PERMAFROST AND PERIGLACIAL PROCESSES
Permafrost Periglac. Process. **10**: 279–288 (1999)

Biological Activity as Influenced by Microtopography in a Cryosolic Soil, Baffin Island, Canada

Gerald Mueller[1]*, *Gabriele Broll*[1] *and Charles Tarnocai*[2]

[1]Institute of Landscape Ecology, University of Muenster, Robert-Koch-Str. 26, 48149 Muenster, Germany
[2]Agriculture and Agri-Food Canada, Research Branch (ECORC), K.W. Neatby Building, 960 Carling Avenue, Ottawa, Ontario K1A 0C6, Canada

ABSTRACT

Biological activity and cellulose decomposition in the topsoil of an east–west oriented slope in the Canadian Arctic were studied in the summers of 1995 and 1996. Two microsites, small mounds and the adjacent troughs, characterize the surface of the study site on a slope. This microtopography results from erosion in the past when the area was not vegetated, and recent frost action. The aim of the study was to describe differences in the decomposition processes and the contributing factors in relation to the microtopography. Biological activity in the soil was measured by the feeding activity of the soil organisms. In both years of the study feeding activity by bait-lamina test and cellulose decomposition by nylon-mesh-bag assessment were higher in the troughs than in the mounds. The C/N ratios and acidity were similar in the zone showing the highest biological activity at both sites, but soil temperatures and water content were different. Soil moisture was found to be the main factor affecting feeding activity and cellulose decomposition at both microsites. Copyright © 1999 John Wiley & Sons, Ltd.

RÉSUMÉ

L'activité biologique et la décomposition de la cellulose au sommet des sols d'une pente orientée est-ouest dans l'arctique canadien ont été étudiées au cours des étés 1995 et 1996. Deux types de microsites, à savoir de petites buttes et des creux voisins, caractérisent la zone considérée. Cette microtopographie résulte à la fois de l'érosion ancienne quand il n'y avait pas de végétation et de l'action récente du gel. Le but de l'étude était de rechercher, en relation avec la microtopographie, des différences dans les processus de décomposition et les facteurs qui interviennent. L'activité biologique dans le sol a été mesurée en considérant l'alimentation des organismes du sol. Au cours des deux années, l'étude de cette alimentation a été mesurée par le test "bait-lamina", tandis que la décomposition de la cellulose était estimée par la technique du sac à mailles de nylon. Les résultats ont montré une évolution plus importante dans les dépressions que sur les buttes. Les rapports C/N et l'acidité ont été semblables dans la zone montrant la plus grande activité biologique des deux sites, alors que les températures du sol et le contenu en eau étaient différents. L'humidité du sol est apparu comme le principal facteur affectant l'alimentation des organismes du sol et la décomposition de la cellulose. Copyright © 1999 John Wiley & Sons, Ltd.

KEY WORDS: Baffin Island; decomposition; feeding activity; microtopography; soil organisms

* Correspondence to: G. Mueller, Institute of Landscape Ecology, University of Muenster, Robert-Koch-Str. 26, 48149 Muenster, Germany. E-mail: muelleg@uni-muenster.de

Contract grant sponsor: German Science Foundation.

CCC 1045–6740/99/030279–10$17.50

Received 16 January 1999
Accepted 6 July 1999

INTRODUCTION

Various factors control Arctic ecosystems. Because of the complexity inherent in ecosystems, it is necessary to encode the detailed characteristics at a small scale (Elliott and Syoboda, 1994). Evans *et al.* (1989) analysed the interactions between topography, snow cover and vegetation, while Young *et al.* (1997) studied the effect of these factors on microclimate and hydrology at a High Arctic site. In permafrost-affected soils, soil genesis and soil ecological processes are also influenced by the microtopography (Bliss *et al.*, 1977; Oberbauer and Oechel, 1989; Shaver *et al.*, 1996). Microtopography controls soil moisture, soil temperature, acidity, and soil nutrient status, which are important factors influencing soil biological processes (Jonasson, 1983; Nadelhoffer *et al.*, 1992; Romanovsky and Osterkamp, 1995; Chapin and Körner, 1995; Schimel *et al.*, 1999). The objectives of this study were to determine the degree of soil faunal activity and cellulose decomposition in an Arctic soil depending on the microtopography. We expected differences in the biological activity of the microsites' mound and trough. Furthermore, we would like to know what were the controlling factors for the soil ecological processes in the soil of these microsites.

STUDY AREA

The study area is located on a slope near Pangnirtung Fiord in Auyuittuq National Park Reserve on the south-western portion of Cumberland Peninsula, Baffin Island (Figure 1). It is part of the Oceanic High Arctic Ecoclimatic Region (Ecoregions Working Group, 1989) and the area is characterized by extremely harsh environmental conditions. Days are cold and short during winter, while moderate temperatures and long days characterize the summer. In Pangnirtung the mean annual air temperature is −9.8 °C and the total annual precipitation is 395 mm. In summer, frequent storms bring precipitation as rain or snow; in winter, precipitation is low (Maxwell, 1980). In the eastern part of Baffin Island the bedrock is composed primarily of Precambrian metamorphics (Taylor, 1981). The study area is underlain by Precambrian igneous granites and quartz monozonites that formed in the Aphebian age and deformed during the Hudsonian orogeny (Jackson and Taylor, 1972). The soils of the Auyuittuq area and those in the park are described by Birkeland (1978) and Bockheim (1979) as Arctic brown and polar desert soils. According to the American soil classification (Soil Survey Staff, 1998) these soils are primarily Gelisols; according to the Canadian soil classification (Soil Classification Working Group, 1998) they are Cryosols. Broll *et al.* (1998) and Tarnocai and Veldhuis (1998) provide information on the characteristics, distribution and genesis of Cryosols occurring in the Pangnirtung Pass area. The study area belongs to the Eastern Arctic Vegetation Zone (Ritchie, 1987). Porsild (1957) described the vegetation on the southern inshore regions as dwarf shrub–sedge–moss–lichen tundra vegetation, and on the highlands and along the northern fiords as stony sedge–moss–lichen tundra. Gray (1989) and Tarnocai and Gould (1998) described the vegetation along Pangnirtung Pass in detail. The surface of the east–west oriented slope (Figure 1 and Table 1) is nearly completely covered by small mounds and troughs. They exhibit height differences of about 30 cm. The area is now entirely vegetated. *Salix arctica*, *Vaccinium uliginosum* and *Bryum algovicum* dominate the vegetation on the trough, while

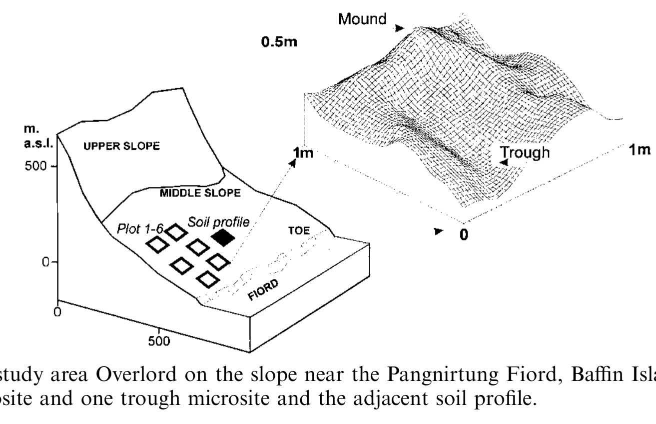

Figure 1 Location of the study area Overlord on the slope near the Pangnirtung Fiord, Baffin Island, with six study plots each including one mound microsite and one trough microsite and the adjacent soil profile.

Table 1 Site and profile description of the study site Overlord.

Location:	lat. 66°23′35″N; long. 65°28′51″W
Elevation:	15 m
Landform:	colluvial blanket with aeolian veneer
Slope:	15%
Drainage:	moderately good
Vegetation:	low shrub–moss–lichen tundra
Parent material:	aeolian sand over colluvium
Soil classification:	Regosolic Static Cryosol

Microsite: mound

Horizon	Thickness range (cm)	Description
Ah	0–4	Very dark greyish brown (10 YR 3/2); silty sand; fine to medium, granular structure; non-sticky, loose, non-plastic consistency; plentiful, fine, oblique roots; extremely acid; wavy horizon boundary
C	15–20	Dark grey (10 YR 4/1); loamy sand; fine to medium, granular structure; non-sticky, loose, non-plastic consistency; few, fine, oblique roots; extremely acid; wavy horizon boundary
2C	15–18	Brown (10 YR 4/3); loamy sand; fine to medium, granular structure; non-sticky, loose, non-plastic consistency; very few, fine, oblique roots; extremely acid; wavy horizon boundary
2Cz	–	Dark greyish brown (2.5 Y 4/2); frozen cobbly sand; ice-cemented material with segregated ice crystals; medium ice content

Microsite: trough

Horizon	Thickness range (cm)	Description
F	0–1	Very dark grey (10 YR 3/1); moderately decomposed organic material; abundant, fine to medium, vertical roots
Ah	6–8	Black (10 YR 2/1); silty sand; fine to medium, granular structure; non-sticky, loose, non-plastic consistency; abundant, fine to medium, oblique roots; extremely acid; wavy horizon boundary
C	5–12	Dark grey (10 YR 4/1); loamy sand; fine to medium, granular structure; non-sticky, loose, non-plastic consistency; roots; extremely acid; wavy horizon boundary
2C	10–15	Brown (10 YR 4/3); loamy sand; fine to medium, granular structure; non-sticky, loose, non-plastic consistency; roots; extremely acid; wavy horizon boundary
2Cz	–	Dark greyish brown (2.5 YR 4/2); frozen cobbly sand; ice-cemented material with segregated ice crystals; medium ice content

Hierochloe alpina, *Luzula arctica*, *Salix arctica* and *Stereocaulon alpinum* dominate on the mound.

MATERIALS AND METHODS

Six study plots (1 m^2 each), each including one mound microsite and one trough microsite, were selected to determine the soil faunal activity and the cellulose decomposition on representative sites of the slope (Figure 1). The bait-lamina test (Törne, 1990; Kratz, 1998) has been used to test feeding activity in the topsoil of the microsites (Kratz *et al.*, 1992; Larink, 1994). The bait material was prepared according to Törne (1990) and consisted of agar-agar (15%), cellulose (70%) and branflakes (15%). The strips, which were perforated by apertures (16 in total) at 5 mm intervals, were implanted in the soil to test the feeding activity at the 0–8 cm depth. Three replicates, each consisting of 16 strips, were placed vertically in the soil at each microsite. The length of time for which these strips are exposed depends on the study site conditions. In Europe 3–14 days have been reported (Törne, 1990; Kratz *et al.*, 1992; Larink, 1994). In the present study, the strips were left in the soil for 14 days during July 1995 and July 1996 to measure feeding activity. After exposure the number of empty holes were counted. Cellulose decomposition was measured by using nylon-mesh bags (Bocock and Gilbert, 1957; Unger, 1966) filled with cellulose (Schleicher and Schuell, no. 512). The 10×10 cm nylon-mesh bags were made of nylon mesh (2 mm mesh), and each contained one sheet of cellulose weighing 2.5 g. Three replicates, each consisting of ten bags, were placed vertically (0–10 cm) in the topsoil at the six locations so that the soil just covered the tops of the bags. After exposure for one year, the loss of mass was calculated after Malkomes (1980). The data on feeding activity and cellulose decomposition were evaluated statistically according to the *U*-test (Mann and Whitney, 1947). The bulk density was determined on all microsites in 1996 using the metal cylinder method (0–2.5; 2.5–5.0; 5.0–7.5 cm depth) (Hartge and Horn, 1989). Also, the water content (vol. %) was measured on all microsites in 0–8 cm by TDR in 1995 and by metal cylinders in 1996. From June 1995 to July 1996 data loggers (DT 3, Elpro, Switzerland) recorded soil temperatures at the 2.5 and 5 cm depths on one of the study plots, comparing the mound and trough microsite.

A soil profile adjacent to the six study plots also including one mound and one trough was described and sampled (Figures 1, 2). The topsoil of this profile was sampled at 2 cm intervals (0–10 cm) and analysed in detail. Two replicates of each soil sample were analysed by standard methods for particle size analysis and pH $CaCl_2$/H_2O (1 : 2.5 dilution of soil and solution) (Carter, 1993). Carbon and nitrogen were measured with an elemental analyser (CARLO ERBA NA 1500).

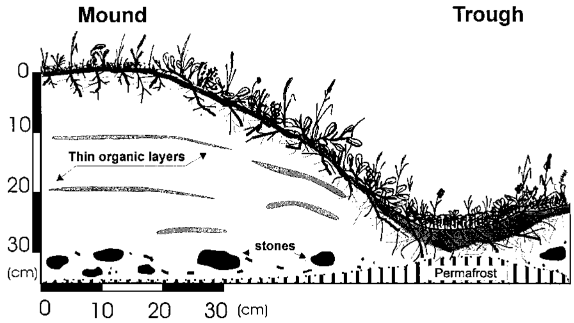

Figure 2 Cross-section of the mound and trough microsites on one study plot of the Overlord study site.

RESULTS

The soil occurring on the 'Overlord' study site was a Regosolic Static Cryosol (Table 1). The parent material consisted of colluvial material mixed with aeolian deposits. Distinct differences were found in the soil organic matter content (Table 2) of the trough and the mound of the soil profile (Figure 2). Only a small amount of litter occurs on the mound, but more soil organic residues accumulated in the trough to form a thin organic layer (1–2 cm thick). The material had an organic carbon content of 48.8% and a total nitrogen

Table 2 Characteristics of the organic layer and the A-horizon on the mound and in the trough of the soil profile (Table 1).

Depth (cm)	Mound				Trough			
	pH (H_2O)	$C_{organic}$ (%)	N_{total} (%)	C/N	pH (H_2O)	$C_{organic}$ (%)	N_{total} (%)	C/N
Organic layer								
2–0	–	–	–	–	n.d.	48.8	1.4	35
A-horizon								
0–2	5.5	2.16	0.12	18	5.4	6.03	0.35	17
2–4	5.2	2.21	0.13	17	5.2	2.75	0.16	17
4–6	5.4	2.20	0.14	16	5.5	1.81	0.14	13
6–8	5.5	1.82	0.13	14	5.5	2.01	0.15	13
8–10	5.6	1.90	0.13	15	5.5	2.01	0.17	12

content of 1.4% with C/N ratio of 35. Thin organic layers were observed at various depths in the mineral horizons, especially within the mound. These organic layers may have resulted from earlier cryoturbation processes and the deposition of a veneer of aeolian material on the surface. Although the carbon and nitrogen contents of the topsoil were generally somewhat higher in the trough than in the mound (except for the 4–6 cm depth), C and N were much higher (approximately three times higher) in the first two centimetres in the trough (Table 2). Despite these differences the C/N ratio is similar for both microsites in the first 4 centimetres below the surface, which is the zone of the highest feeding activity. Below the first 4 centimetres, the C/N ratio decreases with depth. The topsoil (A-horizon) was extremely acidic (pH ($CaCl_2$) 4.4 in the trough and 4.2 in the mound) and had a sandy loam texture (64% sand; 32.6% silt; 3.4% clay) (Table 2).

In the troughs of the six study plots, water content decreased (46% to 17%) and bulk density increased with depth (Figure 3). The mound portions had lower and more consistent values for the water content (25% to 35%) at every depth and higher bulk densities at all depth ranges. During the periods 1–14 July 1995 and 1996 when the bait-lamina strips were exposed, the mound and trough microsites showed different soil temperatures (Figure 4). In both years in July the mound microsite was generally two degrees warmer than the trough at the 2.5 and 5 cm depths, and had a wider range of soil temperatures. The minimum temperature at these depths in the trough microsite was almost 0 °C during both summers.

Feeding activity of the soil organisms could be recognized at all microsites during the study periods in July 1995 and July 1996 (Figure 5). In both years the highest feeding activity occurred at the trough microsites. Differences were significant between the mound and trough microsites with the *U*-test at a significance level of $\alpha = 0.1$. There were also differences between the activity measured in 1995 and 1996. At all microsites, the feeding activity decreased with depth. Linear regression analysis showed mean slopes of −5.3 (1995) and −3.0 (1996) for the mound and −9.3 (1995) and −7.9 (1996) for the trough. There was no activity at the 8 cm depth on any microsite. After one year of exposure the nylon-mesh bags indicated that there was a mean mass loss of cellulose ranging from 19% in the mound to 30% in the trough (Figure 6). The *U*-test indicated significant differences in cellulose decomposition between the microsites at a significance level of $\alpha = 0.1$.

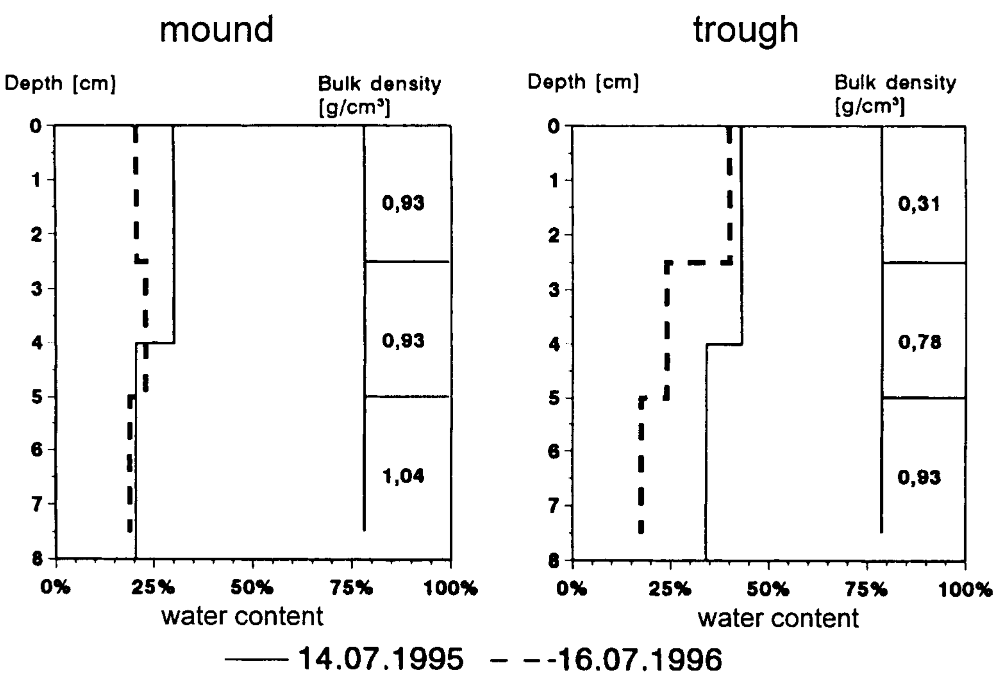

Figure 3 Mean water contents (vol. %) and bulk densities of the mound and trough microsites of the six study plots.

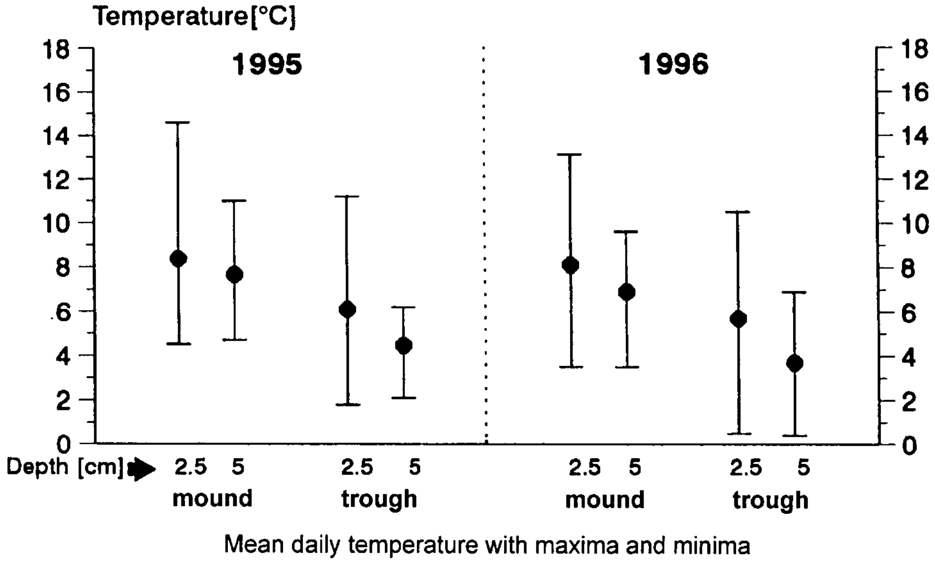

Figure 4 Mean daily soil temperatures at different depths in the mound and trough microsites of one study plot in July 1995 and July 1996.

DISCUSSION

On the Overlord study site, the loss in weight of cellulose and the feeding activity of the soil organisms are higher on the trough microsite than on the mound microsite. Soil faunal activity and decomposition processes are dependent primarily on soil moisture, while soil temperature and the length of the growing season play a minor role, as was evidenced for other sites in the Subarctic and Arctic (e.g. Berg *et al.*, 1975; Widden, 1977; Mueller *et al.*, 1994). On the study site on Baffin island the C/N ratio and the acidity of the mineral soil are similar in the zone of the highest biological activity of the mounds and troughs (0–4 cm below the surface). Therefore, in this case also the influence of the C/N ratio and the acidity cannot be the reason for differences in decomposition. Carbon content and nitrogen content in the zones of the microsites showing highest biological activity are controlled primarily by the microtopography and the plant cover with different biomasses (Figure 2), which influences microclimate (Mueller *et al.*, 1998) and, therefore, soil moisture conditions on the mound and in the trough. Also Shaver *et al.* (1996) and Giblin *et al.* (1991) point out that patterns of plant production and biomass along an Arctic toposequence in Alaska suggest much stronger control by soil environment than by above-ground conditions (Shaver *et al.*, 1996).

The organic mat accumulated on the mound is very thin because of the lichen-heath vegetation, in which lichens form a continuous (>85%) cover between the vascular plants, and produces only a small amount of litter. Heal *et al.* (1981) and Nadelhoffer *et al.* (1992) describe similar conditions for comparable Arctic regions. Other contributing factors may be the abrasive effect of drifting snow that affects the vegetation on these exposed microsites. The mounds are either bare or covered by a thin layer of snow during the winter where in spring only a small amount of meltwater is able to infiltrate the soil. In the spring, when air temperatures are higher, strong winds also dry out the soil. Because precipitation is low during the summer and the mound is well drained, there is little moisture in the topsoil. As a result it is assumed decomposition will be very low owing to the low soil moisture content. It should be noted that, when soil moisture content is very low, decomposition is not so temperature-dependent (Flanagan and Veum, 1974). Highest activity occurs within the 0–4 cm depth (Figure 5) with highest carbon content. Even though mounds are characterized by low soil faunal activity during the short growing season, available organic material is decomposed because the litter input is also low. Also Billings (1973) suggests that lower biomass production at comparable sites could be enhanced by the exposure to winter winds. The decrease in feeding activity at the 4–8 cm depth in these soils

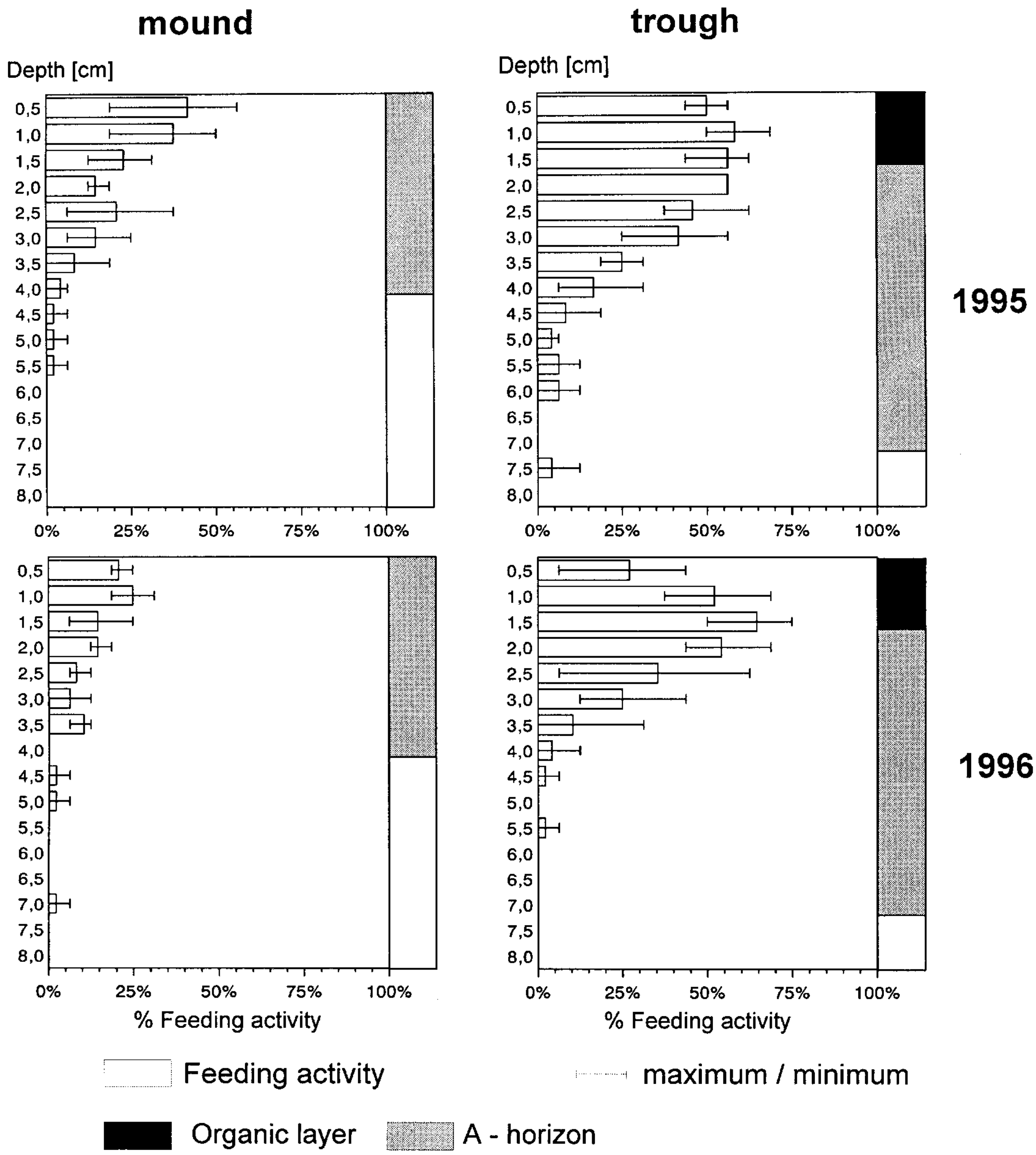

Figure 5 Mean feeding activity in the mound and trough microsites: exposure time was 1–14 July 1995 and 1–14 July 1996 (*U*-test: n = 6, $\alpha = 0.1$).

may be attributed to lower carbon and nitrogen contents as well as to lower temperatures resulting in decreasing population density of organisms (Addison, 1977).

Vegetation in the trough is dominated by mosses and dwarf shrubs, which are common at more moist and protected sites in the Arctic (Bliss *et al.*, 1994; Chapin and Körner, 1995; Shaver *et al.*, 1996). This thick vegetation layer insulates and protects the topsoil (Miller, 1982), producing a shallow thaw depth (active layer) in the troughs. In spring, thawing processes in the soil together with snow patches in the troughs produce meltwater that infiltrates the topsoil. Consequently, as has also been shown by Bliss *et al.* (1977) and Wielgolaski *et al.* (1981), primarily production of vegetation is relatively high in the trough which leads to organic matter accumulation in the soil.

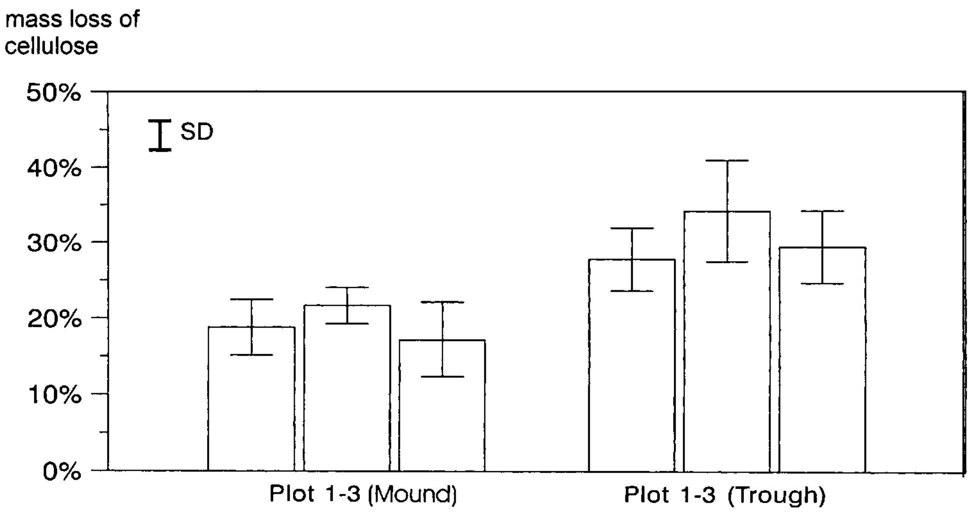

Figure 6 Cellulose decomposition in the mound and trough microsites: exposure time was June 1995 to June 1996 (U-test: $n = 6$, $\alpha = 0.1$).

The resulting organic layer that develops contains partially decomposed moss and shrub material. Moisture and temperature conditions in the mineral soil are only favourable for biological activity during the summer, so feeding activity is naturally high. Some decomposition might occur during the winter (Moore, 1983), but most occurs during the growing season, when the soil warms up (Heal *et al.*, 1981). Accumulation of litter indicates that the soil organisms are not able to decompose all residues during the short growing season. On the study site Overlord, downslope movement of litter followed by accumulation of organic matter in the troughs can be neglected, because in the upper part of the slope only outcropping bedrock exists and therefore the vegetation is fragmentary. Furthermore, strong winds prevent any accumulation of organic matter. Thus, a transport of organic residues directly from the mounds to the troughs seems to be impossible, too.

CONCLUSIONS

Environmental conditions for biological activity vary markedly within a short distance and are strongly affected by the topographic position and associated differences in microclimate. Higher activity and higher cellulose decomposition occur in the trough than in the mound. Although soil temperatures are low at both microsites during the growing season, the feeding activity in the trough and on the mound indicates that the organisms are well adapted to cold temperatures during the growing season. Total organic carbon and nitrogen contents are higher in the trough. C/N ratio and acidity are similar in the zone of the highest biological activity (0–4 cm below the surface) at both microsites. In these cold environments within mound and trough microtopography the water content of the soil is the limiting factor for feeding activity and cellulose decomposition. During the summer the mounds are not only drier, but also exposed to drying winds. The troughs are better protected, even during the summer, and better supplied with moisture than the mounds. Conditions for feeding activity and cellulose decomposition are, thus, more favourable in the troughs. As shown for the biological activity of the two microsites, the moisture status can override the influence of different temperature regimes in microhabitats in the Arctic. Changes in the moisture conditions in these environments caused by changes in precipitation and/or evapotranspiration may affect the ecological processes more than changing temperatures.

The method used for cellulose decomposition (nylon-mesh bags) can be applied in the Arctic, as was proved already in earlier studies. The bait-lamina strips as a new method for these cold environments allow comparisons between feeding activities in the topsoil. Compared with cellulose decomposition only short exposition is needed, but repeated exposition of the bait-lamina strips is recommended in order to characterize the feeding activity during the growing season.

ACKNOWLEDGEMENTS

This study was supported by the German Science Foundation. Parks Canada provided technical assistance and organization, for which we are grateful.

REFERENCES

Addison, J. A. (1977). Population dynamics and biology of Collembola on Truelove Lowland. In Bliss, L.C. (ed.), *Truelove Lowland, Devon Island, Canada: A High Arctic Ecosystem*. University of Alberta Press, Edmonton, Alberta, pp. 363–382.

Berg, B., Kärenlampi, L. and Veum, A. K. (1975). Comparisons of decomposition rates measured by means of cellulose. In Wielgolaski, F.E. (ed.), *Fennoscandian Tundra Ecosystems. Part 1: Plants and Microorganisms*. Springer, Berlin, pp. 261–267.

Billings, W. D. (1973). Arctic and alpine vegetations: similarities, differences and susceptibility to disturbance. *BioScience*, **23**, 697–704.

Birkeland, P. W. (1978). Soil development as an indicator of relative age of Quaternary deposits, Baffin Island, N.W.T., Canada. *Arctic and Alpine Research*, **10**, 733–747.

Bliss, L. C., Henry, G. H. R., Svoboda, J. and Bliss, D. I. (1994). Patterns of plant distribution within two polar landscapes. *Arctic and Alpine Research*, **26**(1), 46–55.

Bliss, L. C., Kerik, J. and Peterson, W. (1977). Primary production of dwarf shrub heath communities, Truelove Lowland. In Bliss, L.C. (ed.), *Truelove Lowland, Devon Island, Canada: A High Arctic Ecosystem*. University of Alberta Press, Edmonton, Alberta, pp. 217–224.

Bockheim, J. G. (1979). Properties and relative age of soils in southwestern Cumberland Peninsula, Baffin Island, N.W.T., Canada. *Arctic and Alpine Research*, **11**(3), 289–306.

Bocock, K. L. and Gilbert, O. J. (1957). The disappearance of leaf litter under different woodland conditions. *Plant and Soil*, **9**, 179–185.

Broll, G., Mueller, G. and Tarnocai, C. (1998). Permafrost-affected soils in the Pangnirtung Pass area, Baffin island, Canada. In Lewkowicz, A.G. and Allard, M. (eds), *Proceedings, Seventh International Conference on Permafrost*. Centre d'études nordiques, Université Laval, Quebec, Nordicana 57, pp. 89–94.

Carter, M. R. (1993). *Soil Sampling and Methods of Analysis*. Lewis, Boca Raton.

Chapin, F. S. III and Körner, C. (1995). *Arctic and Alpine Biodiversity*. Springer, New York.

Ecoregions Working Group (1989). *Ecoregions of Canada. First Approximation*. Ecoregions Working Group of the Canada Committee on Ecological Land Classification. Ecological Land Classification Series no. 23. Sustainable Development Branch, Canadian Wildlife Service, Environment Canada, Ottawa, Ontario.

Elliot, D. and Svoboda, J. (1994). Microecosystem around a large erratic boulder: a high-arctic study. In Svoboda, J. and Freedman, B. (eds), *Ecology of a Polar Oasis, Alexandra Fiord, Ellesmere Island, Canada*. Captus, Toronto, pp. 207–213.

Evans, B. M., Walker, D. A., Benson, C. S., Nordstrand, G. W. and Petersen, G. W. (1989). Spatial interrelationships between terrain, snow distribution and vegetation patterns at an arctic foothills site in Alaska. *Holarctic Ecology*, **12**, 270–278.

Flanagan, P. W. and Veum, A. K. (1974). Relationships between respiration, weight loss, temperature, and moisture in organic residues on tundra. In Brown, J., Miller, P.C., Tieszen, L.L. and Bunell, F.L. (eds), *An Arctic Ecosystem: The Coastal Tundra at Barrow, Alaska*. Cambridge University Press, Cambridge.

Giblin, A. E., Nadelhoffer, K. J., Shaver, G. R., Laundre, J. A. and McKerrow, A. J. (1991). Biogeochemical diversity along a riverside toposequence in arctic Alaska. *Ecological Monographs*, **61**, 415–436.

Gray, B. (1989). Vegetation of Auyuittuq National Park Reserve. In *Auyuittuq National Park Reserve Resource Description and Analysis*. Natural Resource Conservation, Prairie and Northern Region, Canadian Parks Service, Winnipeg.

Hartge, K. H. and Horn, R. (1989). Die physikalische Untersuchung von Boeden. Enke, Stuttgart.

Heal, O. W., Flanagan, P. W., French, D. D. and MacLean Jr, S. F. (1981). Decomposition and accumulation of organic matter in tundra. In Bliss, L.C., Heal, O.W. and Moore, J.J. (eds), *Tundra Ecosystems: A Comparative Analysis*. Cambridge University Press, Cambridge, pp. 587–633.

Jackson, G. D. and Taylor, F. C. (1972). Correlations of major Aphebian rock units in the northeastern Canadian Shield. *Canadian Journal of Earth Sciences*, **9**, 1650–1669.

Jonasson, S. (1983). Nutrient content and dynamics in north Swedish shrub tundra. *Holarctic Ecology*, **6**, 295–304.

Kratz, W. (1998). The Bait–Lamina test–general aspects, applications and perspectives. *Environmental Science & Pollution Research*, **5**, 94–94.

Kratz, W., Mueller, J. and Neinass, J. (1992). Mini-bait-test. A tool of assessing feeding activities of soil living animals and microorganisms. Results from forest ecosystem studies are highly polluted areas, *XI Int. Coll. Soil Zoology*, Jyväskyla, Abstract, p. 134.

Larink, O. (1994). Bait lamina as a tool for testing feeding activity of animals in contaminated soils. In Donker, M.H., Eijsackers, H. and Heimbach, F. (eds), *Ecotoxicology of Soil Organisms*. Lewis, Boca Raton, pp. 339–345.

Malkomes, H.-P. (1980). Strohrottversuche zur Erfassung von Herbizidnebenwirkungen auf den Strohumsatz im Boden. *Pedobiologia*, **20**, 417–427.

Mann, H. B. and Whitney, D. R. (1947). On a test of whether one of two random variables is stochastically larger than the other. *Ann. Math. Statist.*, **18**, 50–60.

Maxwell, J. B. (1980). *The Climate of the Canadian Arctic Islands and Adjacent Waters. Volume I: Environment Canada.* Atmospheric Environment Service, Hull, Quebec.

Miller, P. C. (1982). Environmental and vegetational variations across a snow accumulated area in montane tundra in central Alaska. *Holarctic Ecology*, **5**, 85–98.

Moore, T. R. (1983). Winter-time litter decomposition in a subarctic woodland. *Arctic and Alpine Research*, **15**(3), 413–418.

Mueller, G., Broll, G. and Keplin, B. (1994). Erprobung des Köderstreifentests auf nährstoffarmen Böden an der polaren Waldgrenze in Nord-Finnland. *Braunschweiger Naturkundliche Schriften*, **4**(3), 665–669.

Mueller, G., Broll, G. and Tarnocai, C. (1998). Soil temperature regimes and microtopographic contrast, Baffin Island, N.W.T., Canada. In Lewkowicz, A.G. and Allard, M. (eds), *Proceedings, Seventh International Conference on Permafrost*. Centre d'études nordiques, Université, Laval, Quebec, Nordicana 57, pp. 771–774.

Nadelhoffer, K. J., Giblin, A. E., Shaver, G. R. and Linkins, A. E. (1992). Microbial processes and plant nutrient availability in Arctic soils. In Chapin, FS III, Jefferies, R.L., Reynolds, J.F., Shaver, G.R. and Svoboda, J. (eds), *Arctic Ecosystems in Changing Climate: An Ecophysicological Perspective*. Academic Press, New York, pp. 281–300.

Oberbauer, S. F. and Oechel, W. C. (1989). Maximum CO_2-assimilation rates of vascular plants on an Alaskan arctic tundra slope. *Holarctic Ecology*, **12**, 312–316.

Porsild, A. E. (1957). Illustrated flora of the Canadian Arctic Archipelago. *Natural Museum of Canada Bulletin*, 146.

Ritchie, J. C. (1987). *The Postglacial Vegetation of Canada*. Cambridge University Press, Cambridge.

Romanovsky, V. E. and Osterkamp, T. E. (1995). Interannual variations of the thermal regime of the active layer and near-surface permafrost in Northern Alaska. *Permafrost and Periglacial Processes*, **6**, 313–335.

Schimel, J. P., Gulledge, J. M., Clein-Curley, J. S., Lindstrom, J. E. and Braddock, J. F. (1999). Moisture effects on microbial activity and community structure in decomposing birch litter in the Alaskan taiga. *Soil Biology and Biochemistry*, **31**, 381–838.

Shaver, G. R., Laundre, J. A., Giblin, A. E. and Nadelhoffer, K. J. (1996). Changes in live plant biomass. Primary production and species composition along a riverside toposequence in Arctic Alaska. *Arctic and Alpine Research*, **28**(3), 363–379.

Soil Classification Working Group (1998). *The Canadian System of Soil Classification*, 3rd edn. Research Branch, Agriculture and Agri-Food Canada, Ottawa, Canada, Publication 1646.

Soil Survey Staff (1998). *Keys to Soil Taxonomy*, 8th edn. United States Department of Agriculture, Washington, DC.

Tarnocai, C. and Gould, J. (1998). *Ecosystem and Trafficability Monitoring for Auyuittuq National Park Reserve*. Research Branch (ECORC), Agriculture and Agri-Food Canada, Ottawa (65 pp.).

Tarnocai, C. and Veldhuis, H. (1998). *Soils and Trafficability of Pangnirtung Pass, Auyuittuq National Park Reserve*. Research Branch, Agriculture and Agri-Food Canada, Ottawa (77 pp.).

Taylor, F. C. (1981). Precambrian geology of the Canadian North Atlantic borderlands. In Kerr, J.W., Fergusson, A.J. and Machan, L.C. (eds), *Geology of the North Atlantic Borderlands*. Canadian Society of Petroleum Geologists, Calgary, Canada, pp. 11–30.

von Törne, E. (1990). Assessing feeding activities of soil-living animals. I: Bait-lamina-test. *Pedobiologia*, **34**, 269–279.

Unger, H. (1966). Arbeitsmethoden in der naturwissenschaftlichen und technischen Mikrobiologie. I: Der Gazebeuteltest. *Z. Bakteriol. Parasitenk. Abt. II*, **120**, 60–79.

Widden, P. (1977). Microbiology and decomposition on Truelove Lowland. In Bliss, L.C. (ed.), *Truelove Lowland, Devon Island, Canada: A High Arctic Ecosystem*. University of Alberta Press, Edmonton, Alberta, pp. 505–530.

Wielgolaski, F. E., Bliss, L. C., Svoboda, J. and Doyle, G. (1981). Primary production of tundra. In Bliss, L.C., Heal, O.W. and Moore, J.J. (eds), *Tundra Ecosystems: A Comparative Analysis*. Cambridge University Press, Cambridge, pp. 187–226.

Young, K. L., Woo, M. K. and Edlund, S. A. (1997). Influence of local topography, soils, and vegetation on microclimate at a high arctic site, Ellesmere Island, Canada. *Arctic and Alpine Research*, **29**(3), 270–284.