CHARACTERIZATION OF STORED PEAT IN THE ALBERTA OIL SANDS AREA

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for

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Project LS 5.2

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Minister of the Environment
222 Legislative Building
Edmonton, Alberta

and

The Hon. John Roberts
Minister of the Environment
Environment Canada
Ottawa, Ontario

Sirs:

Enclosed is the report "Characterization of Stored Peat in the Alberta Oil Sands Area".

This report was prepared for the Alberta Oil Sands Environmental Research Program, through its Land System, under the Canada-Alberta Agreement of February 1975 (amended September 1977).

Respectfully,

W. Solodzuk, P.Eng.
Chairman, Steering Committee, AOSERP
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CHARACTERIZATION OF STORED PEAT IN THE ALBERTA OIL SANDS AREA

DESCRIPTIVE SUMMARY

BACKGROUND

The open pit method of oil sands mining involves the stripping of an overburden of peat in much of the mineable area. This surface peat, which is stockpiled, is the only organic material naturally available for rebuilding soil fertility. A peat pile was constructed at Evansburg, Alberta, in 1976 and was monitored as a control for two years. A peat storage area also existed on the Syncrude Lease near Mildred Lake until early in 1978.

The purpose of this research is to investigate the physical, chemical, and biological characteristics of peat in the oil sands area, before, during, and after storage, to establish handling and storage methods that ensure optimum quality of material available for reclamation. Peat was studied for its reaction to wetting, drying, freezing, thawing and the addition of nutrients, in both the field and the laboratory. The information and recommendations provided in this report will be of importance for future reclamation plans and materials handling procedures.

ASSESSMENT

The final report "Characterization of Stored Peat in the Alberta Oil Sands Area" prepared by J.D. Lindsay of the Research Council of Alberta, Soils Division and W.B. McGill and K. Kong of the Department of Soil Science, University of Alberta, has been reviewed and accepted by Alberta Oil Sands Environmental Research Program. It is recommended for wide distribution.

William R McDonald
W.R. MacDonald, Ph.D
Director (1980-81)
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ABSTRACT

Properties of stored peat were studied at sites near Evansburg, Alberta, and on the lease of Syncrude Canada Ltd. at Mildred Lake, Alberta. Physical, chemical, and microbiological properties of stored materials were compared with those of fibric moss peat, mesic moss peat, and mesic fen peat samples from undisturbed sites.

Environmentally induced changes in peat properties were simulated in the laboratory by freeze-drying, air-drying, and thawing peat samples. Air-drying and, to a lesser extent, freeze drying, resulted in deterioration of physical properties and in reduction of microbial activity.

The stored materials at Evansburg consisted entirely of peat whereas at Mildred Lake the materials were heterogeneous peat-mineral mixtures which were grouped as follows: group I, peat predominant; group II, sand predominant; group III, sand-clay mixture; and group IV, peat-sand mixture. Optimum temperatures for microbial activity in the storage piles occurred near the surface and decreased with depth while optimum moisture conditions occurred near the 50 cm depth. Frost penetration was not greater than 1 m in any of the piles.

Storage piles consisting of peat-mineral mixtures which had been fertilized had a somewhat higher level of microbial activity and organic matter decomposition than undisturbed peat or stored, relatively pure peat. Properties of the stored materials which were highly correlated with each other were carbon, nitrogen, respiration rate, enzyme activity, cation exchange capacity, ash content, bulk density, pore volume, and water capacity. Relatively simple methods for the characterization of ash, carbon, and bulk density of stored materials were used.

ACKNOWLEDGEMENTS

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K. Kong was the principal investigator, with J.D. Lindsay of the Soils Department, Alberta Research Council and W.B. McGill of the Department of Soil Science, University of Alberta being part of the project group.

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L.W. Turchenek assisted with the compilation and review of the report.

1. INTRODUCTION

The purpose of this research project was to investigate physical, chemical, and biological properties of stored peat in order to evaluate changes that may take place in the material during periods of prolonged storage.

The open pit method of oil sands mining involves the stripping of overburden in order to expose the oil-bearing McMurray Formation. In a fairly substantial portion of the potentially mineable area, the overburden is characterized by a surface peat deposit. This deposit, therefore, is removed and stockpiled and represents a material that will be useful for reclamation purposes at a later time. The exact length of time that it will remain in storage is unknown at present but it may well be for an extended period of time reaching a decade or more.

The changes that may take place in the properties of the peat during this storage period may affect its value as a reclamation material and the research, therefore, was carried out to monitor and quantify the changes that may occur during storage.

This report consists of three parts. Section 4 deals with the characterization of selected in situ peat samples from the Evansburg and Mildred Lake areas of central and northeastern Alberta. Representative samples of peat that will comprise the storage material were analyzed in terms of their physical, chemical, and biological properties and the results reported in this section.

Section 5 describes the methodology and results of laboratory experiments to simulate the freeze-thaw cycles that the peat will undergo under field conditions. Peat samples were alternately frozen and thawed and nutrients added to the material. Microbiological numbers, CO_2 evolution, enzyme activity, and changes in physical properties were investigated during the course of the experiment.

Section 6 deals more specifically with the stored peat at both the Evansburg and Mildred Lake sites. Since this material contains a significant amount of inorganic or mineral material, particularly at the Mildred Lake site, it was necessary to sample the material extensively for laboratory characterization. In addition, temperature and moisture levels have been monitored on a regular basis in order to establish the annual fluctuation in these parameters. Soil respiration, cellulose decomposition, and some biological and chemical properties of the stored peat are reported upon.

2. RESUME OF CURRENT STATE OF KNOWLEDGE

In studying the physical properties of peat, Puustjarvi (1968) set up a standard method to study the pore volume, air and water capacity in basin peat; Irwin (1968) suggested a method for measuring the bulk density; Boelter (1968) emphasized that bulk density had a relationship to the decomposition rate of peat. In studying freezing, drying, and thawing, Van Dijk and Boekel (1965) mentioned that freezing caused enlargement of pore diameter but, after freezing, shrinkage on drying is much smaller and the removal of water is much less irreversible; they also found that shrinkage has an unfavourable effect on the decomposition of peat. On the other hand, Soebo (1969) found that the freezing and thawing of sphagnum peat reversibly increased the phosphorus content of peat water. Dai and Sparling (1973) suggested the use of a piezometer to measure the hydraulic conductivity in peat. Rycroft et al. (1975) mentioned that hydraulic conductivity has a direct effect on the hydrology of peat and on the ecology of peat vegetation. It has an indirect effect including the operation of soil-water as a regulator of root aeration and mineral nutrient content. Boelter (1968) suggested the use of a wet sieving process to determine the fiber content in peat, and Farnham and Finney (1965) used the fiber content as a criterion for classifying peat and its degree of decomposition. Stanek and Silc (1977) compared the von Post method with the pyrophosphate solubility and rubbed and unrubbed fiber methods of determining degree of peat decomposition. All of them allow peat samples to be categorized into some groups but all suffer from a lack of quantification. It appears that some other more quantitative method may be necessary for use in estimating changes in stored peat.

Much work has been done in studying the chemical properties of peat. Waksman and Stevens (1928, 1929) mentioned that sphagnum peat had a slow carbohydrate decomposition rate because the microorganisms had an insufficient readily available source of energy and nitrogen. Also, the lignin and wax substances are gradually accumulated. Under these conditions the sphagnum bog is acidic and rich in cellulose and in lignin but deficient in nitrogen and mineral nutrient. On the other hand, in sedge peat (fen), cellulose is fairly rapidly decomposed, but the accumulated organic nitrogeneous complexes resist decomposition under the anaerobic conditions.

Puustjarvi (1955) concluded that the carbon content of humic acids from peat was less than for other soils. In investigating 252 peat samples, Puustjarvi (1956) summarized that cation exchange capacity (CEC) varied from 47 to 167 meq/100 g of peat. Drying tended to increase CEC of peat materials of high base saturation but had the reverse effect on peats of low base saturation. Exchange capacity of organics is due primarily to carboxyl and phenolic hydroxyl groups, the latter likely not being very important at low pH. Schnitzer and Desjardins (1965) reported carboxyl acidity for 17 muck and peat samples ranging from 30 to 140 meq/100 g prior to HCl-HF treatment. After treatment, the range increased to 180 to 340 meq/100 g. Total acidity (carboxyl plus phenolic) after treatment ranged from 480 to 740 meq/100 g. Carboxyl, but not phenolic, acidity tended to increase with degree of decomposition of peat. Ion exchange capacity is probably the greatest chemical benefit of peat in reclaiming sandy areas (Logan 1978).

Peat decomposition in Alberta was studied for purposes of agricultural use in the 1930's (Newton 1934, 1936; Walker 1936), for forest nursery use (Hellum 1975), and for tailings sand reclamation (Logan 1978). Peat and muck additions to a sand and a clay have been found to be more effective in increasing organic matter content over a long term than were equal amounts of other organic material such as rye straw, alfalfa, and manure (Sowden and Atkinson 1968). Peat and muck, however, were less effective in increasing yield (Halstead and Sowden 1968), probably due to their slower decomposition and release of nutrients.

Many workers have suggested that amendments, particularly limestone, phosphorus, potassium, and nitrogen, can be used to convert acid bogs into fertile organic soil (Jasmin and Heeney 1960; Wieringa 1963; Schickluna et al. 1968; Van Dijk et al. 1968).

However, Nygard (1954) reported that most of the native vegetation such as black spruce, tamarack, or willow growing in lime-deficient peat soil did not show any deficiency of calcium. Okruszko et al. (1962) stated that liming of muck soils has a detrimental influence on their fertility, mainly due to a decrease in P availability; similar results have been reported by Kuster and Gardiner (1968).

The literature on both chemical and physical properties is extensive and originates from several countries. A very useful and comprehensive review on chemical fractionation of peat and on chemical and physical aspects of organic material in relation to environmental effects is that of Walmsley (1977).

In studying the microbiological population of peat, Waksman and Purvis (1932) mentioned that the existence of cellulose-decomposing bacteria had been found not only in the sedge peats but also in sphagnum peat, but the reaction (pH) of the latter was not favourable for the development of these organisms and the cellulose of the sphagnum plant was highly resistant to decomposition.

Populations of psychrophilic bacteria have been reported at 2×10^6 cells/g peat in the surface fibric horizons of three organic soils in Alberta (Christensen and Cook 1970). The humic horizons contained 3 to 10×10^6 cells/g (oven dry wt.). Mesophiles were about 20% more abundant than psychrophiles. These are similar to values reported for a fen from East Anglia (Stout 1971). Fungi were restricted to the top 25 cm, reflecting their sensitivity to aeration. Microbial populations appear to reach a maximum during August and September in undisturbed peatlands (Christensen and Cook 1970). Nitrifiers are normally present even in acid peats but may need lime to become active (Ivarson 1977). Factors controlling bacterial populations of peat in the field have been examined. Wheatley et al. (1976) calculated regression equations for bacterial numbers in a raised bog profile in Scotland. At depths below 0.5 m, ash content was the predominant variable accounting for variations in bacterial numbers. In the top 50 cm, temperature, phosphorus, and potassium collectively accounted for 88% of the variability in bacterial numbers. The biochemistry and microbiology of peats have been reviewed recently by Given and Dickenson (1975).

Microbial activity in peat has not been studied intensively. In general, the rate of biological oxidation of carbon (C) appears to be slower per unit of C than is the case in other plant materials. This has been ascribed to the presence in peat of inhibiting substances expected to be phenolic in nature (Given and Dickenson 1975; Ivarson 1977). Kuster (1963), however, reported peat components to be both stimulatory and inhibitory to microbial activity. Nitrogen fixation has been reported in peat and it was suggested that fen peats are most active, a rate of 0.5 nmol C_2H_4 $mL^{-1} \cdot h^{-1}$ being found in the laboratory for a fen peat sample from East Anglia (Waughman 1976). An initial reduction followed by stimulation of nitrogenase activity upon exposure of the peat to aeration was observed.

Few studies using enzymatic activities to monitor organic matter decomposition in peat have been published. Mathur and Sanderson (1978) recently suggested the use of non-specific acid phosphatase as an indicator of an extracellular enzymatic environment in peat soils. Considerable literature exists in respect to mineralization of organic carbon by measuring the CO_2 evolution in soil (Bedford 1929; Waksman and Starkey 1924; Dommergues 1960; Stotzky 1960). It should be noted that no references have been found in respect to decomposition rates and changes in properties of moist peat stored in piles.

3. STUDY AREA

Research activities were carried out at Mildred Lake, in the Alberta Oil Sands Environmental Research Program (AOSERP) study area (Figure 1), at a field site near Evansburg, Alberta, and in a laboratory at the University of Alberta.

The field site at Evansburg was established in June 1976, at which time a peat storage pile was constructed on the lease of Banff Mining and Quarrying Co. Ltd. It should be noted that a second field site was set out at Mildred Lake, Alberta, on lease #17 of Syncrude Canada Ltd. in August of 1976 but unfortunately this site was lost to the project in January 1978 as a result of construction activities.

Evansburg was selected as a field research site because at the time some difficulty was being experienced in obtaining lease access in the Mildred Lake area. In order to make use of the full 1976 field season, it was thought advisable to establish a site at Evansburg at which the study could be initiated immediately.

Monitoring, sampling, and field activities have been carried out, therefore, for a somewhat longer period at Evansburg than at Mildred Lake.

At Evansburg the peat pile is approximately 26 m long and 3 m high. The base width is 10 m tapering to 4 m at the crown. The material consists essentially of fibric moss peat with a fairly high content of wood. The peat was put in place by dragline from the area immediately adjacent to the pile. No artificial drainage was installed at the site and therefore the lower portion of the pile is affected by the water table which is near ground surface during a portion of the year. Since the pile was constructed in mid-June, the amount of frozen peat added to the pile was minimal.

Some investigation of an older peat pile was under taken at Evansburg in 1978. Little is known about the history of this pile except that it was built around 1970 with semi-decomposed (mesic)

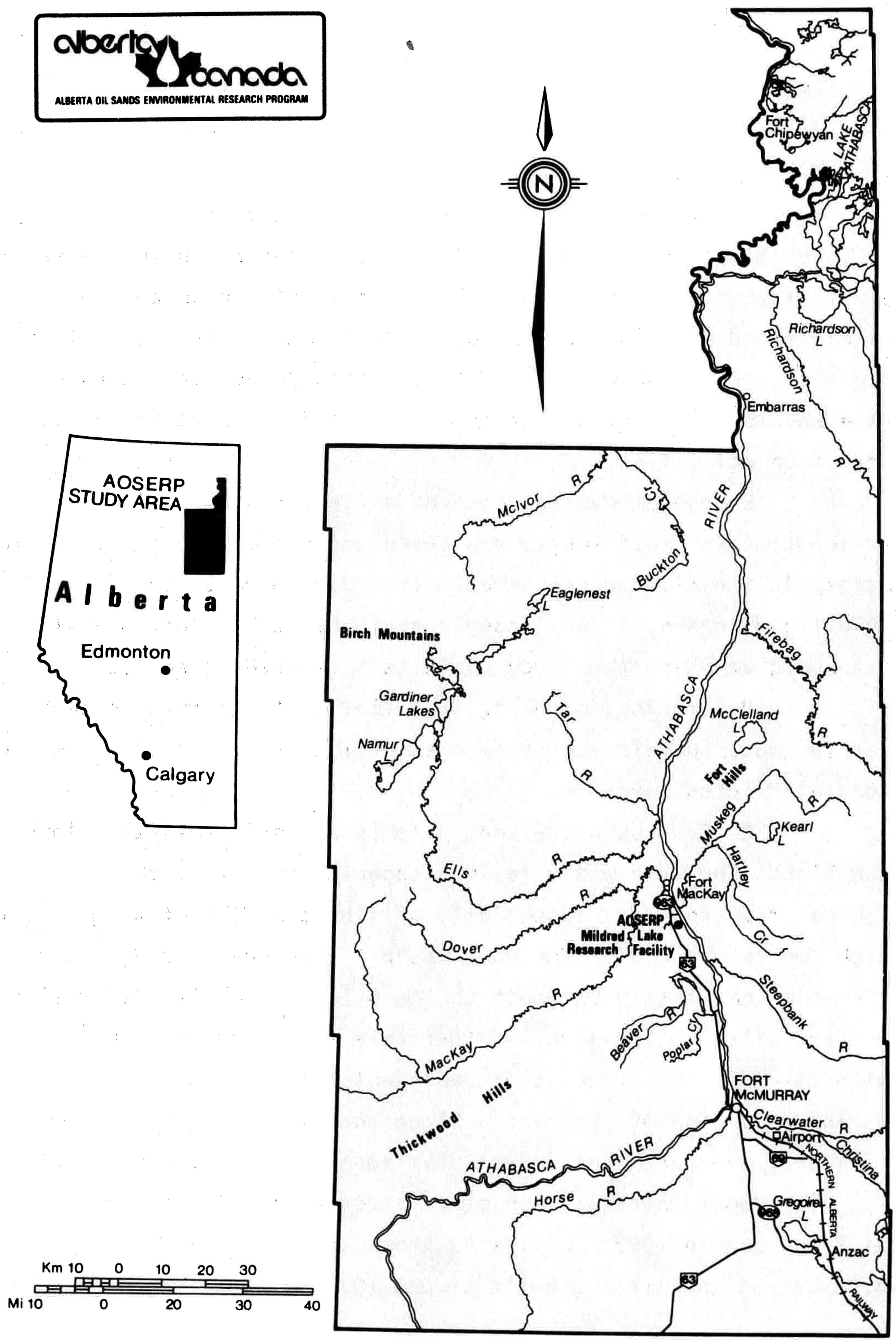

Figure 1. Location of the AOSERP study area.

moss peat. The pile has somewhat the same configuration as the one described above except that it is L-shaped. The overall length is 84 m with a height of 3 m. It is tapered from a base width of 9 m to a crown of 4 m. No artificial drainage was installed at the site.

At the Mildred Lake site, the storage pile was of a different configuration than those at Evansburg. The material (fibric and mesic moss peat) was extracted by overhead loader and hauled to the storage area by truck. The pile was flat-topped, about 3 m high, 300 m wide and 1.5 km in length. The material was piled during the winter months and contained a fairly high component of frozen material initially. Artificial drains were installed and spaced at intervals across the storage area.

Following construction of the storage pile, the area was seeded to several forage species and fertilized heavily in April 1976. A second fertilizer application was made in April 1977. The species sown and the fertilization programs are outlined in Section 9.2.

At Evansburg, the undisturbed site is located about 100 m from the storage pile while at Mildred Lake the undisturbed site is about 2 km distant. At both sites the forest cover is principally black spruce (*Picea mariana*), Labrador tea (*Ledum groenlandicum*), *Sphagnum* spp., and various other mosses. The site at Mildred Lake is slightly more open than the one at Evansburg.

4. GENERAL CHARACTERISTICS OF PEAT

4.1 CLASSIFICATION OF PEAT

Peats are classified in the Organic order of the Canadian Soil Classification System (Canada Soil Survey Committee 1974). Soils of this order are composed dominantly of organic materials. They include most of the soils commonly known as peaty, muck, or bog soils. They occur widely in poorly drained and very poorly drained depressions and level areas in regions of subhumid to perhumid climate, and they are derived from vegetation that grows in such sites.

Specifically, Organic soils contain 17% or more organic carbon (30% organic matter) by weight.

For classification purposes Organic soils are divided into three great groups based upon the degree of decomposition of the organic matter, namely, Fibrisol, Mesisol, and Humisol.

For this study, only two of the great groups have been included in the sampling and investigation. These are the Fibrisol and Mesisol. Field examination has indicated that the Humisol great group is not extensively represented in the oil sands area.

Fibrisols are characterized by the least decomposed type of organic material and are dominated by fibric peat layers. Such layers contain large amounts of well-preserved fiber that can usually be identified as to botanical origin. In relative terms, a fibric layer has a bulk density of less than 0.1 g/cc and a maximum saturated water-holding capacity ranging from 850 to over 3000%.

The Mesisols, on the other hand, are characterized by predominantly mesic peat which is the intermediate stage of decomposition. The mesic layer has intermediate amounts of fiber which are not easily identified as to botanical origin. The bulk density ranges between 0.1 and 0.2 g/cc and the maximum saturated water-holding capacity ranges from 450 to 850% on an oven dry basis.

The Humisols, which have not been included in this study because of their limited occurrence, are the most decomposed organic soils. They have the highest bulk density and lowest water-holding capacity and exhibit the least amount of plant fiber.

For the most part, the organic soils examined and sampled for this study are formed under black spruce (*Picea mariana*) and larch (*Larix laricina*) with a ground cover of mosses (*Sphagnum* spp.), feathermosses, and Labrador tea (*Ledum groenlandicum*). In addition to the soils derived from mosses (bogs), however, there is a fairly widespread occurrence within the oil sands area of organic soils formed from sedges (*Carex* spp.), rushes, and reeds. The properties of such soils, commonly called fens, are quite different from those derived from mosses and for this reason such soils have been recognized and included as part of this study.

In terms of the stripping and storage operation, it is realized that the separation of the moss and fen peats may not be practical; however, it was felt necessary to investigate their properties in order to establish differences. It may well be that, in certain portions of the area, moss peat may dominate the storage material whereas, in other locations, fen peat could well be dominant in the stored material.

4.2 PROPERTIES OF SELECTED PEAT SAMPLES

A number of representative peat samples were obtained from the Evansburg and Mildred Lake research areas for laboratory analyses. These samples included fibric and mesic moss peat and a mesic fen peat from both the Evansburg and Mildred Lake areas. These samples were taken in September 1975 from undisturbed sites.

Physical and chemical properties were investigated in the samples.

4.2.1 Physical Properties

All samples used for the determination of physical properties consisted of fresh peat without being pre-treated or dried. The physical analyses carried out on the samples included the following: moisture content, specific gravity, bulk density, pore volume, air capacity, and rubbed and unrubbed fiber content. In situ hydraulic conductivity measurements have also been recorded at both sites. The results of the physical analyses are shown in Table 1. The methods of analyses employed are described in Section 9.1.

The data indicate that the moisture content in a fibric peat layer is generally higher than in mesic or fen peat. The typical characteristics of a fibric peat are a high fiber content, high void ratio and air capacity, but a low bulk density and ash content.

MacFarlane (1969) suggests that the void ratio gives an indication of the compressibility of a material, the fibric peat usually being very high with the more decomposed mesic peat lower.

The moisture content does not necessarily limit the rate of decomposition of the peat since the peat fiber in its natural state can be broken down by other means such as freezing and thawing or by anaerobic bacterial activity. Therefore, although the fibric peat generally has the highest moisture content, it does not necessarily mean that the decomposition rate will be slower in this type of peat.

With decomposition, however, the physical properties of peat will change, resulting in increased bulk density and ash content, but decreasing fiber content and void ratio. This is seen in Table 1 by comparing the data for the fibric peat and mesic peat samples from the Mildred Lake area.

The data also suggest that, although classified as fibric peat, the samples from the Evansburg area are somewhat more decomposed than those of the Mildred Lake area. The moisture content, pore volume, fiber content, and void ratio are all higher in the Mildred Lake samples, indicating less decomposition. At the same time, bulk density is lower.

The fen peats, although relatively undecomposed, exhibit a higher bulk density and ash content but lower void ratio and fiber content than the undecomposed peat. Such properties may well influence the rate of decomposition in the stored peat.

TABLE 1. Physical properties of peat from the Mildred Lake and Evansburg areas.[a]

Peat Type	Field Moisture (%)[b]	Particle Density (g/cc)	Bulk Density (g/cc)	Pore Volume (%)	Air Capacity (%)	Water Capacity (%)	Fiber content (100 mesh) (%) unrubbed	Fiber content (100 mesh) (%) rubbed	Ash Content (%)	Void Ratio
					Mildred Lake Area					
Fibric	1168	1.48	0.046	97	40	57	95	80	3	31
Mesic	554	1.50	0.072	95	33	62	85	50	5	20
Fen	934	1.61	0.106	93	23	70	35	10	11	14
					Evansburg Area					
Fibric	710	1.54	0.071	95	34	62	90	50	5	21
Mesic	1015	1.50	0.084	94	32	62	75	60	10	17
Fen	608	1.49	0.097	93	35	58	65	28	22	14

[a] Results based on duplicate samples.

[b] % based on dry weight.

4.2.2 Hydraulic Conductivity

Hydraulic conductivity is the apparent velocity of the flow of water through a material in response to a unit hydraulic gradient. In the case of peat, it is related directly to the degree of decomposition of peat in situ. Fibric peat usually has a high hydraulic conductivity, mesic is intermediate, and humic peat is low.

Hydraulic conductivity investigations were carried out at both the Evansburg and Mildred Lake research sites. For the purpose of this study, hydraulic conductivity was determined using a piezometer consisting of a pipe with a perforated cap on the lower end. A hole was augered to the desired depth, a pipe inserted into the hole, and the water pumped out. The rate of water return up to the tube was then recorded.

In each peat profile examined, the hydraulic conductivity was highest in the surface tier and decreased with depth (Table 2). Boelter (1969) has reported that extremely large differences in hydraulic conductivity occur in various peats. The hydraulic conductivity data obtained at the Mildred Lake and Evansburg sites are generally higher than those reported by Boelter (1969) for similar peat types. However, the same general relationship was found in that the hydraulic conductivity was highest in the fibric peat and lower in the more decomposed mesic peat. In all cases, the hydraulic conductivity was lower in the bottom portion of the profiles indicating greater peat decomposition at depth.

At Evansburg, the hydraulic conductivity was determined only in a fibric moss peat. This profile is similar to that of the fibric peat at Mildred Lake except for the presence of considerable wood in the middle layer. In terms of hydraulic conductivity, the results indicate that the site examined at Evansburg is similar to the mesic peat site at Mildred Lake.

Dai and Sparling (1973), using a similar method in Ontario, found that moss peat (sphagnum) had a relatively loose and uniform structure and suggested there was less restriction on the vertical component of water flow, but fen peat had a more or less stratified

Table 2. Hydraulic conductivity in peat.

Peat Type	Layer	Depth	Hydraulic Conductivity[a] (cm/h)
		Mildred Lake	
Fibric	Surface tier	45 to 65	20.3
	Middle tier	70 to 90	8.1
	Bottom tier	105 to 125	3.2
Mesic	Surface tier	30 to 45	6.8
	Middle tier	45 to 75	1.0[b]
	Bottom tier	75 to 120	0.6[b]
Fen	Surface tier	40 to 60	2.2
	Middle tier	60 to 80	1.5
	Bottom tier	80 to 100	0.2
		Evansburg	
Fibric	Surface tier	30 to 40	4.1
	Middle tier	50 to 75	1.9
	Bottom tier	80 to 100	0.07

[a] Mean value of four measurements.

[b] Mean value of five measurements.

structure and the vertical component of hydraulic conductivity was somewhat restricted. Consequently the vertical component in fen peat is lower than in moss peat.

4.2.3 Chemical Properties

The chemical analyses carried out on the samples included the following: pH, total cation exchange capacity, exchangeable cations, base saturation, total nitrogen (N), total carbon (C), available phosphorus (P), and C/N ratio. The methods of analyses employed are described in Section 9.1.

The results of the chemical analyses of the peat samples from the Mildred Lake and Evansburg areas are given in Table 3.

In terms of soil reaction, the fibric moss peat samples were extremely acid, generally in the pH range of 3.7 to 4.0 in H_2O. The mesic peat on the other hand was higher in pH in both the Mildred Lake and Evansburg area samples. At Mildred Lake, this may be due to the near-surface presence of Devonian limestone.

The fen peat samples were highest in reaction ranging from 6.6 to 7.1; again calcium-(Ca) rich groundwater may have resulted in the relatively high pH values.

In terms of C, N, and the C/N ratio, the fibric moss peat from the Mildred Lake area was very low in N content, and the C/N ratio was high. The fen peat was highest in N content (more than 2.0%), and the C/N ratio relatively low. The type of peat and the degree of decomposition undoubtedly accounts for the wide range in N, C, and C/N ratios among the peats sampled.

The relatively low N content and pH in the fibric moss peat material result in a biologically inactive state. This leads to incomplete transformation of organic residues.

In terms of base saturation, the fibric and mesic moss peats at both the Mildred Lake and Evansburg sites had a low base saturation when compared to the fen peats. The fen peat samples were extremely Ca rich and this fact combined with the higher pH and N levels would suggest the material is more biologically active.

Table 3. Chemical properties of peat from the Mildred Lake and Evansburg areas.

Peat Type	pH (H_2O)	Exch. cations (meq/100g)[a] Ca	Mg	K	Na	T.E.C.[b] (meq/100g)	Base sat. (%)	Total C (%)	Total N (%)	C/N	P_2O_5 (ppm)
					Mildred Lake Area						
Fibric	3.7	21.9	14.3	0.4	1.2	116	33	46.8	0.61	77	15
Mesic	5.9	81.3	12.8	0.1	0.3	166	57	39.2	1.47	27	6
Fen	6.6	94.2	10.9	0.1	0.4	110	96	46.5	2.80	17	4
					Evansburg Area						
Fibric	4.0	13.3	2.8	0.3	0.3	115	14	44.9	1.25	36	3
Mesic	5.6	53.1	16.9	0.1	1.1	142	50	44.7	1.48	30	4
Fen	7.1	129.3	19.7	0.2	0.2	165	90	35.1	2.19	16	4

[a] Extracted with 1 N NH_4OAc; meq = milliequivalents.

[b] Total exchange capacity; extracted with 1N NaCl.

4.2.4 Microbiological Study

In comparing the microbial populations in different peats, Table 4 shows that the fen peat contains the highest bacteria numbers and a moderately high fungi count. This is probably due to the less acidic nature of the peat and also the more readily decomposable nature of the material.

The microbial population in a sphagnum fibric peat at Mildred Lake was low in bacteria and fungi numbers, and this is probably due to the fact that the soil reaction (pH 4.0 or less) is highly unfavourable to the growth of bacteria. Furthermore, the cellulose and lignin existing in sphagnum peat is highly resistant to the action of bacteria (Waksman and Purvis 1932). On the other hand, the anaerobic conditions are unfavourable to the development of fungi. However, the sphagnum mesic peat in this area is somehow higher in bacteria population than the fibric peat, but fungi distribution is still low. This increase in bacterial number may be due to root action of the black spruce cover resulting in some movement of calcium or other nutrient to the surface layer.

In fibric peat at Evansburg the fungi and bacteria numbers are relatively high. The difference in microbial population between this site and the Mildred Lake site is not clear. However, the greater percentage of woody material at the Evansburg site may have resulted in the partial development of aerobic conditions leading to an increase in fungi population.

4.2.5 Enzyme Activities

Enzyme activity was estimated as a measure of peat decomposition. The enzyme, cellulase, hydrolizes cellulose in organic matter to produce reducing sugar. Therefore, soil enzymes produced by microorganisms can be used to investigate the humification of organic material (peat). Table 5 shows the cellulase C_1 (which attacks highly ordered forms of cellulose) and B-glucosidase activities are low in moss peat (fibric and mesic layers), but high in fen peats. The low content of cellulase C_1 may be attributed to two

Table 4. Distribution of microorganisms in peats.

Peat Type	Bacteria (No./g dry peat)	Fungi (CFU[a]/g dry peat)
	Mildred Lake	
Fibric	28×10^4	2.1×10^4
Mesic	200×10^4	2.8×10^4
Fen	1600×10^4	27×10^4
	Evansburg	
Fibric	590×10^4	37×10^4

[a] Colony forming units.

Table 5. Enzyme activities in three Mildred Lake peat samples.

Peat Type	Cellulase (C_1) (mg reducing sugar/g carbon/5 days)	Carboxymethyl-cellulase (Cx) (mg reducing sugar/g carbon/24 h)	B-glucosidase (mg saligenin/g carbon/3 h)
Fibric	0.332	0.580	0.131
Mesic	0.341	0.764	0.161
Fen	0.574	0.694	0.575

factors: first, the absence of organisms which can digest the native cellulose; and secondly, the existence of certain inhibitors which serve as protectors for the moss material.

In the first instance, Reese (1968) estimated that about half of the types of organisms present in soil are able to produce enzymes necessary for hydrolysis of common polysaccharides (e.g., cellulose). The organisms accelerate the cellulase synthesizing mechanism only when it comes in contact with cellulose (provided that no other foodstuffs are readily available). A very small amount of cellulase is sufficient to produce a little cellobiose from the cellulose, but more enzyme produces more cellobiose, continuing as long as the cellulosic substrate remains.

For the second reason, Mandel et al. (1961) mentioned that the cellulase inhibitors were found in many plant families and in various parts of plants, including leaves, wood, flowers, fruit, and seed.

Mandel and Reese (1963) also suggest that physical factors may affect the cellulase action. Fungal cellulase in general is stable at $30^{o}C$ from pH 3 to 8 but usually shows optimum activities at pH 4.0 to 5.5 in citrate, phosphate, or acetate buffer. Halliwell (1963) found bacterial cellulase shows higher pH optima, often around 6.0.

Carboxymethylcellulase (Cx) attacks shorter chained cellulose, usually the residue from C_1 action. In the samples examined, it was highest in the mesic layer and lowest in the fibric layer of moss peat. The slightly higher C_1 and Cx activities in mesic peat may be related to the lower fiber content.

The distribution of enzymes may also be related to chemical properties, such as pH, N, Ca, and P_2O_5 content.

4.2.6 Oxygen Uptake

One of the critical aspects of peat use is its rate of decomposition. If it decomposes faster than the rate at which organic material is added through plant growth, the net organic matter content of the soil will decline. To determine if the peat decomposition rate was controlled by degree of decomposition as indicated by fiber content, a series of samples having different fiber contents were incubated and O_2 consumption measured. Bacterial numbers by plate count were also estimated. No clear relationship between O_2 consumption and fiber content was evident but there was a close relationship between O_2 consumption and numbers of bacteria in the various samples (Figure 2). Therefore it appears that factors of the peat and its environment other than fiber content were responsible for its rate of decomposition and that amendments added to peat or sand-peat or overburden-peat mixes substantially affect the rate of peat alteration.

To determine if the addition of fertilizer and lime affected peat decomposition, two peats were incubated with and without additions of N, P, and $CaCO_3$. Oxygen consumption over eight days was measured and is reported in Figures 3 and 4.

In both peats, additions of P increased respiration rate. Only in the fibric peat with low pH and high C/N ratio did additions of $CaCO_3$ increase the rate of decomposition as measured by O_2 uptake. Addition of N appears to actually depress respiration rate in the fen peat. This may have resulted from high NH_3 levels from the $NH_3 + H^+ \rightleftharpoons NH_4^+$ equilibrium. Also NO_2^- may have accumulated and caused some toxicity. Although the pH is on the low side for NO_2^- accumulation (6.6), the presence of NH_4^+ may have raised it high enough in microsites to prevent nitrite oxidation by *Nitrobacter* spp. Similarly, addition of $CaCO_3$ to fen peat had a slight inhibitory effect on respiration rate.

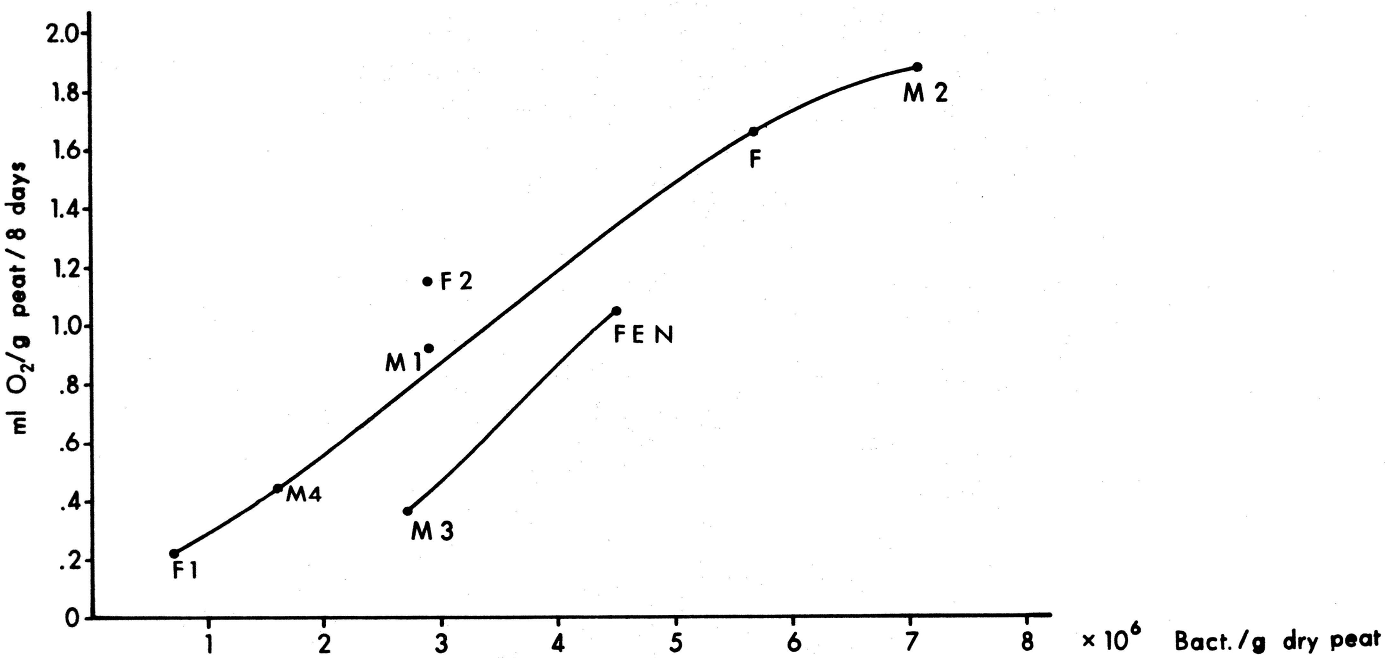

Figure 2. Relationship between number of bacteria as determined by plate counts and O_2 uptake by eight peat samples incubated at 25 ± 0.5°C. F1 and F2: two fibric peats from Evansburg area, M2 and M4: two mesic peats from Evansburg area, M3: Fen peat from Evansburg area, F: fibric peat from Mildred Lake, M1: mesic peat from Mildred Lake, Fen: fen peat from Mildred Lake.

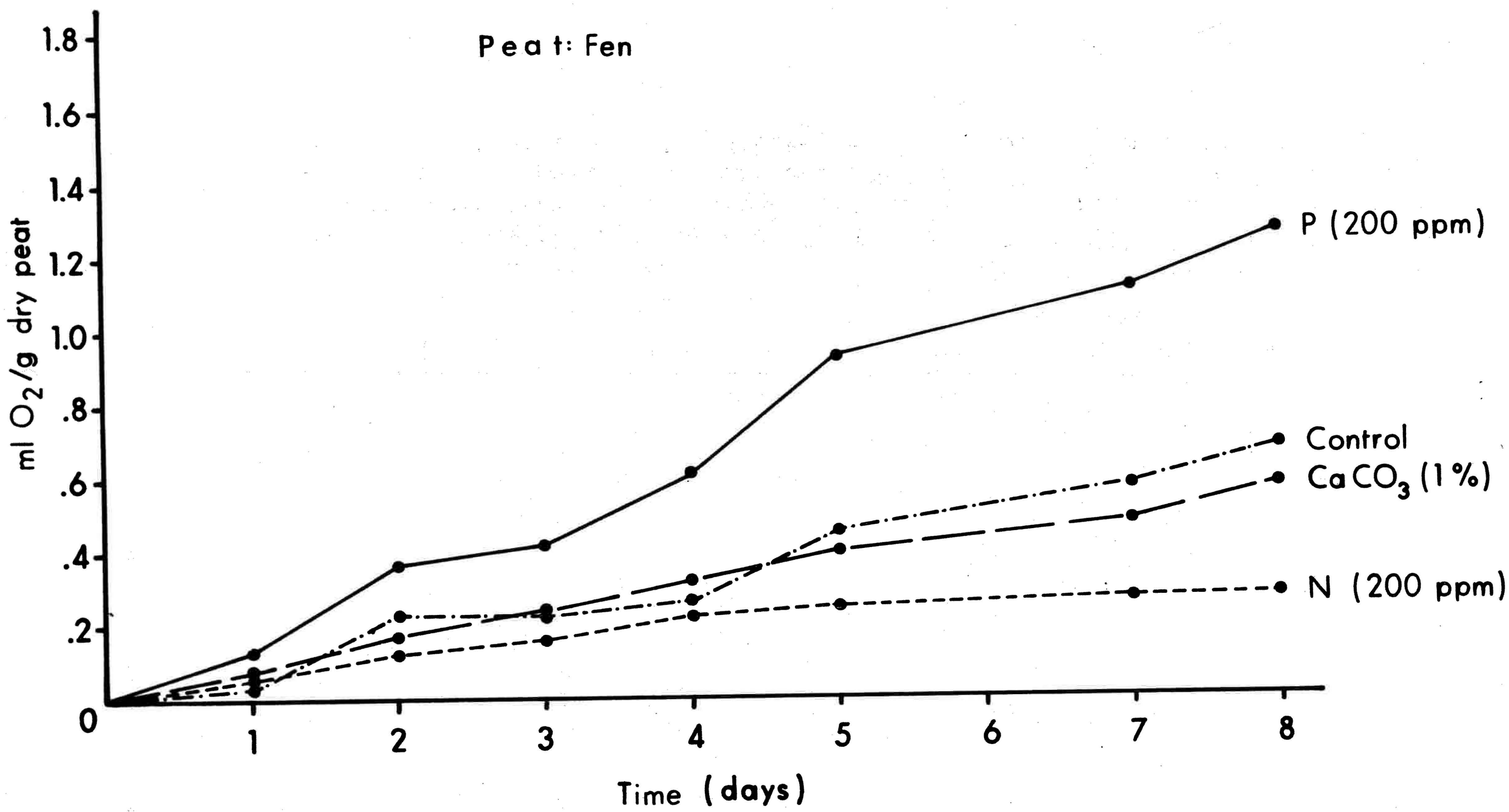

Figure 3. Effect of amendments on O_2 uptake by fen peat sample incubated at 25 ± 0.5°C. Concentrations of N, $CaCO_3$ and P are based on wet weight of the peat.

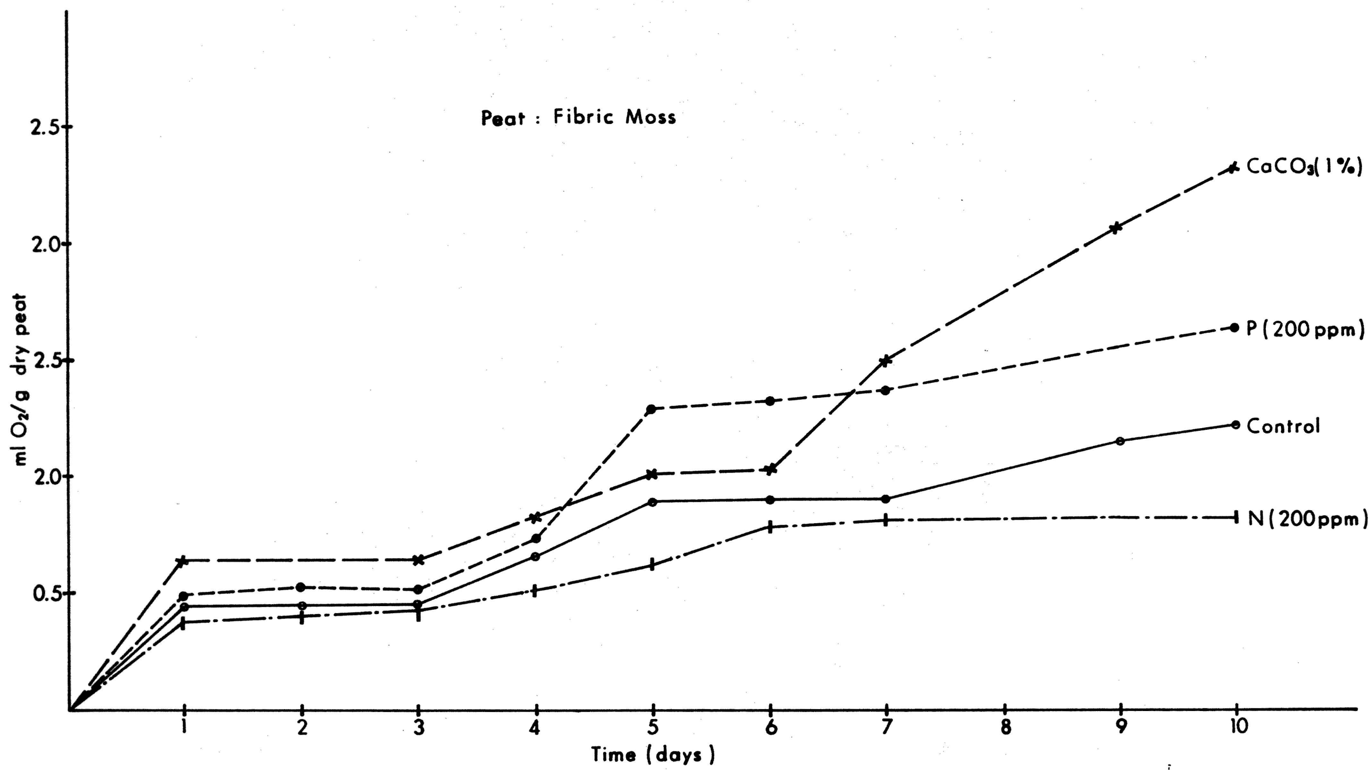

Figure 4. Effect of amendments on O_2 uptake by fibric peat sample incubated at $25 \pm 0.5^{\circ}C$. Concentrations of N, $CaCO_3$ and P are based on wet weight of the peat.

5. EFFECT OF DRYING, FREEZING-THAWING, AND FERTILIZER ADDITIONS TO PEAT

Peat in storage piles is subjected to various climatic influences such as wetting, drying, freezing, and thawing. Little information is available in the literature regarding the specific effects of these processes on stored peats, but changes in chemical and physical properties can generally be expected. Another influence is the addition of readily available nutrients in the form of fertilizers, and of readily decomposable organic matter from the cover crop on storage piles. The effect of adding these is to stimulate the microbial population resulting in more rapid decomposition of peat particles (priming). This in turn can result in alteration of some physical properties. In agriculturally used peatlands, the loss of organic matter resulting from priming by decomposing crop residues has been examined and found not to be a problem (Bingeman et al. 1953; Stotzky and Mortensen 1958). The use of response to priming has been suggested as a means of examining the decomposability of soil organic matter (Dormaar 1975).

Experiments were conducted to determine if priming by glucose occurred in peats from the study area with a view to possible extension of this method to regular monitoring of stored peat. Freezing-thawing, wetting-drying, and addition of nutrients were simulated by sequential treatments in the laboratory under controlled conditions. Conducting the experiment in the laboratory allowed considerable acceleration of rates of changes in peat properties.

5.1 MATERIALS AND METHODS

5.1.1 Treatments

Samples of three types of peat from undisturbed sites in the Mildred Lake area were used: fibric, mesic, and fen. Descriptions of these are given in Section 4.2. The peats were each split into three main treatments. The first portion was kept field-moist and is referred to as "normal" peat, designated by the letter 'n'. The second portion was air-dried and is designated by the letter 'a'.

The third portion, designated by the letter 'f', was freeze-dried to represent the type of drying that occurs during winter in exposed peat. There was one sample of about 3 kg peat per treatment. Each sample was incubated in plastic pots at $25 \pm 0.5^{\circ}C$. On days 7, 14, and 21 the peats were frozen at $-10^{\circ}C$ for 24 hours followed by thawing and incubation for 6 days.

Nutrients and lime were added after the final freeze-thaw cycle on day 28. This consisted of 200 ppm P and N as KH_2PO_4 and $(NH_4)_2SO_4$, and 1% $CaCO_3$.

On day 40, glucose was added at a rate of 216 ppm C on a wet weight basis. UL-^{14}C-glucose was added to the normal treatments of the CO_2 incubation at a specific activity of 7.35 μCi/mg C. This high activity level was used to allow fractionation of the samples at a later date to obtain additional information about the fate of C in peat should this prove necessary. The experiment was terminated after 61 days.

During the course of this experiment, microbial population changes were also estimated to relate them to the respiration rates and to try to determine if any specific group was likely responsible for the changes in physical properties of the peat. Plate counts for bacteria were made on single samples on days 1, 6, 9, 27, 34, and 64. At the same times, duplicate samples were taken for estimation of fungal hyphal lengths by the Jones and Mollison (1948) technique. Numbers of cellulose degraders were estimated for days 1, 27, 34, and 64. Enzyme activities were determined on four replicates on day 1, after the drying treatment.

Physical analyses on single samples of the peat were made after drying and at the end of the experiment. They included fiber content, bulk density, permeability, pore volume, and air and water capacity. All these properties are strongly related to the value of peat for land reclamation.

5.1.2 Measure of CO_2 Evolution in Peats

The method of determining CO_2 evolved in peat is described in Section 9.1. Evolved CO_2 from samples which had ^{14}C-labelled glucose added was collected in the same way but 1.0 mL was removed prior to titration and were counted in a scintillation counter to measure the specific activity of the evolved CO_2 - C (Middleboe et al. 1976). Counting efficiency was measured using the sample channels ratio method (Middleboe et al. 1976). The scintillation cocktail consisted of 0.2 g of POPOP (1.5-bis-[methyl-5-phenyloxozolyl]-benzene) and 8.0 g of PPO (2,5-diphenyloxoazole) dissolved in 2 L of toluene (scintillation grade) after which 1 mL Triton X-100 was added as an emulsifier. Samples 1 mL in size of the NaOH solution containing $^{14}CO_2$ were added to 15 mL of this solution in 20 mL scintillation vials and counted for 1 min (more than 10 000 counts per minute).

5.1.3 Microbial Enumeration

Bacterial counts were made by a soil dilution technique. Serial 10-fold dilutions were made, and 0.1 mL of three suitable dilutions were spread on four replicate plates of Plate Count Agar (Difco). The plates were incubated at room temperature for six to eight days and counted. Fungal plate counts were performed in a similar manner using Rose Bengal-Streptomycin agar. The media used in plate counts is described in Section 9.1.

Lengths of fungal hyphae were estimated by the Jones and Mollison (1948) technique, with modifications based on Parkinson et al. (1971).

Cellulose decomposers were estimated by a most probable number (MPN) technique using test tubes containing a mineral salt medium and a strip of filter paper as the sole carbon source. Visible growth on the filter paper was taken as evidence of cellulose decomposition. Plate counting was not used because cellulose decomposers are very slow growing and, unless the humidity can be accurately controlled, the plates dry out before counts can be obtained.

The method of determination of cellulase C_1, carboxymethyl-cellulase Cx, and B-glucosidase activities is described in Section 9.1.

5.2 RESULTS

5.2.1 Effect of Drying on Physical Properties

Drying affected most of the physical properties examined (Table 6). Bulk density was increased by air-drying fibric and mesic peat but drying had a negligible effect on the bulk density of the fen peat. Freeze-drying was generally less detrimental than air-drying, if increased bulk density can be considered undesirable. Freeze-drying caused a slight reduction in bulk density of fen peat and mesic peat and a slight increase in the fibric peat, but not so great as the effect caused by air-drying.

Pore volume was changed only slightly if at all due to drying but air capacity was affected more severely. Air capacity decreased by 11% in the fibric peat but increased 33% and 43% in the mesic and fen peats, respectively. This may slightly improve the utility of mesic and fen-type peats for reclamation since the air capacity of these peats is at the low end of the scale for vigorous plant growth. Air-drying was generally more effective in altering air capacity than was freeze-drying.

Drying affected the unrubbed fiber content only in the mesic peat in which a slight (6.3%) reduction occurred. The fiber content of the fen peat which was originally low was unaffected by either drying treatment. Drying affected the susceptibility of the fibric peat to crushing. Both methods of drying caused a 5.9% reduction in rubbed fiber content of the fibric peat. Rubbed fiber in the more decomposed mesic peat was affected only by the freeze-drying treatments.

Permeability is one of the main properties controlling the value of peat as a material for reducing erosion from slopes. The permeabilities of all peat samples were low. Drying would have to be considered very undesirable in terms of erosion control in all

Table 6. Effect of air- or freeze-drying on physical properties of three peat samples from the Mildred Lake area.

Peat Type	Treatment	Bulk Density (g/cc)	Pore Volume (%)	Air Capacity (%)	Water Capacity (%)	Void Ratio	Fiber Content Unrubbed (%)	Fiber Content Rubbed (%)	Permeability (cm/h)
Fibric	Normal	0.052	96	39	57	28	95	85	1.58
	Freeze-dried	0.056	96	36	60	26	95	80	0.46
	Air-dried	0.061	96	34	62	23	95	80	0.75
Mesic	Normal	0.086	94	21	73	16	80	55	1.30
	Freeze-dried	0.079	95	28	67	18	75	50	0.40
	Air-dried	0.090	94	28	66	16	75	55	0.38
Fen	Normal	0.119	93	21	72	12	35	<10	1.02
	Freeze-dried	0.107	93	25	68	14	35	<10	0.30
	Air-dried	0.116	93	30	63	13	35	<10	0.18

the peats examined. The effect of drying was greater on permeability than on any other property examined. Air-drying had a less serious effect on the fibric peat than on the other two, with the damage being greatest in the fen peat. Permeability was reduced to about 48% of its original value in the fibric peat but in the fen peat it was reduced to 18% of its original value. The seriousness of this is even greater than the change would appear because the fen peat had the lowest original permeability. Air-dried fen peat had a permeability only 11.6% as great as the normal fibric peat and 24.2% as high as in the air-dried fibric peat. Fen peat and probably also highly humified moss peat may be poorly suited for erosion control in areas where probabilities of desiccation are high. For application to level surfaces as mulch, dried peat would be quite useful from the initial physical standpoint. The more humified peat may be more desirable here. For applications to sloping land as an initial erosion control medium, undried fibric or mesic peat would probably be the most desirable. Logan (1978) favoured mesic peat due to its greater ability to increase water storage capacity.

5.2.2 Effect of Drying on Microbial Distribution and Activity in Peat

Figure 5 shows changes in bacterial counts in mesic peat. The air-dried and freeze-dried samples were similar throughout, with a higher initial count and a lower final count than the normal treatment. Fibric peat followed the same pattern as the mesic, while fen peat was not similar to either of the moss peats. All three treatments of fen peat give dissimilar results (Figures 6 and 7).

Numbers of cellulose decomposers also varied among the three peats, but never accounted for more than 1% of the bacteria) population as determined by plate counts (Figure 8). Fibric peat contained too few for reliable counts. Addition of nutrients caused a rise in the numbers of organisms in mesic peat and a sharp drop in the numbers in the fen peat (Figure 8).

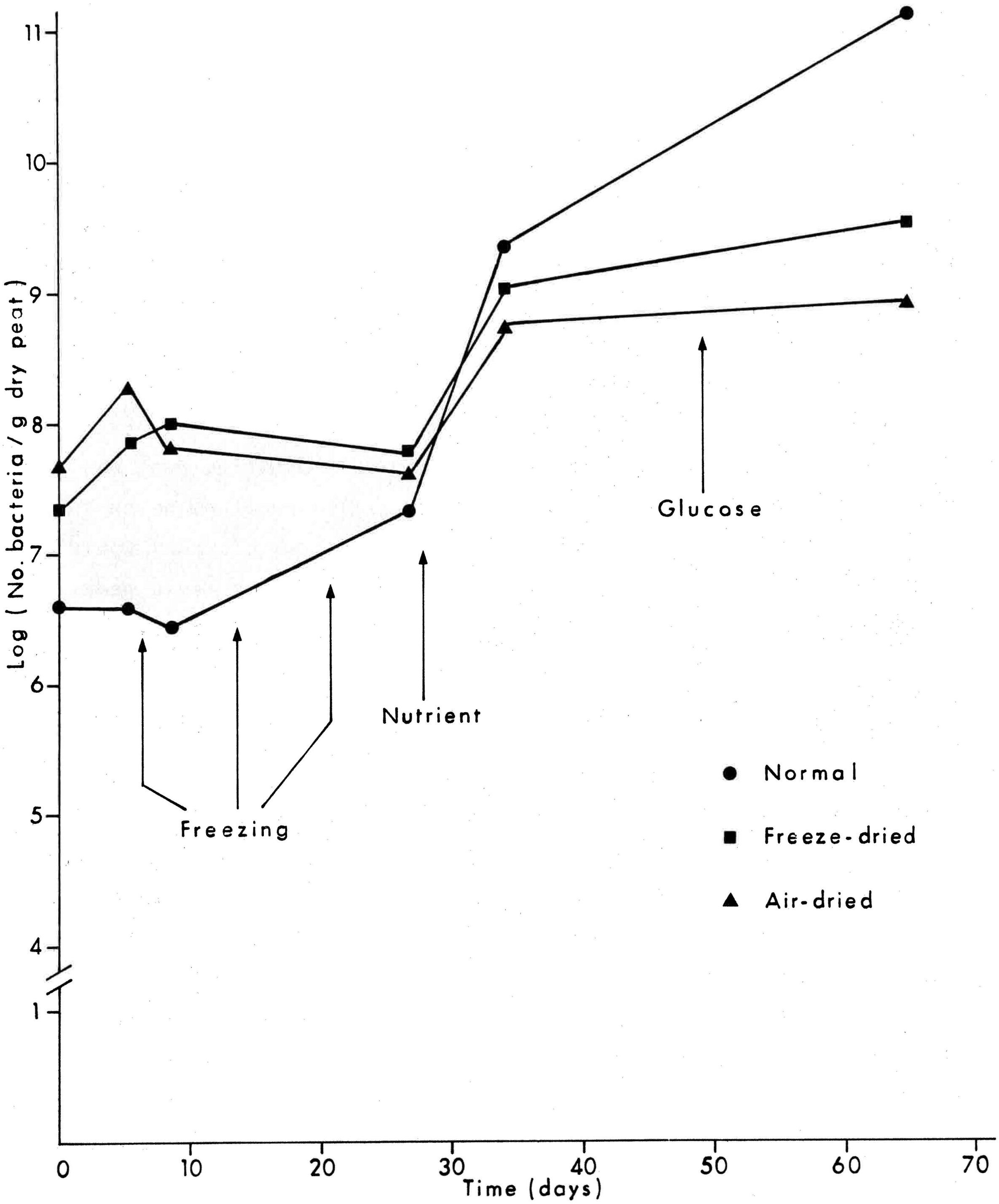

Figure 5. Change in number of organisms in mesic peat following physical and nutrient treatments.

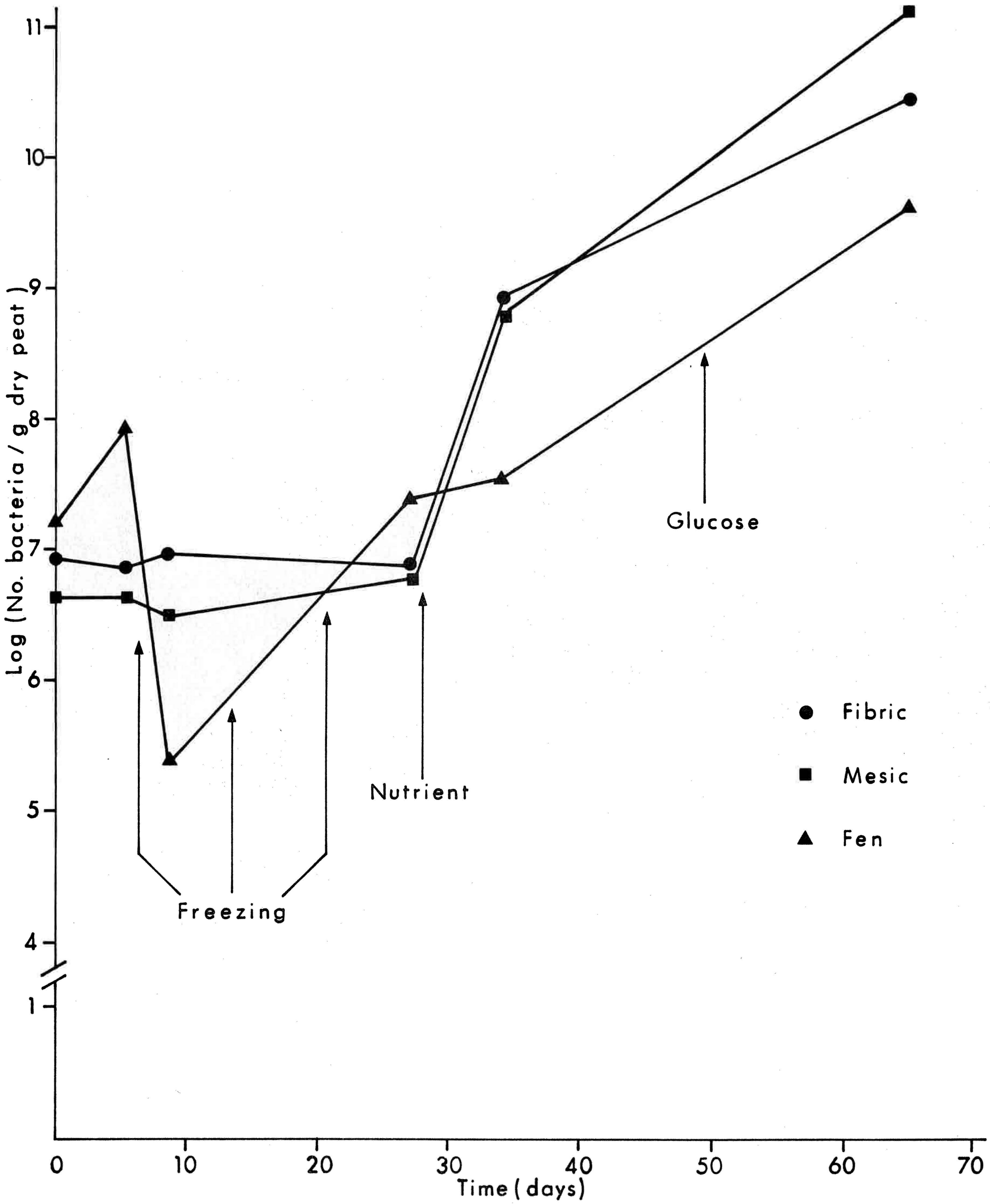

Figure 6. Change in number of organisms in fibric, mesic, and fen peat following physical and nutrient treatments.

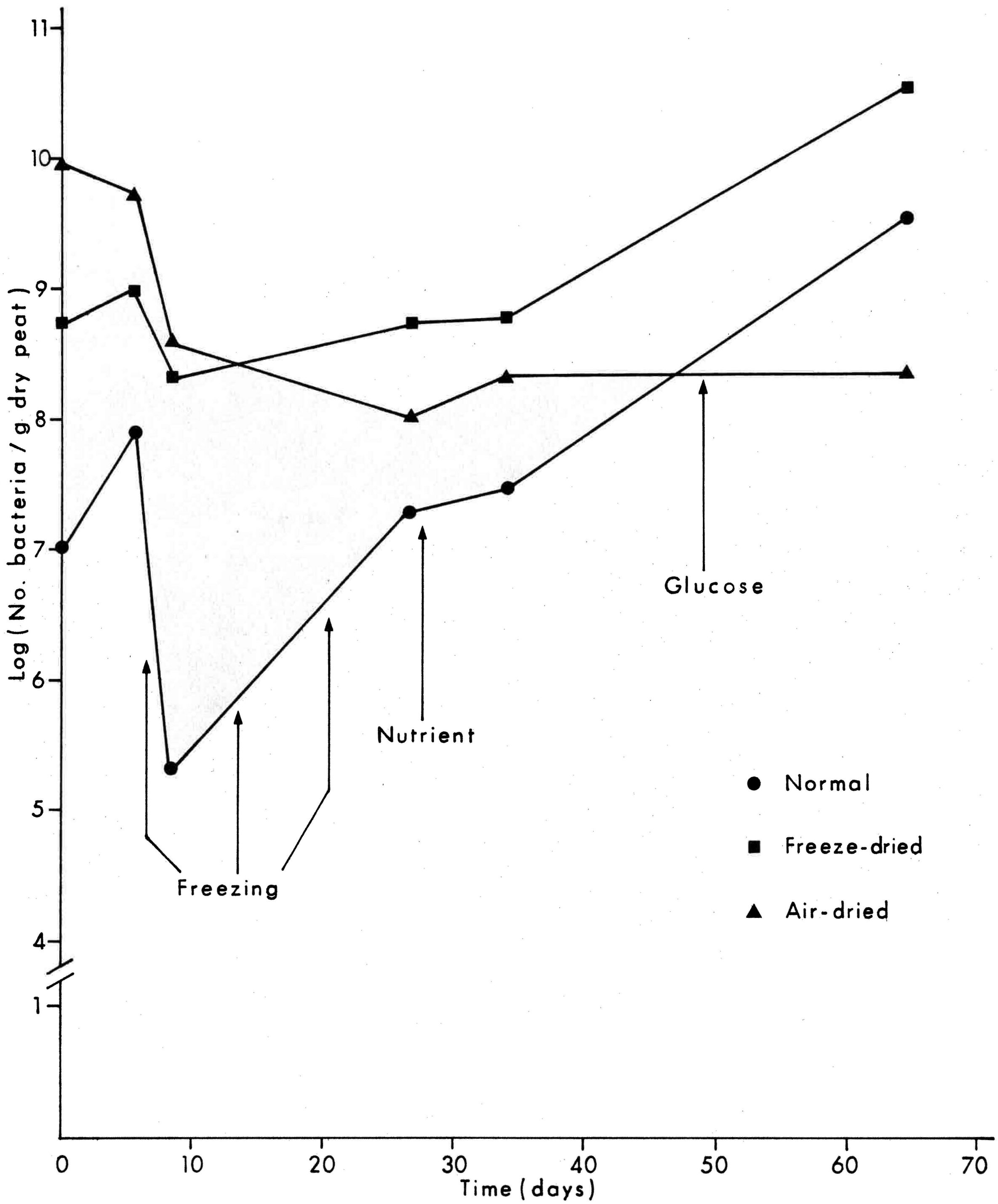

Figure 7. Change in numbers of organisms in a fen peat following physical and nutrient treatments.

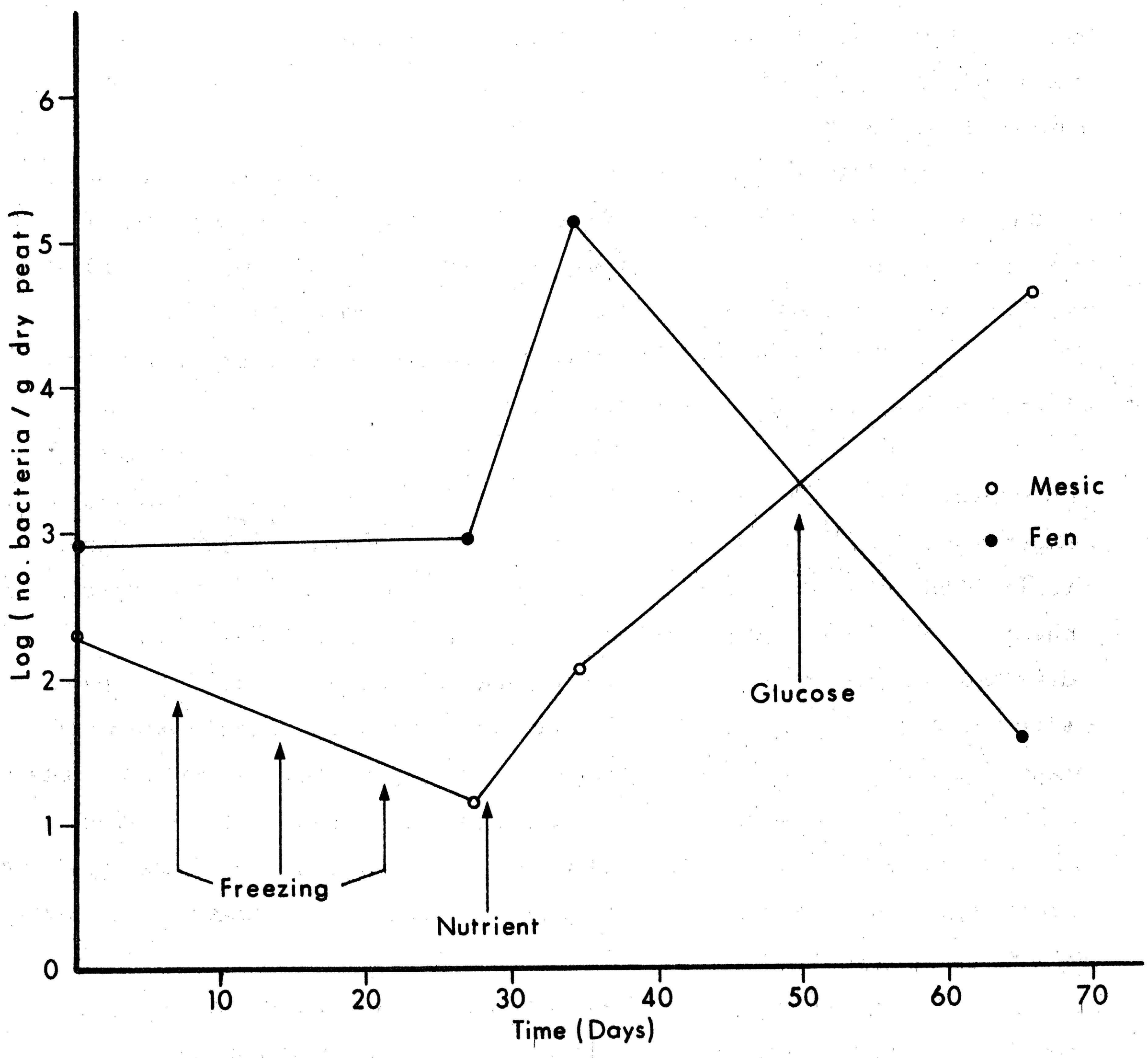

Figure 8. Changes in numbers of cellulose decomposers in normal mesic moss and fen peats following treatments.

The major differences in bacterial numbers among the three peats were between the moss peats and the fen peat. The greatest disparity was in the reaction to nutrient addition--the moss peats showed 100-fold increases while the fen peat reacted only slightly. Part of this disparity may be due to nutrient availability, but the major factor will be pH since most bacteria are inactive at the pH of the moss peats (3.7 to 3.9) while the fen peat has a pH of 6.6, much better for bacterial activity.

The decrease in fungal hyphal lengths from the beginning to the end of the experiment (Table 7) indicates that a portion of the increase in numbers of bacteria is due to metabolism of fungal material rather than the degradation of peat components.

Respiration rates obtained (Figure 9) are consistent with those reported in the literature (Table 8).

Drying affected microbial activities to varying degrees as measured both by enzymatic activity and CO_2 production (Table 9, Figure 9). Activities of enzymes degrading cellulose were substantially reduced in the fen and mesic peat upon drying. Very little change was evident in the fibric moss peat. This implies that a different mechanism of stabilization may be operative in fibric peat than in more decomposed peat. Although activity of cellulose degrading enzymes was reduced after drying, CO_2 production during seven days of incubation following rewetting was greater in the rewetted air-dried moss peats than in the normal samples. Respiration from the fen peat samples, which was almost double that of the two moss peats, was unaffected by drying.

Since the activity of cellulose degrading enzymes was reduced by drying and the soil respiration rate was generally increased by this treatment, a substantial amount of activity occurring in peat may be related to turnover of microobial tissue and not to cellulose degradation. Shields et al. (1974) showed that freeze-thaw and wetting-drying processes substantially increased the rate of loss of C from soil microorganisms in a clay soil. Freezing and thawing were more effective than drying and rewetting. Soil organic matter turnover is closely related to the dynamics of soil microbial

Table 7. Hyphal lengths by phase-contrast microscopy.

Peat Type	(km/g dry weight) Day 0	Day 64
Fibric normal	27	20
Mesic normal	45	36

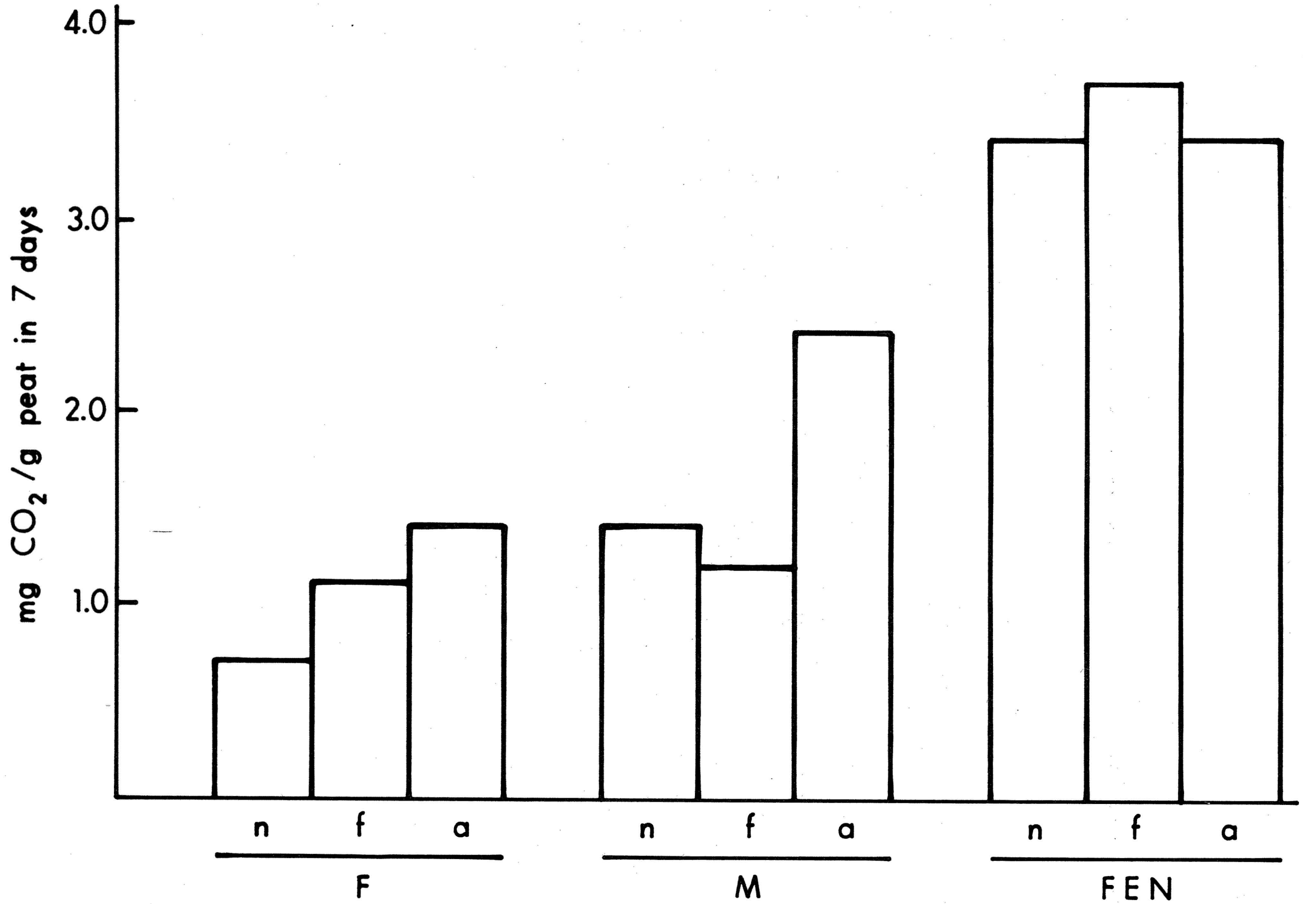

Figure 9. CO_2 production from fibric (F), mesic (M) and fen (FEN) peats remoistened after air-drying (a) and freeze-drying (f), as compared to the control (n). Incubation temperature was 25 ± 0.5°C.

Table 8. Summary of respiration rates from peat materials as found by various workers.

	Comments	Depth	Respiration Rate ($\mu g\ CO_2$-C/g/day)
Stout (1971)	less than 1 day aerobic incubation in lab	0 - 7.5 cm 7.5 - 15 cm 1 m	148.7 20.0 38.9
Stotzky and Mortensen (1958)	muck soil; pH 5.4 C:N = 73.4; 70-day incubation in lab		88.6
Ivarson (1977)	acid bog peat; pH 4.1; 8-month incubation in lab	0 - 15 cm 15 - 41 cm	163.1 52.3
Mathur and Sanderson (1978)	24 Histosol surface samples; respiration inversely related to Cu content		26.6 - 83.2

Table 9. Effect of drying on enzymatic activity of three peats from the Mildred Lake area.

Peat Type	Treatment	Cellulase $(C_1)^a$	Carboxymethyl-Cellulase $(Cx)^b$	B-Glucosidase[c]
Fibric	Normal	0.332	0.589	0.131
	Freeze-dried	0.413	0.335	0.160
	Air-dried	0.383	0.583	0.150
Mesic	Normal	0.341	0.764	0.162
	Freeze-dried	0.181	0.508	0.119
	Air-dried	0.108	0.302	0.117
Fen	Normal	0.574	0.694	0.575
	Freeze-dried	0.171	0.448	0.294
	Air-dried	0.238	0.371	0.453

[a] mg reducing sugar/g dry peat present five days after adding substrate (cellulose powder).

[b] mg reducing sugar/g dry peat present 24 hours after adding substrate (carboxymethyl-cellulose).

[c] mg saligenin/g dry peat present three hours after adding substrate (Salicin).

populations. The effects of external environmental fluctuations on peat decomposition will likely be manifested in part through their lethal effects on soil bacteria and fungi. Much of the CO_2 respired during the seven days following rewetting of a dry peat probably came from decomposition of fungi and bacteria killed during drying. Freeze-drying would be expected to have an intermediate effect because it kills fewer cells. It appears likely then that, over the long term, cycles of drying and remoistening would accelerate turnover of the microbial population, ultimately accelerating decomposition of the peat itself due to utilization of peat C in restoring the biomass C lost to respiration during each successive population regrowth.

5.2.3 Effect of Freeze-Thaw Cycles, Nutrients, and Glucose on Microbial Activity

The treatments imposed affected the rates of CO_2 production in all three peats (Figure 10). The series of freeze-thaw cycles reduced the rate of CO_2 production whereas nutrients and glucose both increased it. At the end of the experiment, the mesic peat sample (normal) had respired 28.9 mg CO_2/g dry peat whereas the respective values for the fen peat sample and fibric sample were 24.0 and 18.1 mg CO_2/g dry peat. More total CO_2 was produced from the dried peats than from the control samples.

During three freeze-thaw cycles, the fen peat continued to produce more CO_2 than the two moss peats. The positive effect of air-drying on respiration rate was still obvious during this phase of the experiment but freeze-drying was starting to show a slight depressing effect. The total CO_2 produced during this phase of the experiment was approximately the same in 21 days as in seven days after rewetting.

Addition of nutrients and lime altered the relative rates of CO_2 production. Whereas the previous (physical) treatments affected all peat samples similarly, these treatments which altered the soil pH and nutrient status had a greater beneficial effect on the moss peats than on the neutral, relatively nutrient-rich fen

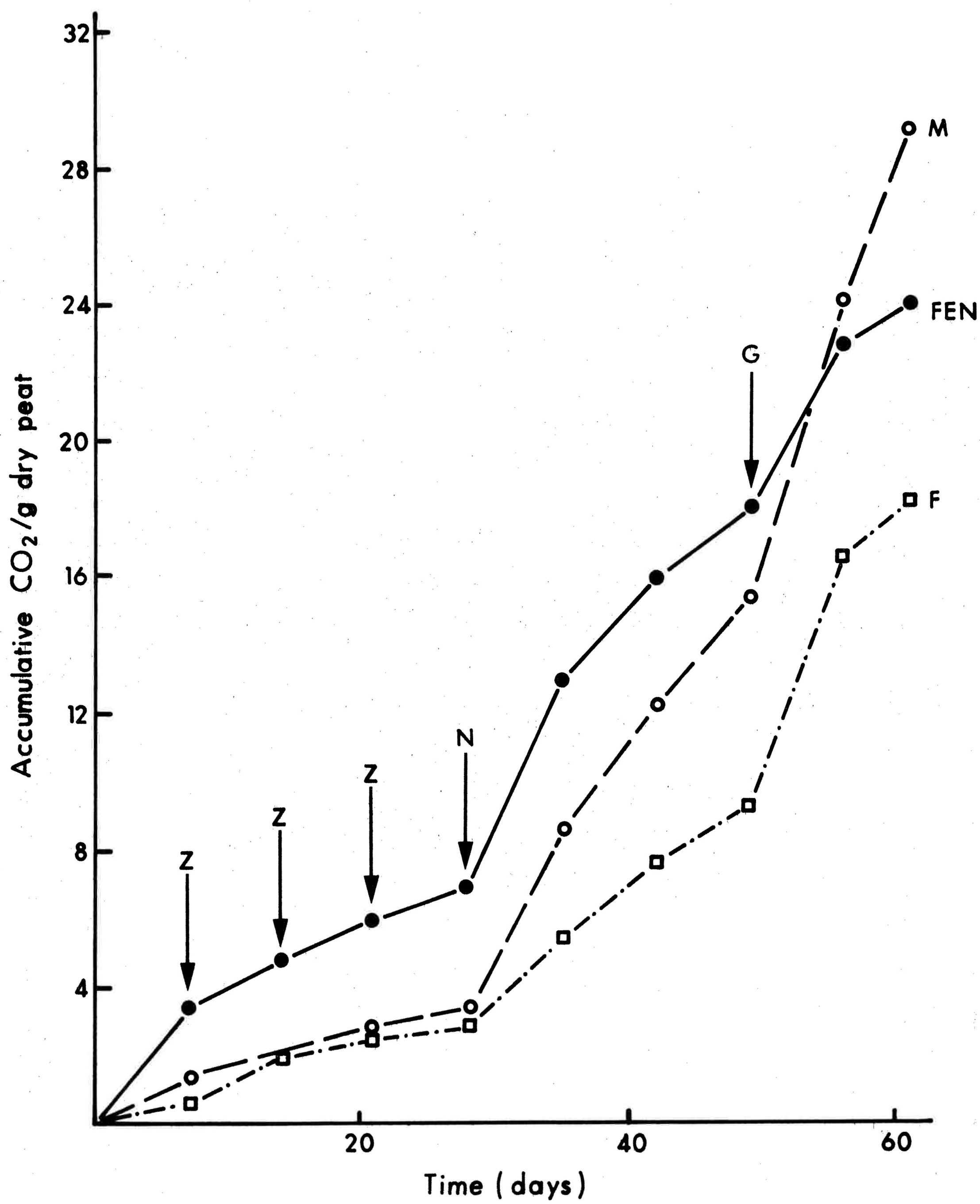

Figure 10. Accumulative CO_2 production from control positions of fibric (F), mesic (M) and fen (FEN) peats during 61 days incubation at 25 ± 0.5°C. Freezing events are designated Z, addition of nutrients by N, and addition of glucose by G.

sample. Thus, during 21 days following nutrient and lime amendment, the mesic peat produced as much CO_2 as did the fen peat. The effect of drying was starting to be masked by this time due to the rapid respiration rate in all samples. The rate of CO_2 produced during the 21 days following nutrient addition was about three times greater than during the 21 days previous.

The trend for chemical and nutritional changes in the peat environment to substantially affect the activity in the peat was even more pronounced when glucose was added to the three peat samples. More CO_2 was produced during 12 days after glucose addition in the moss peats than in the fen sample. Thus the initial dominance of the fen in terms of respiration rate had been completely lost by adding glucose, nutrients, and altering the pH of the peats. The initial marked difference between the samples had disappeared or been reversed.

These results tend to support the hypothesis that peat properties which affect the activity of microbes are probably mainly chemical. The initial chemical properties of a disturbed peat, however, are undoubtedly a result of its past physical environment. The physical effects on soil microbes appear to be mainly temperature and moisture.

Alterations in the physical environment of peats which kill microbes tend to increase respiration rate but have at least an initial depressing effect on activity of enzymes related to cellulose decomposition. The effect of recurrence of treatments such as air-drying which kill microbes can be expected in the long term to increase the rate of peat decomposition by increasing microbial turnover rate. In support of this is the greater overall CO_2 output from the air-dried peat as compared to the control over the 61 days of this incubation. Further evidence for this hypothesis is the rather static size of the bacterial population (as measured by plate count) after drying and during the freeze-thaw portion of the experiment. Therefore, although physical peat properties influence its utility as a reclamation material, they probably have a minor influence on the rate of decomposition of stored peat, especially when stored as an admixture with mineral materials such as occur in the Mildred Lake storage piles. The type of peat material going into a pile probably has little effect on the rate of decomposition within the pile. Decomposition can then be considered to be controlled primarily by pH, nutrients, aeration, temperature, and moisture.

5.2.4 Effect of Microbial Activity on Physical Properties of Peat

Results reported in Figure 5 are generally in agreement with literature data. However, very few if any reports are available describing the effects that microbial activity may have on ameliorating or aggravating problems caused by drying or the role of microbes in altering physical properties of normal peat spread on the soil surface or stored in piles in the field.

The data in Table 10 show the effect of the 61-day incubation on some of the physical properties of the peats. Microbial activity increased bulk density less where the peat had been dried than in the normal peat. This may be attributable to the prior increase in bulk density caused by microbial activity such that, after the incubation period, the bulk density was higher in the normal peat than in the dried peat. The only exception to this was the air-dried fibric peat. Thus, although drying increased bulk density, the dried peats had a lower bulk density at the end of the incubation period than did the normal peat. The drying treatment may therefore have a tendency to stabilize the bulk density at a lower level in the long run. The reasons for this are not immediately obvious.

Pore volume decreased as the increase in bulk density would imply but the decrease was slight. Air capacity was affected to a greater degree. The depressing effect of drying on air capacity in the fibric peat was accentuated by subsequent incubation. Although drying increased air capacity of mesic and fen peat (Table 6), subsequent incubation reduced it again. Generally drying appeared to have a greater effect on air capacity than did incubation in the mesic and fen peats, but the reverse was true for the fibric peat.

Table 10. Effect of 61 days incubation at 25°C with three freeze-thaw cycles, addition of nutrients, glucose and lime on physical properties of peat moistened after air- or freeze-drying.[a]

Peat Type	Treatment	Bulk Density	Pore Volume	Air Capacity	Void Ratio	Fiber Content		Permeability
						Unrubbed	Rubbed	
Fibric	Normal	+17.3%	-0.6%	-22.2%	-4.2	0	0	+777%
	Freeze-dried	+8.9	-0.3	-11.1	-2.0	-5.2%	-12.5%	+728
	Air-dried	+41.0	-1.7	-24.4	-7.2	-10.5	-6.3	+176
Mesic	Normal	+17.4	-1.1	-1.9	-2.8	-6.3	-9.1	+417
	Freeze-dried	+8.9	-0.4	+5.8	-1.4	-2.6	-10.0	+678
	Air-dried	+4.4	-0.2	-13.2	-0.6	-13.3	-18.2	+434
Fen	Normal	+21.8	-1.7	-17.4	-2.5	0	0	+154
	Freeze-dried	ND	ND	ND	ND	0	0	+372
	Air-dried	+6.0	-0.4	-22.0	-10.7	0	0	+459

[a] All values reported as % change over corresponding original value from Table 6.

ND = no data

It would therefore appear that, from the standpoint of air capacity, drying mesic and humified peat would be desirable. Not only does the initial increase in air capacity offset the depressing effect of subsequent microbial decomposition but drying also tends to reduce the loss of air capacity.

The effect of microbial activity on both rubbed and unrubbed fiber content was greater than the initial effect of drying. Drying tended to hasten the rate of loss of fiber, especially rubbed fiber. After incubation dried peats (fibric and mesic) always had lower fiber contents than the corresponding normal peat samples.

As with drying, the most dramatic and important physical alteration caused by microbial activity was in hydraulic conductivity. The adverse effect on hydraulic conductivity was completely overcome by incubation in all three peats. The net result was that, after incubation, the permeability of the normal fen peat was greater than in the normal fibric peat prior to incubation. It would appear that the undesirable permeability levels of fen peats may be overcome by incubation with nutrients and with plants growing on it. This type of peat may in fact improve over time in the field with proper management until it is capable of providing physical amelioration rivalling that of fibric or mesic moss peat. This improvement in permeability is contrary to what might be expected when comparing results of examination of unaltered peats of various stages of decomposition. However, microbial activity within these peats, when exposed to freeze-thaw cycles, nutrients, and extra energy, can increase permeability. The absence of pure peat in the Mildred Lake storage piles must always be kept in mind. Further work to outline the causes of beneficial effects of the treatments imposed is needed.

5.2.5 Priming Effect of Added Carbon

Added organic C and, on occasion, mineral N have been shown to accelerate the rate of decomposition of native soil organic C and N in mineral soils. This has also been reported to happen in cultivated peatlands. If this happens as a result of addition of dead plant residues to sites where peat has been used for reclamation and revegetation has started, peat loss could exceed organic matter addition. The amount of C released due to priming may also serve as a practical measure of degree of humification of peat-C after using it as a surface amendment in the field or when included with mineral admixtures in storage piles.

In this incubation experiment, labelled C was added to the control peats to separate the peat-C evolved from the added glucose-C. The results obtained indicated a sharp increase in rate of evolution of peat-C as a result of glucose addition (Figure 11). Thus, not only did the added glucose increase microbial activity as a result of its direct consumption, it also increased the rate of consumption of peat-C to about twice the rate prior to adding glucose. Glucose-C was consumed 277 times faster than C from mesic peat and 233 times faster than C from fibric peat. The C in the fen peat is more resistant to microbial attack. In this peat, glucose-C was 391 times more readily attacked than the native peat carbon. Thus, in the peat with the highest fiber content and hence the lowest degree of decomposition, the native C was more easily degraded than in the peat that had a higher proportion of humified carbon. This is consistent with data presented by Stout (1971). He reported that the oxidation rate of peat declined with increasing age of the carbon.

The use of this response to priming technique may be valuable for assessing the changes occurring in peat applied to the soil surface in the field. It should help to determine whether the C is becoming more or less resistant to attack and hence if there is an accumulation of relatively undecomposed organic matter. Use of this approach to studying susceptibility to microbial attack of organic matter in Chernozemic soils has been reported by Dormaar (1975). Measurements of relative degrees of decomposition and to some extent actual decay rate estimates of the peat-C and dead plant-C in mixtures of peat and overburden or peat and sand could be facilitated using this technique. Measurement of the physical properties of peat and its degree of decomposition in mixtures with mineral material are very difficult by non-tracer techniques. Methods currently available

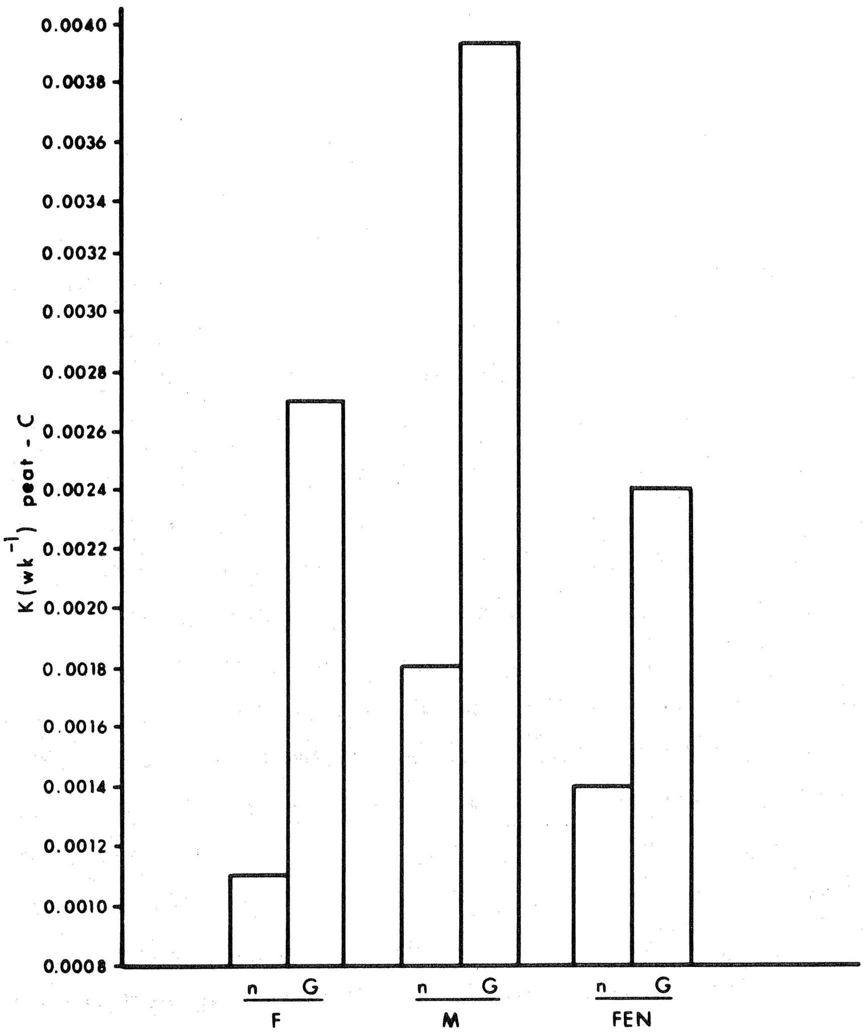

Figure 11. Effect of added glucose on the rate of carbon loss defined as

$$k = \frac{1}{dt} \ln \left(\frac{Co}{C}\right)$$

Where Co = original C content/g dry peat
C = carbon lost from peat as CO_2.

Carbon lost from the glucose which was labelled, was previously subtracted. The n represents the rate of peat-C loss from the control samples during the week immediately prior to adding the glucose. G represents the rate of peat-C loss from the same control samples during one week after glucose addition. Incubation temperature was 25 ± 0.5°C.

are restricted to pure peat. Pure peat does not exist at a restoration site and inclusion of mineral material in storage piles is hard to avoid.

6. STORED PEAT MATERIALS

Sections 4 and 5 dealt with properties of undisturbed peat and with effects of simulating some of the conditions under which peat could be stored. In this section, field and laboratory studies of stored peat are reported. Temperature and moisture conditions in peat storage piles were compared with undisturbed peat to determine if changes such as heating within piles occurred. Cellulolytic activities and soil respiration studies provided information concerning microbial activity in surface and subsurface layers under natural conditions.

Laboratory studies consisted of determining physical and chemical properties, enzymatic activities and respiration rates of stored peat at Mildred Lake for comparison with peat piles at the Evansburg site. Studies were conducted on the Mildred Lake and Evansburg peat storage piles which are described in Section 3.

6.1 FIELD STUDY

6.1.1 Temperature and Moisture Regimes in Peat Storage Piles

6.1.1.1 Method. Soil temperature and mositure fiberglass electrical cells were imbedded in the peat storage piles at both Evansburg and Mildred Lake. Since installation, periodic measurements of temperature and moisture levels have been recorded with a portable soil-moisture temperature meter.

At Evansburg, four sets of cells were installed. On the peat pile, sets were located vertically on the crown position, on the north- and south-facing slopes. In addition, a set of cells was installed in an undisturbed tree-covered location adjacent to the pile. The placement depths of the cells were 50 cm, 100 cm, and 200 cm. A reading was also recorded by hand thermometer at 7 cm and 20 cm.

At the Mildred Lake site, the cells were located at four different locations in the stored material area. Measurements were recorded for depths of 7 cm, 20 cm, 50 cm, 100 cm, and 140 cm. As at Evansburg, a set was also installed in an undisturbed, tree-covered, organic soil area.

6.1.1.2 Results. Figure 12 shows the temperature fluctuations that occurred on the north-facing slope of the Evansburg peat pile for the period October 1976 to November 1978. Figure 13 shows similar information for one of the locations at the Mildred Lake site for the period October 1976 to December 1977.

The development of soil microorganisms is influenced by temperature and moisture. Some microorganisms can survive under low temperature and high moisture content. Flanagan and Scarborough (1974) have pointed out that cellulolytic fungi can survive in a wide range of temperatures down to $-7^{o}C$; some have an optimum cellulase activity at 6^{o} to $8^{o}C$. At these temperatures, however, most of the other enzyme systems do not function well; therefore, in those portions of the peat piles with relatively low temperatures, the cellulolytic organisms may be the most active decomposers. Christensen and Cook (1970) found nearly 10^{7} aerobic bacteria per gram dry peat in some Alberta organic soils. In deeper layers of Mesisols and Humisols, up to 10^{7} psychrophiles, 1.2×10^{7} mesophiles, and 7.5×10^{4} thermophiles were found.

There are optimum temperature and moisture levels for microbial activity. Kononova (1961) suggested that the most active role in the transformation of organic substances belongs to mesophilic microorganisms which develop at about 20^{o} to $30^{o}C$. Flanagan and Veum (1974) suggest that the optimum moisture range for development of microorganisms is 120 to 400% and the optimum temperature approximately 23^{o} to $28^{o}C$. They have also pointed out that moisture levels in excess of 300% depress microorganism respiration rates. However, the moisture regime which begins to attenuate the respiration rate differs for varying temperatures. At lower temperatures (0^{o} to $5^{o}C$), high moisture levels do not exert a depressing effect.

The intensities of microbiological activity given in this report are based on the scale suggested by Kononova (1961) and shown in Table 11.

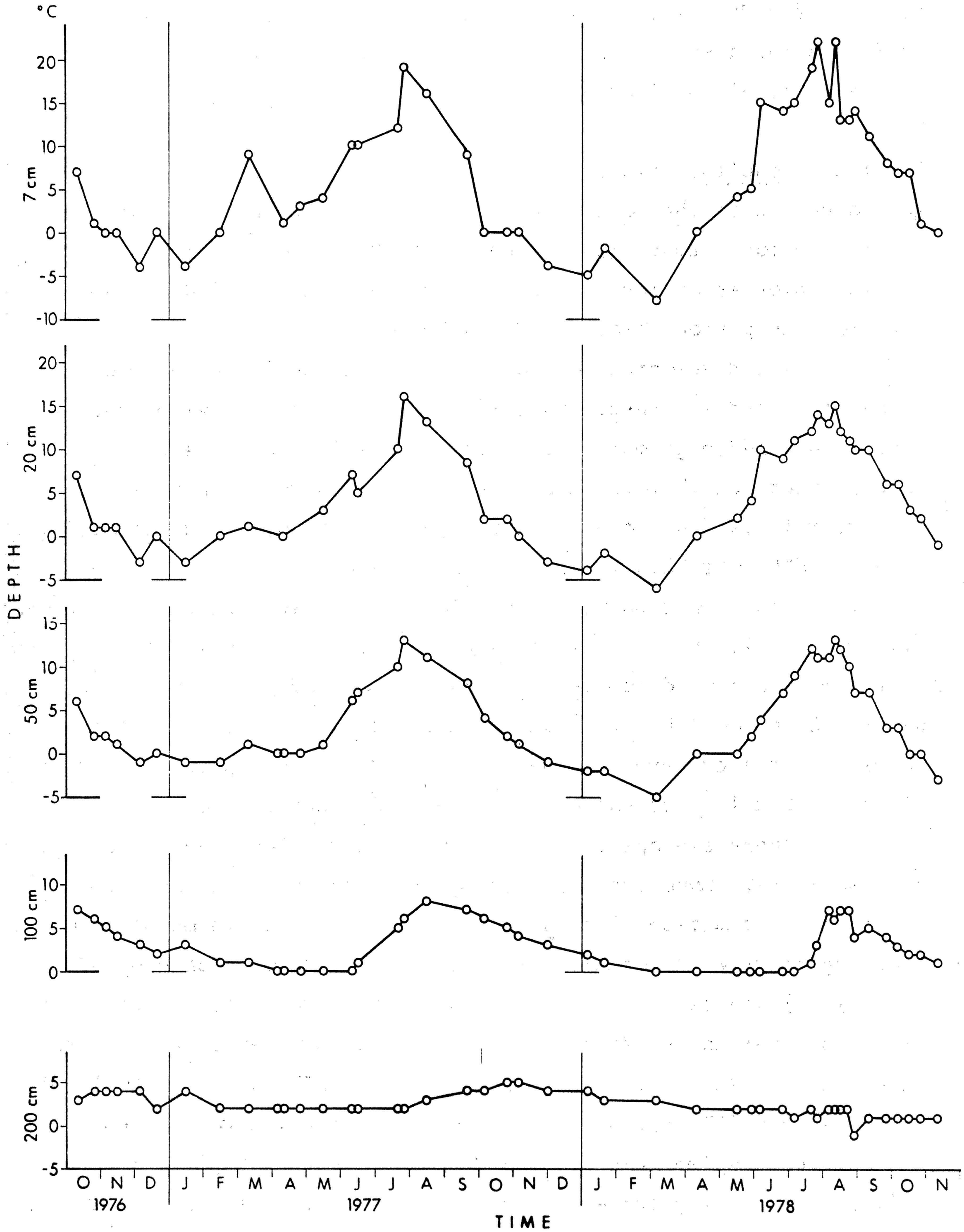

Figure 12. Temperature regime in the Evansburg peat pile.

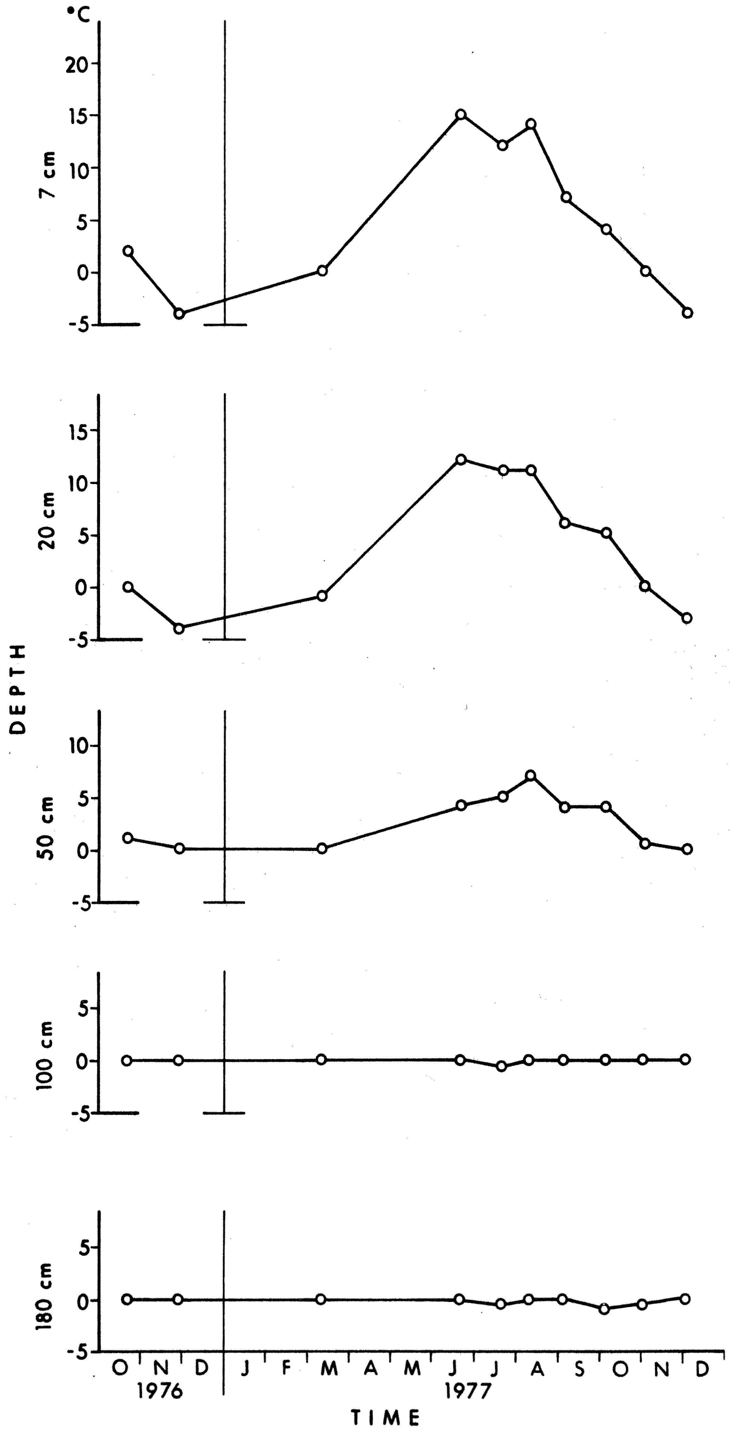

Figure 13. Temperature regime in the Mildred Lake stored materials.

Table 11. Effect of temperature and moisture on the possible intensity of microbiological activity.

Temperature (^{o}C)	Moisture (%) based on dry wt.	Moisture (%) based on wet wt.	Possible intensity of microbiological activity
>30	>400	>80	Weak
30 to 20	400 to 150	80 to 60	Very intensive
20 to 10	150 to 67	60 to 40	Fairly intensive
10 to 5	67 to 25	40 to 20	Weak
<5	<25	<20	Very weak

At Evansburg, the near surface 7 cm layer was above 10^{o}C for about 97 days in 1977 and 106 days in 1978; at the 20 cm depth the data indicate 51 and 71 days; at 50 cm, 41 and 44 days; but at 100 cm and 200 cm the temperature did not reach 10^{o}C at any time.

At the Mildred Lake storage site, the data for 1977 indicate that the surface 7 cm layer was above 10^{o}C for about 101 days; at 20 cm about 71 days; at 50 cm and lower the temperature remained below 10^{o}C for the entire period.

In general, the data for the two sites are somewhat similar and indicate that optimum temperature conditions for microbial activity is restricted in terms of depth to the near-surface layers and does not extend much below 20 to 50 cm. Similar results were found by Christensen and Cook (1970).

The temperature regime in an undisturbed site at Evansburg is shown in Figure 14. The optimum temperature for microbial activity was of shorter duration in the undisturbed site than on the peat pile. This is probably due in part to the shading effect produced by the relatively dense stand of black spruce that covers the site. The above 10^{o}C periods for the various depths were as follows: 7 cm, 68 days in 1977 and 70 days in 1978; 20 cm, 33 days in 1977 and 22 days in 1978; 50 cm, 61 days in 1977 and 0 days in 1978. At the 100 cm and 200 cm depths, the temperature did not reach the optimum for microbial activity at any time of the year.

It is interesting to note that, in the undisturbed site at Evansburg, the surface 7 cm layer was frozen from early November until late February in 1977 and from late October until mid-April in 1978. At the same time, the data indicate that the peat in the undisturbed site during the two years of observation did not generally freeze below the 50 cm level.

Data for the undisturbed Mildred Lake site are shown in Figure 15. The annual temperature trend recorded at this site for 1977 is similar to that at Evansburg. Optimum temperature for microbial activity occurred during the summer months near the surface but at depths of 50 cm and greater the temperature was below the suggested

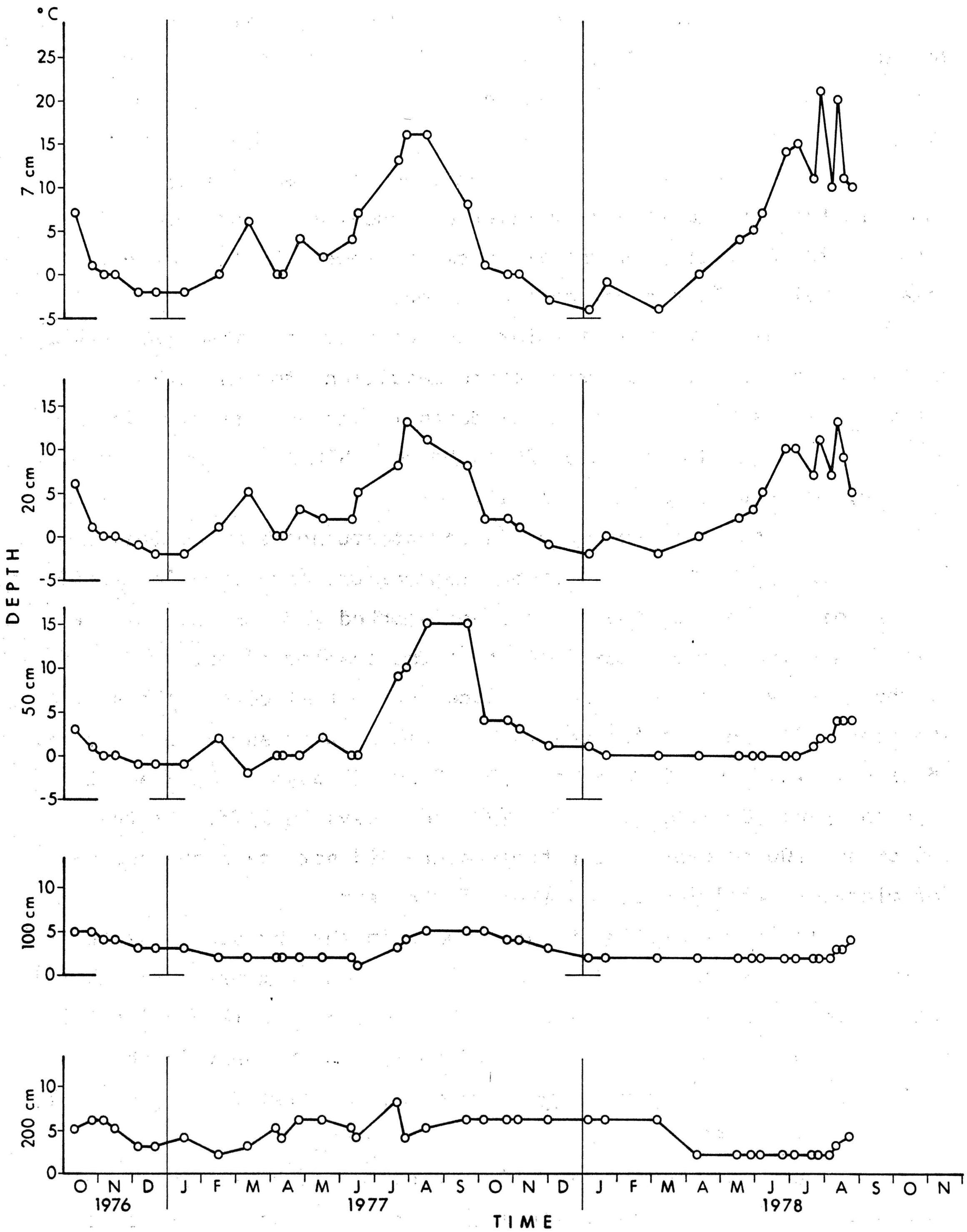

Figure 14. Temperature regime in the Evansburg undisturbed peat site.

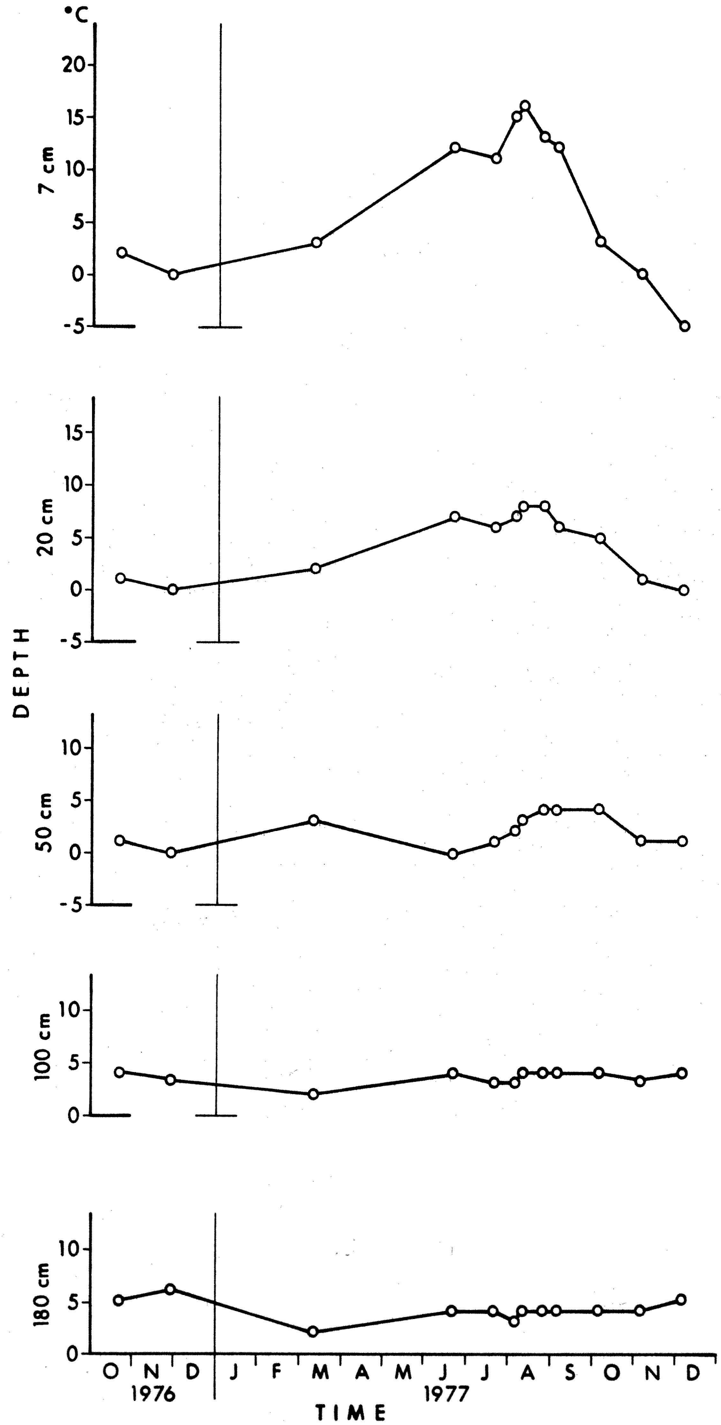

Figure 15. Temperature regime in the Mildred Lake undisturbed peat site.

$10^{o}C$ optimum level. As at Evansburg, the depth of winter freeze appears to extend to about 50 cm from the surface but below this depth the peat remains unfrozen.

In August 1978, a set of fibreglass cells was imbedded in a 9-year old peat pile near the research site at Evansburg. The purpose of this work was to determine whether or not the temperature regime in a stored peat pile will change significantly with time. The cells were located at five depths: 20 cm, 50 cm, 100 cm, 200 cm, and 300 cm. The surface temperature at 7 cm was recorded with a hand thermometer. A comparison of the data at the two sites, that is the 9-year old peat pile with that of the pile constructed in 1976, indicated that the temperature of the peat at comparable depths is similar for the two sites. For example, at the 20 cm depth in August the temperature at both sites was $15^{o}C$ and at 200 cm the temperature was $5^{o}C$ at the old peat pile and $2^{o}C$ at the site established in 1976. For the short period of August to November 1978, the shape and slope of the temperature curves for both sites are similar. These data would suggest that the temperature in the surface and subsurface of the piles does not increase significantly with time as a result of microbial activity. It should be pointed out, however, that the data recorded at the 9-year old peat pile are for a comparatively short period of only four months.

In general, for the reporting period, it would appear that the temperatures at the 7 cm and 20 cm depth at Evansburg and Mildred Lake are suitable for fairly intensive microbial activity during the summer months but at depths of 50 cm or greater the temperature of $10^{o}C$ above which fairly intensive activity occurs, as suggested by Kononova (1961), does not occur or it is of extremely short duration.

Moisture measurements in the stored peat were recorded at times when the temperature was above freezing. Therefore, the results reported herein for surface layers are only for the period June to November.

Data for the Evansburg site are shown in Figure 16 and for the Mildred Lake site in Figure 17. Using the criteria outlined by Kononova (1961), it would appear that the optimum moisture levels

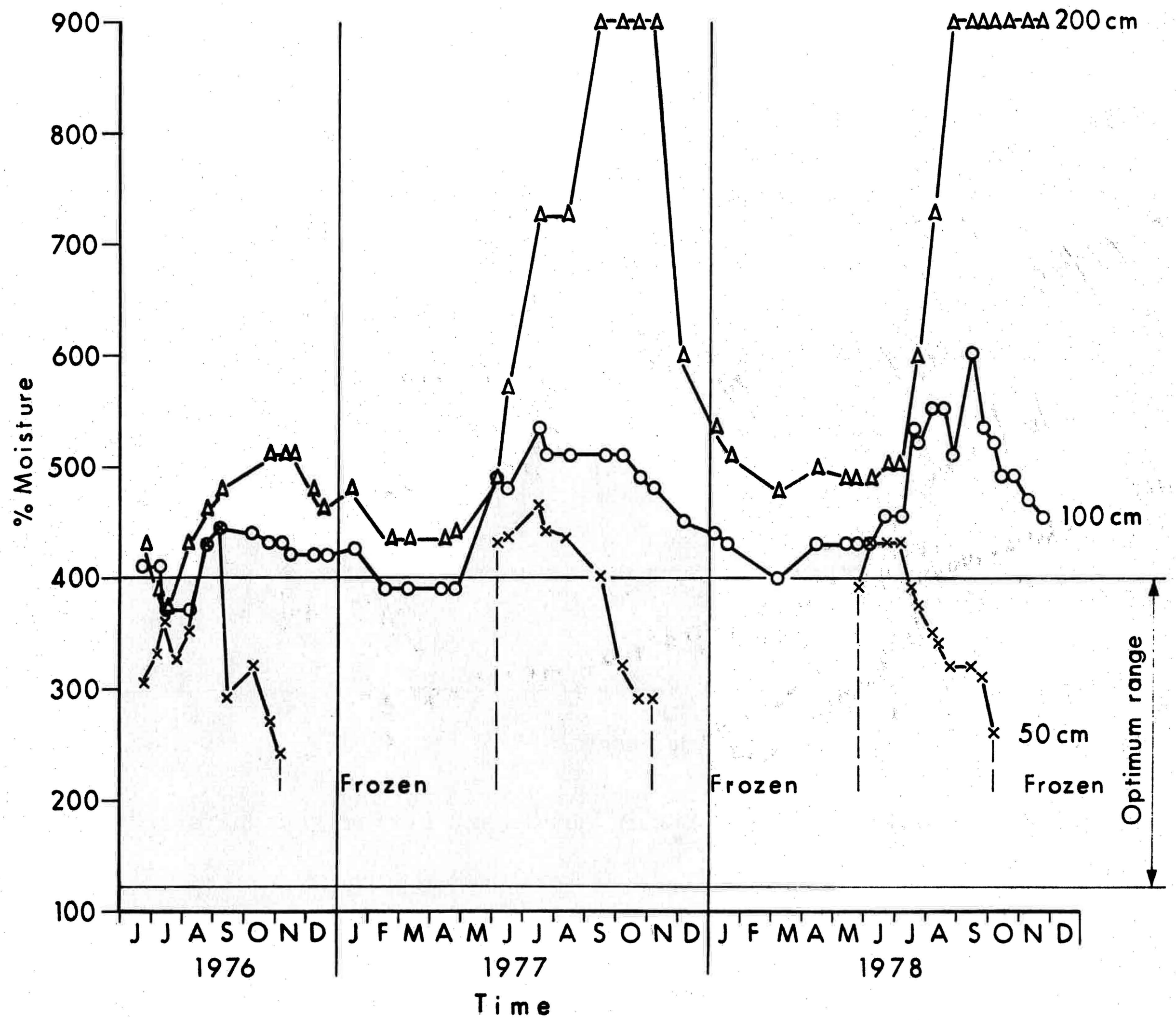

Figure 16. Moisture regime in the Evansburg peat pile.

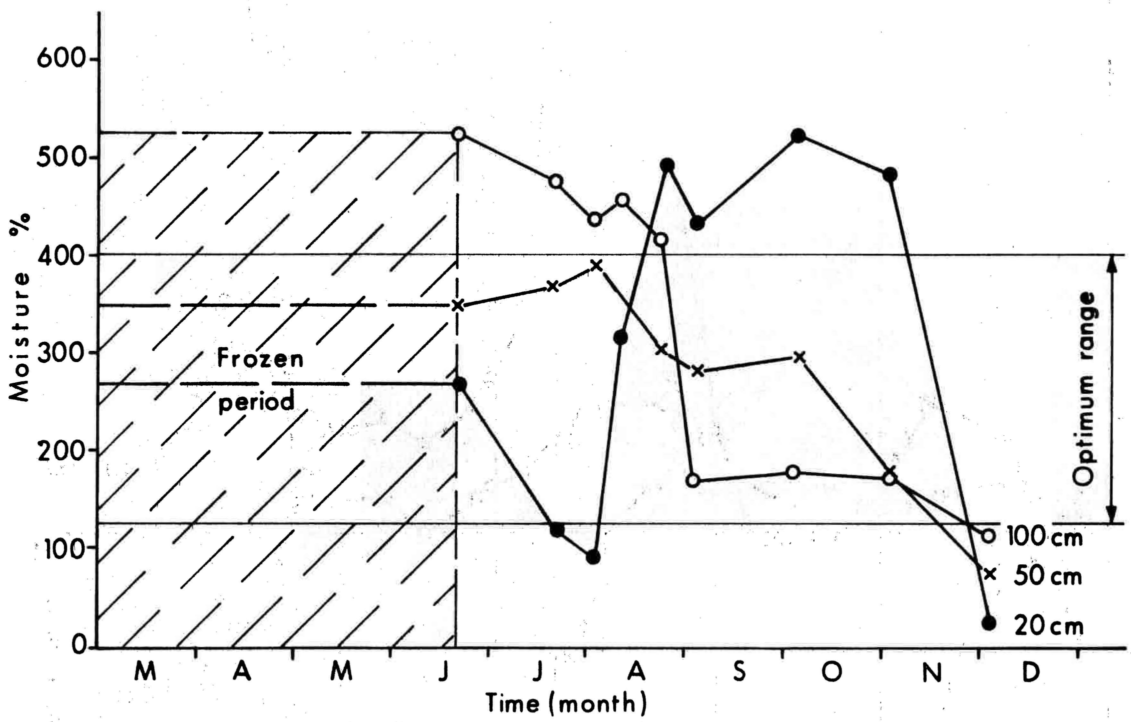

Figure 17. Moisture regime in the Mildred Lake stored peat materials.

at the 50 cm depth at Evansburg occur during the spring and fall. During the summer periods of 1977 and 1978, the moisture content was somewhat above the optimum of 120 to 400%. Moisture contents during summer 1976 were only slightly above optimum. In general, at the 100 cm and 200 cm depths the moisture content is above 400% for most of the year suggesting that optimum moisture conditions for microbial activity do not occur at these particular depths in the Evansburg storage pile.

At the Mildred Lake storage site, the optimum moisture content for microbial activity appears to extend from mid-June until late November at the 50 cm depth, but, at the 20 cm depth, the moisture content is somewhat above the optimum from August to October and at the 100 cm depth from mid-June until mid-August.

The obvious high moisture level at the 200 cm depth at the Evansburg site in both 1977 and 1978 is attributed to the upward movement of surface water from the surrounding area. It does not appear, however, to have reached the 100 cm depth at this site.

Direct comparison of conditions at Evansburg and Mildred Lake may not be meaningful. At Evansburg the stored material is essentially "pure" peat whereas at Mildred Lake the material is a heterogeneous mixture of peat and mineral material. The organic carbon content of the material at Mildred Lake ranges from 2% to 37% whereas at Evansburg the more homogeneous material has an organic C content close to 44% throughout the pile.

The amount of mineral material no doubt drastically affects the microbiological activity. Flanagan and Veum (1974) reported that the respiration rate of microorganisms in a bog with 39% organic carbon content was not limited until a moisture content of 500% was reached at a temperature of 19.5°C. At the same temperature and moisture, the respiration rate was reduced by 70% in an upland tundra soil where the organic matter content was 7.6%. This suggests that, in peat soils, with relatively high organic matter content, the microorganisms are able to tolerate a much higher moisture content than in mineral soils. The pure peat piles at the Evansburg site, therefore, may be expected to have relatively high respiration rates in comparison to the mixed peat and mineral materials in the Mildred Lake piles. At the 50 cm depths where moisture conditions were optimum over much of the summer period in both Evansburg and Mildred Lake storage piles, the opposite situation occurred. Due to possible overriding factors such as vegetative cover and fertilization on the Mildred Lake pile, it is not possible to determine whether the above observations apply to stored peats.

6.1.2 Cellulolytic Activity in Stored Peat Material

The peat piles at Mildred Lake and Evansburg differ in storage conditions and material properties such as proportion of mineral constituents, application of fertilizers, presence of vegetative cover, and drainage characteristics. Decomposition rates of the organic material could also differ. Filter paper discs were embedded in the storage piles in order to obtain some estimate of cellulose loss and to relate degree of decomposition to these factors.

6.1.2.1 Material and methods. At the Mildred Lake site, filter paper was buried in the stored material and in an undisturbed site at depths of 20 cm and 50 cm from the surface. At Evansburg, the filter paper was buried in a 9-year old storage pile and in a 2-year old storage pile on both south- and north-facing exposures. In the older pile, the filter paper discs were placed at a number of depths from the surface to 525 cm (below the base of the pile) and in the younger pile from 25 to 300 cm from the surface.

The filter paper was left for one year at each site and then removed to determine the degree of decomposition by loss in weight.

6.1.2.2 Results. In the Mildred Lake storage pile, the decomposition was greater near the surface than at depth. At the 20 cm depth, the weight loss was 46% as compared to 34% at the 50 cm depth. The greater degree of decomposition near the surface is attributed to aerobic conditions, higher temperatures, and to the application of fertilizer which would stimulate microbiological activity. By comparison, there was little evidence of filter paper decomposition in the undisturbed site. A few brown spots developed on the filter paper, probably as a result of fungal activity, but the weight loss did not exceed 4%. The microbiological activity at this site was not intensive, probably because of low mineral nutrient content and anaerobic conditions resulting from a high water table.

At the Evansburg sites, the results are extremely variable. It would appear that there was little difference between the decomposition rates on the north- and south-facing exposures of either of the peat storage piles. However, there was a noticeable difference in the degree of decomposition of the filter paper between the two storage piles.

In the older pile, the paper was 99% decomposed in the upper 200 cm but, below this depth, there was relatively little decomposition. At the 450 cm depth, for example, the loss in weight was only 3% on the south exposure and 2% on the north.

By comparison, the maximum degree of decomposition in the new pile was 30% at the 125 cm depth. Below and above this depth, the weight loss of the filter paper ranged from about 9% at 25 cm to 13% at 225 cm to between 0 and 7% at the 300 cm depth.

It would appear that the relatively low cellulose decomposition rates at the lower levels of both piles may be attributed to the upward movement of moisture from the water table. It is shown in Figure 16 that during the summer months the moisture content at the 200 cm depth in the younger peat pile is near 900%. This is somewhat higher than the optimum moisture content for microbiological activity. At the same time the temperature in the lower level of the pile (200 cm) did not rise above 5°C which is below the optimum for microbiological activity.

In regard to the high rate of decomposition found in the upper 200 cm of the older peat pile, it is suggested that this is a result of optimum temperature and moisture conditions for microbial activity. At the same time, it has been noted that the peat material originally used for construction of this pile was fairly well decomposed and probably fairly active microbiologically from the time of its placement. Perhaps the nutrient release from the decomposition of this mesic peat is sufficient to stimulate microbiological activity particularly where temperature and moisture conditions are optimum.

These results suggest that, if storage piles are established in low-lying areas with free water or high water tables, decomposition of peat will be slower than if piles are established on well-drained land. Both temperature and moisture conditions would be unsuitable for microbial activity under the wetter conditions.

6.1.3 Soil Respiration Study of Stored and Undisturbed Peat

6.1.3.1 Materials and methods. Soil respiration rate was determined by estimating the CO_2 evolution under field conditions. Measurements were made on samples from a near-surface layer (10 to 20 cm) and from a subsurface layer at 40 cm. The method used is essentially the same as described in Section 9.1. However, instead of using a constant temperature incubator, CO_2 was collected over a 24-hour period in the field when the temperature ranged from 7^{o} to $12^{o}C$.

6.1.3.2 Results. At the Mildred Lake storage site, the mean respiration rate near the surface was lower than in the subsurface layers (Table 12). Rates in the surface layers of the Evansburg peat piles were relatively low (Table 13). At the undisturbed sites, the respiration rates varied with the type of peat. Evolution of CO_2 from fibric peat at Mildred Lake was relatively high in the surface layer as compared to the subsurface layer.

In mesic peat at Mildred Lake and at Evansburg, respiration rates were higher in the subsurface than in the surface layers.

Because respiration rate is affected by a number of environmental factors which may have differed among sites and between layers, results may not be comparable. Some of these factors are: temperature, water content of the peat, addition of nutrient fertilizers,

Table 12. Respiration rates in Mildred Lake peat storage piles and undisturbed peat sites.

Respiration rate based on	Stored Site No. 1		Stored Site No. 2		Undisturbed Peat Site			
					Fibric Moss		Mesic Moss	
	Surface	Subsurface	Surface	Subsurface	Surface	Subsurface	Surface	Subsurface
CO_2 mg/g C/day	1.04	2.06	2.04	2.40	2.47	1.31	0.88	1.22
	±0.13	±0.36	±0.33	±0.39	±0.24	±0.10	±0.11	±0.18

Results are means ± standard error of 25 measurements in stored material, and 12 in undisturbed material.

Table 13. Respiration rates in Evansburg peat storage piles and undisturbed peat sites.

Respiration rate based on	Undisturbed Peat Site		Peat Pile	
	Surface	Subsurface	Site No. 1	Site No. 2
CO_2 mg/g C/day	0.59 ±0.15	1.72 ±0.16	0.53 ±0.04	0.32 ±0.03

Results are means ± standard error of 25 measurements in stored material and 12 in undisturbed material.

plant root density in different layers, plant cover density which determines the amount of solar energy reaching the ground surface, proportion of inorganic material in stored peats, and physical condition of peat as affected by freezing, thawing, and desiccation in surface layers.

A drawback of the method of CO_2 measurement concerns the removal of a sample from a subsurface layer in which the environment is relatively anaerobic. When the sample is exposed to air, the increased oxygen supply could result in a rapid increase in microbial activity. The data should be interpreted, therefore, in terms of indicating the general level of respiration at these sites. These rates are high in comparison to rates measured for peat samples in the laboratory under optimum conditions (Section 5.2.3), and for data reported in the literature for CO_2 evolution from relatively pure peats (Table 8).

The rate of decomposition of stored and undisturbed peat material was estimated from the loss of carbon as CO_2. The calculation was based on the time periods for which the temperature was optimum for microbiological activity. Although maximum activity occurs above $10^\circ C$, according to Kononova (1961), it is assumed that decomposition does take place at lower temperatures and an estimate of decomposition for the time when temperature was above $5^\circ C$ has also been calculated. The annual loss of carbon was calculated by multiplying the number of days the temperature was above $10^\circ C$ or $5^\circ C$ (Figures 12 to 15) by the respiration rate as determined in the field (Tables 12 and 13). An example is:

$$\frac{2.0 \text{ mg } CO_2/\text{g C/day} \times 101 \text{ days}}{1000 \text{ mg/g}} \times \frac{12}{44} \times 100 = 5.6\%$$

The estimated loss of carbon annually is summarized in Table 14. The stored material at the Mildred Lake site had the highest decomposition rate of all the sites examined. At Mildred Lake the decomposition was noticeably higher at the surface than in the subsurface. Also it is apparent that the decomposition is considerably higher in the stored material than in an adjacent undisturbed site.

Table 14. An estimate of carbon loss in stored peat material at the Mildred Lake and Evansburg sites.

Site and Depth	% Carbon Lost Annually			
	Stored Pile		Undisturbed Site	
	T>10°C	T>5°C	T>10°C	T>5°C
Mildred Lake				
7 cm	5.6	9.1	2.6	4.3
20 cm	4.0	9.1	0	3.3
50 cm	0	2.6	0	0
Evansburg				
7 cm	1.4	1.8	1.1	1.8
20 cm	0.7	1.5	0.5	1.7
50 cm	ND	ND	2.9	4.3

This is attributed to the inclusion of mineral material and the application of nitrogen fertilizer to the stored material. Fertilizer would have the effect of stimulating microbial activity particularly at the surface where it is applied. Also the mineral material (sand, silt, and clay) that comprises a substantial part of the stored material at Mildred Lake may also affect the rate of decomposition since it raised the pH and provided a supply of nutrient minerals such as calcium and potassium.

At Evansburg, where no fertilizer was applied and where no mineral material was incorporated, the decomposition rate is much lower than at Mildred Lake. However, it is noted that the rate of decomposition is highest near the surface and decreases with depth. This apparently is in contradiction to the relatively homogeneous distribution of bacteria in these peat piles (Section 9.3) and no reason for this has been determined.

One exception occurred in the undisturbed Evansburg site where an abnormally high respiration rate was calculated at the 50 cm depth. This result is perhaps in error since the temperatures recorded from July to September of 1977 are considered to be questionable.

It would appear from the data that pure stored peat will decompose at a relatively slow rate as compared to mixed organic-mineral material to which nitrogeneous fertilizers have been added. It is interesting to note that, at both Mildred Lake and Evansburg, the rate of decomposition was higher in the disturbed material (stored) than in the adjacent undisturbed sites.

The long-term effect of decomposition on the properties of peat as a reclamation amendment remains speculative. Decomposition will not be beneficial in that a decrease in fiber content and degradation of some physical properties such as pore volume, air capacity, and hydraulic conductivity would result. Logan (1978), however, found that mesic peat was preferable to fibric peat in increasing <u>available</u> water storage of tailings sand. As seen in Section 5.2.4, microbial activity in peat receiving nutrients and an added energy source (such as occurs in the rhizosphere) improved permeability. Although highly decomposed pure peat has a lower permeability than less decomposed pure peat, the same may not hold true for mixtures of peat and mineral materials such as those occurring in storage systems or in reclamation programs in the oil sands area. Indeed, it has frequently been demonstrated that plant residues must decompose in order to have a beneficial effect on structure of mineral soils (McGill and Hoyt 1977). Decomposition would be beneficial, furthermore, in terms of release of plant nutrients which may in the long run reduce the need for fertilizer additions.

6.2 LABORATORY STUDIES

At Mildred Lake the peat storage area consists of a heterogeneous mixture of fibric and mesic moss peat, fen peat, and varying amounts of inorganic material (sand, silt, and clay). Samples were collected to characterize the stored materials and an experiment was designed to compare cellulolytic activities and respiration rates in the different types of organo-mineral material from the storage piles. Physical properties were compared with those of samples collected at Evansburg from peat storage piles of different ages.

6.2.1 Physical and Chemical Properties of Stored Materials at Mildred Lake

6.2.1.1 Materials and methods. In the summer of 1976, 40 samples were taken randomly at the surface (10 cm) and subsurface (40 cm) across the storage area at Mildred Lake. Ninety-six more samples were taken during summer, 1977. These samples were passed through a 5 mm sieve in fresh condition. Half of each sample was air-dried and ground to pass a 2 mm sieve for chemical and physical analyses (Section 9.1) and particle size determinations (McKeague 1978). Differentiation between surface and subsurface samples was not made for the various analyses except as indicated in the results section.

6.2.1.2 Results. The samples obtained from the Mildred Lake storage area were extremely variable in terms of organic matter and mineral content. Based on particle size distribution and organic matter content, the samples were placed in one of four groups for comparison purposes. The criteria used for establishing the groups are shown in Table 15.

Based on criteria from Table 14, 18 samples were placed in group I, 44 in group II, 18 in group III, and 56 in group IV. The proportions of organic and mineral components in the four groups are given in Table 16.

Analysis of the 40 samples collected in 1977 showed that the group I (peat predominant) material was highest in C, N, CEC, exchangeable Ca^{++} and Mg^{++}, and bitumen (Table 17). The materials in group IV (peat-sand mixture) were next highest in these properties. The 15 to 16% carbon associated with the mineral material, which was predominantly fine sand, was about half the level of group I. The C and N contents of the 96 samples collected in 1977 are presented in Section 9.4.

Group III (sand-clay mixture) and group II (sand predominant) materials were very low in carbon content, not exceeding 4.5%. Exchangeable Na^{+} and K^{+}, and extractable P were highest in group III. Group II and III materials were also highest in pH. However, even the pH of the peat predominant group I material was somewhat higher than that of undisturbed fibric and mesic peat (Table 3, Section 4.2.3).

The wide differences in organic-mineral proportions and in chemical properties demonstrate the extremely heterogeneous nature of the stored materials at Mildred Lake. Visual examination of the storage piles showed that mineral materials included a wide range of particle sizes larger than sand (2 mm) and that some of the particles were of limestone origin. The relatively high pH levels and the excess of exchangeable cations over that of total CEC is likely a result of the presence of carbonate minerals. This admixture of materials thus has somewhat different chemical properties from undisturbed peat and likely has different physical and biological properties as well.

Table 15. Classification of stored material at Mildred Lake

Group	Material	Description
I	Peat Predominant	Organic matter >40%
II	Sand Predominant	Organic matter <15%
		Sand and silt >75%
III	Sand-clay mixture	Organic matter <13%
		Sand and Silt >30%
		Clay >20%
IV	Peat-sand mixture	Organic matter >17%
		Mineral material <83%

Table 16. Organic and mineral components of the four designated categories of stored material.

Stored Material	Organic Matter(%)	Mineral Material(%)		
		Sand	Silt	Clay
Group I	50.2 ± 1.8	17.9 ± 3.3	23.2 ± 2.6	8.7 ± 1.5
Group II	9.2 ± 0.6	60.9 ± 1.7	19.7 ± 1.2	10.1 ± 0.6
Group III	10.4 ± 1.7	29.1 ± 4.9	30.2 ± 2.3	31.4 ± 3.9
Group IV	28.2 ± 1.8	38.0 ± 2.2	26.0 ± 1.4	11.0 ± 0.6

Results are means ± standard error of the means for 18 samples in group I, 44 in group II, 18 in group III, and 56 in group IV.

Table 17. Chemical properties of the four categories of stored materials collected in 1976.

Property	Stored Peat Material			
	Group I	Group II	Group III	Group IV
pH (H_2O)	6.2 ± 0.3	6.7 ± 0.2	7.1 ± 0.1	6.4 ± 0.2
Exch. Cations[a] (meq/100g)				
Na	2.4 ± 0.9	0.4 ± 0.1	3.0 ± 0.9	0.9 ± 0.4
K	0.4 ± 0.1	0.1 ± 0.0	0.8 ± 0.2	0.1 ± 0.0
Ca	95 ± 17	28 ± 5	27 ± 3	76 ± 10
Mg	22.0 ± 2.7	4.4 ± 0.5	12.4 ± 2.3	12.0 ± 1.3
CEC (meq/100g)	121 ± 12	23 ± 5	39 ± 4	76 ± 6
Base Sat. (%)	98 ± 5	100	100	100
C (%)	31.8 ± 1.8	4.5 ± 0.7	4.5 ± 1.0	15.5 ± 1.0
N (%)	2.3 ± 0.3	0.5 ± 0.1	0.4 ± 0.1	1.3 ± 0.1
C/N	15.8 ± 2.8	12.5 ± 1.6	11.3 ± 1.0	13.8 ± 1.4
P_2O_5 (ppm)	13.0 ± 2.1	9.3 ± 1.0	29.3 ± 8.4	7.7 ± 0.5
Bitumen (%)	1.6 ± 0.3	0.7 ± 0.2	0.3 ± 0.0	0.8 ± 0.1
Ash (%)	30 ± 3	89 ± 2	87 ± 1	67 ± 2

Results are means ± standard error of means for 7 samples in group I, 13 samples in group II, 6 samples in group III, and 14 samples in group IV.

[a] Exchangeable cations - NH_4 Acetate extractable.

The CEC of the stored materials was strongly related to the C content. About 78% of the variability in CEC can be accounted for by the C content of stored material (Figure 18). Clay content would be expected to affect the CEC, but this apparently is not the case with these materials. The multiple regression of CEC on clay and C was calculated as CEC (meq/100 g) = 10.05 + 3.55 (%C) + 0.277) (% clay). The standard error of the estimate is 19.2 meq/100 g which is only slightly lower than that obtained using %C alone. The clay content ranged from 2 to 47%. The correlation of CEC with % clay was not significant at 95% level.

Physical properties of samples collected in 1977 from the Mildred Lake storage piles were compared after calculating means, standard error, and F ratios (Table 18).

The peat predominant group (group I) is most similar to pure peat (Section 4.2.1) but is somewhat higher in ash content, specific gravity, and bulk density. Groups II, III, and IV are predominantly mineral as reflected by ash content.

Pore volume is an important physical property affecting the hydrologic characteristics of organic soils and stored peat. Puustjarvi (1968) noted that pore size distribution was more significant than pore volume in determining the amount of water retained by non-saturated peat. Excess water is easily drained through the larger pores in peat. Air replaces the water in large pores, thus providing oxygen required by plant roots. Small, continuous pores are important in conducting and storing water, thus ensuring the availability of water for plants.

The physical properties of mineral soils can be improved considerably by mixing with peat (Van Dijk et al. 1968); in a clay soil, pore volume increased by 1.8%, the water volume 0.5%, and air content 1.3 volume % for every 1% increase in organic matter content. The proportions of mineral constituents in the peat storage piles are therefore important in determining the suitability of this material for improving soil physical conditions in reclamation situations.

The pore volume of the stored materials at Mildred Lake was larger in groups I and IV, which contain relatively high amounts

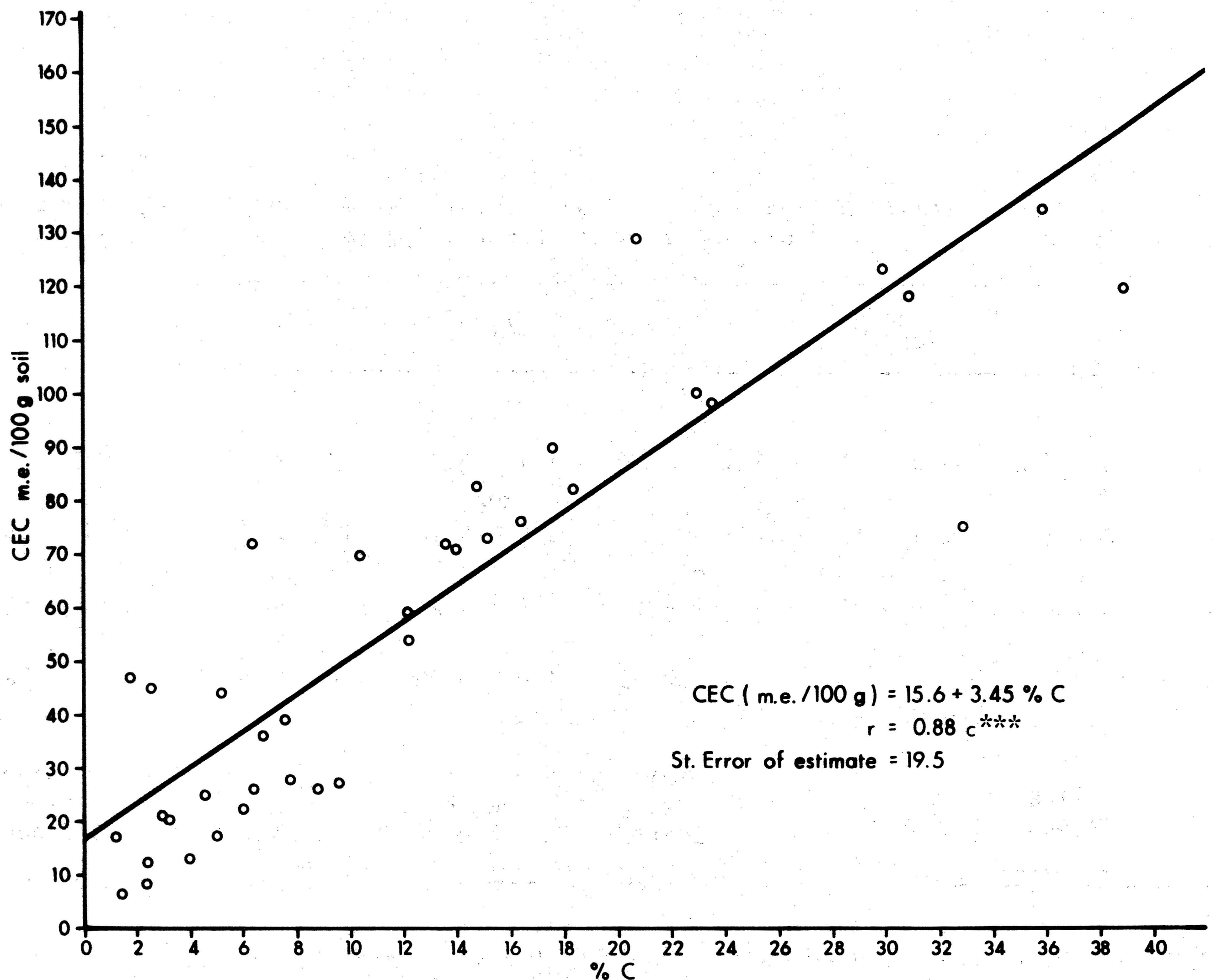

Figure 18. Relationship between cation exchange capacity (CEC) and the total carbon content in stored peat material (*** p<0.001).

Table 18. A comparison of physical properties of four designated categories of stored peat material from Mildred Lake.

Stored Peat Material	Specific Gravity (g/cc)	Bulk Density (g/cc)	Pore Volume (%)	Water Capacity (%)	Air Capacity (%)	Void Ratio	Ash (%)
Group I	1.83 ± 0.06 a	0.24 ± 0.02 a	86.6 ± 0.1 a	76.8 ± 2.3 a	9.8 ± 1.9 a	6.7 ± 0.6 a	42.7 ± 3.3 a
Group II	2.45 ± 0.02 b	0.77 ± 0.06 b	68.6 ± 2.1 b	61.6 ± 1.7 b	7.0 ± 0.8 a	2.7 ± 0.7 b	86.2 ± 0.9 b
Group III	2.29 ± 0.09 bc	0.67 ± 0.11 bc	71.4 ± 3.7 bc	63.3 ± 3.7 bc	8.1 ± 1.8 a	3.1 ± 0.6 b	77.2 ± 4.5 b
Group IV	2.19 ± 0.03 c	0.52 ± 0.03 c	76.5 ± 1.1 c	69.8 ± 1.2 ac	6.7 ± 0.9 a	3.5 ± 0.2 b	68.2 ± 1.8 c
F ratio	39.30*	11.81*	10.17*	9.65*	0.52^{ns}	13.81*	49.61*

Results are means ± standard errors of 8, 27, 8 and 36 samples for groups I, II, III, and IV respectively. Means in the same column followed by the same letter are not significantly different at the 95% level.

ns = not significant at 95% level.

* = p <0.001.

of organic matter, than in the mineral groups II and III. The pore volume was highly correlated with water capacity (Section 6.2.5). This would reflect a large proportion of relatively small pores in the peat. Therefore, the water retention in groups I and IV is much higher than in groups II and III and is more favourable in terms of improving water storage capacity in relcamation situations because of their higher organic matter contents.

Bulk density can be used as a measure of the mineral and organic content in test samples and also for predicting their physical and chemical properties. For instance, Flint and Gersper (1974) indicated that the bulk density is closely related to thermal and hydraulic conductivities and to nutrient concentrations of organic soils. In this investigation bulk density was negatively significantly correlated with pore volume, water capacity, and nitrogen contents of the stored materials (Section 6.2.6). Higher bulk densities in groups II and III of the stored materials therefore indicate lower values for these properties in comparison to the peat predominant groups I and IV. Note, however, that the negative correlation between bulk density and nitrogen should not be confused with the positive correlation generally obtained for peats, since the nitrogen is normally expressed on an ash-free basis in those cases (Walmsley 1977).

Determinations of ash content and bulk density are simple procedures and could, therefore, be useful for general characterization of peat in storage piles. Other physical and chemical properties of stored peat could then be approximated by use of correlations presented in this report and in the literature (Radforth and Brawner 1977; MacFarlane 1979).

6.2.2 A Comparison of the Physical Properties of Stored Peat for Two Different Time Periods at Evansburg

6.2.2.1 Materials and methods. In 1978, samples were obtained from two storage areas at the Evansburg research site. At one location the peat had been piled or stored for nine years while at the other site the peat had been stored for two years. A total of 36 samples were collected from depths of 20 cm, 100 cm, and 200 cm below the surface. In addition, 12 samples were collected from an undisturbed organic soil area at the site.

Complete factorial analyses of the laboratory results were carried out to determine the variance in physical properties of the stored material in accordance with the length of the storage period. The analyses carried out included: bulk density, pore volume, water capacity, and air capacity. The methods of analyses are described by Puustjarvi (1968) and presented in Section 9.1.

6.2.2.2 Results. The physical properties of the stored 9-year old peat, 2-year old peat, and undisturbed peat are compared in Tables 19 and 20. At the near surface 20 cm depth, the bulk density remained essentially unchanged for the 2-year old and 9-year old peats. In the subsurface layers (100 and 200 cm), the 2-year old peat showed a (statistically) significantly higher bulk density than the 9-year old peat. However, in absolute terms, the range in bulk densities at all depths was only 0.10 to 0.12, and both peat piles can therefore be considered to be basically similar throughout. The bulk densities of undisturbed peat were lower than all of those measured in the peat piles.

The air capacity in the surface layer of the old peat pile was significantly higher than that of the new peat pile and the undisturbed peat. Possibly the air capacity has increased as a result of the greater number of freeze-thaw and wetting-drying cycles as compared to the new peat. The laboratory studies (Section 5.2.1) showed that these treatments increased air capacity in mesic and fen peat more than in fibric peat.

Van Dijk and Boekel (1965) suggest that freezing results in a distinct increase in air capacity and also an apparent decrease in the degree of decomposition.

In studying the physical properties of peat in relation to its use as a reclamation amendment, air capacity is perhaps one of the most important factors to be considered. Olsen (1968) pointed

Table 19. A comparison of the physical properties within peat piles stored for different time periods at the Evansburg site.

Material	Bulk Density (g/cc)	Pore Volume (%)	Water Capacity (%)	Air Capacity (%)
9-year old peat (OP)				
20 cm	0.113 ± 0.006 a	92.6 ± 0.4 a	66.5 ± 1.3 a	26.1 ± 1.3 a
100 cm	0.097 ± 0.001 a	93.7 ± 0.1 a	75.3 ± 1.0 b	18.4 ± 1.0 b
200 cm	0.105 ± 0.004 a	93.1 ± 0.3 a	83.3 ± 1.5 c	9.8 ± 1.9 c
F ratio	3.33^{ns}	3.35^{ns}	42.27***	35.83***
2-year old peat (NP)				
20 cm	0.107 ± 0.001 a	92.8 ± 0.1 a	75.9 ± 0.5 a	16.9 ± 0.7 a
100 cm	0.117 ± 0.003 ab	92.4 ± 0.2 ab	80.7 ± 0.8 b	11.7 ± 0.9 b
200 cm	0.123 ± 0.002 b	92.0 ± 0.1 b	82.5 ± 0.8 b	9.5 ± 0.8 b
F ratio	10.7**	9.65**	22.67***	25.42***
Undisturbed peat (UP)				
20 cm	0.081 ± 0.004 a	94.6 ± 0.3 a	77.5 ± 1.9 a	17.1 ± 2.1 a
100 cm	0.078 ± 0.005 a	94.8 ± 0.3 a	81.2 ± 1.8 a	13.6 ± 2.0 a
F ratio	0.23^{ns}	0.21^{ns}	1.99^{ns}	0.34^{ns}

Results are means ± standard error of 6 samples for each depth in 2- and 9-year old peat, and 10 samples in undisturbed peat.

Means in the same column followed by the same letter are not significantly different at the 95% level.

**, *** = p <0.01, 0.001, respectively.

ns = not significant.

Table 20. A comparison of physical properties between peat piles stored for different time periods at the Evansburg site.

Material	Bulk Density	Pore Volume	Water Capacity	Air Capacity	Void Ratio
At 20 cm					
OP	a	a	a	a	a
NP	2	a	b	b	a
UP	b	b	b	b	b
F ratio	16.12***	15.03***	19.58***	12.32***	15.54***
At 100 cm					
OP	a	a	a	a	a
NP	b	b	b	b	b
UP	c	c	b	ab	b
F ratio	31.29***	29.88***	6.55**	6.23**	22.06***
At 200 cm					
OP	a	a	a	a	a
NP	b	b	a	a	b
F ratio	13.81**	12.04**	0.21^{ns}	0.06^{ns}	10.78**

Results are means ± standard error of 6 samples for each depth in 2- and 9-year old peat, and 10 samples in undisturbed peat.

Means in the same column followed by the same letter are not significantly different at the 95% level.

**, *** = p <0.01, 0.001, respectively

ns = not significant.

out that, if there is insufficient oxygen within the soil, oxygen-rich minerals such as nitrate and sulphate may be reduced to nitrite and sulphite which are toxic to plants. Also, Puustjarvi (1968) suggested that, to satisfy the oxygen requirement of roots, the air capacity should be at least 30 to 50% in horticultural peat.

The drainage regime of a peat storage pile would be important in controlling the moisture content, biological activity, and changes in physical characteristics of peat over time. In experimenting with sphagnum moss peat, Olsen (1968) found that, when peat had contact with a drainage underlayer (i.e., a porous medium such as sand), the air content increased in comparison to peat in contact with a solid, non-draining layer. An underlayer such as sand permits capillary drainage of water from the peat as well as drainage by gravity from large pores. Peat on material without capillary drainage or on an underlayer which is water-saturated for a long time would be low in oxygen content, particularly if there is a deficiency of macro-pores.

The peat storage piles at Evansburg have water tables just below their bases and therefore lack capillary drainage. It was shown that air capacity at the surface increased with time, likely as a result of air-drying, freezing, and thawing. The potential for decomposition of peat is also higher in the surface layers as indicated by rapid degradation of cellulose discs in the 9-year old pile. The lower layers do not have increased air capacities and decomposition potentials presumably because of high water contents (Section 6.1.1.2) which are maintained by upward movement of water from the water table by capillary pores. If the peat were resting on a porous medium with the water table somewhat below the ground surface, it is likely that desiccation would occur at greater depths, thereby increasing air capacity and potential decomposition. It is difficult to determine, however, whether oxygen exchange between the surface and drained pores deeper within the piles would be rapid, thereby facilitating activities of aerobic decomposers, and if the peat would dry to such an extent as to affect the structure and air capacity.

Because degradation in the interior of a well-drained peat is possible, limited drainage controlled by a high water table, as at the Evansburg site, may be advisable for long-term preservation of peat. With this system, large pores in the upper part of a peat pile drain rapidly, but capillary pores would maintain a moist condition. Air capacity at the surface or just below the surface would increase progressively without extensive deterioration of peat structures by air drying. The overall higher moisture level in the pile would aid stabilization against wind erosion. For short-term storage, a well-drained peat pile may be more suitable. Air capacity, and possibly decomposition, may increase somewhat, but, at the same time, water capacity would not be greatly reduced. The drier material may also be more suitable for handling in reclamation procedures.

6.2.3 Enzyme Activity in Stored Peat Material at Mildred Lake

Measurements of bacterial numbers and respiration rate reflect the general microbial activity in a sample from a peat pile but do not directly show that peat is being decomposed. Determination of cellulose activities is a more direct indication of peat decomposition because actual structural components of peat particles, cellulose, and its derivatives are hydrolyzed by these enzymes. The objectives of this study, then, were to determine cellulolytic enzyme activities in the heterogeneous stored peat materials at the Mildred Lake site and to compare surface, subsurface, and undisturbed samples.

6.2.3.1 Materials and methods. Samples were taken from the peat storage pile at Mildred Lake at depths of 10 to 20 cm and 40 to 50 cm. Forty samples were taken in July 1976, after the storage pile had been sown and fertilized (Section 9.2). Another 96 samples were taken in July 1977, after a second fertilization. The storage pile was revegetated with a thick cover of legumes and grasses by this time. Cellulolytic enzyme activities were determined by methods described in Section 9.1. Total nitrogen was determined by the semimicro Kjeldahl procedure (McKeague 1978). Carbon was determined by dry combustion using a Leco induction furnace.

6.2.3.2 Results. There was no significant difference between the surface (10 to 20 cm) and subsurface (40 to 50 cm) layers sampled in the storage piles in both 1976 and 1977 (Table 21). The activity of each enzyme was generally low. Cellulase (C_1) activity was relatively unchanged in comparing 1976 and 1977 samples. However, Cx activity increased more than twofold from 1976 to 1977 while B-glucosidase activity decreased about twofold. In comparing enzyme activities of stored materials with that of undisturbed peat, C_1 activity is similar in all materials except fen peat in which it is about 50% higher. Cx activities in undisturbed peat are mainly higher than in stored materials and B activity is variable.

In comparing the enzymatic activities among the four groups of stored materials, the groups highest in organic matter content (I and IV) had the highest activities (Table 22). These groups were significantly different from groups II and III in C_1 and Cx activities but not in B-glucosidase activity. An exception to this was Cx activity in 1977 when group I was lower than the other three. Enzyme activities in group I were generally higher than in group IV, with the above exception, but significant differences occurred only in the 1976 Cx activity and 1977 B activity. B-glucosidase activity in 1977 had the highest F value (37.9) which was significant at the 99.5% level. This indicated low variation within each group of stored materials. Activities of C_1 in 1976 and Cx in 1977 had low F values (3.3 and 1.9), indicating wide variation within each group of materials.

There are various factors to consider when comparing enzyme activities between stored material and undisturbed peat, between surface and subsurface materials, between two sampling times, and among the four different groups or materials. Although the enzyme activities were determined under controlled conditions in the laboratory, the data reflect microbial activities under previous environmental conditions in the field as well as those in the laboratory. Among factors to be considered in comparing differences in cellulolytic activity are temperature, moisture content, pH, nutrient

Table 21. Cellulolytic enzyme activities of undisturbed peat and stored materials at Mildred Lake.

Material	pH	C_1	Cx	B
Undisturbed Peat				
Fibric	3.7	0.706	1.253	0.279
Fen	6.6	1.248	1.509	1.250
Mesic	5.9	0.874	1.959	0.415
Stored Material having Fertilizer added (1976)[a]				
Surface	6.5	0.843	0.436	1.025
Subsurface	6.6	0.783	0.491	1.228
Stored Material after Revegetation[a]				
Surface	6.8	0.868	0.940	0.599
Subsurface	6.5	0.816	1.028	0.451

[a] See Section 9.2.

C_1 = mg reducing sugar/g carbon/5 days

Cx = mg reducing sugar/g carbon/24 h

B = mg saligenin/g carbon/3 h

Table 22. A comparison of enzyme activities in four categories of stored peat material sampled in 1976 and 1977.

Stored Peat Material	Enzyme Activity					
	1976 Samples			1977 Samples		
	C_1	Cx	B	C_1	Cx	B
Group I	0.138 b	0.112 a	0.323 a	0.119 a	0.063 a	0.100 a
Group II	0.058 ab	0.017 b	0.056 b	0.056 b	0.081 a	0.035 c
Group III	0.030 a	0.027 a	0.053 b	0.049 b	0.118 a	0.044 bc
Group IV	0.095 b	0.057 ac	0.140 c	0.112 a	0.092 a	0.075 ab
F ratio	3.3*	5.7***	37.9***	7.7***	1.9^{ns}	9.5***

Results are means of 7, 13, 6, and 14 samples for groups I, II, III, and IV respectively in 1976 samples, and means of 11, 31, 12, and 42 samples for groups I to IV in 1977 samples.

Means in the same column followed by the same letter are not significantly different at the 95% level.

*, *** = $p < 0.05$, 0.001, respectively.

C_1 = mg reducing sugar/g dry soil/5 days; Cx = mg reducing sugar/g dry soil/24 h.

B = mg saligenin/g dry soil/3 h.

ns = not significant.

levels (particularly N), substrate levels, presence of other carbohydrates, aeration, and the relative proportion of lignin in the material (Alexander 1977). The effects of temperature and moisture were discussed in earlier sections and it is evident that these may differ between sampling sites and times. The effects of other carbohydrates, lignin, and aeration were not experimentally assessed in this study. Nutrient, substrate, and pH factors are discussed below.

Changes in pH and certain chemical properties such as increased calcium content may alter enzymatic activity in soil. Kuster and Gardiner (1968) suggested that, with liming in sphagnum peat, the composition of the microflora may be changed both quantitatively and qualitatively. A predominantly fungal flora may be replaced by bacteria which are enzymatically different. Kuster and Gardiner (1968) also suggested that the supply of readily available nutrients, particularly nitrogen, may result in stimulated microbial activity and increased enzyme levels in peat. This confirms Hoffman's (1962) observation that the addition of nitrogen and phosphorus induces increased enzyme activity.

These factors are important in the Mildred Lake storage piles because of the admixture of mineral materials which supply calcium and other nutrient elements, and because of yearly fertilizing practices. The pH of material in the storage piles, as shown in Table 21, is higher than that of undisturbed peat in the same area.

Comparison of cellulolytic enzyme activities in the three types of undisturbed peat (Table 21) shows that C_1 and B activities are low in the fibric and mesic peats, and relatively high in fen peat. Cx activity was intermediate in fen peat. The relatively high activities of these enzymes in fen peat likely are linked to higher pH and higher nutrient status compared to the fibric and mesic moss peats.

In the stored peat materials, C_1 activities were comparable to those of fibric and mesic peats. The rate of peat decomposition during storage therefore appears to be similar to undisturbed peat. The higher B-glucosidase activity in the stored materials in 1976 may be attributed to higher nitrogen levels resulting from fertilization. With establishment of a thick vegetative cover by mid-1977, the B-glucosidase decreased, possibly as a result of all the available N being used by the cover crop.

The pH factor in cellulolytic enzyme activity was investigated by Reese and Levinson (1952) who studied the production of Cx and B-glucosidase by some microorganisms (e.g. *Aspergillus* spp.) using NH_4NO_3 as a nitrogen source and dextrose as a carbon source. With a rise in pH, there was a rapid rise in B-glucosidase concentration, even after the pH reached a constant level of 7.0. The Cx activity also increased rapidly but fell off when a constant pH level was reached. The effect of pH on cellulase activity depends on the organism. In general, the optimum pH for Cx activity in fungi is about 4.0 while the optimum for C_1 is at pH 4.8 (Mandel and Reese 1964). For bacterial cellulase, the pH optimum is about 6.0 (Halliwell 1963). In the stored peat materials at Mildred Lake, Cx activity in 1976 was lower than in undisturbed peats. However, the activity increased in 1977. The higher pH in stored materials as compared to undisturbed peats may be one reason for the reduced Cx activity. The increase in Cx activity after revegetation is more difficult to explain. It may be related to a nutrient factor or possibly to the cover crop itself; production of carbohydrates by roots of the cover crop could provide a more easily utilized substrate for the cellulolytic microorganisms.

The influence of organic carbon on enzyme activities as indicated by correlation factors is presented in Table 23. The cellulase C_1 activity in surface and subsurface materials was highly significantly correlated (r=0.71) with organic carbon content of the stored peat materials sampled in 1976. Cx activity was only slightly significantly correlated (r=0.51) with organic carbon in the surface layer but non-significantly correlated in the subsurface materials (r=0.36). B-glucosidase activity in both surface and subsurface was highly significantly correlated (r=0.73 and 0.89) with the organic carbon.

Table 23. Correlation of cellulase (C_1), carboxymethylcellulase (Cx), and B-glucosidase activities (in 1976[a] and 1977[a] samples) with the factor of total carbon content in stored peat materials.

Enzyme Activity	Horizon	Correlation Coefficient r 1976	1977
C_1	Surface	0.71***	0.41**
	Subsurface	0.71***	0.24
Cx	Surface	0.51*	0.14
	Subsurface	0.36^{ns}	-0.19
B-glucosidase	Surface	0.73***	0.32*
	Subsurface	0.89***	0.10

[a] No. of samples: 1976 - 19 surface, 21 subsurface;
1977 - 42 surface, 38 subsurface.

*, **, *** = $p < 0.05$, 0.01, 0.001, respectively.

ns = non-significant.

The results show that enzyme activity is directly dependent on the amount of carbon available. The lack of correlation between Cx activity and carbon content possibly is related to pH as discussed previously. The results were obtained for samples taken after fertilization and sowing, but prior to establishment of the cover vegetation. Nutrient levels, therefore, may have been near optimum for cellulolytic activity.

The correlation between carbon and enzyme activities in samples taken in 1977 was somewhat lower than in 1976 (Table 24). Only C_1 and B activities in the surface layers were significantly correlated. Possibly, the correlation exists more as a result of added nutrients than as a result of direct dependence on carbon content of the substrate. A small amount of N fertilizer and larger quantities of P and K fertilizers were applied to the stored peat piles in April 1977. Since the fertilizers were broadcast on the surface of the piles, the effect on stimulating microbial and enzymatic activity would be greatest on the surface.

Two other factors which may be important in cellulolytic enzyme activity are the presence of other carbohydrates and of lignin. During the first yearof storage, fresh substrate from peat bogs was subjected to more suitable environmental conditions (higher temperatures, lower moisture, improved aeration) for cellulolytic activity. Thus, readily decomposable substrate would be used by microorganisms at first. Enzyme activity would diminish as the easily decomposable cellulose is depleted. Other peat constituents, particularly lignin, reduce the susceptibility of cellulose to decomposition. This effect is a physical one resulting from the close structural interlinkage between cellulose and lignin in cell walls (Alexander 1977). After revegetation in 1977, the cellulolytic organisms may be more active in decomposing products of the cover crop such as root cells and exudates. Thus, the correlation with carbon could disappear, but levels of enzyme activities would not necessarily change.

Table 24. Correlation of soil respiration rate with enzyme activity and carbon content of stored material sampled in 1976.

Variable: Independent	Variable: Dependent	Correlation Coefficient r
% C	CO_2/g C/day	0.74***
C_1	"	0.44**
Cx	"	0.35*
B	"	0.22^{ns}
% C	CO_2/g soil/day	0.75***

ns = non-significant.

*, **, *** = $p < 0.05$, 0.01, 0.001, respectively.

C_1 = mg reducing sugar/g C/5 days.

Cx = mg reducing sugar/g C/24 h.

B = mg saligenin/g C/3 h.

In summary, cellulase activities indicated relatively low rates of cellulose breakdown by microorganisms in stored peat materials. Although the level of activity was generally dependent on the proportion of carbon in the substrate, there was evidence that increased pH and addition of nutrients increased activities of some of the enzymes. It was previously shown in laboratory incubation studies that addition of lime and nutrients increased microbial activity substantially. In storage piles, therefore, addition of fertilizers and raising the pH of stored peat by mixing with mineral material would likely result in increased microbial activity generally and in accelerated cellulose breakdown.

6.2.4 Relationship Between Cellulolytic Enzyme Activity and Soil Respiration Rate in Stored Material

Enzyme activity in the stored material had a positive relationship with soil respiration (Table 24). There was also a positive, highly significant correlation between carbon content and CO_2 production (Figure 19). The correlation of %C with CO_2 production was high whether based on CO_2/g C/day (0.74) or CO_2/g soil/day (0.75), but the standard error was reduced from 0.02 to 0.001 in the latter case. The activity of C_1 and Cx enzymes was positively correlated with CO_2 production, but B-glucosidase activity was not.

In considering the effects of adding fertilizer to the peat storage piles, the results show that C_1 and Cx are the strict cellulolytic enzymes whose activities depend more on the organic matter level than on nutrients added. When organic matter is utilized by organisms possessing these enzymes, the production of CO_2 will increase. However, B-glucosidase activity was higher with N fertilizer treatment in the field (Table 21). In other words, C_1 and Cx activities are directly related to the general level of microbial activity in the stored materials. B-glucosidase, however, is more dependent on one or more other factors, particularly N supply.

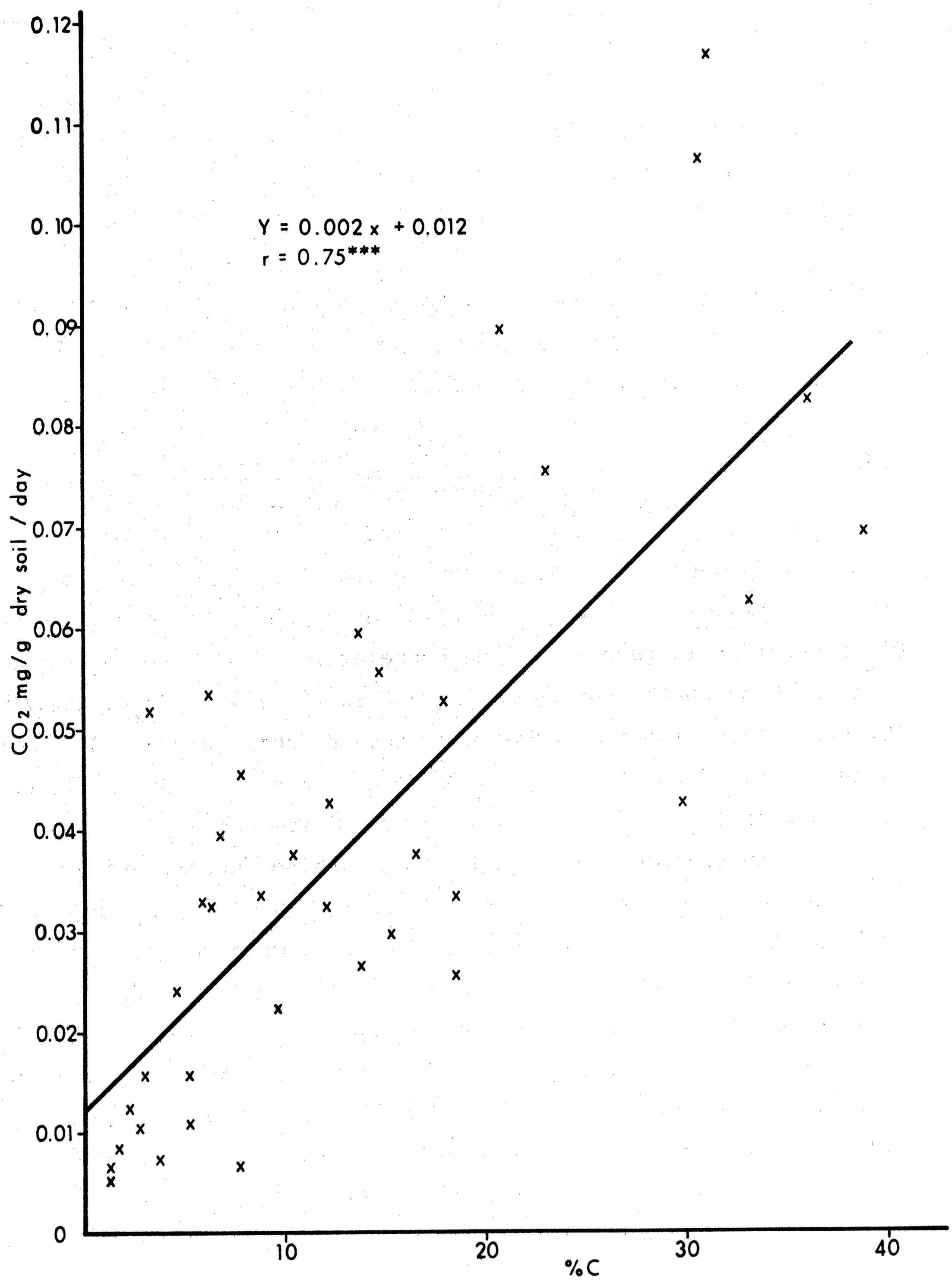

Figure 19. Correlation of soil respiration rate with total carbon content of stored material.

6.2.5 General Discussion on the Relationships Among Physical Properties, Chemical Properties, and Cellulolytic Enzyme Activities in Peat Storage Piles at Mildred Lake

The correlation of 15 properties measured in 80 samples collected at Mildred Lake in 1977 is presented in matrix form in Table 25. The expected correlation among the activities of C_1, Cx, and B-glucosidase occurs only in the surface layers. This may reflect more suitable environmental conditions for cellulose decomposers in the surface (10 to 20 cm) as compared to the subsurface layers (40 to 50 cm).

C_1 and B-glucosidase activities are significantly correlated with C and N only in the surface layers as shown previously. B-glucosidase activity is negatively correlated with sand content (as well as ash content and specific gravity, all of which are variables dependent on each other). B-glucosidase activity was correlated in the surface layers with C, N, and silt content. According to preliminary t-tests, the relationship between B-glucosidase activity and nitrogen ($r=0.64$) and silt ($r=0.54$) are significant at the 0.01 confidence level. The equation describing the multiple regression between those variables was calculated as follows: B-glucosidase activity (mg saligenin/100 g soil/3 h)=5.9 (N%) + 0.22 (Silt %) - 2.8. This equation explains about 52% ($R^2=0.52$) of the enzymatic activity. The standard error of estimate is 3.36 mg saligenin/100 g soil which is only slightly lower than that obtained by using %N alone (3.67 mg saligenin/100 g soil). The estimate for the correlation of B-glucosidase activity with N and silt is highly significant at the 1% level.

The interpretation of these data suggests that, for each additional gram of nitrogen in 100 g of soil, B-glucosidase activity would increase by 5.9 mg saligenin as compared to an increase of 0.22 mg saligenin for each additional gram of silt. Therefore, it is suggested that nitrogen in the surface of the stored material is the main stimulating agent for B-glucosidase. The effect of silt may be an indirect one that affects some soil physical properties which in turn affect enzymatic activity.

Table 25. Correlation matrix of 15 variables in 42 surface and 38 subsurface samples obtained in 1977 from the Mildred Lake peat storage piles.

C1	1														
Cx	0.34* -0.02	1													
B	0.36* 0.03	0.50*** 0.03	1												
Sp	-0.31* -0.28	-0.16 0.16	-0.31* -0.19	1											
Db	-0.15 -0.30	-0.12 0.16	-0.18 -0.36*	0.39** 0.82***	1										
P V	0.11 0.28	0.24 -0.19	0.27 0.37*	-0.46** -0.76***	-0.57*** -0.99***	1									
W C	0.14 0.25	0.33* -0.16	0.18 0.34*	-0.29 -0.78***	-0.48** -0.94***	0.81*** 0.93***	1								
A C	-0.05 0.09	-0.13 -0.08	0.17 0.10	-0.29 0.02	-0.18 -0.17	0.37* 0.21	-0.25 -0.15	1							
Ash	-0.46 -0.25	-0.13 0.15	-0.38* -0.25	0.82*** 0.92***	0.38* 0.82***	-0.52*** -0.80***	-0.38* -0.77***	-0.25 -0.10	1						
Sand	-0.29 0.05	-0.09 -0.09	-0.37* -0.27	0.71*** 0.67***	0.30 0.64***	-0.42** -0.60***	-0.27 -0.54***	-0.25 -0.19	0.70*** 0.74**	1					
Silt	0.01 -0.31	0.07 0.25	0.34* 0.29	0.11 -0.19	0.00 -0.27	0.11 0.24	0.07 0.17	0.07 0.19	-0.18 -0.24	-0.74*** -0.75***	1				
Clay	0.03 -0.28	-0.11 0.43**	-0.02 -0.11	-0.04 0.20	-0.10 0.27	0.05 -0.30	-0.02 -0.35*	0.10 0.15	0.07 0.26	-0.51*** -0.30	0.49*** 0.44**	1			
C	0.41** 0.24	0.14 -0.19	0.32* 0.10	-0.85*** -0.46**	-0.38* -0.46**	0.51*** 0.44**	0.37* 0.49**	0.27 -0.12	-0.95*** -0.46**	-0.70*** -0.21	0.15 -0.12	-0.13 -0.37*	1		
N	0.36* 0.16	0.17 -0.21	0.46** 0.23	-0.83*** -0.84***	-0.41** -0.81***	0.46** 0.79***	0.38* 0.80***	0.15 0.01	-0.86*** -0.89***	-0.63*** -0.70**	0.21 0.16	-0.15 -0.22	0.86*** 0.48**	1	
pH	0.02 -0.05	0.09 0.10	0.03 -0.02	0.48** 0.66***	0.21 0.68***	-0.04 -0.64***	-0.03 -0.64***	-0.02 -0.03	0.28 0.63***	0.33* 0.62***	-0.15 -0.40*	-0.11 0.06	-0.33* -0.21	-0.42** -0.61***	1
	C1	Cx	B	Sp	Db	P V	W C	A C	Ash	Sand	Silt	Clay	C	N	pH

C1 Cellulase activity
Cx Carboxymethylcellulase activity
B B-glucosidase activity
Sp Specific gravity
Db Bulk density
PV Pore volume
WC Water capacity
AC Air capacity
C Carbon content
N Nitrogen content

Upper numbers - surface
Lower numbers - subsurface

* $p < 0.05$
** $p < 0.01$
*** $p < 0.001$

The correlation of B-glucosidase with pore volume and water capacity is an indirect one in that these physical properties are highly correlated with C and N.

The highly significant correlation of water capacity with pore volume is related to the relatively high proportion of capillary pores in the peat. Air capacity does not have as significant a correlation, due to a relatively lower proportion of large pores (Section 6.2.2.2).

The lack of significant correlation between pH and enzyme activities indicates that the pH range in the materials studied was not large enough to have an effect. Whether or not the pH range was optimal was not indicated, but results in Section 6.2.3 suggest that pH may be beyond the optimum only for Cx activity.

The matrix shows that some peat properties which are among the most important in determining its suitability for reclamation or storage are highly correlated with each other. These are ash content, bulk density, C and N contents, pore volume and air capacity. A simple method for approximate characterization of stored peat would consist of determining any one of these properties and inferring the others from their regressions on each other. The easiest of these to determine are ash content, requiring a high temperature furnace, C content, requiring a C analyzer, and bulk density, requiring a careful and highly replicated sampling procedure. Methodology for the other properties is relatively time consuming.

7. GENERAL CONCLUSIONS

7.1 GENERAL CHARACTERISTICS OF PEAT

Generally the characteristics of the peats--fibric and mesic moss and mesic fen peat from the Mildred Lake and Evansburg areas--showed a broad range of physical and chemical properties. Fibric moss peat was decomposed least in terms of fiber content and ash content. The fen peat had the lowest fiber content and highest ash content. In terms of bulk density the fibric peat was lowest indicating little decomposition as compared to the mesic moss and fen peat. Pore volume, air capacity, and hydraulic conductivity were highest in fibric and lowest in mesic fen peat. Water capacity was about the same or higher in mesic peat as compared to fibric peat.

The fibric peat samples were extremely acidic, pH 3.7 to 4.0, as compared to the fen peat which ranged from pH 6.6 to 7.1. The presence of calcium-rich groundwater probably accounted for the higher pH values in the fen peat. In terms of exchangeable cations, the fibric moss peat was relatively base unsaturated as compared to the fen peat. The mesic peat was intermediate between the two.

Total nitrogen was low in the fibric moss and relatively high in the fen peat. This was reflected in the C/N ratios which were 36 to 77 in fibric moss peat, 27 to 30 in the mesic moss peat, and 16 to 17 in fen peat.

The microbiological populations were highest in the fen peat and lowest in the fibric moss. The relatively low pH values and low nitrogen content probably limited microbiological activity in the fibric peat.

The enzyme activity and O_2 uptake were correlated with the microbiological population. They were lowest in the fibric and mesic moss peats and highest in the fen peat. Studies of biological activity suggested that factors of the peat on its environment other than fiber content were responsible for its rate of decomposition and that amendments added to peat or sand-peat or overburden-peat mixes substantially affect the rate of peat alteration.

7.2 EFFECT OF DRYING, FREEZE-THAWING, AND FERTILIZER ADDITIONS TO PEAT

Drying affected most of the physical properties of peat. Bulk density was increased in fibric and mesic moss peat but had a negligible effect on the mesic fen peat. Freeze-drying was generally less detrimental than air-drying if increased bulk density can be considered detrimental. At the same time, drying decreased permeability in all peats examined.

Drying also had an effect on the microbial activity in the peats examined. Activities of enzymes degrading cellulose were substantially reduced in the fen and mesic moss peat but little change occurred in the fibric moss peat.

The series of freeze-thaw cycles reduced the rate of CO_2 production in all samples.

In terms of added nutrients and lime, the CO_2 evolution increased in the mesic moss peat to the point that it equalled that of the relatively nutrient rich fen peat.

The addition of glucose to the three peat samples had a pronounced effect on the microbial activity, particularly the fibric and mesic moss peats. As with the addition of lime and nutrients, the glucose-treated moss peat samples approached the fen in terms of CO_2 produced. Much of the extra CO_2 produced came from the peat and not the glucose.

It was noted that air-drying and freeze-drying of peat samples affected the physical properties of the peat in terms of decreasing the permeability. However, after incubating the samples for 64 days, the trend was reversed and the permeability increased.

Considering the laboratory research in terms of field application, it would appear that fen peat and probably highly humified moss peat may be poorly suited for erosion control in areas where probabilities of desiccation are high. For application to level surfaces as mulch, dried peat would be quite useful from the initial physical standpoint. The more humified peat may be more desirable here. For applications to sloping land as an initial erosion control medium, undried fibric or mesic moss peat would probably be the most desirable.

Measurements of relative degrees of decomposition and to some extent actual decay rate estimates of peat-carbon and dead plant carbon in mixtures of peat-overburden or peat-sand could be facilitated by the priming technique. Measurement of the physical properties of peat and its degree of decomposition in mixtures with mineral material are very difficult by direct non-tracer techniques. Methods currently available are restricted to pure peat. Pure peat does not exist at a restoration site and inclusion of mineral material in storage piles is hard to avoid.

7.3 STORED PEAT MATERIALS

At both the Evansburg and Mildred Lake sites, the optimum temperatures for microbial activity occurred for the longest period near the surface and decreased with depth. Below the 50 cm depth, the temperature did not reach the optimum of 10°C suggested by Kononova (1961). Therefore, on the basis of temperature the microbial activity will be greatest near the surface. There is no evidence of internal heating due to anaerobic decomposition at either of the storage piles at Mildred Lake or Evansburg.

In terms of moisture content, optimum conditions for microbial activity occurred for the longest period at the 50 cm depth. At the 20 cm and 100 cm depths, the moisture conditions were both above and below optimum at different times of the year.

7

A comparison of cellulolytic decomposition by use of filter paper discs indicated that maximum activity occurred in the 9-year old peat pile at Evansburg. This is probably due to the peat being fairly well decomposed, therefore biologically active, at the time it was piled. Also, the results might indicate that the piles, particularly at the surface, will become more active with time. A greater degree of decomposition at the Mildred Lake site as compared to the new (2-year old) pile at Evansburg can be attributed to the incorporation of inorganic material and fertilization of the site.

The results of field respiration studies strongly indicate that piling of peat and subsequent incorporation of inorganic material and fertilization will result in enhanced carbon loss (i.e., decomposition). Carbon loss in the heterogeneous Mildred Lake stored material was about four times greater than in the relatively pure Evansburg stored peat. Generally, the decomposition was highest at the surface due to aerobic conditions, higher temperatures, and application of fertilizers in the case of the storage piles at Mildred Lake.

Laboratory characterization of the stored material at Mildred Lake showed it to be a heterogeneous mixture of materials which could be classified into four categories ranging from predominantly peat to predominantly sand or sand plus clay. The classification has no practical application in use of this material for reclamation purposes, but it does aid in understanding the variations in chemical and physical properties. If selective stockpiling of the different types of materials is considered necessary, the classification could provide a basis for differentiating the materials in the field.

The pore volume and water capacity of the peat predominant materials were higher than those of predominantly mineral groups and, therefore, are more favourable for improving soil conditions for plant growth. If the stored material is to be used as a surface amendment in reclaiming tailings sands, consideration could be given to stockpiling the peat-predominant and mineral-predominant materials separately. Use of relatively pure peat would be particularly important in reclaiming sand on steep slopes.

In peat piles at Evansburg, the main changes in properties after stockpiling were an increase in air capacity and a decrease in water capacity of the surface layers. Physical properties of peat at depths of 100 cm and greater remained unchanged from those of undisturbed peat. The changes in the surface layers appeared to become more pronounced with age of the pile.

The drainage system of a peat storage pile appeared to affect the amount of change in physical properties, especially air capacity. Maintenance of relatively wet conditions in a pile would depress the rate of decomposition in peat. Long-term effects of wet or dry storage conditions, however, require further investigation.

Cellulolytic enzyme activities in the stored material at Mildred Lake differed from undisturbed peat due to changes in pH and nutrients available, among other factors. The higher pH of stored material is thought to depress Cx activity while added N appeared to stimulate B-glucosidase activity. Cellulase activity was correlated with total carbon content and with respiration rate. Either cellulolytic activity or respiration can be used as an index of decomposition, although respiration rate may be preferrable since cellulose breakdown accounts for only a portion of the organic matter decomposed. Due to the lack of a control site in the field, the effects of added N, pH, and other factors on cellulolytic enzyme activity are inconclusive.

Some effects of peat decomposition are to reduce fiber content, pore volume, air capacity, and hydraulic conductivity, and to increase water storage capacity and available nutrient content. Undecomposed, fibric peat would probably be most effective in reclamation situations requiring erosion control. Where erosion is not a problem, use of moderately decomposed (mesic) peat may have greater benefit.

Determinations of ash content, carbon content or bulk density are simple methods for approximate characterization of stored peat materials. Other properties such as nitrogen content, pore volume, and water capacity can be approximated by using the high correlations among these properties. Long-term effects of storage conditions, however, require further investigation.

8. REFERENCES CITED

Alexander, M. 1977. Introduction to Soil Microbiology, 2nd ed. John Wiley and Sons, New York. 467 pp.

Bedford, R.H. 1929. The decomposition of peat measured by carbon dioxide evolved. Sci. Agric. 9:522-532.

Bingeman, C.W., J.E. Varner, and W.P. Martin. 1953. The effect of the addition of organic materials on the decomposition of an organic soil. Soil Sci. Soc. Amer. Proc. 17:34-38.

Boelter, D.H. 1968. Important physical properties of peat materials. Proc. 3rd Int. Peat Congr., Quebec. 150-154.

Boelter, D.H. 1969. Physical properties of peats as related to degree of decomposition. Soil Sci. Soc. Amer. Proc. 33:606-609.

Canada Soil Survey Committee. 1974. The system of soil classification for Canada. Canada Dept. of Agr. Publ. 1455. 255 pp.

Christensen, P.J., and F.D. Cook. 1970. The microbiology of Alberta muskeg. Can. J. Soil Sci. 50:171-178.

Dai, T.S., and J.H. Sparling. 1973. Measurement of hydraulic conductivity of peats. Can. J. Soil Sci. 53:21-26.

Dommergues, Y. 1960. La notion de coefficient de mineralisation du carbone dans les sols. Agron. Trop. 15:54-60.

Dormaar, J.F. 1975. Susceptibility of organic matter of Chernozemic Ah horizons to biological decomposition. Can. J. Soil Sci. 55:473-480.

Farnham, R.S., and H.R. Finney. 1965. Classification and properties of organic soils. Advance. Agron. 7:115-162.

Flanagan, P.W. and A. Scarborough. 1974. Physiological groups of decomposer fungi on tundra plant remains. Pages 159-181 in A.J. Holding, ed. Soil organisms and decomposition in tundra. Tundra Biome Steering Committee, Sweden. 395 pp.

Flanagan, P.W. and A.K. Veum. 1974. Relationships between respiration, weight loss, temperature and moisture in organic residues in tundra. Pages 249-279 in A.J. Holding, ed. Soil organisms and decomposition in tundra. Tundra Biome Steering Committee, Sweden. 395 pp.

Flint, P.S. and P.L. Gersper. 1974. Nitrogen nutrient levels in Arctic tundra soils. Pages 375-387 in A.J. Holding, ed. Soil organisms and decomposition in tundra. Tundra Biome Steering Committee, Sweden. 395 pp.

Given, P.H., and C.H. Dickenson. 1975. Biochemistry and micro-biology of peats. Pages 123-212 in E.A. Paul and A.D. McLaren, eds. Soil biochemistry. Vol. 3. Marcel Dokker, New York.

Halliwell, G. 1963. Measurement of cellulase and factors affecting its activity. Pages 71-92 in E.T. Reese, ed. Advances in enzymic hydrolysis of cellulose and related materials. Pergamon Press, London. 299 pp.

Halstead, R.L., and F.J. Sowden. 1968. Effect of long term additions of organic matter on crop yields and soil properties. Can. J. Soil Sci. 48:341-348.

Hellum, A.K. 1975. Selecting peat for rearing coniferous container seedlings. For. Chron. 51:200-202.

Henin, S., G. Monnier and A. Combeau. 1958. Méthode pour l'étude de la stabilité structural des sols. Ann. Agr. 1:71-90.

Hofmann, E. 1962. The origin and importance of enzymes in soil. Rec. Progr. Microbiol. 8:216-220.

Hoffman, G., and M. Dedeken. 1965. Eine methode zur colorimetrishen bestimmung der Beta-glucosidase-aktivitat im boden. Z. Pfl. Dung. Bodenk. 108:193-198.

Irwin, R.W. 1968. Soil water characteristics of some Ontario peats. Proc. 3rd Int. Peat Congr., Quebec. 219-223.

Ivarson, K.C. 1977. Changes in decomposition rate, microbial population and carbohydrate content of an acid peat bog after liming and reclamation. Can. J. Soil Sci. 57:129-137.

Jackson, M.L. 1958. Soil chemical analysis. Prentice-Hall Inc., Englewood Cliffs, N.J. 498 pp.

Jasmin, J.J., and H.B. Heeney. 1960. Reclaiming acid dome peat bogs for agricultural use. Can. Dept. Agr. Publ. 1089. 17 pp.

Jones, P.C.T., and J.E. Mollison. 1948. A technique for the quantitative estimation of soil micro-organisms. J. Gen. Microbiol. 2:54-69.

Kirkham, D. 1946. Proposed method for field measurement of permeability of soil below water table. Soil Sci. Soc. Amer. Proc. 10:58-68.

Kononova, M.M. 1961. The natural factors of humus formation. Pages 203-230 in Soil organic matter. Pergamon Press, New York. 450 pp.

Kuster, E. 1963. Influence of peat and peat substances on the metabolism of fungi. Pure and Applied Chem. 7:611-617.

Kuster, E., and J.J. Gardiner. 1968. Infuence of fertilizers on microbial activity in peat land. Proc. 3rd. Int. Peat Congr., Quebec. 314-317.

Logan, R.J. 1978. Peat as a soil amendment for tailing sand reclamation. M.Sc. Thesis. Dept. of Soil Sci., Univ. of Alberta, Edmonton. 202 pp.

MacFarlane, I.C. 1969. Engineering characteristics of peat. Pages 78-115 in I.C. MacFarlane, ed. Muskeg engineering handbook. University of Toronto Press, Toronto. 287 pp.

Mandel, M., W. Howlett, and E.T. Reese. 1961. Natural inhibitors of cellulase. Can. J. Microbiol. 9:957-959.

Mandel, M., and E.T. Reese. 1963. Inhibition of cellulase and B-glucosidase. Pages 115-158 in E.T. Reese, ed. Advances in enzymic hydrolysis of cellulose and related materials. Pergamon Press, London. 299 pp.

Mandel, M., and E.T. Reese. 1964. Fungal cellulases and the microbiol decomposition of cellulosic fabric. Develop. Ind. Microbiol. 5:5-20.

Martin, J.P. 1950. Use of acid, rose bengal, and Streptomycins in the plate method for estimating soil fungi. Soil Sci. 69:215-232.

Mathur, S.P., and R.B. Sanderson. 1978. Relationship between copper contents, rates of soil respiration, and phosphatase activities of some Histosols in an area of southwestern Quebec in the summer and fall. Can. J. Soil Sci. 58:125-134.

McGill, W.B. and P.B. Hoyt. 1977. The effect of forages and rotation management on soil organic matter. Pages 33-80 in Proc. of Alberta Soil Science Workshop, Feb. 1-2, 1977. Alberta Agriculture, Edmonton. 212 pages.

McKeague, J.A., ed. 1978. Manual on soil sampling and methods of analysis, 2nd ed. Prepared by the subcommittee on Methods of Analysis of the Canada Soil Survey Committee. Can. Soc. Soil Sci., Ottawa. 212 pp.

Middleboe, U., D.R. Nielsen and D.A. Rennie. 1976. Tracer manual on crops and soils. Tech. Rept. Series No. 171. Intern. Atomic Energy Agency, Vienna. 277 pp.

Newton, J.D. 1934. A study of the composition and utilization of Alberta Peats. The Ann. of Appl. Biol. 21:251-266.

Newton, J.D. 1936. Composition and fertilization of Alberta peats. Sci. Agr. 16:245-252.

Nygard, I.J. 1954. Identification of lime-deficient peat soil. Soil Sci. Soc. Amer. Proc. 18:188-192.

Okruszko, H., G.F. Warren, and G.F. Wilcox. 1962. Influence of calcium on phosphorus availability in muck soil. Soil Sci. Soc. Amer. Proc. 16:68-71.

Olsen, O.B. 1968. Peat and other substrates. Proc. 3rd Int. Peat Congr., Quebec. 264-267.

Parkinson, D., T.R.G. Gray, and S.T. Williams. 1971. Methods for studying the ecology of soil micro-organisms. Handbook 19, Blackwell-IBP, Oxford. 116 pp.

Puustjarvi, U. 1955. On the humic acids of peat soils. Acta Agr. Scand. 5:257-279.

Puustjarvi, U. 1956. On the cation exchange capacity of peats and on the factors of influence upon its formation. Acta Agr. Scand. 6:410-448.

Puustjarvi, U. 1968. Fixing peat standards. Peat and Pl. News, 1:3-8.

Radforth, N.W., and C.O. Brawner, eds. 1977. Muskeg and the northern environment in Canada. By the Muskeg Subcommittee of the NRC Associate Committee on Geotechnical Research. Univ. of Toronto Press, Toronto and Buffalo. 399 pp.

Reese, E.T. 1968. Microbial transformation of soil polysaccharides. Pages 535-577 <u>in</u> Organic matter and soil fertility. Pontificae Academiae Scientiarum Scripta varia 32. Wiley Interscience Div., John Wiley and Sons, Inc. New York.

Reese, E.T. and H.S. Levinson. 1952. A comparative study of the breakdown of cellulose by microorganisms. Physiol. Plant. 5:345-367.

Roberge, M.R. 1976. Respiration rates for determining the effect of urea on the soil-surface organic horizon of a black spruce stand. Can. J. Microbiol. 22:1328-1335.

Rycroft, D.W., D.J.A. Williams and H.A.P. Ingram. 1975. The transmission of water through peat. II. Field experiments. J. Ecol. 63:557-568.

Schickluna, J.C., J.F. Davis, R.E. Lucas, L.T. Wang. 1968. The response of potatoes and onions to applied phosphorus and potassium and a study of the availability of native phosphorus to those crops grown on a Houghton muck. Proc. 3rd Int. Peat Congr., Quebec. pp. 318-323.

Schnitzer, M., and J.G. Desjardins. 1965. Carboxyl and phenolic hydroxyl groups in some organic soils and their relation to the degree of humification. Can. J. Soil Sci. 45:257-264.

Schnitzer, M., and J.G. Desjardins. 1966. Oxygen-containing functional groups in organic soils and their relation to the degree of humification as determined by solubility in sodium pyrophosphate solution. Can. J. Soil Sci. 46:237-243.

Shields, J.A., E.A. Paul, and W.E. Lowe. 1974. Factors influencing the stability of labelled microbial materials in soils. Soil Biol. Biochem. 6:31-37.

Soebo, S. 1969. On the mechanism behind the effect of freezing and thawing on dissolved phosphorus in Sphagnum fuscum peat. Sci. Report Agr. College, Norway. 48:1-10.

Somogyi, M. 1945. A new reagent for the determination of sugars. J. Biol. Chem. 160:61-73.

Sowden, F.J., and H.J. Atkinson. 1968. Effect of long term annual additions of various organic amendments on the organic matter of a clay and a sand. Can. J. Soil Sci. 48:323-330.

Stanek, W., and T. Silc. 1977. Comparison of four methods for determination of degree of peat humification (decomposition) with emphasis on the von Post method. Can. J. Soil Sci. 57:109-117.

Stotzky, G. 1960. A simple method for the determination of the respiratory quotient of soils. Can. J. Microbiol. 6:439-452.

Stotzky, G., and J.L. Mortensen. 1958. Effect of addition level and maturity of rye tissue on the decomposition of a muck soil. Soil Sci. Soc. Amer. Proc. 22:521-524.

Stout, J.D. 1971. Aspects of the microbiology and oxidation of Wicken fen soil. Soil Biol. and Biochem. 3:9-26.

Van Dijk, H., and P. Boekel. 1965. Effect of drying and freezing on certain physical properties of peat. Netherlands J. Agr. Sci. 13:248-260.

Van Dijk, H., J. van der Boon, and P. Boekel. 1968. Chemical and physical properties of mineral soils ameliorated with "Horticultural Peat". Proc. 3rd Int. Peat Congr., Quebec. 334-340.

Waksman, S.A., and E.R. Purvis. 1932. The microbiological population of peat. Soil Sci. 34:95-113.

Waksman, S.A., and Starkey, R.L. 1924. Carbon dioxide evolution as an index of soil fertility. Soil Sci. 17:141-161.

Waksman, S.A., and K.R. Stevens. 1928. Contribution to the chemical composition of peat. I. Chemical nature of organic complexes in peat and methods of analysis. Soil Sci. 26:113-137.

Waksman, S.A., and K.R. Stevens. 1929. Contribution to the chemical composition of peat; The role of microorganisms in peat formation and decomposition. Soil Sci. 28:321-340.

Walker, K.H. 1936. Composition of some Alberta peats. Sci. Agr. 16:499-502.

Waughman, G.J. 1976. Investigation of nitrogenase activity in rheotrophic peat. Can. J. Microbiol. 22:1561-1566.

Walmsley, M.E. 1977. Physical and chemical properties of peat. Pages 82-130 in N.W. Radforth and C.B. Brawner, eds. Muskeg and the northern environment in Canada. Univ. Toronto Press. 399 pp.

Wheatley, R.E., M.P. Greaves, and R.H.E. Inkson. 1976. The aerobic bacterial flora of a raised bog. Soil Biol. Biochem. 8:453-460.

Wieringa, K.T. 1963. The humification of high moor peat. Plant and Soil. 18:53-70.

Williams, B.L. 1974. Effect of water table level on nitrogen mineralization in peat. Forestry 47:195-202.

Youngs, E.G. 1968. Shape factors for Kirkham's piezometer method for determining the hydraulic conductivity of soil in situ for soil overlying an impermeable floor or infinitely permeable stratum. Soil Sci. 106:235-237.

9. APPENDICES

The following appendices include details of laboratory methods used in this study and additional data on the peat storage piles.

9.1 METHODS OF ANALYSES

9.1.1 Physical Properties

a) Moisture Content - Twenty grams of moist peat were dried to constant weight at 90°C. Moisture content was calculated on the basis of the oven dry samples.

b) Bulk Density - Moist peat was placed in a 2 L container with a perforated bottom. The container was submerged in water for 24 h, and then removed and allowed to drain for 2 h. The bulk density is reported as the oven dry weight of peat per unit volume after drainage.

c) Pore Volume - Pore volume is the total space of air and water in peat. It was calculated from:

$$Vp = \frac{Dp - Db}{Dp} \times 100$$

where: Vp = pore volume %

Dp = particle density (g/mL) using a 100 mL volumetric flask as a pycnometer

Db = bulk density (g/mL)

d) Water Capacity - Water capacity is the total space of water in peat. It was calculated from:

$$\text{Water capacity} = \frac{\text{wt. of wet peat - wt. of dry peat}}{\text{vol. of wet peat}} \times 100$$

e) Air Capacity - Air capacity is the difference between pore volume and water capacity.

f) Void Ratio - Void ratio is the ratio of the volume of space to the volume of soil solids. For this study void ratio was calculated as follows:

$$e = \frac{Vp}{100 - Vp}$$

where: e = void ratio

Vp = pore volume

g) Ash Content - Ash content is the percent of original material remaining as residue after heating at 450°C for 16 h in an electric muffle furnace.

h) Fiber Content - Fiber content is expressed as the percentage of the organic material retained by a 100 mesh screen either with or without rubbing.

i) Saturated Hydraulic Conductivity - Hydraulic conductivity was determined using a piezometer, in this case a pipe with a perforated cap on the lower end. A hole was augered to the desired depth, the piezometer placed in it, the water pumped out and the rate of water return up the tube determined. Hydraulic conductivity was then determined according to the equation of Kirkham (1946):

$$\text{Conductivity} = \frac{\pi\ r^2\ \ln\ (hi/hj)}{A\ (tj-ti)}$$

where: h = head; difference between water level and water table in tube

r = radius of tube

t = time from start of experiment

A = shape function estimated from Youngs (1968)

j) Permeability - The measure of permeability in the laboratory was a simple apparatus designed by Henin et al. (1958). The K value was calculated based on the following equation:

$$K\ (cm/h) = \frac{CV}{HS}$$

where: C = height of soil samples in cm

V = volume of water passing through the column

H = head, height of water in column in cm

S = cross-sectional area of tube in cm^2

9.1.2 Chemical Properties

a) Soil Reaction - pH was determined in water (solution to peat ratio of 2.5:1), using a calomel electrode.

b) Base Saturation - Base saturation is reported as the sum of Ca + Mg + K + Na extracted with ammonium acetate at pH 7.0 calculated as a percentage of the total exchange capacity as determined with sodium chloride (McKeague 1978).

c) Nitrogen - Total nitrogen was determined by the semi-micro Kjeldahl procedure (McKeague 1978).

d) Phosphorus - Phosphorus was extracted with 0.002 N sulphuric acid and the orthophosphate measured colorimetrically using the molybdophosphoric blue colour method (Jackson 1958).

e) Carbon - Organic carbon was determined by dry combustion, using a LECO induction furnace.

9.1.3 Microbiological and Biochemical Properties

a) Bacterial numbers - Heterotrophic bacteria were estimated from plate counts in which soil dilutions were spread on agar media containing various nutrients. The plates were incubated and the colonies formed were counted and converted to bacteria per gram oven dry weight of sample. The medium used for plate counts in these experiments was Plate Count Agar (Difco).

b) Fungal numbers - Fungi were estimated from plate counts using the medium of rose bengal-streptomycin agar with a composition as follows:

Glucose	10.0 g
Peptone	5.0 g
KH_2PO_4	1.0 g
$MgSO_4 \cdot 7 H_2O$	0.5 g
Agar	15.0 g
Rose Bengal	33 mg

The medium is cooled, and streptomycin is added to give a concentration of 30 mg/mL (Martin 1950).

c) Measure of CO_2 evolution - 100 g moist peat were placed in a 600 mL plastic container with a tightly sealed lid. Evolved CO_2 was collected in 10 mL 0.2N NaOH contained in a 50 mL beaker. The unused NaOH was back-titrated with 0.1N HCl to the thymolphthalein end-point after precipitation of carbonates with $BaCl_2$

(Dommergues 1960). The NaOH was changed daily. Containers with only NaOH were used as controls and were otherwise treated in the same manner as those containing peat. The CO_2 evolved was calculated from the consumption of HCl by the formula:

$$\text{mg } CO_2 = 2.2\ (Q_1 - Q_2)$$

where: Q_1 = mL of HCl (0.1N) titrated in control

Q_2 = mL of HCl (0.1N) titrated in soil sample

Coefficient of mineralization of carbon:

$$\frac{CO_2 - C}{C}$$

where: $CO_2 - C$ = mg $CO_2 - C$ evolved by soil

C = total carbon content in soil

d) Enzyme Activities -

1) C_1 activity - A 10 g sample of fresh soil was weighed and put into a 50 mL Erlenmeyer flask with 20 mL of phosphate buffer solution (0.0667M Na_2HPO_4 and 0.0667M KH_2PO_4, pH = 6.0) containing 0.01% of Merthiolate and 10 mL of 2% cellulose solution, using cellulose powder Whatman CC41, which acts as a substrate. This mixture was then incubated at 37°C for five days. At the end of this period, the mixture was filtered through a fast filter paper. The reducing sugar was determined by employing the copper reagent method described by Somogyi (1945).

2) Cx activity - The procedure followed was the same as for C_1 activity determination except that carboxymethyl-cellulose (Sodium salt CMC-FHSP) was used as the substrate and the incubation time was 24 h.

3) B-glucosidase activity - B-glucosidase activity was determined by the method of Hoffman and Dedeken (1965) using Salicin as substrate.

9.2 SEEDING AND FERTILIZING RATES OF PEAT STORAGE PILES AT MILDRED LAKE

Treatment Date:	9, 10 April 1976
Seed Mixture:	Creeping Red Fescue
	Smooth Bromegrass

	Slender Wheatgrass
	Canada Bluegrass
	Timothy
	Pubescent Wheatgrass
	Mixed Blossom Sweet Clover
	Rhizomatous Alfalfa
	Birdsfoot Trefoil
	Sainfoin
Seed Application:	90 lbs/ac
Fertilizer Application:	Ammonium Sulphate (21-0-0) - 20 lbs/ac
	Ammonium Phosphate (11-55-0) - 75 lbs/ac
	Urea (46-0-0) - 120 lbs/ac
	Potassium Chloride (0-0-60) - 60 lbs/ac
Treatment Date:	11 April 1977
	Ammonium Phosphate (11-48-0) - 140 lbs/ac
	Ammonium Nitrate (34-0-0) - 35 lbs/ac

9.3 BACTERIAL POPULATIONS IN THE EVANSBURG PEAT PILES

Depth[a]	Bacteria numbers - No. of bacteria/g dry peat	
	2 yr. old peat pile	9 yr. old peat pile
20 cm	3.8 x 10^7	21 x 10^7
50 cm	6.1 x 10^7	9.5 x 10^7
100 cm	3.4 x 10^7	5.1 ·10^7
200 cm	69 x 10^7	270 x 10^7
300 cm	13 x 10^7	17 x 10^7

[a] Depths of peat samples from the surface.

9.4 CARBON AND NITROGEN CONTENTS OF THE FOUR CATEGORIES OF STORED MATERIALS AT MILDRED LAKE SAMPLED IN 1977

Stored Peat Material	C%	N%	C/N
Group I	27.45 ± 1.11 a	1.55 ± 0.13 a	18.55 ± 1.20 a
Group II	5.68 ± 0.38 c	0.39 ± 0.03 c	15.32 ± 0.79 a
Group III	8.75 ± 1.70 c	0.58 ± 0.13 c	14.67 ± 1.73 a
Group IV	14.22 ± 0.55 b	0.93 ± 0.06 b	15.93 ± 0.63 a
F ratio	108.64***	38.61***	1.79^{ns}

Results are means of 11, 31, 12, and 42 samples for groups I, II, III, and IV respectively. Means in the same column followed by the same letter are not significantly different at the 95% level.

*** = $p < 0.001$.

ns = not significant.

10. AOSERP RESEARCH REPORTS

1.		AOSERP First Annual Report, 1975
2.	AF 4.1.1	Walleye and Goldeye Fisheries Investigations in the Peace-Athabasca Delta--1975
3.	HE 1.1.1	Structure of a Traditional Baseline Data System
4.	VE 2.2	A Preliminary Vegetation Survey of the Alberta Oil Sands Environmental Research Program Study Area
5.	HY 3.1	The Evaluation of Wastewaters from an Oil Sand Extraction Plant
6.		Housing for the North--The Stackwall System
7.	AF 3.1.1	A Synopsis of the Physical and Biological Limnology and Fisheries Programs within the Alberta Oil Sands Area
8.	AF 1.2.1	The Impact of Saline Waters upon Freshwater Biota (A Literature Review and Bibliography)
9.	ME 3.3	Preliminary Investigations into the Magnitude of Fog Occurrence and Associated Problems in the Oil Sands Area
10.	HE 2.1	Development of a Research Design Related to Archaeological Studies in the Athabasca Oil Sands Area
11.	AF 2.2.1	Life Cycles of Some Common Aquatic Insects of the Athabasca River, Alberta
12.	ME 1.7	Very High Resolution Meteorological Satellite Study of Oil Sands Weather: "A Feasibility Study"
13.	ME 2.3.1	Plume Dispersion Measurements from an Oil Sands Extraction Plant, March 1976
14.		
15.	ME 3.4	A Climatology of Low Level Air Trajectories in the Alberta Oil Sands Area
16.	ME 1.6	The Feasibility of a Weather Radar near Fort McMurray, Alberta
17.	AF 2.1.1	A Survey of Baseline Levels of Contaminants in Aquatic Biota of the AOSERP Study Area
18.	HY 1.1	Interim Compilation of Stream Gauging Data to December 1976 for the Alberta Oil Sands Environmental Research Program
19.	ME 4.1	Calculations of Annual Averaged Sulphur Dioxide Concentrations at Ground Level in the AOSERP Study Area
20.	HY 3.1.1	Characterization of Organic Constituents in Waters and Wastewaters of the Athabasca Oil Sands Mining Area
21.		AOSERP Second Annual Report, 1976-77
22.		Alberta Oil Sands Environmental Research Program Interim Report to 1978 covering the period April 1975 to November 1978
23.	AF 1.1.2	Acute Lethality of Mine Depressurization Water on Trout Perch and Rainbow Trout
24.	ME 1.5.2	Air System Winter Field Study in the AOSERP Study Area, February 1977.
25.	ME 3.5.1	Review of Pollutant Transformation Processes Relevant to the Alberta Oil Sands Area

26. AF 4.5.1 Interim Report on an Intensive Study of the Fish Fauna of the Muskeg River Watershed of Northeastern Alberta
27. ME 1.5.1 Meteorology and Air Quality Winter Field Study in the AOSERP Study Area, March 1976
28. VE 2.1 Interim Report on a Soils Inventory in the Athabasca Oil Sands Area
29. ME 2.2 An Inventory System for Atmospheric Emissions in the AOSERP Study Area
30. ME 2.1 Ambient Air Quality in the AOSERP Study Area, 1977
31. VE 2.3 Ecological Habitat Mapping of the AOSERP Study Area: Phase I
32. AOSERP Third Annual Report, 1977-78
33. TF 1.2 Relationships Between Habitats, Forages, and Carrying Capacity of Moose Range in northern Alberta. Part I: Moose Preferences for Habitat Strata and Forages.
34. HY 2.4 Heavy Metals in Bottom Sediments of the Mainstem Athabasca River System in the AOSERP Study Area
35. AF 4.9.1 The Effects of Sedimentation on the Aquatic Biota
36. AF 4.8.1 Fall Fisheries Investigations in the Athabasca and Clearwater Rivers Upstream of Fort McMurray: Volume I
37. HE 2.2.2 Community Studies: Fort McMurray, Anzac, Fort MacKay
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41. AF 3.5.1 Acute and Chronic Toxicity of Vanadium to Fish
42. TF 1.1.4 Analysis of Fur Production Records for Registered Traplines in the AOSERP Study Area, 1970-75
43. TF 6.1 A Socioeconomic Evaluation of the Recreational Fish and Wildlife Resources in Alberta, with Particular Reference to the AOSERP Study Area. Volume I: Summary and Conclusions
44. VE 3.1 Interim Report on Symptomology and Threshold Levels of Air Pollutant Injury to Vegetation, 1975 to 1978
45. VE 3.3 Interim Report on Physiology and Mechanisms of Air-Borne Pollutant Injury to Vegetation, 1975 to 1978
46. VE 3.4 Interim Report on Ecological Benchmarking and Biomonitoring for Detection of Air-Borne Pollutant Effects on Vegetation and Soils, 1975 to 1978.
47. TF 1.1.1 A Visibility Bias Model for Aerial Surveys for Moose on the AOSERP Study Area
48. HG 1.1 Interim Report on a Hydrogeological Investigation of the Muskeg River Basin, Alberta
49. WS 1.3.3 The Ecology of Macrobenthic Invertebrate Communities in Hartley Creek, Northeastern Alberta
50. ME 3.6 Literature Review on Pollution Deposition Processes
51. HY 1.3 Interim Compilation of 1976 Suspended Sediment Date in the AOSERP Study Area
52. ME 2.3.2 Plume Dispersion Measurements from an Oil Sands Extraction Plan, June 1977

53.	HY 3.1.2	Baseline States of Organic Constituents in the Athabasca River System Upstream of Fort McMurray
54.	WS 2.3	A Preliminary Study of Chemical and Microbial Characteristics of the Athabasca River in the Athabasca Oil Sands Area of Northeastern Alberta
55.	HY 2.6	Microbial Populations in the Athabasca River
56.	AF 3.2.1	The Acute Toxicity of Saline Groundwater and of Vanadium to Fish and Aquatic Invertebrates
57.	LS 2.3.1	Ecological Habitat Mapping of the AOSERP Study Area (Supplement): Phase I
58.	AF 2.0.2	Interim Report on Ecological Studies on the Lower Trophic Levels of Muskeg Rivers Within the Alberta Oil Sands Environmental Research Program Study Area
59.	TF 3.1	Semi-Aquatic Mammals: Annotated Bibliography
60.	WS 1.1.1	Synthesis of Surface Water Hydrology
61.	AF 4.5.2	An Intensive Study of the Fish Fauna of the Steepbank River Watershed of Northeastern Alberta
62.	TF 5.1	Amphibians and Reptiles in the AOSERP Study Area
63.	ME 3.8.3	Analysis of AOSERP Plume Sigma Data
64.	LS 21.6.1	A Review and Assessment of the Baseline Data Relevant to the Impacts of Oil Sands Development on Large Mammals in the AOSERP Study Area
65.	LS 21.6.2	A Review and Assessment of the Baseline Data Relevant to the Impacts of Oil Sands Development on Black Bears in the AOSERP Study Area
66.	AS 4.3.2	An Assessment of the Models LIRAQ and ADPIC for Application to the Athabasca Oil Sands Area
67.	WS 1.3.2	Aquatic Biological Investigations of the Muskeg River Watershed
68.	AS 1.5.3 AS 3.5.2	Air System Summer Field Study in the AOSERP Study Area, June 1977
69.	HS 40.1	Native Employment Patterns in Alberta's Athabasca Oil Sands Region
70.	LS 28.1.2	An Interim Report on the Insectivorous Animals in the AOSERP Study Area
71.	HY 2.2	Lake Acidification Potential in the Alberta Oil Sands Environmental Research Program Study Area
72.	LS 7.1.2	The Ecology of Five Major Species of Small Mammals in the AOSERP Study Area: A Review
73.	LS 23.2	Distribution, Abundance and Habitat Associations of Beavers, Muskrats, Mink and River Otters in the AOSERP Study Area, Northeastern Alberta
74.	AS 4.5	Air Quality Modelling and User Needs
75.	WS 1.3.4	Interim Report on a Comparative Study of Benthic Algal Primary Productivity in the AOSERP Study Area
76.	AF 4.5.1	An Intensive Study of the Fish Fauna of the Muskeg River Watershed of Northeastern Alberta
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78.	LS 22.1.1	Habitat Relationships and Management of Terrestrial Birds in Northeastern Alberta

79. AF 3.6.1 The Multiple Toxicity of Vanadium, Nickel, and Phenol to Fish.
80. HS 10.2 & HS 10.1 History of the Athabasca Oil Sands Region, 1980 to 1960's. Volumes I and II.
81. LS 22.1.2 Species Distribution and Habitat Relationships of Waterfowl in Northeastern Alberta.
82. LS 22.2 Breeding Distribution and Behaviour of the White Pelican in the Athabasca Oil Sands Area.
83. LS 22.2 The Distribution, Foraging Behaviour, and Allied Activities of the White Pelican in the Athabasca Oil Sands Area.
84. WS 1.6.1 Investigations of the Spring Spawning Fish Populations in the Athabasca and Clearwater Rivers Upstream from Fort McMurray; Volume I.
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88. AF 2.0.1 Ecological Studies of the Aquatic Invertebrates of the Alberta Oil Sands Environmental Research Program Study Area of Northeastern Alberta
89. AF 4.3.2 Fishery Resources of the Athabasca River Downstream of Fort McMurray, Alberta. Volume 1
90. AS 3.2 A Wintertime Investigation of the Deposition of Pollutants around an Isolated Power Plant in Northern Alberta

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