

MICROBIAL ECOLOGY OF SOILS FROM WILKES LAND,  
ANTARCTICA: I. THE BACTERIAL POPULATION  
AND ITS ACTIVITY IN RELATION TO  
DISSOLVED ORGANIC MATTER

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**Abstract:** During a comprehensive research program carried out on soils from the Antarctic Continent (Casey Station, Wilkes Land) emphasis was laid on the bacterial population, its state of activity and corresponding relationships to particulate and dissolved organic nutrients. The bacterial population is characterized by epifluorescence microscopy with regard to different size classes and its variability. Organic nutrients are described by particulate organic nitrogen, carbon and particulate carbohydrates as well as by dissolved amino acids and moncarbohydrates. Bacterial activity is determined by uptake and respiration of labelled glucose. The results indicate a fairly active microbial population although actual numbers and biomass of bacteria show low levels in comparison with other environments. Dominant factors for bacterial activity (uptake of glucose and biomass production) are free dissolved moncarbohydrates and amino acids in connection with total organic carbon and moisture content. Respiration, however, shows a quite different pattern of variation. The most active part of the bacterial population is the size class of small rods (1-1.5  $\mu\text{m}$ ).

## 1. Introduction

Antarctic soils are in a rather primary state with regard to biological and biochemical properties. Low amounts of organic matter are regarded to determine the state of this ecosystem at low levels (SMITH, 1985). For large areas, *e.g.* the desert plains of Victoria Land, figures of biomass and microbial activity are often at or below detection level (VESTAL, 1988a, b). Those rates of low microbial activity are generally caused by the prevailing conditions of low temperature and humidity which act as overall stress factors, especially during thaw-freeze cycles (WYNN-WILLIAMS, 1982), and in combination with high sublimation and evaporation due to desiccating winds and strong solar radiation. Nevertheless, large areas of coastal environments of the continent are covered by dense mats of mosses or spread by lichens and thus forming ecological systems of autotrophic and heterotrophic organisms. The process of recycling is mainly due to bacteria and fungi rather than to grazing animals (SMITH, 1977).

Bacteriological studies in the Antarctic environment have shown the occurrence of a wide range of microorganisms by cultural methods in nearly all environments (*e.g.*, CAMERON *et al.*, 1970; LEONARDI *et al.*, 1987; LINE, 1988). Those studies on viable bacteria, however, refer mainly either to the regions of the Victoria Land Dry Valleys

or to the milder regions of the Subantarctic Islands. This holds also true for determinations of total number and biomass by direct counts (*e.g.*, CLARHOLM and ROSSWALL, 1980; FRENCH and SMITH, 1986; GROBLER *et al.*, 1987; WYNN-WILLIAMS, 1988); RAMSAY (1983) and RAMSAY and STANNARD (1986) analyzed bacterial populations of soils from penguin rookeries at Ross Island. Papers dealing with bacterial activity are even scarce (GROBLER *et al.*, 1987; VESTAL, 1988b), although some investigations were performed in order to describe overall respiratory activity of the microbial community (WYNN-WILLIAMS, 1984).

In this paper, an attempt is made to describe the bacterial population and its actual activity by samples from an environment near Casey Station, Wilkes Land, located on the continent and influenced by the nearby coastline. The bacterial population is characterized by epifluorescence microscopy (ZIMMERMANN *et al.*, 1978), activity parameters are determined by use of the non-kinetic approach of the uptake of labelled glucose, a substrate which can be regarded as a model for the metabolism of dissolved carbohydrates (BÖLTER, 1981). The figures of these parameters are discussed in relation to some other edaphic factors in order to get an idea for the description of the microbial processes in this environment of the protoranker soils (TEDROW and UGOLINI, 1966) of coastal East Antarctica.

## 2. Materials and Methods

### 2.1. Sampling and environment

Sampling was carried out at a hill (40 m above sea level) about 1 km south of Casey Station, Wilkes Land. The area of sampling was about 250 m<sup>2</sup>, covered by large boulders and stones of granite. In between these outcrops are smaller areas of some square meters of plain sand, covered partly by moss cushions, crustose and fruticose lichens, and/or algae. A detailed description of the area around Casey Station is given by SMITH (1986). The following cardinal temperatures were recorded during the study period with respect to exposition: Mean temperature: 1.7–2.8°C; minimum temperatures: –10.0 to –8.8°C; maximum temperatures: 24.0–34.0°C (BÖLTER *et al.*, 1989).

Surface samples, partly covered with dead moss cushions, crustose lichens or algae, as well as profiling samples to a depth of 8 cm, were collected and immediately deep frozen until analysis in the laboratory in Kiel. The samples were collected in November/December 1985, and were analyzed in 1986. Table 1 shows the origin of the samples and a brief description of them.

The effect of freezing on the samples was tested by ATP contents and CO<sub>2</sub> gas exchange measurements (KAPPEN *et al.*, 1986) through comparing field data with those from laboratory experiments. Differences in these data were negligible, *i.e.* without statistical significance. Although this result cannot be applied to all properties analyzed, it will be possible to rely on the data from laboratory experiments as descriptors for processes and concentrations in the environment-bearing in mind all possible artefacts.

### 2.2. Microscopy

Epifluorescence microscopy was used to determine bacterial numbers and biomass according to the method of ZIMMERMANN *et al.* (1978). Approximately 1 g of a sample

Table 1. List of samples and their origins by the depth profiles.

Sample No.	Description	Depth layer (cm)
C 1	Organic layer on sand	0-2
C 2	Sand	2-4
C 3	Sand	3-7
C 5	Loamy sand	0-1
C 6	Loamy sand	1-3
C 7	Loamy sand	3-5
C 8	Sand with algae	0-1
C 9	Sand	1-3
C10	Sand	3-5
C11	Sand	0-2
C12	Sand	2-4
C13	Sand	4-6
C14	Organic layer on sand	0-1
C15	Sand	1-3
C16	Sand	3-5
C17	Sand	0-2
C18	Sand	2-4
C19	Sand	4-6
C22	Sand with algae, lichens	0-1
C25	Sand with lichens	0-1
C27	Sand with small mosses	0-2
C28	Sand with lichens	0-1
C29	Sand covered with algae	0-1
C30	Organic layer on sand	0-1

“Organic layers” were generally dry moss cushions, overgrown by lichens, very dry samples. The predominant lichens in samples C22 and C28 were *Candelariella* sp. and *Buellia* sp. in sample C25. Mosses and algae were not determined.

was put into 20 ml of particle-free water and treated by an ultrasonicator (50 mW, 30 s). An aliquot of this was filtered through a polycarbonate membrane filter (Nucleopore, pore size 0.2  $\mu\text{m}$ ) and the bacteria are analyzed for size distribution. The size classes were: cocci < 0.5  $\mu\text{m}$ , 0.5–1  $\mu\text{m}$ ; rods 0.5–1  $\mu\text{m}$ , 1–1.5  $\mu\text{m}$ , 1.5–2.5  $\mu\text{m}$ , 2.5–4  $\mu\text{m}$ , > 4  $\mu\text{m}$ . These size classes were chosen after examination of previous subsamples and set to these thresholds in order to give the best fit for the overall population. Mean bacterial volumes of the size classes (except for bacteria > 4  $\mu\text{m}$ , which were measured individually) served as data for the estimation of biomasses by using a conversion factor given by SCHLEGEL (1976).

### 2.3. Glucose uptake

The measurement of glucose uptake and respiration follows generally the methods of MEYER-REIL (1978) and BÖLTER *et al.* (1981). Subsamples (approx. 1 g) were put into 10 ml sterile water and incubated in time series (10, 20, 30 min) in triplicate after adding of 26 ng of D-<sup>14</sup>C(U)-glucose (New England Nuclear, 358 mCi/mmol). After ultrasonic treatment (50 mW, 30 s) 10 ml of this solution was filtered through membrane filters (Sartorius, cellulose nitrate, pore size 0.2  $\mu\text{m}$ ) and the activity on the filters was counted

in a liquid scintillation counter by external standard quench correction. Respiration measurements were performed by trapping  $^{14}\text{CO}_2$  in ethanol amine after acidification of the samples with 0.5 ml 5N  $\text{H}_2\text{SO}_4$  (HARRISON *et al.*, 1971). Since the addition of water changes the original environment, these data should be regarded as potential ones. All measurements were corrected by blanks and for the original subsample weights.

Incorporated material was used for measurement of the net uptake of glucose ( $NUp$ );  $NUp$  plus respired glucose ( $R$ ) yields the gross uptake ( $GUp$ ). Gross uptake divided by the amount of added substrate yields the turnover time ( $T_t$ ). By introducing the actual concentration of glucose ( $glc$ ), an estimation of the actual uptake ( $AUp$ ) can be made by multiplication of  $GUp$  by a factor  $F$  which is given by the ratio of  $(^{12}\text{C-Glc} + ^{14}\text{C-Glc})/^{12}\text{C-Glc}$ , where  $^{14}\text{C-Glc}$  and  $^{12}\text{C-Glc}$  refer to the concentrations of the glucose fractions. Further,  $F \times NUp$  serves as a figure of bacterial biomass production,  $F \times R$  gives the remineralization rate. From  $GUp$  and  $R$  the amount of respired material ( $\%R$ ) can be calculated. These recalculated figures of bacterial biomass production, glucose uptake and remineralization rate have to be regarded under the assumption that glucose serves as a unique and preferred substrate for bacterial activity (MEYER-REIL *et al.*, 1980; BÖLTER, 1981). All incubations were performed at three temperatures, 5, 15, and 25°C, which cover a reasonable span of soil temperatures with active microbial activity.

#### 2.4. Carbohydrates and amino acids

The determination of carbohydrates and free amino acids follows the procedures given by DAWSON and LIEBEZEIT (1983). In brief, carbohydrates are determined by a class reaction of a borohydride complex and measured photometrically. Free mono-carbohydrates (MCHO) are determined directly after cold water extraction of the samples, particulate carbohydrates (PCHO) after hydrolysis (1N HCl, 20h, 100°C). Free amino acids (FAA) are determined after cold water extraction. The detection runs fluorometrically after reaction with *o*-phthalaldehyde. The terminology (MCHO, PCHO, FAA) follows the methodological description of DAWSON and LIEBEZEIT (1983). D-glucose and L-glycine serve as standards, respectively. It is assumed that the extraction by cold water refers as close as possible to the directly available amount of these substrates for bacterial metabolism. IVARSON and SOWDEN (1969) showed this for amino acids during a methodological comparison.

#### 2.5. Other edaphic factors

Some other characteristics, such as water content and loss on ignition, are used for this study. The methods of measurement of these characters follow standard procedures of current text books (*e.g.*, SCHEFFER *et al.*, 1984).

#### 2.6. Statistical analysis

All statistical procedures were performed according to a program bloc (BÖLTER *et al.*, 1980) at the PDP-10 (DEC-System) of the Kiel University computer center. The data set used for this study comprised 24 samples and 43 characters (*cf.* Table 1).

### 3. Results

#### 3.1. The bacterial population

Figure 1 depicts numbers and biomass of the bacterial population. The original figures show a variation between  $0.95 \times 10^6$  bact.  $g^{-1}$  w.wt. and  $93.1 \times 10^6$  bact.  $g^{-1}$  w.wt. The high mean value of  $27.42 \times 10^6$  bact.  $g^{-1}$  w.wt. is mainly due to the samples 8, 17, 18, 19. Bacterial biomass varies between 0.007 and  $0.964 \mu g C g^{-1}$  w.wt. and shows a mean value of  $0.234 \mu g C g^{-1}$  w.wt. Although these figures show wide spans, they can be regarded to fulfill the conditions of a normal distribution according to the test of DAVID *et al.* (1954) and the corresponding table of PEARSON and STEPHENS (1964). This holds also true for the ratio of biomass: number which shows a mean value of  $8.04 \times 10^{-12}$  mg C cell $^{-1}$  but shows a much less variation ( $3.05$ – $13.46 \times 10^{-12}$  mg C cell $^{-1}$ , cf. Table 2), the corresponding variation coefficient is 34.15%. Highest values of this ratio can generally be monitored in surface samples which show a mean value of  $9.64 \times 10^{-12}$  mg C cell $^{-1}$  vs.  $7.17 \times 10^{-12}$  mg C cell $^{-1}$ , for deep layer samples. A significant separation between these figures by the corresponding confidence intervals is not possible. However, these data can be used to describe the general trend. This trend can be seen also in the distributions of the size classes (Table 2). The highest contribution with respect to the total bacterial biomass shows the fraction of small rods ( $0.5$ – $1 \mu m$ ) with 38.7% in mean, followed by the next class of rods ( $1$ – $1.5 \mu m$ ) with 27.3%. Both fractions of cocci represent 12.2% of total biomass. The small tods seem to be most stable fraction ( $V_k = 34.5\%$ ). The total number, however, is govoned by the small cocci which show in mean a portion of 52.6%, followed by the smallest rods (32.3%).

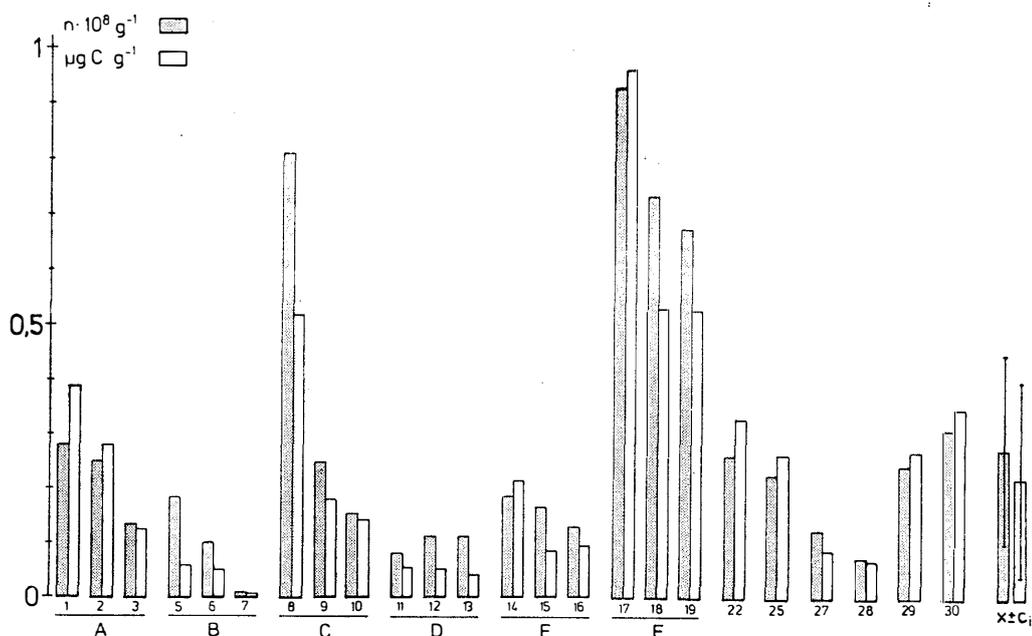


Fig. 1. Bacterial number (shaded columns) and biomass (open columns) of soil samples from Wilkes Land, Antarctica. Letters A–F refer to depth profiles. The bars on the right hand side indicate the mean values of number and biomass, respectively, and their confidence intervals ( $x \pm c_i$ ).

Table 2. Bacterial population analyzed from Wilkes Land, Antarctica. The data given are percent values of the different size fractions of the bacteria (in  $\mu\text{m}$ ) in relation to total number (TBN) (first row) and total biomass (TBB) (second row) for each sample. The ratio of TBB/TBN carries the unit  $\text{fg cell}^{-1}$ .

Sample	TBB/TBN	Cocci <0.5	Cocci 0.5-1	Rods 0.5-1	Rods 1-1.5	Rods 1.5-2.5	Rods 2.5-4
1	13.46	37.50	3.25	30.30	20.80	7.50	1.00
		3.87	1.56	21.30	38.44	28.35	6.49
2	11.24	43.50	1.50	31.00	18.50	4.80	0.80
		5.36	0.86	25.93	40.72	21.33	5.79
3	9.36	58.00	2.00	20.80	12.50	6.80	0
		8.57	1.38	20.78	32.96	36.31	0
5	3.05	82.80	1.30	14.80	0.80	0.50	0
		37.58	2.62	45.45	6.07	8.28	0
6	5.12	75.80	1.00	17.30	3.80	1.50	0.80
		20.69	1.29	31.98	18.30	14.92	12.82
7	7.42	54.80	0.50	30.80	12.80	1.30	0
		10.26	0.32	38.78	42.31	8.33	0
8	7.28	52.80	1.30	34.30	10.80	0.80	0.30
		10.03	1.10	44.19	36.50	5.20	2.97
9	7.41	42.30	2.00	48.30	7.00	0	0.50
		7.90	1.73	61.16	23.35	0	5.85
10	9.28	48.80	1.80	37.80	6.80	3.00	2.00
		7.30	1.22	38.34	18.04	16.36	18.73
11	6.44	61.80	1.30	28.00	6.50	2.50	0
		13.28	1.26	40.89	24.97	16.67	0
12	4.73	73.30	1.30	20.00	4.00	1.50	0
		21.51	1.70	39.82	20.95	16.02	0
13	3.86	70.80	0.50	27.80	1.00	0	0
		25.34	0.85	67.41	6.41	0	0
14	11.69	39.30	3.00	36.30	15.80	4.80	0.50
		4.65	1.64	29.11	33.28	20.47	3.71
15	5.15	61.20	0.80	34.30	3.30	0.50	0
		16.40	0.93	62.25	15.55	4.87	0
16	6.79	70.00	0	24.50	0.50	2.80	2.20
		14.40	0	34.19	1.83	20.61	28.96
17	10.35	34.80	1.00	46.30	14.50	3.50	0
		4.70	0.63	42.43	35.01	17.24	0
18	7.84	47.50	0.50	43.80	5.30	2.50	0.50
		8.44	0.41	52.75	16.66	16.18	5.56
19	7.84	46.30	0.80	42.00	9.30	1.80	0
		8.20	0.62	50.56	29.30	11.31	0
22	12.56	49.30	0	31.50	9.80	7.50	1.50
		5.43	0	25.57	19.19	30.11	10.34
25	11.36	41.80	4.30	28.80	18.80	6.00	0.50
		4.96	2.34	23.19	39.81	25.99	3.71
27	7.41	69.50	1.50	17.50	9.80	1.30	0
		12.94	1.31	22.17	32.50	8.52	0
28	9.44	46.80	0.80	29.80	15.80	6.50	0.50
		6.88	0.52	29.65	41.32	17.05	4.58
29	11.15	26.30	1.50	51.80	18.30	1.75	0.50
		3.27	0.87	43.61	40.46	7.91	3.88
30	11.20	27.80	3.80	46.50	19.00	3.00	0
		3.43	2.15	38.99	41.92	13.51	0
Mean values	8.40	52.62	1.49	32.26	10.23	3.01	0.48
		11.06	1.14	38.67	27.33	15.36	4.73

When comparing these data of the surface samples with those of deeper layers, the greatest difference in numbers was found concerning rods 0.5–1  $\mu\text{m}$  (33.71/43.6%), 1–1.5  $\mu\text{m}$  (32.5/22.2%), and with respect to total number for the small cocci (47.5/57.69%). These differences, however, cannot be verified by statistical tests, as their figures  $\pm$  confidence level ( $P < 0.05$ ) show wide overlappings.

### 3.2. Metabolism of glucose

The uptake of  $^{14}\text{C}$ -labelled glucose exhibits figures of wide range. The coefficients of variability are larger than 100%. Thus, mean values may serve only for a description of a general trend with regard to the different temperatures (Table 3). Highest values can be monitored at 15°C indicating an optimum of bacterial glucose metabolism at this temperature. It should be pointed out that respired glucose shows a range of 60–70%.

Table 3. Bacterial activities measured in soil samples from Wilkes Land, Antarctica. Data represent mean values of all samples (A), surface samples (B), and deep layer samples (C),  $\pm$  confidence limit (95%) for three incubation temperatures.

Bacterial activity		5°C	15°C	25°C
Turnover time (h)	(A)	15.7 $\pm$ 12.1	10.3 $\pm$ 7.8	9.9 $\pm$ 7.5
	(B)	5.5 $\pm$ 3.5	4.0 $\pm$ 2.4	4.6 $\pm$ 2.7
	(C)	25.1 $\pm$ 15.3	16.6 $\pm$ 11.1	14.8 $\pm$ 10.5
Respiration (%)	(A)	67.4 $\pm$ 12.7	65.5 $\pm$ 12.9	69.8 $\pm$ 12.0
	(B)	66.0 $\pm$ 13.5	67.8 $\pm$ 12.9	70.0 $\pm$ 11.7
	(C)	68.7 $\pm$ 11.5	63.3 $\pm$ 12.3	69.7 $\pm$ 12.3
Actual uptake ( $\mu\text{g Glc g}^{-1}$ w. wt. $\text{h}^{-1}$ )	(A)	4.22 $\pm$ 4.51	5.72 $\pm$ 5.63	4.17 $\pm$ 3.65
	(B)	8.51 $\pm$ 6.22	10.11 $\pm$ 6.87	7.85 $\pm$ 4.13
	(C)	0.65 $\pm$ 0.46	1.69 $\pm$ 1.66	1.11 $\pm$ 0.68
Remineralization ( $\mu\text{g Glc g}^{-1}$ w. wt. $\text{h}^{-1}$ )	(A)	2.96 $\pm$ 3.26	3.80 $\pm$ 3.82	3.10 $\pm$ 2.77
	(B)	6.01 $\pm$ 4.59	6.94 $\pm$ 4.68	5.81 $\pm$ 3.01
	(C)	0.41 $\pm$ 0.28	1.02 $\pm$ 0.96	0.83 $\pm$ 0.57
C-production ( $\mu\text{g C g}^{-1}$ w. wt. $\text{h}^{-1}$ )	(A)	0.47 $\pm$ 0.51	0.70 $\pm$ 0.72	0.40 $\pm$ 0.39
	(B)	0.94 $\pm$ 0.68	1.19 $\pm$ 0.92	0.76 $\pm$ 0.49
	(C)	0.09 $\pm$ 0.07	0.25 $\pm$ 0.27	0.10 $\pm$ 0.05

Figure 2 shows the individual values for the lowest incubation temperature (5°C) which can be regarded as a frequently occurring temperature in this environment during the austral summer (BÖLTER *et al.*, 1989). As already shown for the figures of biomass and numbers, highest figures of glucose metabolism occur in the surface samples.

The ratio of bacterial biomass production *vs.* bacterial biomass exhibits also great variability. The values are not correlated to sampling depth or incubation temperature. Further, there are no correlations with any other parameter except with the concentration of MCHO ( $P < 0.05$ ) and the ratios of PCHO/MCHO and FAA/MCHO ( $P < 0.01$ ); these last two correlations are negative.

### 3.3. Organic nutrients

Table 4 shows the results of the analyses of organic nutrients. Again, surface samples exhibit highest amounts although there are wide ranges as described by the

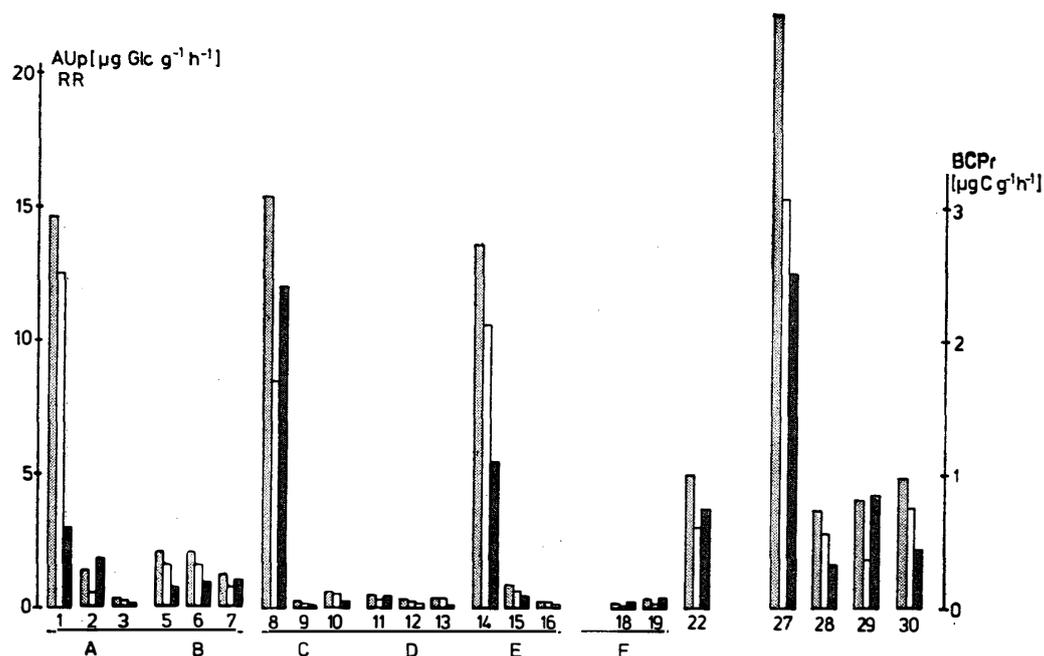


Fig. 2. Measurements of glucose metabolism of bacteria in soil samples at 5°C from Wilkes Land, Antarctica: Figures of actual uptake (AUp, light shaded columns), remineralization rate (RR, open columns), and bacterial carbon production (BCPr, dark shaded columns) which is based on the net uptake of glucose.

Table 4. Organic nutrients and water content measured in soils from Wilkes Land, Antarctica.

		WC	LOI	PON	POC	POC/ PON	FAA	PCHO	MCHO	PCHO/ MCHO	FAA/ MCHO
A	$x \pm$	22.59	6.65	0.22	2.77	10.14	80.25	169.80	22.05	12.05	6.61
	<i>c</i>	15.61	6.35	0.15	2.66	2.96	80.14	134.26	17.58	7.81	6.86
B	$x \pm$	33.57	11.04	0.32	4.74	12.69	136.23	272.22	32.36	17.10	10.41
	<i>c</i>	20.24	8.90	0.18	3.31	2.89	106.29	171.99	22.99	11.53	9.01
C	$x \pm$	11.61	2.26	0.11	0.81	7.60	24.26	67.37	12.59	7.37	3.13
	<i>c</i>	3.06	0.45	0.04	0.24	1.54	14.81	27.54	7.30	3.10	2.37

The columns contain the mean values ( $x$ )  $\pm$  corresponding to confidence levels (*c*) for water content (abbreviation: WC, data given in: %), loss on ignition (LOI, %), particulate organic carbon (POC, %), particulate organic nitrogen (PON, %), POC/PON, free amino acids (FAA,  $\mu\text{g g}^{-1}$  w. wt.), particulate carbohydrates (PCHO,  $\mu\text{g g}^{-1}$  w. wt.), dissolved monosaccharides (MCHO,  $\mu\text{g g}^{-1}$  w. wt.), PCHO/MCHO, FAA/MCHO. The rows A, B, and C refer to all samples, the surface samples and the deeper horizon samples, respectively.

confidence intervals. It should also be pointed out that the surface samples show highest values of water content. The amounts of free amino acids exceed those of free carbohydrates evidently.

The ratio of POC/PON, however, points to a better "quality" of the organic matter in the deeper horizons. This ratio can also be used to separate surface samples from deep layer samples significantly, *i.e.* they have no overlapping figures with regard to their confidence limits. Corresponding coefficients of variability are 31.3 and 24.1%, respectively.

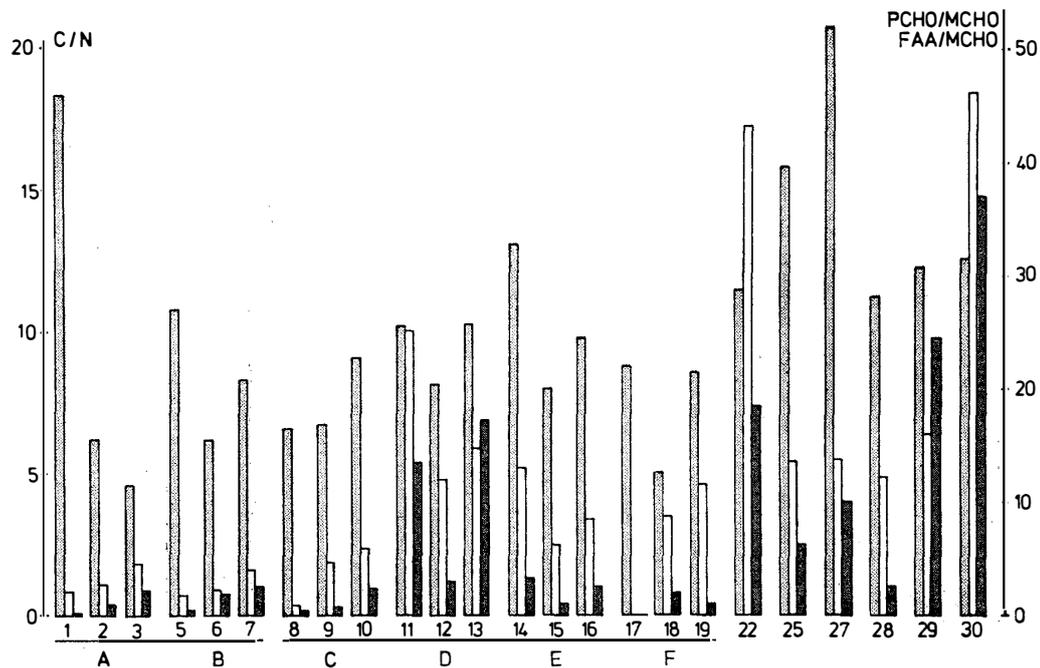


Fig. 3. Illustration of the organic matter of soil samples from Wilkes Land, Antarctica: Carbon vs. nitrogen (C/N, light shaded columns), particulate carbohydrates vs. moncarbohydrates PCHO/MCHO, open columns), and free amino acids vs. moncarbohydrates (FAA/MCHO, dark shaded columns).

Data of these ratios are presented in Fig. 3. The ratios PCHO/MCHO and FAA/MCHO follow generally the same trend, *i.e.* low figures in surface samples and increasing figures with depth. This indicates a worse supply of available carbohydrates in relation to PCHO and FAA and may support the decreasing activity of glucose metabolism with depth as shown above. However, these ratios have wide spans and cannot be used as significant indexes between surface and deep layer samples.

### 3.4. Correlation analysis

The data given above are analyzed by a non-parametric rank correlation analysis. The results are presented in a correlation matrix where the correlation coefficients are transposed to symbols (Fig. 4). The first group of properties, water content and particulate matter, shows a high degree of intercorrelations. Relationships are also highly significant in the ratio of bacterial number and biomass, the number of rods (1.5–2.5  $\mu\text{m}$ ), free amino acids and particulate carbohydrates, and the uptake parameters of glucose. The size classes of small rods and small bacteria are negatively correlated with these parameters.

The parameters of total bacterial number and biomass are also highly intercorrelated. They are negatively correlated with numbers and biomass of small cocci (number and biomass) and show significant positive relationships to the biomasses of rods (0.5–1.5  $\mu\text{m}$ ). Individual size classes fluctuate generally independently, this part of the matrix is only partly filled with symbols. The rods (1–1.5  $\mu\text{m}$ , number and biomass) show significant relations to the uptake parameters and thus seem to be the most important group of bacteria in relation to metabolic processes.

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. . . &+ . . . . &						13 biom.rods 1.5-2.5µm
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. . . -** - - . . . . +.						15 numb.cocci <0.5µm
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. . . + . . . . -.						17 numb.rods 0.5-1µm
. . . & .+&+ .&&+&&+&+&+ . - * - .						18 numb.rods 1-1.5µm
. . . + . . . . .						19 numb.rods 1.5-2.5µm
. . . . .						20 numb.rods 2.5-4µm
. . . & &&. &&&&&&+&+&+ . ***.						21 faa
. . . &+ .&&&&&&&&&. -**.						22 pcho
. . . - - .&&&&&&&&&. . + +						23 mcho
. . . &. . -** . * -						24 pcho/mcho
. . . . . *** . *						25 faa/mcho
. . . . . &&&&&&&&. ***.						26 aup 5°C
. . . . . &&&&&&&&. ***.						27 bcpr 5°C
. . . . . &&&&&&. ***.						28 rr 5°C
. . . . . &&&&&. **-						29 aup 15°C
. . . . . &&&&. **-						30 bcpr 15°C
. . . . . &&&. **-						31 rr 15°C
. . . . . &&. ***.						32 aup 25°C
. . . . . &. ***.						33 bcpr 25°C
. . . . . ***.						34 rr 25°C
. . . . . &&.						35 tt 5°C
. . . . . &.						36 tt 15°C
. . . . . +						37 tt 25°C
. . . . . &&.						38 r% 5°C
. . . . . +.						39 r% 15°C
. . . . .						40 r% 25°C
. . . . . &						41 bcpr/tbb 5°C
. . . . . &						42 bcpr/tbb 15°C
. . . . .						43 bcpr/tbb 25°C

Fig. 4. Correlation matrix (Spearman rank correlation) of the characters used in this study. The symbols indicate correlations between characters: &: positive correlation, 1%-level; +: positive correlation, 5%-level; \*: negative correlation, 1%-level; -: negative correlation, 5%-level. Abbreviations: (1) wc: water content, (2) loi: loss on ignition, (3) poc: particulate organic carbon, (4) pon: particulate organic nitrogen, (5) C/N: ratio of particulate organic carbon to nitrogen, (6) tbn: total bacterial number, (7) tbb: total bacterial biomass, (8) tbn/tbb: ratio of total bacterial number to biomass, (9)–(14) biom. cocci: portions of the different size classes with regard to biomass and (15)–(20) number, (21) faa: free amino acids, (22) pcho: particulate carbohydrates, (23) mcho: monocarbohydrates, (24) (25) ratios of these compounds, (26)–(43) parameters of bacterial activity at different temperatures: aup: actual uptake of glucose, bcpr: bacterial C-production, rr: remineralization rate, tt: turnover time of glucose, r%: partition of respired material.

Free amino acids and carbohydrates show overall relationships with the uptake parameters of glucose and related turnover time. Monocarbohydrates show also a positive correlation to the ratio of C-production vs. biomass. Parameters of actual glucose metabolism and those of the turnover times are all strongly intercorrelated. The partitions of respired material are uncorrelated to any of these descriptors as well as to those of dissolved and particulate amino acids and carbohydrates, respectively. The ratio of C-production vs. biomass remains also generally uninfluenced by any other descriptor, only the ratios PCHO/MCHO and FAA/MCHO show some connections as mentioned above.

#### 4. Discussion

Growth patterns and life processes are widely considered to be low in severe environments like the Antarctic where some dominant environmental factors, such as light, temperature, moisture and nutrients, are often insufficient to maintain metabolic processes at high levels. Further, changes in these factors are rapid and large. INO (1985) stated that organisms in those environments should have short recovery periods for their metabolism and showed this for some lichens. Because of the low growth rates of plants (INO, 1983, 1985; KAPPEN, 1983) it is assumed that the complete food web acts at low levels of activity (SMITH, 1985), *i.e.* low rates of primary production yield low amounts of organic matter to sustain the detritus food web.

The bacterial population showed a variation between 0.95 and  $93.1 \times 10^8$  bacteria  $g^{-1}$  w.wt. soil and exhibited a biomass between 0.007 and  $0.964 \mu g C g^{-1}$  w.wt. These values are considerably lower than those from other investigations in Antarctic or Subantarctic soil samples, *e.g.* GROBLER *et al.* (1987) as well as RAMSAY and STANNARD (1986) find bacterial numbers in the range of  $10^{10}$  cells  $g^{-1}$  in soils from Marion Island and from the vicinity of penguin rookeries on Ross Island, respectively. These values, however, may be due to the quite different environmental conditions. My data are rather comparable to those by PARINKINA (1974) who found  $0.75\text{--}300 \times 10^8$  bacteria  $g^{-1}$  in soils of the subarctic and tundra zone. The wide ranges of sampling sites as well as apparent discrepancies between different investigations may also be due to methodology.

The intersample variability is well documented by the changes in the fractions of the size classes (Table 2), showing the heterogeneity of the samples by this analysis. In this study, very small cells (cocci and rods) dominate the bacterial population, therefore give only low values of bacterial biomass. Small cells, however, can be regarded as more efficient in obtaining resources than larger cells (JENKINSON *et al.*, 1976). They have a better ratio of biovolume vs. surface in order to obtain nutrients.

Turnover times of glucose (*cf.* Table 3) show low figures and indicate a quite active bacterial population which also reacts positively on temperature shifts. GROBLER *et al.* (1987) found turnover times in the same order of magnitude when using the kinetic approach under field conditions. The data on actual uptake are in the range of other environments, *e.g.* MEYER-REIL (1978). MEYER-REIL *et al.* (1980) found figures for the uptake of glucose with mean values of  $0.254 \mu g Glc g^{-1} h^{-1}$  and  $0.17 \mu g Glc g^{-1} h^{-1}$  in sediments of a temperate marine environment.

The data on bacterial C-production given in Table 3 suggest also a short biomass

turnover (as calculated from bacterial biomass vs. bacterial biomass production). Figures between 0.25 and 0.4 h (surface samples) and between 0.72 and 2.08 h (deep layer samples) can be calculated for the three incubation temperatures, which seem to be extremely short and have to be proved by other methods. These calculations, however, must be regarded as rather rough and speculative, because several factors have important influence though these are not considered here, namely the active part of the population, the amount of glucose which is actually available to the bacteria, the amount of glucose which is in biochemically exchange with other comparable material, and the amount of glucose which may be excreted by bacteria. Some of the factors are discussed by MEYER-REIL *et al.* (1980) and shown to be of great importance for further calculations with regard to the microbial food web and should give rise to further investigations.

A positive effect of temperature can be shown by the course of the activity parameters, although they seem to be in maximum at about 15°C. This value, however, needs more validation of smaller temperature intervals. Although this points to the fact that microbial activity in this environment is not generally adapted to low temperatures, it agrees with the common idea that microorganisms live at sub-optimal temperatures for most of their time. This goes along with results from BAKER (1974) who found optimum temperatures for viable bacteria in the range of even 25°C. LATTER and HEAL (1971) found many isolates growing best at 13°C in comparison to 1 and 25°C and also BENOIT and HALL (1970) described a predominantly mesophilic population of viable bacteria from the Dry Valleys region.

The partition of respired material shows values in the range of 60–70%. These figures are higher than those observed by comparable methods. MEYER-REIL *et al.* (1980) accept a mean value of 40% for their calculations. MEYER-REIL (1978), however, gives a mean value of 8% for bacteria from marine sediments, a figure which was found also by GROBLER *et al.* (1987) in this range for soil samples from Marion Island. These low values, however, may be due to other facts like releasing of fermentation products and/or preference of glucose in anabolic processes. Thus, it renders difficulty in comparing these data directly without more information about the dominant prevailing substrates and the active bacterial population.

When considering the amount of respired material after one hour (by extrapolating the data of the remineralization rates), the relating figures for the temperatures 5, 15 and 25°C are 12.2, 16.5 and 17.3% of the total amount of glucose (MCHO), respectively. This increase of respiration concomitant with temperature is evident and can be shown for 17 samples, two of which show a maximum at 15°C, the other remain stable at low levels (2–5%). These results correspond the data from HOROWITZ *et al.* (1972) who described biological activity in soils from the Dry Valleys by means of <sup>14</sup>CO<sub>2</sub>-evolution from labelled glucose and amino acids. Their measurements accounted for 1–20% loss of labelled material after incubation times of 0.5–1 h.

These figures for the amount of respired glucose are definitely high but we have to consider that they are obtained from short-term incubations which cannot be extrapolated linearly. Data in ZUNINO *et al.* (1982) obtained from long-term incubations of agricultural soils show a best fit to a geometrical function with figures of 26 to 79% <sup>14</sup>C in CO<sub>2</sub> from glucose after 16 weeks incubation. HOROWITZ *et al.* (1972) and RAMSAY and STANNARD (1986) discuss the possible effect of extracellular enzymes on CO<sub>2</sub>-evolu-

tion. It was shown by BÖLTER (1989) that surface samples from this area are very active on several hydrolytic enzymes.

Further, the fact of a priming action (which means a change in the actual decomposition rate of the natural substrates caused by additions of organic matter) (JENKINSON, 1971) has to be taken into account, and the disturbance factor on the original sample. This last fact was shown to be responsible for an enhanced activity in marine sediments (*cf.* MEYER-REIL, 1978). It has to be borne in mind that the original nutrient state is drastically affected by the addition of labelled material. Although the addition of labelled glucose during the experiments carried out in this study did not exceed 2–5% of the concentration of measured dissolved carbohydrates, an addition of about 2% of labelled compounds did not affect metabolic rates in soils (JENKINSON, 1971).

Considerable amounts of dissolved and particulate organic matter are shown in Table 4. Unfortunately, there are no comparable data available which allow a satisfying discussion of these figures of amino acids and carbohydrates, thus they have to be regarded as some baselines which have to be confirmed by further analyses. They represent a valuable potential in high energy substrates in order to energize the microbial community, a fact which is of special importance in low organic matter quality sites (FLANAGAN, 1986).

The high abundance of polysaccharides can be used as an index to a primary stage in soil formation (MARTIN *et al.*, 1972), as they are important in promoting a stable aggregate structure. Microscopic inspection of the samples shows some evidence of slimes on small sand grains and also give the impression of a glue between them and other detrital material. These slimes look like spider webs and seem to be highly effective in forming small niches. They may be produced by bacteria but they may be also important resources for their nutrition.

The C/N ratio refers to a condition of the organic matter which is in quite good condition for microbial degradation. STEVENSON (1986) claimed that net mineralization (the production of ammonia and/or nitrate) should occur at C/N ratios below 20; higher values indicate a state of immobilization of free inorganic nitrogen. Although these descriptors can be regarded as direct influences on bacterial activity and nutrient cycling, we have to look for the "winner" in this system who takes advantage of this process. Normally, the microflora competes with primary producers for mineralized products. As such, simple sugars drive immobilization of inorganic nutrients which would otherwise be available for plants (STEVENSON, 1986). In Antarctic soils there are no higher plants and, hence, the nutrient cycle has to make a shortcut via a possible microbial loop where bacteria, fungi and possibly protozoa share this job.

The results from this study show us a great potential of the bacterial population to react quite effective on these environmental conditions, although they occur only for a short period in the range of a few hours, in the field. The stress of sub-optimal conditions for most time of the year, however, did not change their general pattern of a life strategy which favors milder conditions than those of the Antarctic habitat. These short-term favorable life conditions may be responsible for the enhanced levels of carbohydrates and amino acids. More data are needed on the other parts of this food web and their actual activity, especially fungi and algae in order to get a better idea of the lower organisms role in this environment.

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