THE MICROBIOLOGY OF SOME PERMAFROST SOILS IN THE MACKENZIE VALLEY, N.W.T.*

Introduction

The microbial population of Arctic soils, in North America, has been investigated to only a limited extent. Thermophilic bacteria have been isolated and identified from Arctic soils and waters by McBee and McBee[1], and McBee and Gaugler[2]. Boyd[3] studied the seasonal changes in the bacterial flora of 3 northern soils. Fungi isolated from Alaskan soils have been described [4, 5] and Brockman and Boyd[6] showed that myxo bacteria were present in the Arctic soils of Alaska and Canada. Recently Boyd and Boyd[7] showed that bacteria were present in the permafrost of the Alaskan Arctic.

This paper reports on the general microbial flora of 4 profiles representing 3 different types of soil from the Canadian Arctic. Emphasis has been placed on the effect of incubation temperature on microbial numbers and genera of fungi isolated.

Materials and methods

Soils

The soil samples were obtained by Mr. J. H. Day in July 1960 while studying soils in the lower Mackenzie Valley. Two soils were selected from the tundra at Reindeer Depot and two soils from the tundra-boreal forest transition at Inuvik. Samples of the soil horizons were removed with a sterile trowel, placed in sterile plastic containers, refrigerated in insulated boxes containing dry ice and shipped immediately by air to Ottawa, and again refrigerated at −5°C. until the samples could be plated. The average time lapse between sampling and plating was from 8 to 10 months.

Profile 1 represents an organic soil. It was collected on the tundra, 2 miles east of Reindeer Depot on a poorly drained site. It had a mucky surface which was underlain by fibrous peat and was frozen below a depth of 10 inches.

Profile 2 represents a Subarctic Gleyed Acid Brown Wooded soil. It was collected on the tundra, 2 miles east of Reindeer Depot on a moderately drained microknoll near the toe of a long 2 per cent east-facing slope. This soil had developed from a clayey glacial till and was frozen below a depth of 14 inches. It can be classified as an Orthic Cryaquent in the 7th Approximation of the U.S.D.A.[8]

Profile 3 represents a Subarctic Brown Wooded soil. It was collected in the tundra-boreal forest transition region in an experimental garden plot at Inuvik. The sampling site had a 15 per cent slope, was well drained and had been under cultivation for 4 years. This soil had developed from gypseous clay glacial till and was frozen below a depth of 70 inches. According to the 7th Approximation[8], the soil is an Orthic Cryudent.

Profile 4 also represents a Subarctic Brown Wooded soil. It was collected 10 feet from the Inuvik experimental garden plot under undisturbed tundra-forest vegetation. The profile was similar to number 3 except for the uncultivated surface layer. Small ice crystals were found at a depth of 16 inches.

Some chemical characteristics of the soils are given in Table 1; a more complete description of the soils, landform, climate, vegetation, geology and permafrost of this area has been published by Day and Rice[9].

Media and cultural conditions

Bacteria and actinomycetes were enumerated on soil-extract agar and numbers of fungi were obtained by plating on peptone dextrose agar containing rose bengal and chlortetracycline[10]. Plates were incubated at 25°C, 10°C.

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Table 1. Plate counts (x 10^4 per g. of dry weight) of soil horizons collected from the Arctic.

Horizon	Depth inches	pH	O.M. %	N %	Bacteria 25°C.	Bacteria 10°C.	Bacteria 4°C.	Actinomycetes 25°C.	Actinomycetes 10°C.	Actinomycetes 4°C.	Fungi 25°C.	Fungi 10°C.	Fungi 4°C.
Profile 1 — Organic Soil													
F-H	1−10	4.1	92.0	1.9	85	106	71	4	*	*	18	15	9
HZ	10−12	4.2	91.0	2.3	30	21	33	6	6	*	17	16	16
Profile 2 — Subarctic Gleyed Acid Brown Wooded													
Bfm	0−5	4.7	5.0	0.1	64	46	50	18	18	16	2	2	1
Bg	5−9	4.7	4.9	0.2	150	161	100	16	16	17	0.7	0.7	0.7
Cg	9−23	5.3	4.3	0.2	5	7	3	0.8	0.4	0.2	0.004	0.003	0.002
Cz	23−28	5.2	31.2	0.7	3	2	2	0.5	0.3	0.2	0.02	0.02	0.02
Profile 3 — Subarctic Brown Wooded (Cultivated)													
Ap	0−4	5.6	10.8	0.4	1,400	700	560	28	*	*	6	8	4
C	4−15	6.5	3.5	0.1	275	125	50	*	*	*	0.2	0.2	0:2
Cg	15−28	7.4	1.9	0.1	75	72	17	*	*	*	0.01	0.01	0.01
Cy	28+	7.1	2.3	0.1	7	5	4	*	*	*	0.006	0.006	0.005
Profile 4 — Subarctic Brown Wooded (Uncultivated)													
F-H	3−0	5.8	92.0	1.6	1,700	1,100	200	230	350	60	40	30	15
Bm	0−5	6.2	4.7	0.2	400	200	80	50	15	5	5	5	4
C	5−16	7.5	2.1	0.1	287	241	212	4	2	*	2	2	2
Cz	16+	7.2	3.4	0.03	41	32	1	*	*	*	2	2	0.6

*Counts less than 1,000 per g.

and 4°C. For each incubation temperature quintriplicate plates of 3 soil dilutions were made. Cultures held at 25°C. were incubated for 1 to 2 weeks before counts of bacteria and actinomycetes were made and colonies of fungi picked for subculturing. Cultures held at 10°C. and 4°C. were incubated for 2 to 4 weeks. For identification of fungi, approximately 100 cultures per incubation temperature were isolated and subcultured on potato dextrose agar slants.

Results

In general, the numbers of microorganisms decreased with depth; the decrease being of greater magnitude in the permafrost layers (Table 1). Microbial numbers were lower in the tundra area (profiles 1 and 2) than in the tundra-boreal forest transition area (profiles 3 and 4). Cultivation of these latter soils has reduced microbial population. Taking the profiles collectively, the results show that soils in this arctic region are able to support large populations of microorganisms. At an incubation temperature of 25°C. the largest numbers of bacteria, actinomycetes and fungi were 1,700 x 10^4, 230 x 10^4, and 40 x 10^4, respectively. At 4°C. the largest counts were 560 x 10^4, 60 x 10^4, and 16 x 10^4, respectively.

The temperature of incubation affected appreciably the number of bacteria and actinomycetes in soils (profiles 3 and 4) from the tundra-boreal forest transition area; numbers decreased as the incubation temperature decreased. The degree of decrease was greater for actinomycetes than for bacteria. On the other hand, there was very little evidence of this with soils (profiles 1 and 2) from the tundra area. Numbers of fungi for both areas appeared to remain fairly constant for all temperatures of incubation.

The percentage incidence of fungi in the 2 areas examined are shown in Tables 2 and 3. Unidentified fungi, mostly sterile forms (hyaline and dark) were isolated only occasionally and are not reported. The number of genera present in these Arctic soils appears to be low; only 11 genera in the 2 areas studied were identified. Two of the common genera of soil fungi[11] *Penicillium* and *Mucor* are well distributed in the profiles of all soils examined. Species of *Aspergillus* and *Fusarium* which are abundant in soils of temperate regions[11] were absent. Also the frequently isolated soil fungus *Trichoderma* was found only in the lower horizon of profile 3.

Table 2. Percentage incidence of fungi isolated from the tundra area.

Genus	Profile 1						Profile 2*								
	1–10″			10–12″			0–5″			5–9″			23–28″		
	25°C.	10°C.	4°C.	25°C.	10°C.	4°C.	25°C.	10°C.	4°C.	25°C.	10°C.	4°C.	25°C.	10°C.	4°C.
Penicillium	51	20	9	20	—	1	40	37	24	57	82	25	57	26	19
Mucor	7	16	9	80	100	98	28	27	61	26	8	46	33	50	48
Pseudogymnosascus	—	—	—	—	—	—	7	18	15	15	6	13	9	15	25
Mortierella	26	58	82	—	—	—	—	—	—	—	—	10	1	9	8
Phialophora	16	6	—	—	—	—	—	—	—	—	—	—	—	—	—
Cladosporium	—	—	—	—	—	1	—	—	—	2	—	2	—	—	—
Oidiodendron	—	—	—	—	—	—	25	18	—	—	—	—	—	—	—
Chrysosporium	—	—	—	—	—	—	—	—	—	—	4	4	—	—	—
Total cultures examined	81	51	110	127	131	132	101	101	62	88	50	52	67	62	73

*The fungal flora in the 9–23 inch layer were not identified.

There is some difference in fungal patterns between the 2 soils of the tundra area (Table 2). *Pseudogymnosascus* and *Oidiodendron* were absent in the poorly drained organic soil but fairly abundant in the moderately well drained mineral soil. Also, a significant proportion of the isolates of the surface layer of the organic soil belonged to the genus *Phialophora*. This genus was absent in the mineral soil. In general, at room temperature, the most common genus from both sites was *Penicillium*. At 4°C. species of *Mucor* or *Mortierella* predominated.

Comparing the 2 profiles from the tundra-boreal forest transition area (Table 3), *Pestalotia* and *Trichoderma* were found only in the cultivated soil, whereas *Humicola* and *Oidiodendron* only in the uncultivated. In both soils *Penicillium* together with *Mucor* were the predominant fungi at 25°C. Decreasing the temperature to 10°C. increased the relative frequency of *Chrysosporium* and in most cases a temperature of 4°C. brought about a strong dominance of *Chrysosporium*.

Discussion

The results obtained in these experiments clearly demonstrate that Arctic soils in Canada support large populations of microorganisms. Total counts in excess of several million per gram are observed even when the incubation temperature remains at 4°C. These data confirm the observations of Boyd[3] who found that Arctic soils in Alaska contain relatively large numbers of microorganisms.

Microbial counts of the tundra-boreal forest transition soils showed that numbers of bacteria and actinomycetes decreased as the temperature of incubation decreased; in the case of the tundra soils this shift was not as noticeable. Possibly the permafrost layer within the profile of the latter soils has resulted in a selection of types of bacteria and actinomycetes that tolerate and grow at temperatures near freezing.

It seems that the total genera of soil fungi recognized is much less in these Arctic soils than in soils studied from Alaska. In contrast to the 11 genera isolated in these studies Cooke and Lawrence[4] identified 22 genera from recently glaciated Alaska soils. The absence of the common soil isolates *Aspergillus* and *Fusarium* and the scarcity of *Trichoderma* suggests that such fungi are not favoured by cold climate. In this connection Alexander[12] has stated that the relative incidence of *Aspergillus* and *Fusarium* sems to be greater with proximity to the equator. Also Sewell[13] obtained evidence that *Trichoderma viride* could be isolated in great abundance during summer

Table 3. Percentage incidence of fungi isolated from the tundra-boreal forest transition area.

Genus	Profile 3											
	0–4″			4–15″			15–28″			28+		
	25°C.	10°C.	4°C.	25°C.	10°C.	4°C.	25°C.	10°C.	4°C.	25°C.	10°C.	4°C.
Penicillium	47	53	20	38	6	7	64	27	21	32	26	14
Mucor	33	16	21	6	15	9	11	19	5	32	22	36
Pseudo-gymnosascus	4	6	4	5	—	—	—	—	—	8	10	14
Pestalotia	3	5	4	2	—	3	3	6	—	—	5	7
Mortierella	—	5	14	4	4	9	—	—	—	—	5	8
Phialophora	—	—	—	6	2	—	9	9	—	16	—	14
Cladosporium	—	—	—	—	—	—	—	11	16	—	—	—
Trichoderma	—	—	—	—	—	—	—	—	—	12	32	7
Humicola	—	—	—	—	—	—	—	—	—	—	—	—
Oidiodendron	—	—	—	—	—	—	—	—	—	—	—	—
Chrysosporium	13	15	37	39	73	72	13	28	58	—	—	—
Total cultures examined	70	81	81	59	53	58	70	54	61	25	19	14

Genus	Profile 4											
	3–0″			0–5″			5–16″			16+		
	25°C.	10°C.	4°C.	25°C.	10°C.	4°C.	25°C.	10°C.	4°C.	25°C.	10°C.	4°C.
Penicillium	20	35	29	71	12	—	7	15	3	18	56	21
Mucor	63	48	19	8	10	4	29	20	5	46	12	15
Pseudo-gymnosascus	7	8	35	—	12	11	12	4	11	4	2	7
Pestalotia	—	—	—	—	—	—	—	—	—	—	—	—
Mortierella	—	—	—	—	—	—	5	8	10	—	5	16
Phialophora	—	—	—	—	—	—	2	1	—	4	4	—
Cladosporium	—	—	—	8	—	6	—	—	—	21	18	35
Trichoderma	—	—	—	—	—	—	—	—	—	—	—	—
Humicola	6	2	2	5	9	—	—	—	—	5	3	—
Oidiodendron	—	—	—	—	—	—	18	4	11	—	—	—
Chrysosporium	4	7	15	8	57	79	27	48	60	2	—	6
Total cultures examined	111	100	75	85	67	72	82	89	92	78	108	75

months from an acid heathland, but was absent in the winter. It would also appear that soil type and/or moisture conditions exert an effect on the distribution of certain fungi in the tundra soils from Reindeer Depot. Species of *Pseudogymnosascus* and *Oidiodendron* were found in the mineral soil but not in the poorly drained organic soil, whereas *Phialophora* spp. were found only in samples of the latter soil.

Although species of *Pestalotia* have been identified only occasionally from Alaskan vegetation[14] they were isolated in these studies from the cultivated garden plot of the tundra-boreal forest transition area but not from the adjacent uncultivated land. Perhaps this genus has been introduced with garden crops, for many of the 102 species of *Pestalotia* are plant parasites[15]. If these fungi were introduced and since their relative abundance is not affected by incubation temperature (Table 3), it might suggest that members of this genus can indeed adapt to arctic habitats.

Perhaps the most interesting feature of these experiments was the influence of temperature on the predominance of fungi isolated. On plates at room temperature *Penicillium* had the capacity to become dominant or co-dominant with *Mucor*. At 4°C. species of *Mucor* or *Mortierella* predominated in soils from the tundra area. In the tundra-boreal forest transition area a striking increase in the relative abundance of

Chrysosporium was evident as the incubation temperature decreased. Ten cultures of this latter fungus picked at random were identified as *Chrysosporium pannorum* (Link) Hughes 1958. It is cellylolytic, grows at low temperatures, and has been identified from Japanese Antarctic expeditions[16]. Although occasional rock surface temperatures above 32°C. have been reported in Polar regions[17], one might assume that in the Arctic where in general the soil temperatures in the summer remain well below 25°C., such fungal genera as *Chrysosporium, Mucor* and *Mortierella* would be more competitive and play a greater role in colonizing and decomposing dead organic matter than they would in more temperate climates.

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Ornithological Observations in the Askinuk Mountains and Scammon Bay area, Yukon Delta, Alaska

Our two-man party arrived at the village of Scammon Bay on 10 May 1965. Conditions were essentially still those of winter and the migratory birds, particularly cranes, geese and ducks, only began to arrive a few days later. In the course of 7½ weeks, the Askinuk Mountains were crossed on foot from north to south in three well separated transects; the coast from Scammon