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Soil Respiration Rate on the Contrasting North- and South-Facing Slopes of a Larch Forest in Central Siberia

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Abstract

In an attempt to evaluate global warming effects, we measured the soil respiration of the contrasting north- and south- facing slopes of a larch forest in central Siberia, located at Tura City in the Krasnoyarsk District, Russia. The north-facing slope is assumed to be the present condition while the south-facing slope may stand for the future warm condition. As a result of differences in solar radiation, there were clear differences between the north- and south- facing slopes in terms, for example, of the active layer as the growth rate of larch trees. The soil respiration rate was higher on the south-facing slope than on the north-facing slope. At the temperature of 15°C, soil respiration rate of the south-facing slope was ca. 6.2 $\mu mol CO_2.m^{-2}s^{-1}$, which was about 0.6 times lower than that of broad-leaved forests in Hokkaido. There was an exponential correlation between soil temperature at 10 cm depth and the efflux of CO_2 from the soil surface. Various conditions (soil temperature, nitrogen content and soil water content) seemed to be more favorable for soil respiration on the south-facing slope.

Key words: Soil respiration, Central Siberia, North and south facing slope, Nitrogen content, Root biomass

Introduction

The atmospheric CO_2 concentration is increasing yearly, inducing global greenhouse conditions. On a global scale, seasonal decreases in atmospheric CO_2 concentrations coincide with the growing seasons in the Northern Hemisphere. The Siberian Taiga covers the eastern Eurasian Continent, and this area is considered to be a major terrestrial carbon sink (Tans *et al.* 1990; Ciais *et al.* 1995, Schulze *et al.* 1995, 1999). Therefore, many studies have been carried out to evaluate the capacity of CO_2 fixation and storage (Schulze *et al.* 1999, Wirth *et* 1999), and CO_2 flux in Siberian forested ecosystem (Hollinger *et al.* 1998). However, most of the studies had hardly examined the estimation of soil respiration, maybe because of some methodological difficulties in keeping processes of natural CO_2 diffusion etc. (Koizumi *et al.* 1991, Bekku *et al.* 1995). Recently, it has become appeared that an understanding of carbon efflux is necessary if we are understand the role of forest soil as a source of the carbon evolution and as a carbon pool.

In larch stands in central Siberia, the carbon allocation below ground is higher than that in other boreal and subalpine conifer forests (Kajimoto *et al.* 1999). Therefore, the carbon efflux, released from the soil as CO_2 should be evaluated in order to help us predicting the extend of global changes. We predicted that biological activities on a north-facing slope would be lower than those on a south-facing slope because of a lower soil temperature and a shallow permafrost table. In facts, photosynthetic rate and nutrient level of the south-facing slope were 1.3 time higher than those of north-facing slope in central Siberia (Koike *et al.* 1998, 1999). Ambient temperature in high latitude is predicted to increase 3 to 5°C in future greenhouse condition (IPCC 1995). Wit use of the contrasting north- and south-facing slope in central Siberia, it is predicted that different soil respiration rate would be detected due to different soil temperature and nutrient condition at the both slopes. The north facing slope is assumed to be the present condition while the south-facing slope may show the future warm condition (Kojima 1994, Koike *et al.* 1998).

To test our prediction, we selected contrasting north- and south-facing slopes in a larch forest in central Siberia and measured the soil respiration rate, the amount of roots and the nitrogen concentration on both slopes. From our results, we suggest a relationship between the

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soil respiration rate and micro-environmental conditions.

Material and Methods

1) Study site

The study site was located near the western edge of a continuous permafrost region in central Siberia (64°19' N, 100°13' E; 200 m a.s.l.). The site was located in the Tura Experimental Forest near Kochechom River in the Krasnoyarsk District, Russia. Larch forests faced each other on the north- and south-facing slopes (Fig. 1). The soil samples were also obtained at the Putorana Mountain (68°N, 100°E, 300 m a.s.l.)

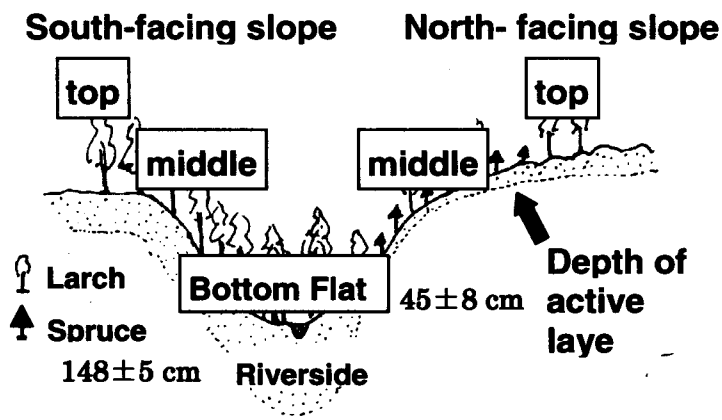


Fig. 1. Schematic representation of the landscape at the study site

Table 1. Summary of the characteristics of the study site

	South-facing slope	North-facing slope
Vegetation	*Vaccinium* sp., *Betula*. sp.	Lichen, *Picea* sp., *Ledum* sp.
Photosynthetic rate	High	Low
Growth	Fast	Slow
Depth of active layer	120~150 cm	30~50 cm

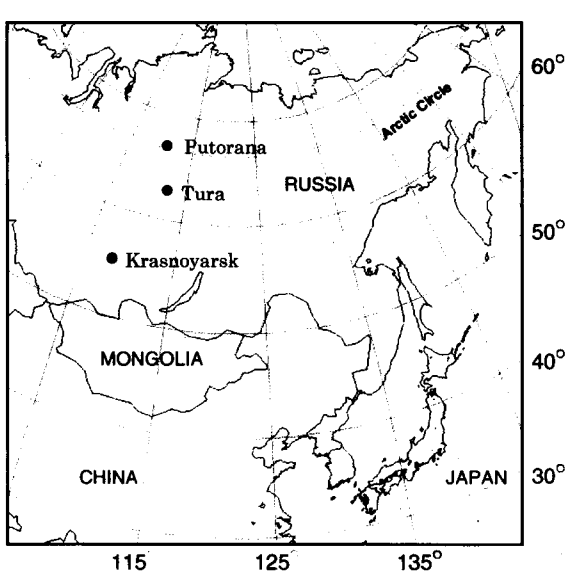


Fig. 2. Map of the study site.

where the "Table mountain" was well developed (Photo 1; Fig. 2), which results are added as an appendix part.

With respect to growing conditions, the landscape on the north- and south-facing slopes was very different in terms, for example, of the thickness of the active layer and the ground vegetation (Table 1, Appendix). The north-facing slope was covered with lichens and mosses, in contrast the south-facing slope was characterized by the evergreen Ericaceae shrubs (Photo 2).

Description of soil profile was as follows; Thick moss and lichen layer (10 to 20 cm) developed on the soil surface in the north-facing slope, on the other hand, dense Ericacious shrubs (mainly *Vaccinium vitis-idaea*) developed on the south-facing slope, without moss layer. Soil type of the study sites was classified into Pale Yellow soils by Russian system (Yershov

A： Over view of the "Table mountain"

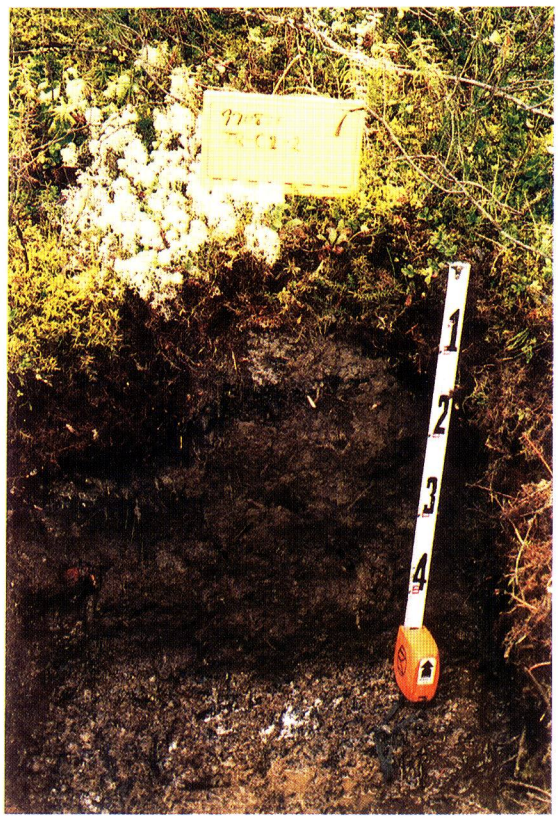
B： A view of vegetation on the "table" with young larch

C： Edge of the "table"

Photo 1. A view of the Putorana mountain

A : North-facing slope

B : South-facing slope



C : Soil profile at the north-facing slope with permafrost

D : Soil profile at the south-facing slope (depth was 130cm)

Photo 2. North- and south-facing slope at the Tura

1995, 1996), or Gelic Cambisols in FAO system (Rieger 1983). Soil profiles on the north-facing slope showed shallow permafrost table, ranging from ca. 30 cm to 60 cm, with thin A horizon. Biological activity seemed to differ between the north- and south-facing slopes because of micro-topographical differences. Koike *et al.* (1998) previously discussed shoot growth and the photosynthetic characteristics of larch on these same slopes.

2) Measurement of soil respiration rates

We measured soil respiration rates per area on the north-facing slope, in the bottom flat and on the south-facing slope of the study site using a portable gas analyzer (LI-6200; LiCor, Lincoln, NE, U.S.A). The analyzer had a closed air-circulation system, which enhanced the accuracy of measurements. We also measured the soil temperature at 5 cm and 10 cm below the surface. Soil respiration rate per area was calculated following function (LI-COR 1997);

$$Sr = kPV / SA(T + 273)[(\delta C/\delta t + C/(1000-W)\ \delta W/\delta t]$$

where Sr is soil respiration rate ($\mu mol.m^{-2}s^{-1}$), k = 1.2028 (constant), P is atmospheric pressure (Kpa), V means total system volume (cm^3), SA means enclosed surface area of soil (cm^2), T is air temperature (°C) in the chamber, C stands for CO_2 concentration ($\mu mol.mol^{-1}$), t means the time (min.) and W is H_2O concentration ($mmolH_2O.mol^{-1}$).

In order to access different soil respiration rate, soil core samples (20 cm^2 x 5 cm) at each sampling point were immediately obtained after the measurements. Replication of measurement of soil respiration was 5 to 6 times per each study point. Soil core samples were also sampled from the depth of 10 cm for the north-facing slope and 80 cm for the south-facing slope for comparison of different condition. We separated roots and organic matter including humus from the soil core samples at three depths (5, 10, 15 cm) to evaluate the amount of roots on the two slopes.

3) Laboratory analysis

Using the soil samples (ca. 10 cm^3 each) obtained from the north-, south-facing slopes, the burnt site in 1994 at the Tura Experiment Forest and the study site of Putorana mountain, we tried to measure the dependence on temperature of the soil respiration rate. We placed two cores at least from each study point. We put one set of soil core samples in the chamber and warmed them from 5°C to 45°C to measure the soil respiration rate. It took for 5-10 minutes to measure soil respiration rate. During the camber was warmed upto the decided temperature, the soil samples were wrapped in plastic bags to keep soil moisture content. The temperature of the samples was measured with a thermometer inserted in the center of the core sample. The water content of the rest sample of soil cores was determined as following formula;

Soil water content (%) = (FM – DM) / FM x 100,

where FM means fresh mass of core (g) and DM is dry mass of core.

All measurements were carried out during August 3-6, 1999, except for nitrogen analysis. After the transporting soil samples to Japan, we also determined total nitrogen content of soil core samples (ca. 10 cm^3 each) by dry combustion under circulating oxygen using an analyzer (Sumigraph NC-800, Sumica, Osaka, Japan).

Results

1) Soil respiration rates at the north- and south-facing slope

The soil respiration rate was highest on the middle part of the south-facing slope and lowest at the top of the north-facing slope. Figure 3 shows the CO_2 efflux rates for the north- and south-facing slopes and the bottom flat. The trend reflected the larger amount of solar radiation on the south-facing slope. At the temperature of 15°C, soil respiration rate of the south-facing slope was ca. 6.2 $\mu molCO_2.m^{-2}s^{-1}$. However, most temperature regime of the north-facing slope was less than 9°C and soil respiration data was scattered. Thus, we could not infer the absolute value of soil respiration of the north-facing slope because of quite limited number of measurement. Root amounts on the south-facing slope were larger than on the north-facing slope (Fig. 4). The amount of litter or organic matter including humus at the soil surface (0-5 cm) on the south-facing slope was largest.

2) Relationship between the temperature and the soil respiration rate of soil

The relationship between soil temperature (at 10 cm depth) and soil respiration rate is shown in Figure 5. There was no difference in CO_2 efflux of soil surface between the north- and south-facing slope at the temperature range from 5.5 °C to 17.8°C. On the south-facing slope, the soil respiration rate was correlated with soil temperature ($R=0.821$, $P<0.001$). A similar tendency was found in the bottom flat. On the north-facing slope, by contrast, there was no clear relationship between the soil temperature and soil respiration rate. We found earthworm in the core soil sample (marked with asterisk, *) obtained from north-facing slope and bottom flat. However, we could not find these earthworms

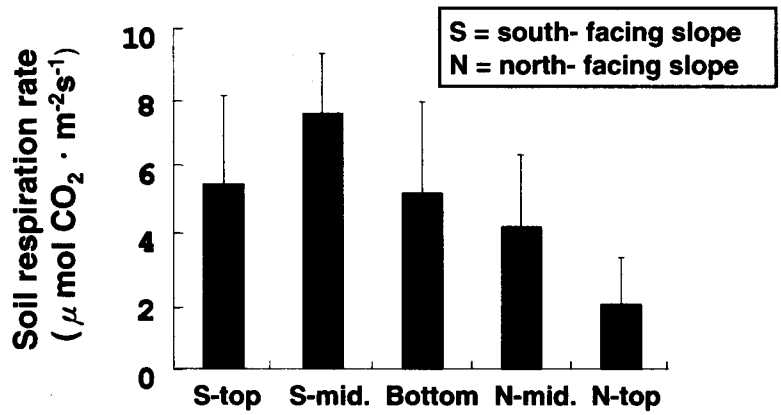


Fig. 3. Soil respiration rate at various sites.

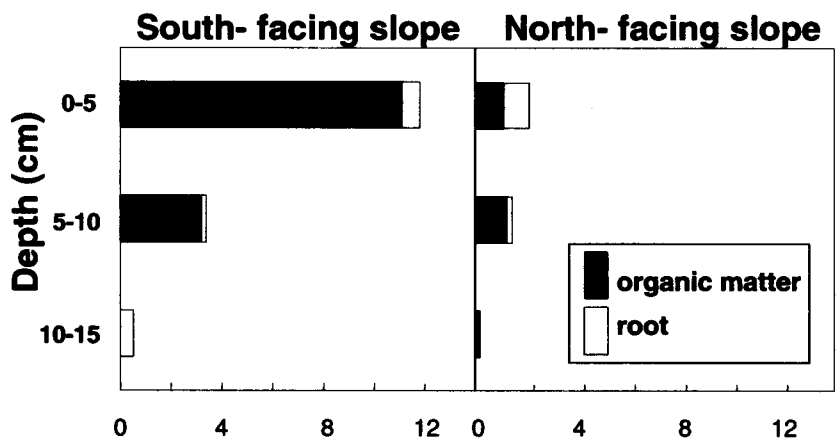


Fig. 4. The amount of root and humus at the three depth of the north- and south-facing slope

during the field measurement.

3) Laboratory analysis of soil sample

We examined the relationship between soil respiration and soil temperature in the laboratory. With samples from the north- and south-facing slopes, the soil respiration rate increased exponentially with soil temperature (Fig. 6). Soil respiration rates of the core sample from the south-facing slope (south soil) were higher than those of the core sample from the north-facing slope (north soil).

Soil water content was highest on the north-facing slope (Fig. 7) and lowest on the south-facing slope. The nitrogen content of soil was higher on the south-facing slope than on the north-facing slope (Fig. 8). In the bottom flat, the nitrogen content was intermediate between the values on the north- and south-facing slopes.

Discussion

We measured the soil respiration of the contrasting north- and south- facing slopes of a larch forest in central Siberia to order to evaluate global warming effects. Kojima (1994) reviewed that in Yukon Territory vegetation of northern Canada, the north-facing slope had permafrost layer with tundra plants including lichen but the south-facing slope lacked it with spruce and mosses which might be a xeric vegetation under global warming. The north- facing slope is assumed to be the present condition while the south-facing slope may stand for the future warm environment with xeric vegetation type (Kojima 1994, Koike *et al.* 1998a, 1998b). Because of higher photosynthetic rate and nutrient concentration (e.g. nitrogen, potassium and calcium) of larch needles of the south-facing slope (Koike *et al.* 1998b), biological activities including soil respiration may be higher than the north-facing slope. In fact, soil respiration of core samples obtained from the south-facing slope was higher than from the north-facing slope (Fig. 6) under laboratory condition. Matsuura and Abaimov (1999, 2000) showed different soil composition and nitrogen mineralization capacity between the contrasting two slopes. We may consider the change in future vegetation of the Tura Experiment Forest based on there environmental and biological difference.

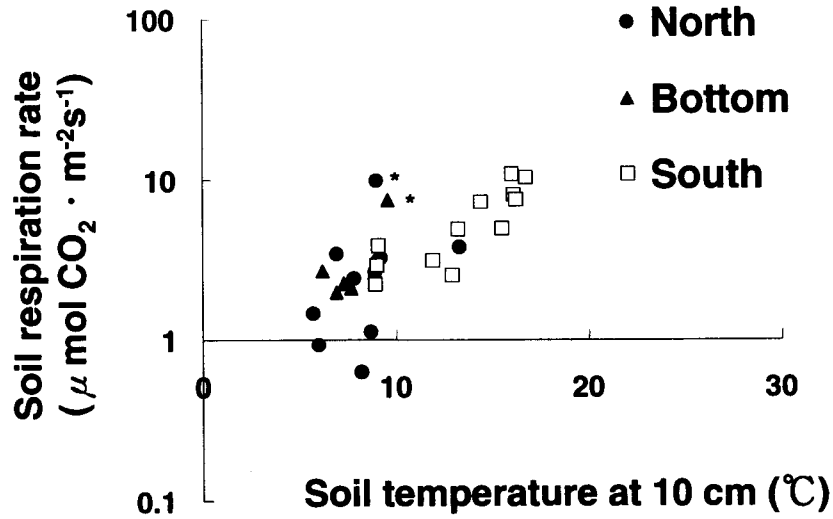


Fig. 5. Relationship between the soil respiration rate and the soil Temperature at 10 cm depth
*: There was an earthworm in the soil core.

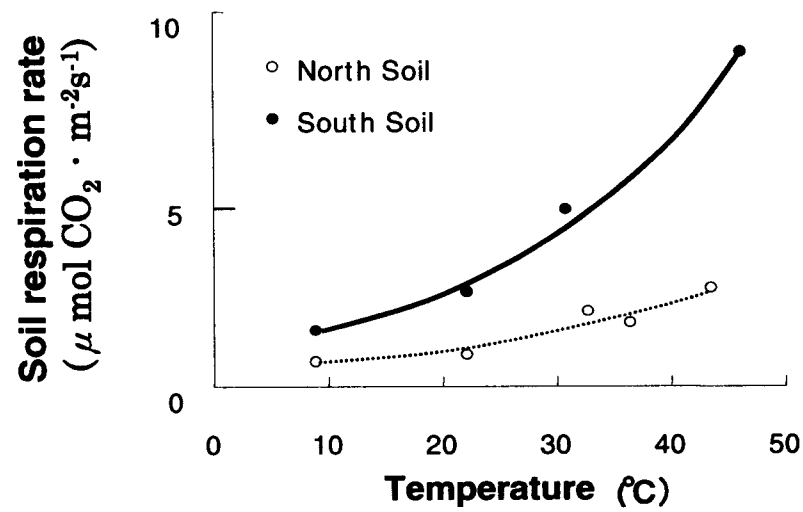


Fig. 6. Relationship between the soil respiration rate and the measurement temperature.

In field measurement (Fig. 5), temperature dependency of soil respiration was detected only for south-facing slope, but not for the north-facing slope, which may be due to the range of lower temperature regime at the north-facing slope (temperature ranged 5 °C and 8°C). With use of core samples of soil, soil respiration rate per 10 cm^3 of the south-facing slope was 1.3 times higher than that of the north-facing slope (Fig. 6). However, different methods of measuring soil respiration rate could not directly compare with each other.

Sawamoto *et al.* (2000) showed soil respiration rate of different sites including eastern Siberian forest (Sakha Rep. Russia) and Hokkaido. At the same temperature range of 15°C, soil respiration rate of deciduous boradleaved forest developed on immature volcanic ash, mountain birch (*Betula ermanii*) forest, and spruce (*Picea glehnii*) forest was estimated to be around 8.5, 8.4, 12.5 and 12.0 $\mu mol CO_2.m^{-2}s^{-1}$, respectively. Soil respiration rate of the south-facing slope in the Tura Experiment Forest was ca. 6.2 $\mu mol CO_2.m^{-2}s^{-1}$. Of course, the study season was different each other. We should know the seasonal trend of soil respiration rate in order to estimate net CO_2 flux in ecosystems (Schulze *et al.* 1999, Maier and Kress 2000).

Why was different value of soil respiration rate found between both slopes? Soil respiration rates on the south-facing slopes was higher than the north-facing slope, reflecting the larger amount of solar radiation on the south-facing

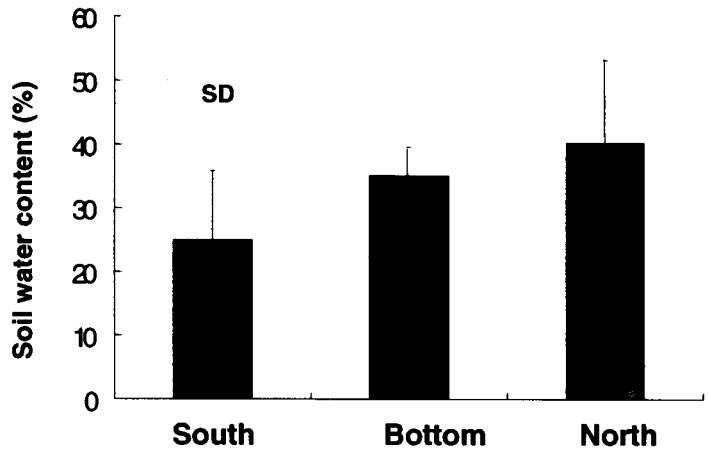


Fig. 7. Soil moisture content at the three sites.

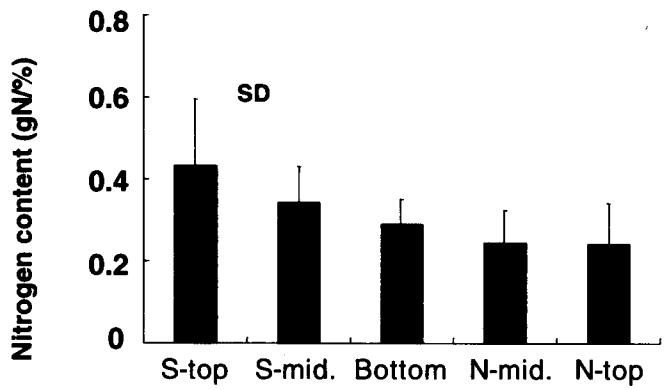


Fig. 8. Nitrogen content of the soil cores at various locations.

slope. The highest respiration rate, found in the middle of the south-facing slope (Fig. 2), might have been due to the strongest heating, which was, in turn, associated with the steeper slope there.

Soil respiration rates are affected by various factors, such as soil temperature, soil water content, nitrogen content, and biological activity, and the effect of each of these factors should be examined (see also Appendix). Sawamoto *et al.* (1997) has already noted that both the soil water content and the soil temperature strongly affect soil respiration rates. According to previous study (Sawamoto *et al.* 1997, Maier and Kress 2000, Matsuura and Abaimov 1999, 2000) and results of our study, soil respiration rate depends on soil water content, which might regulate the activities of soil micro-organisms. Soil respiration includes both roots and micro-organisms in rhizosphere. Under field, it is very difficult to separate the contribution of respiration originated from roots of plant or micro-organisms in rhizosphere. With incubation of soils in laboratory, the origin of soil respiration tried to separate from roots of plants and micro-organisms (Sawamoto *et al.* 1999). In our survey, we found different distribution of roots from surface to bottom. However, the amount of roots in soil core samples were too scattered to get the tendency to infer the contribution of roots to total soil respiration.

Moreover, it appeared that soil respiration on the north-facing slope was influenced not only by soil temperature but also other biological and environmental factors. Our laboratory analysis suggested that the metabolisms of root and soil microbes might be more active on the south-facing slope than on the north-facing slope when we compared broader range of measurement temperature (Yanagihara *et al.* 2000). Sawamoto *et al.* (1999) found that CO_2 production rate of east Siberian forest increased with increasing incubation temperature and total carbon content in the sample.

With regard to nitrogen content (Fig. 8), our results indicated that soil conditions on the south-facing slope were more advantage ours for acceleration of microbial metabolism than those of the other sites. Organic nitrogen is essential for the growth of soil micro-organisms and large

amounts of nitrogen might be associated with reflected high-level microbial activities.

Differences are amounts of roots and organic matter including humus between the north- and south-facing slopes indicated that biological activities were higher on the south-facing slope. However humus is considered to be the result of microbe digestion, and its role in soil activities is still not clear. Therefore, in further experiment, we should try to analyze the physiological activities of the organic matter as they impact on the rhizosphere.

Acknowledgments

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Appendix

Table. List of flora of the north- and south-facing slope at Tura.

South-facing slope	North-facing slope	Bottom flat
Arctostaphyllos uva-ursi	*Arctous erythrocarpa*	*Arctous erythrocarpa*
Aulacomnium palustre	*Aulacomnium palustre*	*Aulacomnium palustre*
Aulacomnium turgidum	*Aulacomnium turgidum*	*Aulacomnium turgidum*
Cetraria cucullata	*Carex* sp.	*Dicranum* sp.
Cetraria islandica	*Cetraria islandica*	*Peltigera aphthosa*
Cladina rangiferina	*Cladina rangiferina*	*Peltigera sp.*
Cladina rangiferina	*Dicranum undulatum*	*Pleurozium schreberi*
Empetrum nigrum	*Hylocomium splendens*	*Vaccinium uliginosum*
Peltigera aphthosa	*Larix gmelinii*	*Vaccinium vitis-idaea*
Peltigera malaceae	*Ledum palustre*	
Vaccinium vitis-idaea	*Peltigera malaceae*	
Vicia sp.	*Pleurozium schreberi*	
	Poa palustris	
	Ptilidium ciliare	
	Vaccinium vitis-idaea	

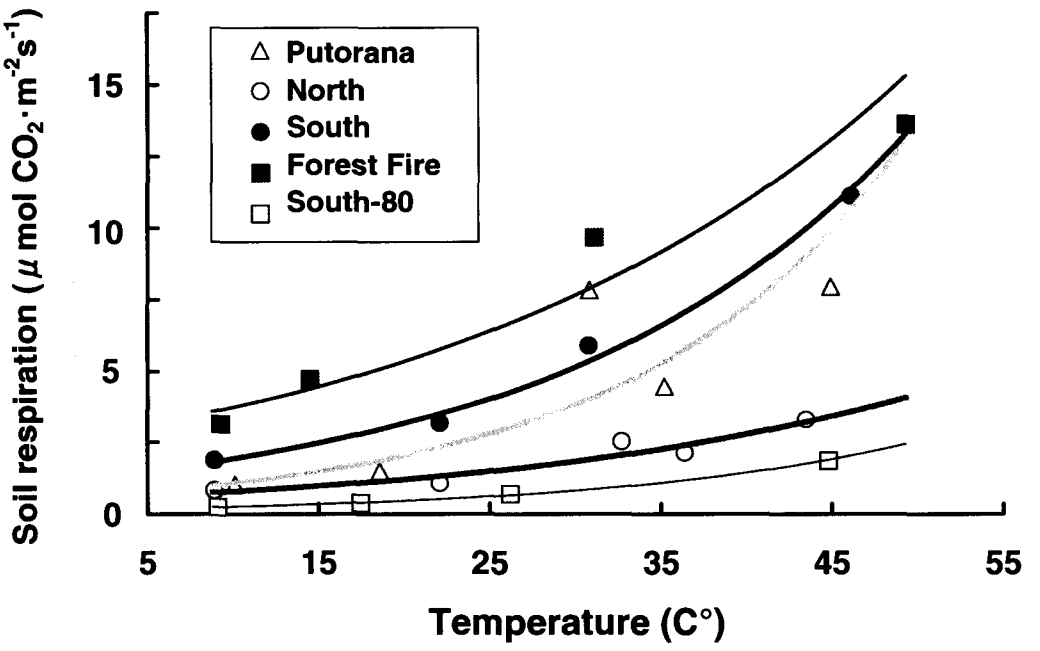

Figure A. Relationship between the soil respiration rate of various sites and the measurement temperature.

Surface soil obtained from the burnt sites at Tura Experiment Forest after the fires in 1994 was higher among the cores samples tested. The sample soil cores of the Putorana Mountain showed rather higher respiration rates.

Putorana: The surface soil at 5 cm depth of the Putorana mountain site. Main tree species was larch and a kind of alder.
North: Core of the north-facing slope (site 7)
South: Core of the south-facing slope (site 7)
Forest fire: Core of the postfire in 1994
South-80: Core of the south-facing slope at 80cm