MICROBIAL BIOMASS IN RELATION TO PRIMARY SUCCESSION ON ARCTIC DEGLACIATED MORAINES

Yukiko Bekku[1], Atsushi Kume[2], Takayuki Nakatsubo[3],
Takehiro Masuzawa[4], Hiroshi Kanda[1] and Hiroshi Koizumi[5]

[1]*Department of Biology, National Institute of Polar Research,
Kaga 1-chome, Itabashi-ku, Tokyo 173-8515*
[2]*Center for Forest Decline Studies, Faculty of Integrated Arts and
Sciences, Hiroshima University, Higashi-Hiroshima 739-0046*
[3]*Department of Environmental Studies, Faculty of Integrated Arts and
Sciences, Hiroshima University, Higashi-Hiroshima 739-0046*
[4]*Department Biology, Faculty of Science,
Shizuoka University, Shizuoka 422-8017*
[5]*Institute for Basin Ecosystem Studies,
Gifu University, Gifu 501-1193*

Abstract: Microbial biomass in arctic soil was examined in relation to a primary succession on arctic deglaciated moraines in Ny-Ålesund, Svalbard (79°N, 12°E). Soil samples at four study sites representing different successional stages were collected at every 1 cm depth from the soil surface to 3 cm depth in early August 1995. Microbial biomass was measured with a substrate-induced respiration procedure. The microbial biomass was highest at the soil surface (0–1 cm depth) in all successional stages, and decreased to a negligible amount at 3 cm depth. Mean microbial biomass in 0–2 cm layer increased from 0.06 mgC g^{-1}soil d.w. in the youngest site to 1.03 mgC g^{-1}soil d.w. in the oldest site, which is comparable to ecosystems in warmer regions. Throughout all successional stages, there was positive high correlation between soil carbon or nitrogen content and microbial biomass.

key words: arctic soil, microbial biomass, soil carbon and nitrogen content, primary succession

Introduction

Global warming caused by increasing greenhouse gases in the atmosphere could bring an increase in global mean surface temperature of between 1.3 and 2°C (Gates *et al.*, 1992). Especially in arctic regions, temperature could increase by 3 to 7°C (Gates *et al.*, 1992). Given that global warming is expected to be faster and more pronounced in high latitudes, warming will have a particularly strong impact on arctic terrestrial ecosystems (Walker, 1996). Ecosystem development, namely primary succession, could be a prominent feature of arctic deglaciated areas, where we can see various communities on different aged moraines ranging from bare land colonized by pioneer species to dense vegetation with later successional species. Especially in the high arctic where available nutrients are highly limited, soil heterotrophic microorganisms play an important role in the progress of

primary succession through decomposition of soil organic matter resulting in nutrient recycling (Smith, 1993; Wild, 1993; Nadelhoffer *et al*., 1992). If the warming increases the decomposition rate by stimulating soil microbial activities, species composition in the different stages of primary succession might be altered by changes in nutrient availability (Chapin *et al*., 1996). Decomposition rate depends on both microbial biomass and respiratory activity. Thus, in order to predict the effects of warming on the decomposition rate, it is important to elucidate the relationship among microbial biomass, respiratory activity and environmental factors such as temperature, soil water content, substrate quality and quantity. However, there have been neither quantitative studies of soil microbial biomass in arctic ecosystems except for a few studies (Bunnell, 1980; Cheng and Verginia, 1993), nor studies of changes in the microbial biomass with progress of primary succession in arctic ecosystems.

Our objectives are to know 1) the amount of soil microbial biomass in arctic soil, and 2) how the biomass changes with progress of primary succession. This report is part of a larger study examining the process and function of the material cycle in arctic primary succession. In a subsequent study, response of microbial respiration to temperature, namely temperature dependence of the respiration, will be reported (Bekku *et al*., submitted).

Materials and Methods

Study Site

The study area is located in front of East Brøgger glacier near Ny-Ålesund, Svalbard in Norway (79°N, 12°E). Annual mean air temperature and precipitation in this area were $-5.7°C$ and 487 mm, respectively (source: Norsk Polarinstutt). Four study sites were chosen in a primary successional series on different aged moraines. Site-1, situated just in front of the glacier toe, became ice-free only recently (within 30 years ago) and had little plant cover. Site-2 was on a moraine with a few scattered vegetation patches (mainly *Saxifraga oppositifolia* L., *Poa alpina* L. and *Draba* spp.). Site-3 was on a small moraine where approximately 17% of the ground surface is bared, 30% is covered with algal crust, and 53% is covered with mosses and vascular plants (mainly *Salix polaris* Wahlenb, *Luzula confusa* Lindeb. and *Poa alpina*,). Site-4 was on the oldest moraine where almost all of the ground surface was covered with algal crust, lichens, mosses and vascular plants (mainly *Salix polaris, Saxifraga oppositifolia* and *Luzula confusa*). A more detailed description is given by Nakatsubo *et al*. (1998).

Measurement

Soil samples were collected from each site with 6 subsamples in early August 1995. At Sites-1 and -2, soil of 0–0.5 cm, 0.5–2 cm and 2–3 cm layers were sampled with a soil corer ($\phi = 9$ cm). At Site-3 and Site-4, soil under the green moss or at the surface where no green moss layer exists was taken by cutting a 10×10 cm block of the organic soil material with a knife to a depth of 3 cm, and then cutting it into every 1 cm layers. Plant roots and stones in soil samples were removed with a 2-mm mesh sieve.

The microbial biomass was measured by the substrate-induced respiration procedure (Anderson and Domsch, 1978; Cheng and Virginia, 1993). Approximately 30 g of soil

from each layer in the respective site was placed in a petridish; then 1% glucose solution was added to the soil sample to bring the soil water content to near its holding capacity. Substrate-induced respiration was measured at 22°C using a soil respiration measuring system with continuous open-air flow system (BEKKU *et al.*, 1997) using an infra-red gas analyzer (LI-6250, LI-COR, Lincoln, USA). After the measurement, soil samples were oven dried at 105°C for 3 days, and weighed. The soil total carbon and nitrogen contents were measured using a CHN/O elemental analyzer (Perkin Elmer 2400II, Connecticut, USA).

Results and Discussion

Vertical profiles of soil microbial biomass at Site-1 to Site-4 are shown in Fig. 1. At all sites, the biomass was largest in the upper 0–5 mm layer and decreased to a negligible amount at 2–3 cm depth. The biomass at all depths was largest at Site-4, and smallest at Site-1. Figure 2 shows vertical profiles of soil carbon (C) and nitrogen (N) contents at each site. The profiles of C- and N contents show the same trends as those of microbial biomass at each site. At Site-1 where there is little microbial biomass, the C- and N contents were extremely low at all depths. With progress of vegetational succession, carbon and nitrogen were deposited between 0–1 cm in the soil surface layer (Fig. 2), and the biomass increased in that layer (Fig. 1). At Site-4, the C- and N contents were relatively high in all layers, corresponding to the increase in microbial biomass in all layers.

Mean microbial biomass and soil C- and N contents between 0–2 cm depths increased with progress of succession (Table 1). The biomass ranged from 0.06 mgC g^{-1}soil d.w. at
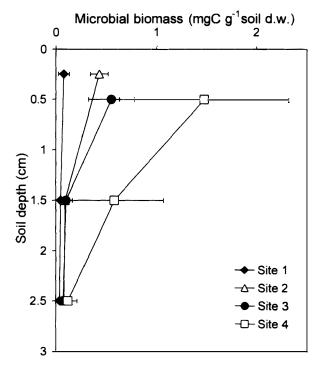

Fig. 1. Vertical profiles of soil microbial biomass in the respective study sites.
◆, Site-1; △, Site-2; ●, Site-3; □, Site-4. Bars indicate standard deviations.
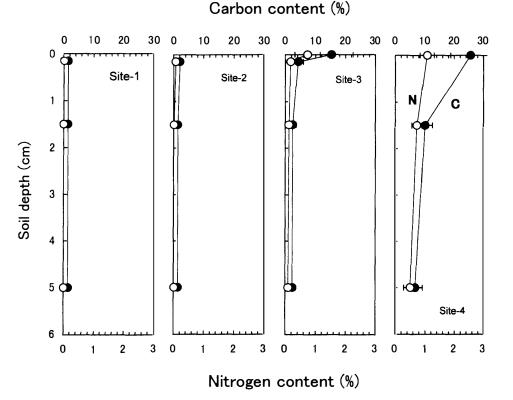
Carbon content (%)

Fig. 2.   Vertical profiles of soil carbon and nitrogen contents in the respective study sites.
●, carbon content; ○, nitrogen content.   The data represents mean value of six subsamples.

Table 1.   Mean microbial biomass, carbon and nitrogen contents contained in soil between 0 and 2 cm depth.

	Site 1	Site 2	Site 3	Sie 4
Microbial biomass (mgC g^{-1} soil d.w.)	0.06 (0.04)	0.26 (0.05)	0.33 (0.15)	1.03 (0.67)
Soil carbon content (%)	1.6 (0.03)	1.81 (0.12)	6.96 (1.67)	14.5 (2.24)
Soil nitrogen content (%)	0.02 (0.002)	0.05 (0.008)	0.37 (0.08)	0.83 (0.12)
C/N	80 (6.5)	35 (5.1)	19 (1.1)	17 (0.27)

Values are mean of six subsamples.   Figures in parentheses indicate SD.

Site-1 to 1.03 mgC g^{-1}soil d.w. at Site-4.   The C- and N contents were very low at Site-1 (1.6% and 0.02% respectively), and increased with succession to C content of 14.5% and N content of 0.83% at Site-4.   The carbon to nitrogen ratio (CN ratio) was extremely high (80) at Site-1, and decreased with progress of succession to 17 at Site-4.

Throughout all successional stages, there was positive high correlation between soil C- or N content and soil microbial biomass with determination coefficients of 0.82 and 0.72, respectively (Fig. 3).   However, the biomass measured in the present study was smaller than that in Alaskan tundra (68°N, 149°W) measured by Cheng and Virginia (1993) using the same method, even with the same C- and N contents in the soil (Fig. 3).   This would
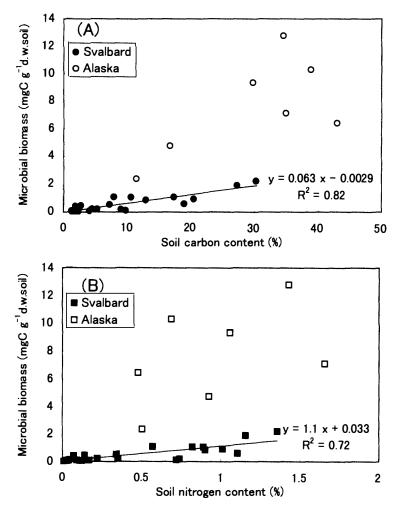
Fig. 3. Relationships between soil microbial biomass and soil carbon content (A) or soil nitrogen content (B) in Svalbard (black symbols) and in Alaska (open symbols) measured by CHENG and VIRGINIA (1993).

be mainly caused by differences in climatic conditions between the two fields. In Svalbard, the temperature and period of the growing season suitable for decomposition should be lower and shorter, since Svalbard is located more than 10°north in latitude than their field in Alaska. Moreover, contents of recalcitrant chemical constituents in litter such as lignin may be higher in Svalbard due to the severe climatic conditions. Soil organic matter in northern ecosystems generally tends to be less decomposable than in warmer ecosystems due to high lignin content (NADELHOFFER et al., 1992).

Table 2 summarizes the soil microbial biomass reported by other researchers. Although soil microbial biomass in Svalbard was lower than that at the Alaskan tundra, the biomass in Svalbard was comparable with those measured in other ecosystems. Most noteworthy is that the biomass in Svalbard reaches more than two times of that in tropical ecosystems in India.   Though the microbial biomass in arctic ecosystems is generally lower than those in ecosystems in warmer regions (HEAL et al., 1981), these results indicate that the soil microbial biomass in arctic ecosystems may not be less than those in other ecosystems.

Table 2. Soil microbial biomass from several ecosystems.

Ecosystem	Location	Biomass (mgC g⁻¹ soild. w.)	Method[a]	Author
Arctic primary succession	Svalbard (79°N, 12°E)	0.06–1.03	SIR	The present study
Arctic tundra	Alaska (68°N, 149°W)	2.3–13	SIR	CHENG and VERGINIA (1993)
Alpine primary succession	Austria (47°N, 11°E)	0.042–2.3	SIR	INSAM and HASELWANDTER (1989)
Permanent pasture	North Wyke, England	1–1.7	FE	LOVELL et al. (1995)
Secondary succession	Southern Bohemia	0.42±0.22	FI	SANTRUCKOVA and STRASKRABA (1991)
Cultivated-land	Germany (51°N, 11°E)	0.2–0.9	SIR	INSAM and DOMSCH (1988)
Tropical forest, savanna, cropland	India (24–26°N, 82–85°E)	0.21–0.46	FE	SINGH and SINGH (1995)

[a]Method for measuring microbial biomass: SIR, substrate induced respiration procedure; FE, fumigation extracted method; FI, fumigatiton incubation method.

This study shows that soil microbial biomass in Svalbard increased with increasing soil carbon and nitrogen contents through primary succession, and that the biomass in arctic ecosystems was comparable to those in ecosystems in warmer regions.   This would suggest the existence of soil microbial flora that adapt to their cold and severe environment. If future global warming increases soil temperature and plant productivity, soil microorganisms would be greatly affected by changes in habitat temperature, substrate quality and quantity.   However, there has been little study that shows how the microbial activity and the resultant nutrient supply actually change as a result of negative or positive feedback among plant, soil and atmosphere in global warming.   In order to understand the feedback mechanisms, functional, quantitative and experimental studies on the respective biological processes and their combinations should be continued in further scientific research programs.

Acknowledgments

References

ANDERSON, J.P.E. and DOMSCH, K.H. (1978): A physiological method for the quantitative measurement of microbial biomass in soil. Soil Biol. Biochem., 10, 215–221.
BEKKU, Y., KOIZUMI, H., OIKAWA, T. and IWAKI, H. (1997): Evaluation of four methods for measuring soil respiration. Appl. Soil Ecol., 5, 247–254.
BUNNEL, F.L., MILLER, O.K., FLANAGAN, P.W. and BENOIT, R.E. (1980): The microflora: Composition,

biomass, and environmental relations. An Arctic Ecosystem. The Coastal Tundra at Barrow, Alaska, ed. by J. Brown et al. Pennsylvania, Hutchinson & Ross, 255–290.

Chapin, F.S. III, Hobbie, S.E. and Shaver, G.R. (1996): Impacts of global change on composition of arctic communities: Implications for ecosystem functioning. Global Change and Arctic Terrestrial Ecosystems, ed. by W.C. Oechel et al. New York, Springer, 221–228.

Cheng, W. and Virginia, R.A. (1993): Measurement of microbial biomass in arctic tundra soils using fumigation-extraction and substrate-induced respiration procedures. Soil Biol. Biochem., 25, 135–141.

Gates, W.L., Mitchell, J.F.B., Boer, G.J., Cubasch, U. and Meleshko, V.P. (1992): Climate modelling, climate prediction and model validation. Climate Change 1992, the IPCC Scientific Assessment, ed. by J.T. Houghton et al. Cambridge, Cambridge University Press, 96–134.

Heal, O.W., Flanagan, P.W., French, D.D. and Maclean, S.F. (1981): Decomposition and accumulation of organic matter. Tundra Ecosystems: A Comparative Analysis, ed. by L.C. Bliss et al. London, Cambridge University Press, 587–633.

Insam, H. and Domsch, K.H. (1988): Relationship between soil organic carbon and microbial biomass on chronosequences of reclamation sites. Microbial Ecol., 15, 177–188.

Insam, H. and Haselwandter, K. (1989): Metabolic quotient of the soil microflora in relation to plant succession. Oecologia, 79, 174–178.

Lovell, R.D., Jarvis, S.C. and Bardgett, R.D. (1995): Soil microbial biomass and activity in long-term grassland: Effects of management changes. Soil Biol. Biochem., 27, 969–975.

Nadelhoffer, K.J., Giblin, A.E., Shaver, G.R. and Linkins, A.E. (1992): Microbial processes and plant nutrient availability in arctic soils. Arctic Ecosystems in a Changing Climate. An Ecophysiological Perspective, ed. by F.S. Chapin III et al. San Diego, Academic Press, 281–300.

Nakatsubo, T., Bekku, Y., Kume, A. and Koizumi, H. (1998): Respiration of the below-ground parts of vascular plants: Its contribution to total soil respiration on a successional glacier foreland in Ny-Ålesund, Svalbard. Polar Res., 17, 53–59.

Santruckova, H. and Straskraba, M. (1991): On the relationship between specific respiration activity and microbial biomass in soils. Soil Biol. Biochem., 23, 525–532.

Singh, S. and Singh, J.S. (1995): Microbial biomass associated with water-stable aggregates in forest, savanna and cropland soils of a seasonally dry tropical region, India. Soil. Biol. Biochem., 27, 1027–1033.

Smith, R.I.L. (1993): The role of bryophyte propagule banks in primary succession: Case-study of an Antarctic fellfield soil. Primary Succession on Land, ed. by J. Miles and D.W.H. Walton. Oxford, Blackwell, 55–78.

Walker, B.H. (1996): Global change and terrestrial ecosystems: The GCTE research programme for the arctic. Global Change and Arctic Terrestrial Ecosystems, ed. by W.C. Oechel et al. New York, Springer, v–xii.

Wild, A. (1993): Soils and the Environment: An introduction. Cambridge, Cambridge Univ. Press, 287 p.