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PATTERNS OF SOIL MICROBES AND SOIL ORGANIC MATTER CHARACTERISTICS IN A PERIGLACIAL ENVIRONMENT AT KING GEORGE ISLAND (MARITIME ANTARCTIC)

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ABSTRACT

Soil organic matter and microbial communities were analysed during a study in periglacial environments at King George Island. Sampling was carried out in January 1996 in the admiralty Bay region along two transects with different distance to the coast, starting points were close to the Ecology Glacier. Different ecological situations were met, barren freshly deglaciated landscapes, young and old moraines. Soil cover shows different stages of plant colonization, from sparse to dense fields by lichens, mosses and higher plants. The moraines also have influences of birds, active and relic penguin colonies are located in this area. Methods applied were the thermogravimetric method for analyses of soil organic matter and epifluorescence microscopy for analyses of the microbial communities. Total organic carbon contents increase with distance to the glacier. This is also true for that share of carbon which can be regarded as biodegradable although its content is untypically low. Concomitantly, the transects show an increasing tendency for bacterial biomass with increasing distance from the glacier. The transect far from the coast reveals higher figures for these parameters. A great variability in size classes of bacteria refers to changes in the microbial communities. Good correlations between biodegradable carbon and bacterial biomass can be found. Close relationships of microbiological properties can also be established to soil cover and other factors describing soil organic matter. Several interrelationships within individual fractions of the organic carbon are discussed with special respect to soil development.

KEY WORDS: periglacial environment - soil organic matter - microbes

INTRODUCTION

Soil organic matter, microorganisms, and related microbial activity are generally closely related to ecological parameters. This holds true for many environments and was found in very close relation even in soils of virgin state or nutrient poor environments (Wynn-Williams, 1990, Bolter, 1992). Periglacial environments of the southern Polar Regions have been used for intensive studies on these relationships with special respect to the amounts of dissolved organic substances. Data from these studies in maritime and continental Antarctic environments show that considerable amounts of low weight organic material can be found. These organics have been described as leaching products from cryptogams and were mainly identified as carbohydrates, polyols (Tearle, 1987, Roser et al., 1992, 1994, Melick, Seppelt, 1994), free amino acids were found (Bölter, 1990) as well. The availability to heterotrophic bacterial communities has been studied by Bölter (1993) and Melick et al. (1994).

Despite high amounts on polyols in relation to photosynthetically active mosses and lichens, levels of such "free floating" products are low. In order to sustain the metabolism in barren or only poorly vegetated soils or during low production times of cryptogams, microbes have to make use of other materials than leaching products. By excretion of exoenzyms and hydro-lysing particulate matter or other high structural compounds, e.g. cellulose or hemicellulose from plant debris (Melick et al., 1994, Bölter, 1992), microbes get access to low weight organic matter. Hence, structural carbohydrates serve as a potential pool for nutrition. Its analysis, however, is difficult; an approach to it is the method of thermogravimetry (Kristensen, 1990, Siewert, Nitschke, 1998) and its derived results can provide further insights into the delicate interplay of decomposition and heterotrophic production of organic matter.

Soils of King George Island were analysed recently by Fabiszewski and Wojtun (1993), Bölter et al. (1994, 1997, and 1999), Blume et al. (1996, 1997) and Kuhn (1997). These investigations were carried out in the vicinity of Arctowski Station and thus serve as some base lines for this study.

MATERIALS AND METHODS

Samples were taken during a Czech expedition to the maritime Antarctic in January 1996, to Arctowski Station (King George Island). Sampling took place along two transects which were outlined a year before by M. Olech and D. Kuhn parallel to the coast line (Kuhn 1997, Jahns, 1999). They started at the Ecology Glacier, going to the north across moraines with different types of vegetation (Table 1). For this study, we analysed the upper soil layers (0-5 cm) for their bacterial communities by acridine orange staining and epifluorescence microscopy. The organisms were measured for their length put into size classes. Data on their biovolume and surface were calculated by geometrical factors (Bölter et al., 1993, Bölter, 1995).

The organic matter was analysed with the thermogravimetric method (Siewert, 1996; Siewert and Nitschke, 1998). The deep frozen soil samples were air dried after thawing, sieved during 2 mm, and stored at 76 % relative humidity for a comparable amount in bound water. The analysis was carried out with sample weights at about 1 g in 0.8 ml crucibles from 25 °C to 950 °C with a heating rate of 5 K / min in air current with 76 % relative humidity at 25 °C. Data analysis with special application software provides information on the carbon, nitrogen, clay and carbonate content of the sample. It also possible to determine the biodegradable and humified components of soil organic matter (SOM) and the volume of bound water.

RESULTS

Microbial community

The data of total bacterial counts are displayed in Fig. 1. Both transects show a clear trend to elevated figures with increasing distance from the glacier edge.

At transect A, data were found to range between 6.2 and 152 * 10^6 bacteria per gram dry soil. Four groups of sites can be established for this transect: AO, Al, A2, A4, A5 (6.2 - 17.4 * 10^6 cells/g d.wt), A3, A4, A6, A7 (31.9 - 51.6 * 10^6 cells/g d.wt), A8, A9, A10, All, A12 (70.2 - 94.5 * 10^6 cells/g d.wt.), A13, A14, A15 (118 -152 * 10^6 cells/g d.wt.).

The elevated figure at site A3 ($48.7*10^6$ cells/g d.wt), which is also reflected in its data on bacterial biomass and surface, is not related to an increase in plants but possibly due to soil algae, which were found in higher abundance during the microscopic inspections. Slight decreases during the run from A8 to A15 must be attributed to small scale changes in plant cover and herewith related supply of organic matter. Highest counts can be found in the vicinity of penguin nests (A13-A15).

The course oftransect B exhibits higher counts generally (25.2 to 980 * 10^6 cells/g d.wt,). Sites Bl to B6 show lowest counts (25.2 - 105 * 10^6 cells/g d.wt.). Although the plant cover at these sites is very sparse or even nil, the more sheltered region obviously allows a better growth of a microbial community. This is in relation to a higher abundance of soil algae which can be traced back in elevated data on chlorophyll a (0.26 - 0.78 u,g/g d.wt. Bölter, unpubl.). Sites B7 to B12 show a steady increase from 219 - 660 * 10^6 cells/g d.wt. with the exception of site B10 showing the maximum. All these sites have a dense vegetation cover with mosses, lichens, and higher plants to varying degrees (see Table 1).

These data on bacterial abundance are reflected by those of bacterial biomass and bacterial surface. Corresponding minima and maxima for transects A and B, respectively, were found between 0.02 and 0.8 µg C/g d.wt. for transect A, and between 0.15 and 4.0 µg C/g. d.wt. for transect B. Values for bacterial surface range from 0.03 to 1.02 cm^2/g d.wt. for transect A, and from 0.3 to 5.49 cm^2/g d.wt.

Parameters of total bacterial counts, biomass, and surface are correlated at high levels. Mismatches in correlations between these data sets are due to changing properties of the bacterial communities (Fig. 2), i.e. its composition. As such, highest proportions of cocci (cells <0.5 µm) are found at sites Al and A2 (88 and 87% of the total counts, respectively).

The contribution of cocci of the other sites varies between 44 (A14) and 73% (A13) or the total counts. At transect B the contribution of cocci generally between 54 and 68%, only sites B4 and B5 show lower values, 33.1 and 27.4%, respectively.

Within the rod shaped bacteria, the highest contributions to the individual communities are figured out by the size class 0.5-1 µm. Other bacterial sizes show only minor abundance, generally below 5%, maximally 9.5% at site B5.

Soil organic matter (SOM)

Fig. 3 presents the total carbon content and the amount of biodegradable components determined with weight losses in the temperature area from 280 °C to 290 °C. Both parameters show an increasing trend with the distance from glacier edge with higher variations on total organic carbon. The amount of biodegradable components is very low except in samples A13, A14, A15 and B9, B10, Bl 1, B12.

Interrelations between humified and biodegradable components are presented in shares of weight from SOM losses in Fig. 4. Samples from both transect show very high deviations from natural soils, not influenced by human activity. All points are outside of the tolerance range. The sample with the lowest deviation is A14.

Fig. 5 displays interrelations between weight losses of bound water and humified components. Samples A4, A6, A7, B5, and B9 do not show deviations. The highest deviations are found in samples Al, A8, A10, Bl, B4, All. These samples have the lowest content of biodegradable components and total organic carbon in Fig. 3.

Interrelations between biomass

The quantified with thermogravime-try biodegradable components correlates with the total biomass (B = 0.82), with the total bacteria number (B = 0.81) and with the total bacteria surface (B = 0.81). Fig. 6 shows an example of these interrelations. The regression parameters from both transects are similar and do not distinguish significantly.

Discussion of SOM characteristics

The content of biodegradable components in both transects are untypical low. The results are more typical for B- and C- horizons found in natural soils from other regions but not for upper soil layers studied here. Furthermore in A - Horizons the thermogravimetric indicator of biodegradable components is usually about ten times lower than the total organic carbon content. In analysed antarctic soils samples the biodegradable components are frequently more than 15 - 20 times lower.

Reduced contents of biodegradable components can usually be observed in soils with long time periods of increased mineralisation and/or of reduced input of fresh organic matter (for example in agriculture soils; Korschens, 1998). Hence, the productivity of biological processes can also be low due to climate conditions.

But such processes could not explain the deviations from the tolerance range in Fig. 4. The humification is depended from biological transformation processes of biodegradable components (Scheffer, Schachtschnabel, 1989). Reduced biodegradable components may not increase the accumulation of humified components what was confirmed by normal relationships between components of SOM in tundra soils from other regions in Russia (Siewert, unpublished).

The deviations of samples in Fig. 4 from tolerance range are higher as in Fig. 5. Any samples show reduced content of biodegradable components and normal content of humified components. Because of the higher biological stability of humified components these results could only be caused by changes in soil formation.

Correlation between microbiological data and biodegradable components (Fig. 6) confirm the well-known influence of biodegradable components on organism activity and the usefulness of both methods. By this reason, discovered spatial variations with microbiologic methods and thermogravimetric determination of biodegradable components are similar in both transects.

CONCLUSIONS

The data on the microbial communities reflect a poor nutritional state of the organic matter in these soils. Bacteria keep in small size at nearly all sites. Changes in biomass are primarily due to increasing counts rather than by increasing individual size. Similar observations were made during earlier studies in this environment as well as at other places in the Antarctic and Arctic (Bolter, 1995, Bolter, Pfeiffer, 1997). Small size, however, reveals a high specific surface of the cells and thus possibly provides a better access to small amounts of organic matter. Hence, this effect seems to be more due to a survival strategy than to starvation (Jenkinson et al., 1976).

The transect also shows a great variability in the bacterial communities. Generally, the relationships of higher bacterial biomass to higher amounts of total organic matter can be confirmed. This becomes obvious when comparing data on total counts with total organic

matter (LOI, Bölter, unpubl.) or to our data on carbon and nitrogen. The decreasing C/N-ratio is another indicator of higher quality, degradability and thus it is of higher nutritional value.

The thermogravimetric characteristics of SOM confirm the data about microbial communities. The poor nutritional state of the organic matter is reflected in the low absolute content of biodegradable components and in different disproportions between components of SOM.

Using experiences from other studies about tundra soils, paleochernozems (Siewert, 1999) and different agriculture soils in any climatic zones the found disproportion's could be regarded as disturbances in soil formation and caused by long term processes of biological degradation of SOM without input of fresh organic residues. Due to the normal formation of humified components in some samples and there biological stability these changes have to be situated after a period of normal soil formation in far past. Presently the compensation of disturbances by activity of plants and soil biomass is probably not complete because of the climate conditions.

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Tab. 1 Descriptions and data of sampling sites (Olech, Kuhn, Elster, pers. comm.)
1) glac. = glacier, mor. = moraine,
2) distance (meter) from glacier edge
3) gras = Deschampsia antarctica partly associated with Colobanthus quitensis, moss = Polytrichum poliferum, Drepanocladus uncinatus, partly overgrown with crustose lichens, lich = Usnea antarctica, algae = Prasiola crispa

Sample	location[1)]	distance[2)]	vegetation[3)]	cover (%)
A0	glacier edge	2	nil	0
A1	mor. foot	32	nil	0
A2	mor. top	37	nil	0
A3	mor. slope	55	nil	0
A4	mor. top	93	gras	<1
A5	mor. valley	129	gras, moss	1
A6	mor. top	142	gras, moss	1
A7	mor. food	146	gras, moss	1
A8	mor. top	167	gras, moss	5
A9	mor. slope	176	gras, moss	5
A10	mor. top	188	gras, moss	5
A11	mor. top	203	gras, moss, lich	5
A12	mor. valley	221	gras, moss, lich	50
A13	mor. top	233	gras, algae	90
A14	mor. top	245	gras, algae	100
A15	mor. slope	306	gras, algae	100
B1	mor. foot	16	nil	0
B2	mor. slope	32	nil	0
B3	mor. top	76	gras	<1
B4	depression	106	gras	<1
B5	mor. food	116	gras	<1
B6	depression	133	gras, moss	5
B7	mor. slope	141	gras, moss, lich	30
B8	depression	181	gras, moss	80
B9	mor. foot	184	gras, moss	90
B10	mor. slope	213	gras, moss, lich	95
B11	mor. slope	231	gras, moss, lich	60
B12	mor. top	237	gras, moss, lich	100

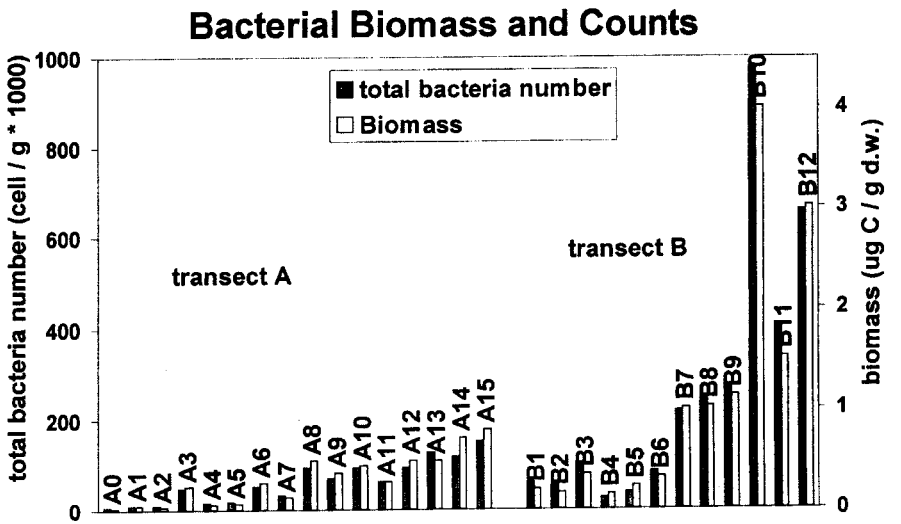

Fig. 1 Data of total bacteria counts of transects A and B.

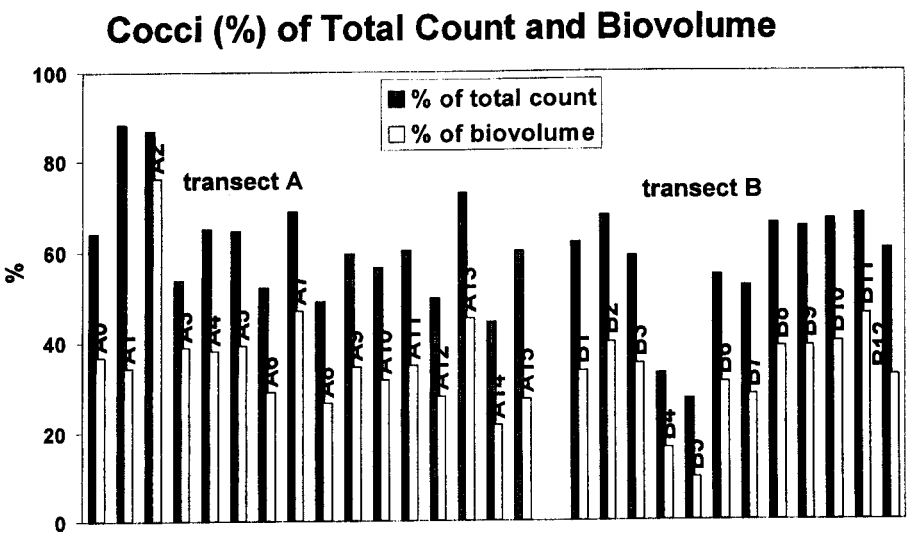

Fig. 2 Contributions of cocci to the total bacterial counts.

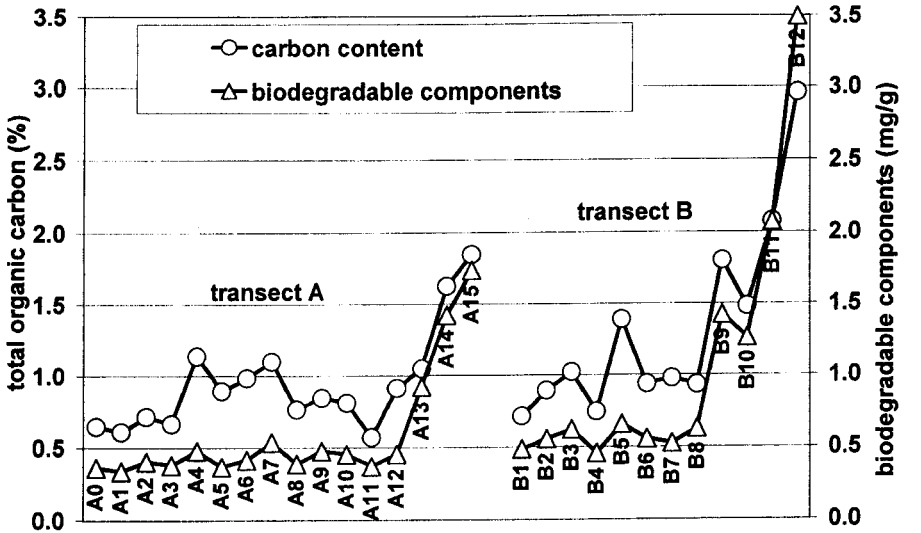

Fig. 3 Content of biodegradable components of SOM (mg/g) and total carbo content (%) in the soil samples from transects A and B.

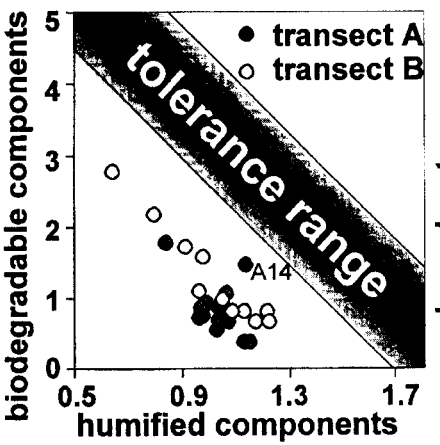

Fig. 4 Contents of humified and biodegradable components in shares by weight of SOM losses (%) in comparison with undisturbed soil samples.

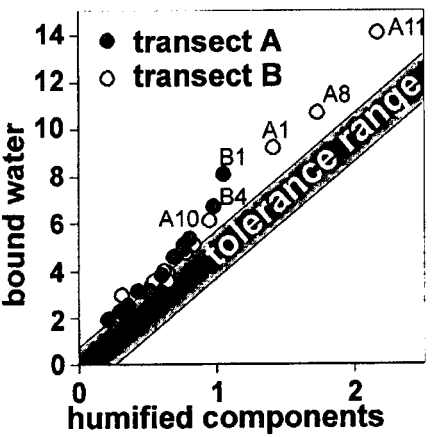

Fig. 5 Relationships between bound water and humified components in SOM (mg / g sample / % total carbon content).

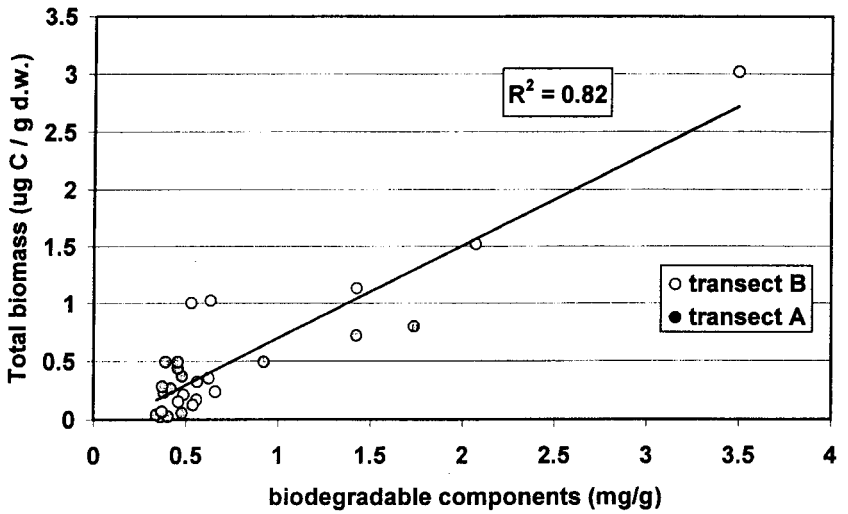

Fig. 6 Regression dependence between biodegradable soil components and total biomass.