given vegetation type, both quantities and rates of soil net N, NH_4^+-N and NO_3^--N increased as the soil moisture increased (Table 4).

DISCUSSION AND CONCLUSION

Soil C mineralization

The CO_2 flux maximums on the second day of the incubation period agree with the results of incubation experiment in a study of CO_2 emissions from Ultisol in mid-subtropical China (Iqbal et al. 2009). Considering the existence of active and slow pools for soil organic carbon (SOC) (Zhang et al. 2007), we prudently attributed the rapidly released CO_2 of the early incubation stages to the active SOC pool. C mineralization gradually slowed down to the point of a virtual steady state, because the slow SOC pool dominated the mineralization process as the active one was exhausted.

The relationship between soil moisture and C mineralization was reflected in an increase in the rate of the latter as the water content rose within a specific moisture range, whereas higher or lower soil moisture levels would inhibit C mineralization (Wang et al. 2003).

The average field water content of soils on Changbai Mountain was found to be 60% (Zhou, Ouyang 2001), and the inhibition water content level was approximately 20% (Liu, Fang 1997). Our data showed that within this moderate moisture regime, both the rate and the quantity of soil C mineralization increased with increasing moisture for soils of a given elevation/vegetation type. (Figs. 1 and 2). This agrees with Wang et al. (2003). Since a 20% moisture level was closer to the inhibition level, treatments with 20% water content did not change very much during the 42-day incubation period. Elevation and associated vegetation type partially influenced soil C mineralization, since the latter was strongly regulated by the activity of soil microbial activity, which was affected by soil pH, soil texture and other factors influencing the soil nutrient status (Guo, Gifford 2002). Generally, low pH contributed to lower C mineralization. Our data showed a similar trend (Table 1, Figs. 1 and 2). But the relationship between soil C mineralization and elevation was not exact, suggesting that the regulation process of C mineralization is complex and might be co-regulated by other factors such as SOC and total N content of soils (Guo, Gifford 2002).

At the end of the incubation experiment, the quantities of accumulative C mineralization varied from 229.52 to 1358.39 CO_2-C mg·kg^{-1} (Fig. 2), which is within the previously reported ranges (Zhuge et al. 2005; Wang et al. 2007). Potential mineralizable C (C_0) and potential rate of initial C mineralization (C_0k) were also controlled by soil moisture for a given elevation/vegetation type in this study. This may be due to the fact that the soil water content could alter microbial conditions and ultimately affect C_0 and C_0k. According to the effect on k and C_0k, we divided the 4 elevation levels into 3 groups 800 m, 1,600–1,800 m and 2,000 m, which was similar to the groups of soil organic matter of those 4 elevations (Table 1). The partial influence of elevation and associated vegetation type and the effect of moisture-elevation interaction on C_0 and C_0k indicated that the environmental effect on C_0 and C_0k was complex and deserves further study in the future.

Soil N mineralization

Most of the previous studies showed that NH_4^+-N and NO_3^--N increased during the incubation period (Li et al. 1995; Zhou, Ouyang 2001). Our data agreed with those results. Comparatively, the quantities of mineralized NH_4^+-N were higher than those of NO_3^--N in this paper (Table 4), which agreed with the studies of Zhou et al. (2001), who indicated that the main source of inorganic N was NH_4^+-N for forests on Changbai Mountain. Our data showed a positive correlation between soil moisture and soil N mineralization, which agreed with most of the previous studies that soil N mineralization was determined by soil moisture (Li et al. 1995; Zhou, Ouyang 2001).

Some previous reports argued that the soil N mineralization rate increased as the elevation rose (Hart, Perry et al. 1995; Zhuang et al. 2008). However, those studies were mainly limited in field research and the temperature of different elevations often dominated the mineralization process in those studies. Our data of laboratory studies showed that the elevation partially affected N mineralization but without a clear pattern, because instead of the temperature the soil moisture became a dominant factor for N mineralization in this paper. On the other hand, soil N mineralization was related to soil pH, since the optimum pH for nitrification microbes was about 8.0 (Robinson 1963). Net N mineralization rates generally decreased as the elevation increased and soil pH decreased. The moisture-elevation interaction affected mainly NO_3^--N mineralization rate, maybe NO_3^--N was more sensitive to environmental factors. However, the difference in N mineralization between forests and Alpine tundra demonstrated that plants, especially trees, may indirectly influence soil N mineralization. Zhou and Ouyang (2001) found that within water content of 46–54%, the N mineralization rates increased as moistures rose for two types of soils on Changbai Mountain. Zhuang et al. (2008) reported that N mineralization quantities increased as elevations rose for soils on Tatachia, Taiwan. Therefore, soil moisture and elevation might influence the soil N mineralization significantly. However, our study showed that soil N mineralization was determined by soil moisture, and elevation was an indirect factor that might impact soil N mineralization through different moisture and pH levels.

Our experiment demonstrated that soil C and N mineralization is strongly impacted by soil moisture during the 42-day incubation experiment while temperature is maintained at 20°C. For the given vegetation type of Changbai Mountain, soil C and N mineralization rate, potential mineralizable C (C_0) and potential rate of initial C mineralization (C_0k) all increased as the soil moisture rose. Both

NH_4^+-N and NO_3^--N increased after the incubation experiment. Comparably, both quantities and rates of NH_4^+-N mineralization were higher than those of NO_3^--N for each soil moisture treatment. Elevation or vegetation type partially affected rates of soil C and N mineralization. According to the effect on k and C_0k, the 4 elevation levels could be divided into 3 groups, i.e. 800 m, 1,600–1,800 m, and 2,000 m. By the effect on net N mineralization rate, the 4 elevation levels could be divided into 2 groups, i.e. forests (elevation 800–1,800 m) and Alpine tundra (elevation 2,000 m). The moisture-elevation interaction significantly affected soil C and NO_3^--N mineralization, but the effect on NH_4^+-N mineralization was not significant. The complex mechanisms of soil C and N mineralization of Changbai Mountain should be investigated by our continued studies in the future.

Acknowledgements

We would like to thank Dr. Bernard J. Lewis at University of Missouri for editing assistance.

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Received for publication June 3, 2010
Accepted after corrections May 17, 2011

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